Building a Well-Equipped Skilled Technical Workforce by Adopting the Framework for a Cross-Disciplinary STEM Core

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Abstract: STEM technician education programs face a world in which cutting-edge technologies are transforming existing industries and creating new ones at an unprecedented pace. In light of this, the NSF ATE project Preparing Technicians for the Future of Work conducted industry site interviews and regional convenings of academic partners and industry leaders representing a wide range of technical fields to learn how technology impacts technician job tasks and roles. Through these activities, the project identified three skill areas common across multiple technologies and deemed essential for future STEM technicians: data knowledge/analysis, advanced digital literacy, and business knowledge/processes. These "cross-disciplinary STEM core" skill sets and recommendations for integrating them into technical programs are described in A Framework for a Cross-Disciplinary STEM Core. To facilitate adoption of the Framework at a systemic level, the project is sharing an adoption toolkit with concrete steps a college can take, tools it can use with employers to prioritize STEM Core skill sets and faculty activities for identifying where prioritized skills are taught within existing program curriculum and instructional gaps where new cross-disciplinary skill sets could be easily integrated.

Keywords: future of work, technician education, cross-disciplinary, skilled technical workforce

Introduction

In 2016, the National Science Foundation issued its Ten Big Ideas, among them the study of the Future of Work at the Human-Technology Frontier. Inspired by the NSF charge to the scientific community to study "how constantly evolving technologies are actively shaping the lives of workers [1]," the NSF Advanced Technological Education (NSF ATE) project Preparing Technicians for the Future of Work adopted a scope of work dedicated to the education of STEM technicians that the National Science Board dubbed the Skilled Technical Workforce— "individuals who use S&E [science and engineering] skills in their jobs but do not have a bachelor's degree"— and declared them a "critical, but often overlooked segment of our STEM-capable workforce" [2].

STEM technicians and technician education programs face a world in which advancements driven by artificial intelligence, machine learning, and myriad other emerging and converging technologies are transforming existing industries and creating new ones at an unprecedented pace. Today's technicians are immersed in diverse platforms and interrelated systems that once belonged to single industry sectors. While demand for positions involving tasks that can be automated is declining, new occupations are emerging [3]. Rapid technological change means that technician jobs are converting to what some call "hybrid jobs" and "superjobs" [4], requiring "skills which are in demand across multiple emerging professions" [5]. The skilled technical workforce, sitting at the center of this disruption, needs a broad, cross-disciplinary skill set to enable them "to navigate a dynamic landscape of accelerating change: job losses, job changes, and job creation" [6]. With these challenges in mind, how—and what—do we teach new technicians?

Approaches to Identifying What Future Technicians Need to Know

Preparing Technicians for the Future of Work conducted a series of research activities, including industry interviews and regional convenings of academic partners and industry leaders from a wide range of technical fields, to learn how technology is impacting job tasks and roles and to ascertain whether there are skills that will be applicable and necessary across sectors. The concept of cross-disciplinary skills has been explored within STEM [7] or STEM-enabled disciplines. It is becoming, of necessity, an idea that advanced technology programs are embracing (e.g., data analysis within biotechnology [8], entrepreneurship in engineering [9], automation and blockchain within renewable energy [10], and cybersecurity within robotics/automation programs [11]).

To begin exploring issues relevant to the future of work, the project held a meeting of NSF ATE Center Directors and industry advisors to identify challenges facing industry, the technical workforce, and technician educators as a result of rapidly changing technology. The participants frequently mentioned topics related to data analysis, digital literacy, and business knowledge as the content that should be addressed across all technical disciplines. Within these three broad content areas, the project developed an initial list of potential skills for consideration. Development of the initial skills list used grounded theory research [12] to build knowledge. Grounded theory research involves data collection, systematic coding/categorization, and analysis to identify the key themes and patterns within the data. Thus, a "grounded theory" emerges from the data rather than the testing of specific hypotheses.

The initial list of potential skills for discussion was compiled following a systematic review of the literature, a review of existing competency models and skills standards, conference sessions, and interviews at industry sites and with subject matter experts. Using this methodology, the project team compiled a list of 400+ potential skills that they then reviewed and grouped into skill sets within the three categories identified at the original meeting. The skill sets were whittled down to approximately 15 per revised category: data knowledge/ analysis, advanced digital literacy, and business knowledge and processes. Fig. 1 displays the categories and associated skill sets—the Cross-Disciplinary STEM Core— alphabetically.

DATA KNOWLEDGE AND ANALYSIS	ADVANCED DIGITAL LITERACY	BUSINESS KNOWLEDGE AND PROCESSES
Manipulating and interpreting data to resolve issues and using Excel and other common software proficiently to accomplish tasks	Understanding digital communications and networking, cybersecurity, machine learning, sensors, programming, and robotics at a higher than introductory level	Understanding the value chain and business practices of an enterprise and applying principles of ethical adoption of new technologies
Analytics tools	Artificial intelligence/ machine learning	Business cycles
Computational thinking	Automation/robotics	Blockchain
Data analysis	Basic programming	Communication
Data backup and restoration	Cloud literacy	Continuous process improvement
Databases	Digital fluency	Customer/stakeholder analysis
Data fluency	Digital twins	Entrepreneurship
Data life cycle	Edge computing	Ethics
Data management	Function block diagram programming	Lean processes
Data modeling	Human-Machine Interface (HMI)	Market trends
Data storage	Internet of Things (IoT)	Overall Equipment Efficiency (OEE)
Data visualization	Network architecture	Return on Investment (ROI)
Query languages	Network communication	Risk management
Spreadsheets	Security controls	Supply and demand
Statistics		Supply chains
		Vertical and horizontal integration

Fig. 1. The three skill areas and associated skill sets of the Cross-Disciplinary STEM Core.

In a subsequent meeting of a special interest group (SIG) on the future of work, the list was refined further with a ranking procedure often used with grounded theory research. It is sometimes referred to as "dot voting" or "dotmocracy" coding [13]. The use of dot voting as a tool for grounded theory research has been promoted since the 1960s [14]. At the meeting, each subject matter expert and industry advisor voted on the 43 skill sets in order of perceived importance for entry-level technicians in the future. The votes were then reviewed, and initial priorities were established, as shown in Figures 2-4. While this preliminary ranking is a good starting point, the project team believes that prioritization is best accomplished by region because industry needs will vary, as our regional convenings demonstrate. Comparison data from the national SIG [Fig. 2-4] and regional convenings [Tab. 1] illustrate this point. Further evidence of the importance of considering skills at a regional level was evident upon review of the two questions added to the EvaluATE survey in 2020. A content analysis of the responses revealed great diversity across NSF ATE projects, again reinforcing the conclusion that regional work is important when discussing cross-disciplinary technician skills needed for the future. That said, the project is still interested in trends nationally; an employer survey is underway that will yield prioritizations sorted by advanced technology fields that may interest the technician education community. Preliminary data will be available in May 2023, and readers are encouraged to ask their industry partners to respond.

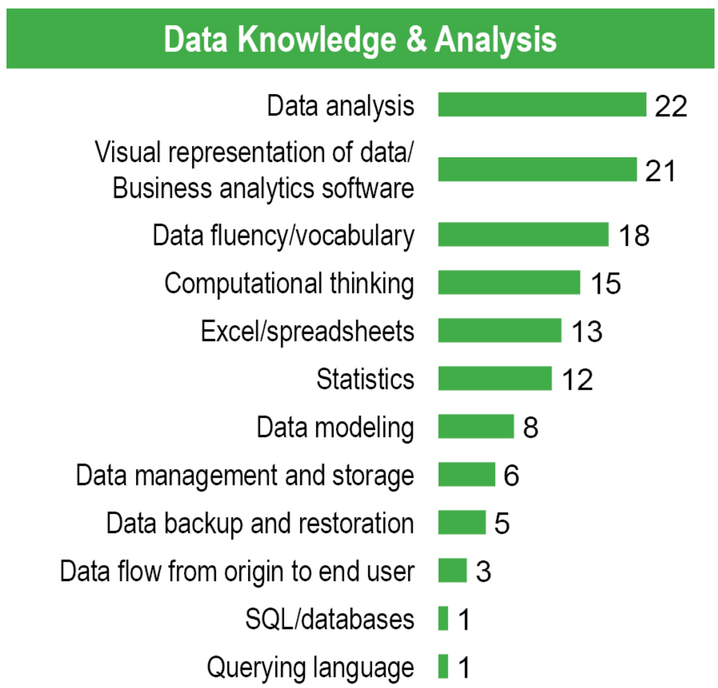

Fig. 2. National SIG initial prioritization of data knowledge and analysis skill sets by the tallied number of votes (2019).

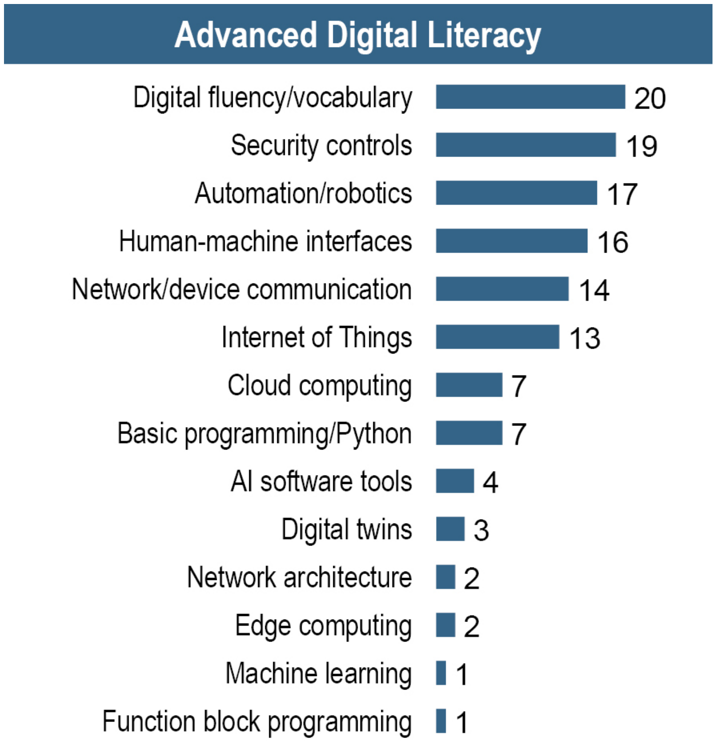

Fig. 3. National SIG initial prioritization of advanced digital literacy skill sets by the tallied number of votes (2019).

Fig. 4. National SIG initial prioritization of business knowledge and processes skill sets by the tallied number of votes (2019).

The Cross-Disciplinary STEM Core Framework

The skill sets within the Cross-Disciplinary STEM Core, as illustrated in Figure 1, are essential ingredients in today's technician education because they transcend narrow job specialization. As markets shift and companies adopt new technologies to keep pace, technicians must be able to move laterally to other jobs, learn new techniques, and work with new equipment. Technicians possessing the broader skills and knowledge found in the Cross-Disciplinary STEM Core will be more flexible in the types of work assignments they can accept, thus more valuable to employers and better suited for continued employment and promotion. The critical skill areas, associated skill sets, and recommendations for including them in technical programs are described in the project's white paper, A Framework for a Cross-Disciplinary STEM Core [15].

The Framework calls for employer prioritization of the Cross-Disciplinary STEM Core skills at a local or regional level. While the SIG data provides a national benchmark for comparison and the project will continue to examine national data, the data collected at regional convenings of stakeholders through a variety of methods (i.e., polls, interviews, discussions, surveys) revealed that the skills priorities differ somewhat across locales. Table 1, for example, illustrates the top data knowledge analysis skills sets across locations. While there is some overlap (e.g., computational thinking appears on all lists), there are also differences.

Table 1. Comparison of Prioritization of Data Knowledge and Analysis Skill Sets by Convening Region

Texas Gulf Coast: San Jacinto College (2020)	Arizona Sun Corridor: Maricopa Community Colleges (2021)	Southeast Wisconsin: Gateway Technical College (2022)
Data literacy/ fluency	Analytics tools Data analysis	Computational thinking/Data literacy (tie)
Analytics tools/ Statistics (tie)	Data visualization	Data management
Computational thinking/Data visualization (tie)	Computational thinking	Data modeling/ Spreadsheets (tie)

The North Carolina dataset was determined using a pilot instrument with a significantly different question, thus that data is not presented here.

The data from each regional convening was reviewed, and skill areas that would be the focus of their work were identified. This approach, reviewing data from multiple sources to build understanding, strengthens the conclusions. At the same time, the project acknowledges that identified priorities will need periodic updates to reflect the impact of evolving technologies on technician work roles. Another component of the Framework, incorporating cross-disciplinary skills into associate degree technician programs, is encouraged within NSF ATE projects, as evidenced by the ATE Program Solicitation, which calls for projects to "educate traditional students and returning learners to develop and apply technical, professional, industry-related, and entrepreneurship knowledge, skills, and competencies within the context of a technician education program" [16]. The conundrum is where and how to add cross-disciplinary content to associate degree programs. A starting point is for faculty to integrate cross-disciplinary lessons into existing courses rather than attempting to add new courses to an already full curriculum. Integrated lessons help students see a broader perspective of content relationships. Teaching the Cross-Disciplinary STEM Core might look like integrating data analysis and visualization into a bio-, geo-, or agricultural technology course. Taking cross-disciplinary instruction to a higher level might mean working with faculty members from different departments or programs to team-teach a skill set while highlighting its use in their respective fields.

Steps Toward Adoption of the Framework

Ideally, colleges will take a systemic approach to implement the cross-disciplinary STEM Core, as everyone has roles: faculty, instructional leaders, employer partners, and even college presidents. Innovations that promote cross-disciplinary teaching within the context of the regional workforce require stakeholder conversations that elicit employer needs, addressing those needs through integrated classroom activities, and providing faculty development.

Recognizing that systemic initiatives can be daunting, the project created Adopting the Cross-Disciplinary STEM Core: A Toolkit for Action containing steps and practical tools which can be adapted to facilitate the adoption of the Cross-Disciplinary STEM Core Framework in a local context [17]. The Toolkit is not prescriptive but instead encourages institutional flexibility. The steps can be completed in a non-linear way, with tasks running concurrently. The intent is for it to serve as a guide that encourages colleges to become familiar with the Framework and adopt a cross-disciplinary approach to preparing students for a rapidly-changing future.

The Toolkit lays out six steps, as listed in Figure 5, to facilitate the adoption of the Cross-Disciplinary STEM Core Framework in a local context. Each step begins with a checklist for determining college readiness to take recommended actions and then provides practical tools for implementing the actions.

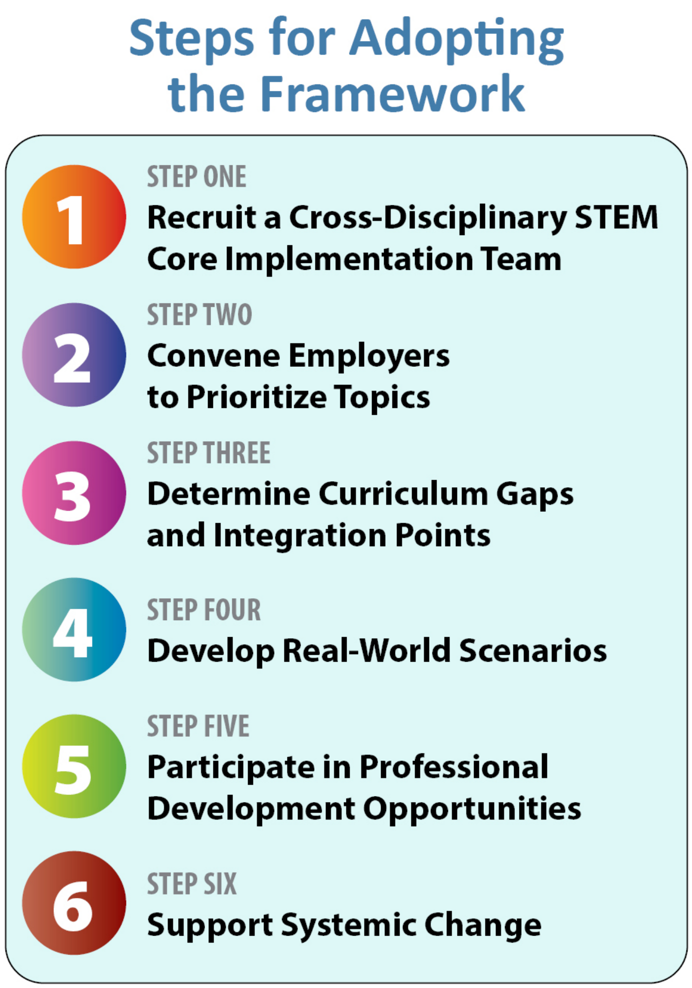

Fig. 5. Steps for Adopting the Framework for a Cross-Disciplinary STEM Core

Step 1, for example, is to invite faculty and administrators from multiple technical specializations across the college to a brief meeting introducing the Framework and to solicit volunteers and a team lead to help shepherd implementation and facilitate future meetings. Tools for facilitating Step 1 include a presentation for introducing faculty to the Cross-Disciplinary STEM Core and an adoption timeline for the implementation team to use.

Importance of Employer Engagement

The Toolkit's Step 2 showcases the vital role that regional employers play in adopting a less-siloed way of thinking about technician education. In Step 2, the college implementation team solicits employer prioritization of the Cross-Disciplinary STEM Core skills based on regional workforce needs. Their input will assist programs in determining which new skills to integrate. The suggested format for engaging employers is adaptable to participating colleges' and employers' needs and circumstances. This activity can be conducted in several ways – via face-to-face convening of employers, web-conferenced focus groups, or individual phone interviews. In addition, the Toolkit includes an online employer survey instrument that asks regional employers to rate skill sets within Advanced Digital Literacy, Data Knowledge/Analysis, and Business Knowledge/Processes on a scale of 1 to 4, with four being the most important and one being least important for entry-level technicians that their company will hire in the next 12-24 months.

The value of this step cannot be overstated. Robust employer engagement is essential in postsecondary technical training because, simply put, the primary purpose of the training is to help students develop the skills employers require in their workplaces. To be competitive in today's rapidly evolving high-technology marketplace, employers must have a sufficient pool of qualified job candidates with a strong work ethic and up-to-date technical skills. Unfortunately, many employers struggle to find the technicians they need. The Q1 2023 ManpowerGroup Employment Outlook Survey states that 76% percent of employers in manufacturing and in IT are ready to hire but cannot find the workers with skills they need [18]. Achieving optimum results in developing and sustaining a qualified workforce requires "ever-closer alignment between what goes on in the classroom and what graduates will be called upon to do in the workplace" [19]. Without input from employer partners, educators are poorly positioned to know precisely what those skill needs are. Experience has shown that employers welcome the opportunity to be involved.

Supporting this, the NSF ATE solicitation states that employers must be committed partners in all ATE projects. Moreover, several ATE projects focus specifically on industry partnerships. For example, the "Engaging Educators, Strengthening Practice: Creating & Sustaining Successful Industry-Education Partnerships" project (DUE #1931215), administered through Bellevue College in Washington, seeks to develop curriculum and support services and resources to assist educators in establishing and sustaining industry partnerships [20]. The ATE project "Building Pathways to Innovation in Skilled Technical Workforce Education Through Strategic Employer Engagement" (DUE #2039395) seeks to develop employer engagement with technical education programs by building on the Business Industry Leadership Team (BILT) model, a proven method for strategic employer engagement. Developed by the National Convergence Technology Center at Collin College, the BILT model enables colleges to develop employer relationships that yield in-depth workforce intelligence. BILTs differ from conventional business advisory committees by their greater frequency, specificity, and depth of employer input [21].

Determining Curriculum Gaps and Natural Integration Points

Step 3 of the Toolkit outlines actions for identifying where the skills prioritized by area employers are taught within existing programs and instructional gaps where cross-disciplinary skill sets could be easily integrated. The tool provided for this step is the Cross-Disciplinary STEM Core Curriculum Matrix, which faculty can annotate from multiple programs to denote existing lessons addressing the prioritized skills and potential integration points. Assisted by subject matter experts, the Preparing Technicians for the Future of Work project created instructional cards representing each of the three broad skill areas to support the implementation of the Cross-Disciplinary STEM Core [22]. The cards provide concise introductory activities that can be integrated into a broad range of technical programs. Both student and instructor content are built around real-world scenarios designed to introduce newcomers to the topic without having to add new courses to an already full program.

Development of Scenario-Based Instruction

Instructors who are ready to write their cross-disciplinary course material are advised in Step 4 to start with the development of real-world scenarios. The instructional cards created by the project can serve as a template. Cross-disciplinary lessons based on real-world scenarios help students see the content relationships between disciplines and prepare them to collaborate in the workplace. Well-designed scenarios:

- contain fact-based stories with input from regional employers,
- provide workplace context for the Cross-Disciplinary STEM Core skill sets,
- prepare students to examine a complex situation, and
- illustrate the need for using an integrated, cross-disciplinary instructional approach [17].

Employer engagement is again essential in this step. The Toolkit provides a checklist and interview template for instructors to use with employers to draft real-world scenarios drawn from local industry. After discussing skill sets within the cross-disciplinary STEM core, the interviewer should ask the employer to identify a challenging situation where a technician might encounter those skill sets. The interview template prompts the interviewer to record the specific steps a technician will need to take to address the problem and achieve a favorable outcome. This scenario then forms the basis for a cross-disciplinary lesson.

Initial Steps Toward College Adoption of the Framework

Widespread integration of cross-disciplinary STEM core skill sets into technical programs requires professional development. Step 5 describes how program leaders like deans and department chairs, instructors, and college administrators need to be introduced to the recommendations within the Framework for including advanced digital literacy, data knowledge and analysis, and business knowledge and processes in technical courses. The Toolkit includes a Cross-Disciplinary STEM Core Professional Development Plan that can serve as a checklist for identifying skill sets for faculty development.

Fundamental starting points are the definition of cross-disciplinary skills as applicable in many disciplines and the cross-disciplinary integration of skills as the teaching of skills within a traditionally unrelated discipline (e.g., basic programming within a biotech program). Faculty need professional development that guides them toward identifying cross-disciplinary integration points in their courses and effectively using scenarios demonstrating real-world use of the cross-disciplinary STEM core. In project-led learning opportunities, Florida, North Carolina, Wisconsin, and Texas instructors have implemented cross-disciplinary skills using the instructional cards, providing feedback, and planning activities that further cross-disciplinary collaboration. In Texas, for example, an instructor at San Jacinto College used the Data Literacy/ Fluency card activity with students in her drone pilot program as a capstone project. In the past, they had not gathered and analyzed their own data. The instructor collaborated with faculty in IT to learn more about using spreadsheets for graphing in Excel and with an industry partner in engineering to get assistance in analyzing data. At Rowan-Cabarrus Community College (NC), an IT instructor integrated the activity from the Entrepreneurship card, with its scenarios situated in industry 4.0, manufacturing, and IT hardware installation, into an Introduction to Ethical Hacking course. The activity led to discussions about the “entrepreneurial mindset,” the relationship between IT and I4.0, and the role of IT and business start-ups. At Palm Beach State College (FL), an instructor teaching Introduction to Biotechnology Laboratory integrated the Spreadsheets activity into all lab reports for the course, beginning with the first experiment. In each of these cases, faculty found natural cross-disciplinary integration points within their courses. It’s easy to see how this instructional strategy lends itself to bigger collaborative experiences for students and faculty, such as project-based learning.

Next Steps

While the first five steps of the Toolkit provide tools for college teams to use as they consider new instructional possibilities, Step 6 is a call to action for college presidents. Presidents can serve as catalysts of institutional change through messaging and funding supporting a cross-disciplinary collaboration culture. They are uniquely positioned to incorporate the implementation of the Framework for a Cross-Disciplinary STEM Core into the college’s strategic plan or promote it through a college-wide initiative.

Going forward, the project is offering technical assistance to colleges that wish to adopt the Framework. This involves coaching teams of colleges as they implement the Toolkit and work toward systemic instructional change in technician education programs. Teams from San Jacinto College, Brazosport College, Lee College, and Alvin Community College form the first cohort. They will be provided with actionable steps, practical tools, and professional development to support their institutions' Fall 2023 adoption of the Framework. Each college will select a multi-disciplined team of 3-4 faculty and administrators to participate in cohort activities and lead the initiative at their college. A series of case studies from this initiative will be shared with the field.

Another ongoing project activity that has the potential to benefit the field is a national survey of employers in advanced technology sectors, asking them to rate the importance of the 43 skill sets in advanced digital literacy, data knowledge and analysis, and business knowledge and processes. Employer partners of community colleges are encouraged to participate at https://www.surveymonkey.com/r/PtFOW_Employers_2023. Results may prompt a reexamination of the original Cross-Disciplinary STEM Core.

Conclusion

Educational innovations are more likely to be successful with wide buy-in and collaboration among instructional leaders and technical program faculty across disciplines and departments. Stated broadly, programs need to: prioritize topics from the cross-disciplinary STEM core that are most important to regional industry sectors, determine where in the curriculum new topics can be integrated, collaborate with employer partners to create instructional scenarios that have real-world value, provide faculty support for including new, cross-disciplinary content, and adopt a future-facing attitude of collaboration that aligns skills across programs with employer demand and anticipates the technician workforce needs of the future. Armed with direct input from regional industry leaders, community colleges should be well-positioned to lead continued regional dialogues on the future of work and coalesce support around stakeholder-driven expectations for technician education. Academic partners, industry leaders, and economic development professionals collaborating as thought partners in framing, testing, refining, and supporting strategies that transform technician education will assure continued regional competitiveness.

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