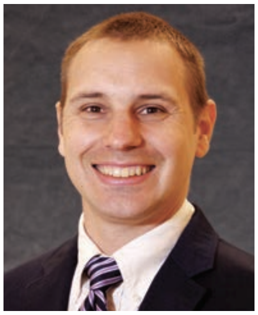

Letter from the Editor

Peter D. Kazarinoff

Department of Computing and Engineering, Portland Community College, Portland, OR 97219, USA

Keywords: J ATE, Journal of Advanced Technological Education

The Technician Education Community,

On behalf of myself, the J ATE Editorial Board, and our staff, I am excited to present the Journal of Advanced Technological Education (J ATE) Volume 2, Issue 1. J ATE is the peer-reviewed journal for community and technical colleges involved in technician education. J ATE is cross-discipline and covers all technologies under the National Science Foundation (NSF) Advanced Technological Education (ATE) Program. J ATE is open access: free to submit and free to read. All of our articles are released under a creative commons license.

We welcome your article in the next issue of J ATE. Here at J ATE, we strive not only to maintain high standards of quality and transparency in our review process, but also to be welcoming, inviting, and helpful to new authors. Our goal is to guide your manuscript through the publication process and to help you produce your best work possible.

This is J ATE's second full year, and we have seen remarkable growth. This issue contains five invited letters, and eleven full articles. Compared to our first issue, this is double the number of articles and about double the number of pages! *J ATE is growing*.

The theme of this issue is *Industry Engagement*.

Industry engagement is essential for successful community and technical college technician programs and happens with academic technician programs in a variety of ways. For example, industry regularly hires students and its representatives serve on advisory boards. Industry employees often work as part-time instructors, provide guest lectures, facilitate mock interviews, and interact on many different levels with students, faculty, and staff. This issue of J ATE highlights the work of several industry-academic collaborations.

The next J ATE issue will focus on undergraduate research at community and technical colleges. The submission deadline is **May 31, 2023**. Submit your article to J ATE and become a published author.

We invite you to join our community. Besides writing and reading J ATE, you can participate in several ways:

- Join our monthly Readers Group, Writers Group, or Reviewers Group
- Participate in our Professional Development Workshop Sept. 12-14, 2023
- Serve as a J ATE Reviewer
- Visit us at the HI-TEC Conference and NSF ATE PI Conference

If you have an article idea, don't hesitate to get in touch with me or any of the other J ATE Editors. We'd love to chat with you about your ideas and how to turn your great research into a published paper.

In Teaching and Learning,

Peter

Peter D. Kazarinoff
Editor-in-Chief

Invited Letter: Greetings from the National Science Foundation!

Keywords: NSF, ATE, Technician Education

As a program officer with the National Science Foundation's Advanced Technological Education Program (ATE), I am pleased to support the Journal of Advanced Technological Education (J ATE) and all its contributions to the technician education community. Congratulations to J ATE for 2 Years and 3 issues of publishing success.

The theme of this issue, Industry Engagement, is well aligned with work being done in the various Projects and Centers that make up a significant portion of the ATE program's portfolio. One of the many assets of the nation's community colleges is their opportunity to create and align credentials of economic value with regional industry needs. Meaningful engagement with regional industries is a dynamic process that has the potential to result in a partnership with a noticeable impact.

One of the core principles of the ATE program is that the degrees and certificates from two-year colleges hold enormous value. They have the kind of value that is occasionally sought after in the baccalaureate degree, but they require less time and are more accessible. The value of degrees and certificates increases with the participation of regional industry. When industrial partners see that their role on an advisory board or a business and industry leadership team (BILT) results in students completing with high-demand skills, the path from education to employment becomes easier to navigate. Industries that are able to hire local residents are in a good position to drive economic development for all residents.

The Journal of Advanced Technological Education supports two-year community and technical colleges with technician education programs in advanced technology industries. These programs include micro and nano technology, biotechnology, autonomous vehicle technology, advanced manufacturing, cybersecurity, environmental technology, and engineering. J ATE also disseminates important information about mentoring and evaluation in these programs. In addition, this journal supports all two-year colleges looking to establish, refine, or grow their advanced technology programs.

I encourage all members of the ATE community to consider the publication of your program's results. There are more than 1,000 community and technical colleges throughout the United States, and they are simultaneously similar and unique. Projects dealing with the conversion of automotive programs to hybrid and electric, for example, are of great interest throughout the country. A rural college with the only automotive program in a six-county area, through a published article in this peer-reviewed journal, has the potential to inspire similar colleges throughout the country. The same can be said of an indoor agricultural program located at a community college in the heart of a city. With each publication, the value of the ATE program grows, and more community colleges can gain the confidence to engage regional industry to drive regional economic growth.

I am one of three program officers at the National Science Foundation on rotation from a community college. With the entire division, we are working to advocate for community colleges at the agency. Serving my country as a program officer and supporting the goals of the ATE program is a truly rewarding experience.

As a proud supporter of technician education and a public servant with the National Science Foundation, I encourage your active participation in this community. You can support the ATE community by telling your story through submitted articles and by reviewing the articles submitted by your peers. Finally, you can be part of the dissemination process by sharing these articles with your peers and the colleagues who can benefit from them.

Mike Davis
Program Officer, ATE Program
The National Science Foundation

Invited Letter: Siemens Digital Industries Works with Education Partners to Offer Hands-On Learning

Keywords: Siemens Digital Industries, automation and digitalization, manufacturing, education-industry partnerships

Siemens Digital Industries (DI) is an innovation leader in automation and digitalization. Closely collaborating with partners and customers, DI drives digital transformation in the process and discrete industries. With its Digital Enterprise portfolio, DI provides companies of all sizes with an end-to-end set of products, solutions, and services to integrate and digitalize the entire value chain. Optimized for the specific needs of each industry, DI's unique portfolio supports customers to achieve greater productivity and flexibility. In addition, DI is constantly adding innovations to its portfolio to integrate cutting-edge future technologies.

Siemens DI believes the future of manufacturing must be taught in our schools today. To facilitate this, we provide several educational programs that partner with technical colleges to provide hands-on learning and experience on our automation software and hardware. These programs include Siemens Cooperates with Education (SCE), Siemens Mechatronics Systems Certification Program (SMSCP), Lifelong Educational Advantage Program (LEAP), and Siemens Go-PLM.

Participating as an industrial employer with the Preparing Technicians for the Future of Work ATE project team has provided Siemens with the ability to contribute to the tactile execution of educational priorities and influence the strategic direction of industry's collaboration with educational institutions in a positive fashion. The ability to share concepts and practices with others in industry has contributed to changes in our approaches to educational partners and customer conversations.

Of great benefit to educational institutions, the outcomes from these efforts have included understanding skills needs for manufacturing over the next decades. This provides the framework to build a curriculum so that students leave the institution 'work ready' and prepared to face industry challenges today.

Gail Norris
Director, SITRAIN Digital Industries Learning-US
Digital Industries-US
Siemens Industry, Inc.

SIEMENS

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 Computational thinking Data analysis Data backup and restoration Databases Data fluency Data life cycle Data management Data modeling Data storage Data visualization Query languages Spreadsheets Statistics	Artificial intelligence/machine learning Automation/robotics Basic programming Cloud literacy Digital fluency Digital twins Edge computing Function block diagram programming Human-Machine Interface (HMI) Internet of Things (IoT) Network architecture Network communication Security controls	Business cycles Blockchain Communication Continuous process improvement Customer/stakeholder analysis Entrepreneurship Ethics Lean processes Market trends Overall Equipment Efficiency (OEE) Return on Investment (ROI) Risk management Supply and demand 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.

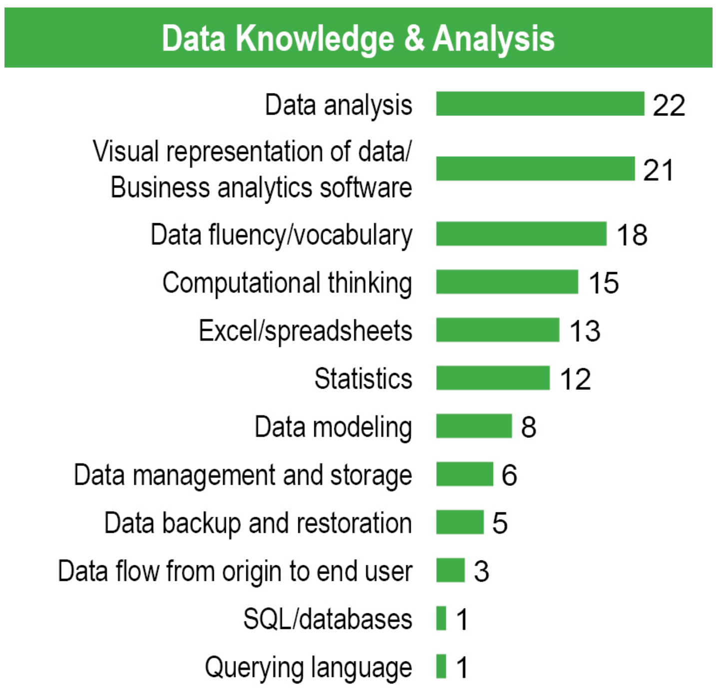

Fig. 2. National SIG initial prioritization of data knowledge and analysis skill sets by the tallied number of votes (2019).

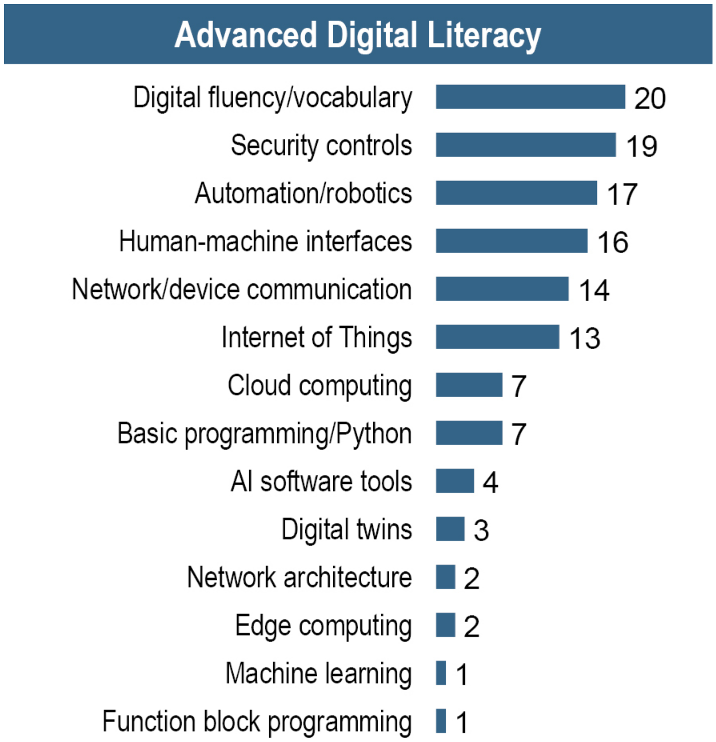

Fig. 3. National SIG initial prioritization of advanced digital literacy skill sets by the tallied number of votes (2019).

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.

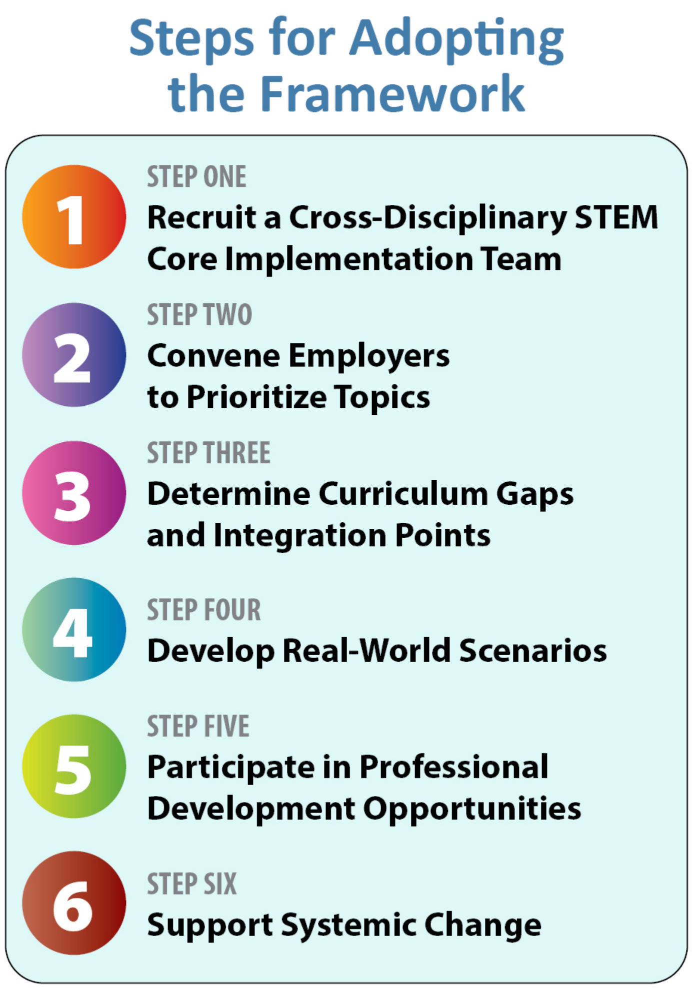

Fig. 5. Steps for Adopting the Framework for a Cross-Disciplinary STEM Core

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.

Acknowledgments. This material is based in part upon work supported by the NSF ATE award DUE #1839567.

Disclosures. The authors declare no conflicts of interest.

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Future of Work Skills Integration with Florida Manufacturers' Technician Skill Needs

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Abstract: Different perspectives on the "Future of Work" can cause disconnections between the technician skills needed by industry and those taught by the educational programs preparing technicians to participate in Industry 4.0 (I4.0) manufacturing environments. Variations in the methodology of identifying, grouping, and describing technical skills and skill areas are driven by variations in sources of information and the industries and locales they represent. This paper summarizes for the ATE audience a FLATE (Florida Advanced Technological Education Center of Excellence) project [1]—Technician Future of Work Issues Caucus for Florida Community Colleges and Manufacturers (DUE 1939173)—that compared the skills needed by Florida manufacturers to the skills taught at two-year Florida colleges, and then mapped those skills to the I4.0 skills identified by a national sampling of technology-focused industries carried out by the CORD project Preparing Technicians for the Future of Work (DUE 1839567) [2].

Specifically, the paper (i) reviews the I4.0 technology skills identified by the Boston Consulting Group; (ii) presents I4.0 skill interactions with the results from the CORD and FLATE projects; and (iii) maps Florida-identified technician skill needs to the Cross-Disciplinary STEM Core skills identified at the national level by the CORD project. The paper also summarizes the process for integration of the I4.0 technology-related skills into the AS engineering technology program offered by twenty-two colleges in the Florida State College System [3,4,5].

Keywords: Industry 4.0 Technology, Future of Work Skill Areas, Florida Skills Needs, Advanced Manufacturing Education

Introduction

Industry 4.0 (I4.0) environment requires technicians who can drive practical applications of I4.0 technologies by applying the appropriate engineering principles in engineering operation technology (OT) scenarios. To be effective, technician education must provide up-to-date, reliable, and relevant instruction that creates and cultivates professionals across its target workforce. Periodically, events demand alterations and even major adjustments in this education. The manufacture of transistor devices to replace vacuum tube technology and the launch of Sputnik are two 20th-century examples. More recently, technologies that integrate sensors, final control elements, and communication capabilities to send and receive data and operating instructions directly to and from manufacturing systems and subsystems is a dominant driver of innovation in STEM education. Applications of this new wave of I4.0 engineering and engineering technologies are finding their way into many technology areas and demanding societal adjustments.

Methods

The Caucus Process

The skill areas and skill set data reviewed in this paper were acquired using a caucus protocol for two projects supported by the National Science Foundation Advanced Technological Education (NSF ATE) program. In this paper, the projects are referred to as follows:

FL Caucus: Technician Future of Work Issues Caucus for Florida Community Colleges and Manufacturers (DUE 1939173; conducted by FLATE)

FoW: Preparing Technicians for the Future of Work (DUE 1839567; conducted by CORD)

The caucus approach was used because it put the experts in front of each other and allowed for small group activities and open dialog among participants. The projects originally planned for all activities and events to be in-person. Unfortunately, the COVID-19 pandemic caused both to shift to virtual events. FoW began hosting during the ATE leadership caucus, one conference special interest group (SIG) meeting, and its first regional in-person convening. The remaining events had to be conducted virtually. FL Caucus replaced its planned initial caucus with a questionnaire focused on entry-level manufacturing skills and two virtual caucus events separated by several months to provide time to review and analyze the data collected.

Although some of the events went by names other than "caucus" (e.g., "convening," "SIG"), they are all considered caucus events because of their format, agendas, and outcomes. Industry professionals and educators from multiple sectors and disciplines attended all. The attendees heard from subject matter experts and produced and prioritized lists of skills. Project teams reviewed and condensed the lists and distributed them to participants for review and approval. Caucus protocols involved initial exploration, confirmation of findings, and final review. All caucus events included keynote presentations that allowed participants to collectively consider expert views and guidance and focus on the event's overall goal. Both projects found the caucus process productive, whether in-person or virtual and a workable and convenient process for producing the desired outcomes.

Results and Discussion

Industry 4.0 and Future of Work Skill Areas and Skill Sets

Integrated technology systems and subsystems are being injected into industry at an ever-accelerating pace. Figure 1 presents the I4.0 technologies identified by the Boston Consulting Group [6]. These technologies are impacting, and will continue to impact, the technician preparation degree programs supported by the NSF ATE program, as is shown in Figure 2. The items shown in the two figures drove FoW's goal of identifying the I4.0 skills technicians need and what adjustments two-year technical degree programs should make to prepare technicians for this new multi-skill environment. There have been various graphic depictions of Industry 4.0 technologies and their interconnectedness, including anywhere between nine and twelve technologies that might highlight slightly different technologies than the representation developed by the Boston Consulting Group. For example, some, including one by Technord [7] with ten technologies and Digital Twins and MES/ Advanced Control Systems. Others include Artificial Intelligence and Machine Learning, which could be considered a technology of augmented and/or virtual reality or digital twins.

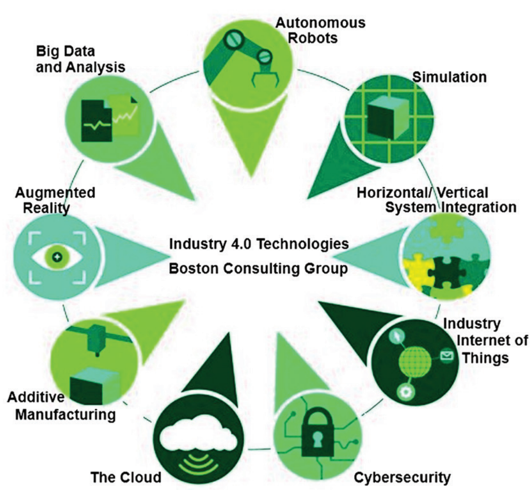

Fig. 1. Industry 4.0 Technology [1]

Fig. 2. NSF-ATE Technologies [2]

FoW began with a data collection phase. A caucus event (NSF ATE Leadership Caucus) was convened in December 2018 in Alexandria, Virginia. It brought together the Principal Investigators from the ATE Centers that support the technologies shown in Figure 2, industry representatives involved in the technologies in Figure 1, the project's Industry Advisory Committee, and program experts from NSF for a two-day meeting. These experts were formed into subgroups to discuss the cross-disciplinary STEM and "soft skills" expectations for technicians in their professional environments.

The FoW team grouped the skills identified by caucus attendees into three areas: Data Knowledge and Analysis, Advanced Digital Literacy, and Business Knowledge and Processes. The three areas are defined as follows:

(i) Data Knowledge and Analysis: Understanding, interpreting, and manipulating data to resolve issues using Excel and other common software proficiency to accomplish tasks.

(ii) Advanced Digital Literacy: Understanding digital communications and networking, cybersecurity, machine learning, sensor, programming, and robotics at a higher than introductory level.

(III) Business Knowledge and Processes: Understanding the value chain and business process of an enterprise and applying principles of ethical adoption of new technologies.

These three skill areas and their associated skill sets were disseminated at regional convenings. Participants in these events represented multiple disciplines and focused on emerging cross-disciplinary skills sets. Their contributions continue to inform the project's outcomes and dissemination strategy. The three skill areas, their associated skill sets, and suggested implementation strategies are presented in the FoW document titled "A Framework for a Cross-Disciplinary STEM Core" [8]. In addition, a 2019 report from the American Association of Community Colleges (AACC), the Arconic Foundation, and the National Coalition of Advanced Technology Centers (NCATC) offers a related view of the need for cross-cutting curriculum updates through the lens of integrating Industry 4.0 technologies [9].

Future of Work Skills in Florida Manufacturing

An early result of exploring I4.0 skill needs on the manufacturing floor at the national level was the recognition that manufacturers in different regions of the country and from different manufacturing sectors have different (though overlapping) expectations for the engineers and technicians in their work environments. Therefore, one of the FL Caucus's goals was to identify what emerging I4.0 skills are required on Florida's manufacturing floors. The project's first step was identifying the I4.0 skill sets expected by Florida manufacturers of the graduates of Florida's two-year AS Engineering Technology (ET) degree program, which focuses on advanced manufacturing.

Four of the nine I4.0 technologies shown in Figure 1 emerged through this exploration: Additive Manufacturing, Autonomous Robots, Cybersecurity, Industry Internet of Things, and Simulation. In Florida, these manufacturer-identified I4.0 skill needs differ according to variables such as the manufacturer's size, its primary products and processes, and where the company is implementing emerging technologies. For example, for the over 130 small-to-medium manufacturers polled, engineers and technicians in their facilities are not currently using Augmented Reality applications.

The next phase of the FL Caucus was to distinguish between skill sets needed by manufacturers and the skills currently being taught in the AS ET program. Figure 3 shows the results of two questionnaires that asked industry personnel and educators to prioritize the top five emerging skills needs. The figure's four blue labels—Autonomous Robots, Simulation, Industry Internet of Things, and Additive/Subtractive & Advanced Materials—correspond to I4.0 technologies shown above in Figure 1. (Whereas Figure 1 refers to "Additive Manufacturing," in Figure 3 we have altered that to "Additive/Subtractive & Advanced Materials" because the manufacturers always combined those technologies during the FL Caucus sessions.

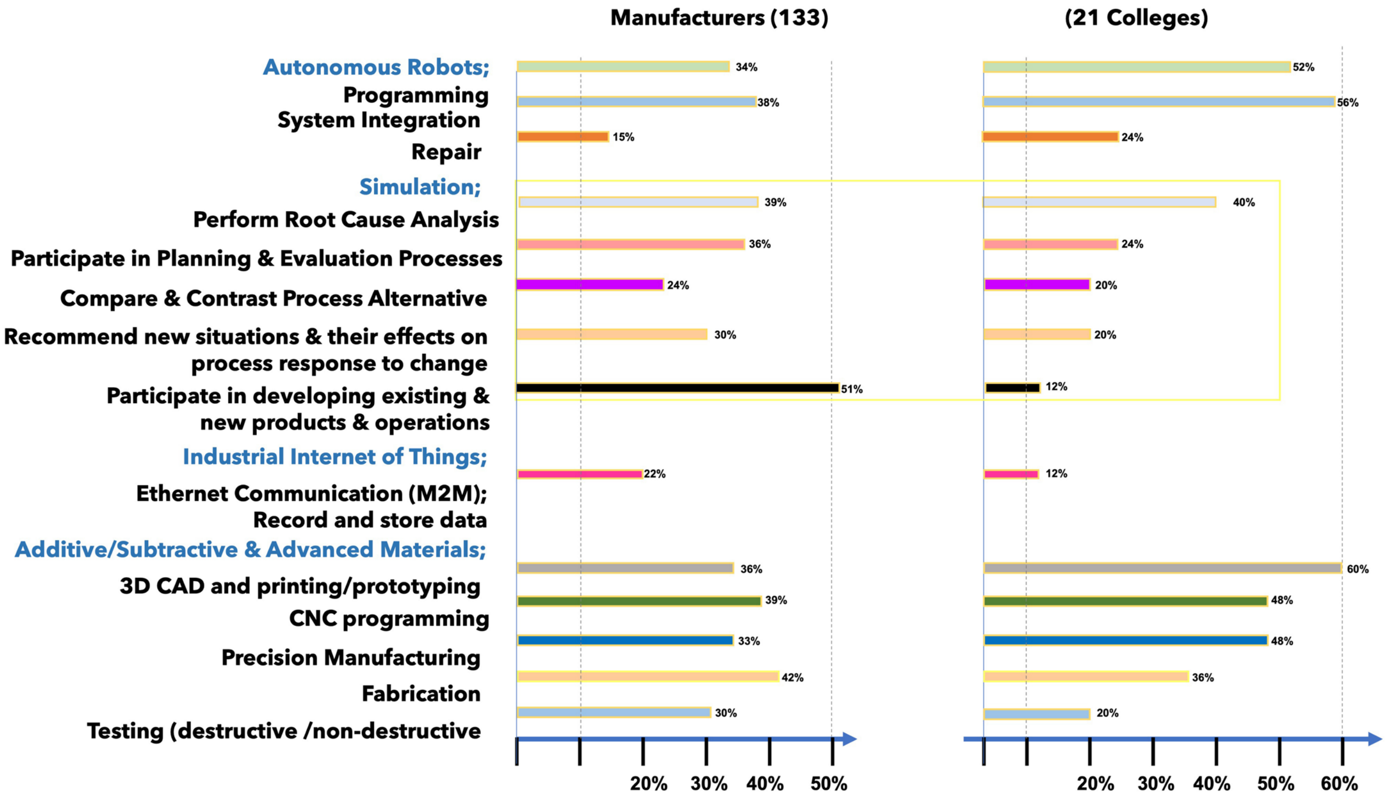

Fig. 3. Industry 4.0 Skills as Prioritized by FL Caucus Participants

The bars in the figure reflect the percentages of participant groups that identified skills needed (133 industry participants) and skills currently being taught (21 college faculty). Fifty percent of the manufacturers indicated a need for technicians to "Participate in developing existing & new products & operations," while only about 10 percent of the college faculty indicated that those skill subsets were being taught. In some cases, the colleges placed more emphasis on a given skill area than the manufacturers' need warranted. For example, while only 36 percent of the manufacturers indicated that "3D CAD and printing/prototyping" were needed skills, 60 percent of college faculty said those skills were being taught. Sometimes the two groups were closer to an agreement. Neither the manufacturers (22 percent) nor college faculty (12 percent) showed strong interest in "Ethernet Communications (M2M); Record and store data." (Those relatively low numbers do not reflect on the importance of the Industrial Internet of Things in general but are because few Florida industries are currently implementing those technologies.)

Florida Manufacturer-Identified Industry 4.0 Needed Skills

Participants in FL Caucus also identified the categories of manufacturing-related technician skills needed in Florida. Just as there are regional differences in the pronunciation and meanings of English words and phrases, terminology pertaining to I4.0 skills varies at the regional level. Figure 4 shows an alphabetical list of the 37 skills most frequently identified by the FL Caucus participants. Some of the items, numbers 7 and 27, for example, map directly to a skill in Figure 3: "3D CAD and Printing/Prototyping." Item 36 maps directly to "Perform Root Causes Analysis," a skill categorized under "Simulation" in Figure 3. The skills that do not obviously align were mapped after discussion by the project team and caucus participants.

1 Ask 5 Whys
2 Brainstorming
3 Cloud
4 Critical Thinking
5 Data Integrity
6 Programming
7 Prototyping
8 Quality Testing
9 Test & Executing
10 Three D Printing
11 Write SOP

12 Data Interpretation
13 Destructive Testing
14 Fishbones
15 Integrating Systems, PLC
16 Interdisciplinary Skills
17 Material Knowledge
18 Material Testing
19 Provide Design Data
20 Reverse Engineering
21 Support Mockup/Test
22 Troubleshooting
23 Use Root Cause Analysis

24 Awareness of the Security Requirements
25 Basic Understanding of Databases & Networks
26 Building/ Assembling Prototypes
27 CAD Layout for Production Processes
28 Diagnose & Understand Full Process
29 Ensure Measurement has Uncertainty Stated
30 Human Factors and Interactions
31 Identify Opportunities for Improved Products
32 Integration Eng. Tech. / Adv. Mfg. / Computing
33 Knowledge of Product Standards and Regulations
34 Math, Communication, Teamwork, Solve Problem
35 Spreadsheet Creation & Manipulation
36 Use Technical Tools to Identify Root Causes
37 Write Technical Reports including Data

Fig. 4. Needed Skills as Verbalized by FL Caucus Participants

Florida Technician Skill Map to Cross-Disciplinary Skills

The FoW project team mapped the 37 Florida-identified skills shown in Figure 4 to the national profile described in the project's "Framework for a Cross-Disciplinary STEM Core." The resulting alignment is shown in Figure 5. (The FL Caucus-identified skills are shown in red.) The headings of the three columns in the figure are the skill areas identified in the FoW Framework: Data Knowledge and Analysis, Advanced Digital Literacy, and Business Knowledge and Processes. The associated skill sets are listed alphabetically: 14 under Data Knowledge and Analysis, 13 under Advanced Digital Literacy, and 15 under Business Knowledge and Processes.

Data Knowledge and Analysis		Advanced Digital Literacy		Business Knowledge and Processes	
Analytics Tools	37,23,36	Artificial Intelligence Machine Learning	16	Blockchain	
Data Analysis	19	Automation/Robotics	10,22	Business Cycle	
Computational Thinking	2,22,34	Basic Programing	6	Communication	11,12,30,34,37
Data Backup, and Restoration		Cloud Literacy	3	Customer/Stakeholder Analysis	30,31
Databases	37,25	Digital Fluency		Continuous Process Improvement	31
Data Life Cycle		Digital Twin	32	Entrepreneurship	7,20
Data Fluency	5,29	Edge Computing	32	Horizontal & Vertical Integration	15,22,28
Data Management	37	Function Block Diagram	27	Ethics	12
Data Storage		Programming	6	Lean Processes	1,23
Data Modeling	12	Network Communications	25	Logical Chains	
Data Visualization	37	Human-Machine Interface (HMI)		Market Trends	31
Query Languages		Industry Internet of Things		Overall Equipment Efficiency (OEE)	8,9
Spreadsheets	34,35	Network Architecture		Return On Investment (ROI)	
Statistics	34	Security Controls	24	Risk Management	30,33
				Supply and Demand	

Fig. 5. FL Caucus-Identified Skills Mapped to FoW-Identified Skills

Figure 5 shows the alignment of the FL Caucus-identified skills to the skills identified in the FoW Framework. For example, the first skill set under the heading Data Knowledge and Analysis, Analytics Tools, aligns with FL Caucus skills 37, 23, and 36 in Figure 4. In addition, Figure 5 data indicated that 89 percent of the skills shown in Figure 4 are aligned to FoW Framework-identified skills. By contrast, four skill sets in the Data Knowledge and Analysis skill area of the FoW Framework were not specifically identified by FL Caucus participants as important emerging skills.

Four skill areas shown in Figure 5—Data Backup and Restoration, Data Life Cycle, Data Storage, and Query Languages—may reflect more on the stage of I4.0 implementation by Florida's small/medium manufacturers than on the current need for their technicians to possess those skills. Small/medium manufacturers are investing in new process equipment that supports their manufacturing missions and includes a suite of input/output (IO) communication options. However, sensors and final control elements that use those I/O options are not yet included in their process schemes. It is interesting to note that the Florida manufacturers' responses to emerging needs include several skills that focus on working with data at a higher level, and it would be expected that more specific responses such as "Data Backup and Restoration," "Data Life Cycle," "Data Storage," and "Query" will be brought into Florida technician preparation programs during the 2024 triannual review cycle. Thus, the remaining skill sets are "waiting in the wings" for their call to action. Similar analyses can be made for items in the other two skill areas. Differences in wording and interpretation probably account for most of the remaining non-aligned skills.

Skill Insertion into 2-Year Technician Programs

The next phase of I4.0 skill integration into Florida's ET technician workforce required the insertion of identified Figure 4 skills into AS ET degree programs. Although twenty-three state colleges offer the degree, the curriculum for the degree's first year of study is identical in all those colleges. The second year of coursework is similar among the colleges, with variations that allow each college to address industry sectors in their service areas. Variations in these second-year course options make each program unique and increase the difficulty of maintaining uniformity throughout the state. This uniformity is critical since AS ET degree holders from any of the twenty-three colleges can transfer their degree-related courses into any ABET BS ET program in Florida. The vehicle for unification is the Florida Department of Education (FDOE) Standards and Benchmarks, which apply to all CTE and AS degree programs in the state [10].

The FL Caucus leadership team reviewed relevant FDOE Standards and Benchmarks with the objective of tagging the skills in Figure 4 to existing standards. The team determined that 33 skills were directly tied to FDOE Standards, while there were no connections to four skills: Basic Understanding of Databases & Networks, Cloud, Data Integrity, and Data Interpretation. In addition, five skills were identified as having "questionable connections": Building/Assembling Prototypes, Integration of Engineering and Technology, Advanced Manufacturing and Computing, Interdisciplinary Skills, and Writing Technical Reports, including Data. FDOE oversees updating its standards and benchmarks for each AS degree and CTE program on a three-year cycle. The FDOE review team of educators and industry professionals will need to address the missing and questionable connections to ET degree standards and benchmarks that have been identified by this work during the next review cycle.

Conclusion

I4.0 technologies are being infused into manufacturing environments at an ever-accelerating pace. Consequently, the skill needs of technicians and engineers in the emerging ET workplace demand that technical faculty and their programs take immediate steps to insert knowledge and "hands-on" instruction that focuses on the skills that support I4.0 technologies. For experienced two-year technician preparation faculty, the challenge of doing so may stem more from the new vocabulary associated with I4.0 than from faculty expertise. Results from these NSF projects reveal both linkages and disconnections between existing programs and I4.0 skill needs and demonstrate impact-verifiable facilitating pathways that apply nationally and regionally.

Acknowledgements. This work was funded by the National Science Foundation under ATE DUE #1839567 and DUE #1939173.

Disclosures. The authors declare no conflicts of interest.

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Enhanced Podcasts as Content Acquisition Tools

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Abstract: Podcasts are a cohesive instructional tool for professional development. When podcasts include enhancements such as resource links, transcripts, and learning resources, they can be described as *content acquisition podcasts* (CAP) grounded in the Cognitive Theory of Multimedia Learning. The author presents a logic model for podcast design that identifies the outcomes and impact of CAPs. As a method for professional development, podcasts are shown to be further enhanced by guidance documents that help learners identify and align content to their needs. A complete profile of a podcast is presented as a scenario to illustrate the design and methodology of the approach. As an extension, learner-created podcasts are highlighted as a method of promoting active engagement and collaborative learning.

Keywords: pedagogical methods, podcasts, podcasting, professional development, active learning

Introduction

The future workplace will require technicians who can navigate complex environments in which existing jobs are constantly evolving and new jobs are being created. Likewise, educators are faced with a technical skills landscape that is constantly evolving and changes quickly. How does, how can an educator keep pace? For professional development, podcasts can provide a personalized, timely, and convenient approach.

This article reviews podcasts as a professional development tool and posits how podcasts can be enhanced to deliver content supported by the cognitive theory of multimedia learning. This approach is illustrated by scenarios in which podcasts catalyze content acquisition and increase accessibility through multimedia approaches, linked resources, and transcripts.

Leveraging Podcasts for Preparing Technicians for the Future of Work

The National Science Foundation-funded project *Preparing Technicians for the Future of Work* [1] faces challenges that include rapidly accelerating advancements in technology. This means resources for learning and professional development on these emerging topics may not yet be available. The project aims to:

- Develop recommendations and resources for updating STEM technical programs,
- Identify industry's perception of the future of work and implications for technician education, and
- Identify new technologies impacting technician education.

The project has developed numerous future-facing strategies and resources designed to help achieve its goals. These include creating a framework [2] and toolkit [3] for adopting a cross-disciplinary STEM core to provide essential foundational skills for students in technician preparation programs. The project has also produced 44 podcasts that can support the development of the framework's foundational skills by identifying perceptions, implications, and technologies that will impact future workforce requirements in STEM fields.

Podcasts as Pedagogy

Podcasts are beginning to displace print media for people worldwide who seek to engage with information in novel ways. In addition, podcast creators increasingly prioritize accessibility by publishing transcripts alongside audio content and linking supplemental material [4]. There is growing evidence of the potential for enhanced podcasts to deliver content on demand for a variety of diverse audiences [5]. Podcasts offer the possibility of creating instructional materials that are both easy to use and grounded in validated instructional design principles [6].

Content acquisition podcasts (CAP) deliver a cohesive instructional product. CAPs differ from regular podcasts and other multimedia in that they are grounded in Mayer's Cognitive Theory of Multimedia Learning [7] (CTML). CTML grew out of cognitive load theory, which holds that all learners have limited cognitive processing capacity at any given time and that if that capacity is overloaded, new learning is unlikely. Instruction should therefore be designed and delivered to keep learners' limited cognitive levels from becoming overwhelmed [8].

Method: Podcast Design

Podcasts could be described as contextual interviews. CAPs utilize *structured* contextual interviews in which questions are designed to elicit not only responses but also the background behind the responses. This provides essential context that can enrich the learning experience. A CAP may include a call to action that challenges the listener to take that action as a step in their own professional development. Furthermore, the design of a CAP can utilize a storytelling approach. The value of stories as "a powerful structure for organizing and transmitting information" and as a learning tool is well recognized [9]. A CAP in which content is amplified via a story increases listener engagement.

Motivation and Outcomes of Podcast Listening

The literature supports the idea that "openness to experience, interest-based curiosity, and need for cognition positively predicted podcast listening" [10]. As an outcome, podcasts can create connections to subject matter experts and a larger community that shares and adopts podcast content. Additional outcomes and impacts are shown in the logic model in Figure 1. This is not a general logic model, but highlights the outcomes and impacts that relate specifically to advanced technological education.

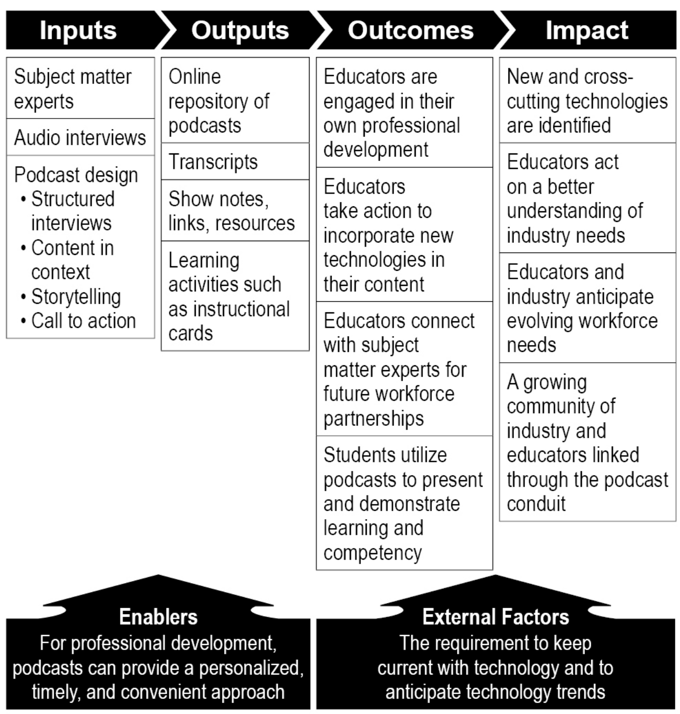

Fig. 1: Logic Model for Professional Development Through Enhanced Podcasts

Method: Podcasts for Professional Development

For those involved in preparing the skilled technical workforce [11], there is a need, demand, and requirement to keep current with technology and to anticipate technology trends. This currency must be reflected in classrooms and training environments. Traditional methods of professional development, such as attending workshops with slide presentations and (where possible) gaining hands-on skills with specific equipment, are often inadequate in today's educational environment. Today's technology educators are more likely to turn to multimedia platforms such as podcasts for self-directed professional development that is more personalized, timely, and convenient than the conventional approach.

Professional Guidance

For technology educators seeking professional development, assessing and choosing resources that align with their needs may be challenging. To address this challenge, the *Preparing Technicians for the Future of Work* project prepared a user-friendly reference guide [12] that shows essential takeaways from each podcast. Users can quickly find the technology or skill featured in an episode along with that podcast's key discoveries and suggested actions.

The reference guide is organized into four topical categories:

- Automation, Robotics, and Advanced Manufacturing
- Digital Skills, Digital Mastery, Digital Twins, and Simulation
- Industry, Factory, and Education Trends
- New Skills, New Generations of Students

Table 1 shows an excerpt from the guide. Users can quickly "discover" facts and trends and pursue professional development opportunities associated with those topics.

Table 1: Sample of *What Educators Should Know and Do about Preparing Technicians for the Future of Work*

Topic and Episode(s)	Discovery	Recommended Action
1. The Emerging Workforce of Advanced Manufacturing Podcast (PC) 35(a)	In Advanced Manufacturing, **Adopt AI or Fall Behind.**	Realize the importance of artificial intelligence and machine learning in technician training. Review this article(e) and this podcast(f) on the subject.
2. A Robot for Every Technician? PC13(b) and PC22(c)	**A robot for every technician** is an emerging trend in the workplace.	Ask yourself if it is possible for you to consider something similar in your education and training space? A robot (or an automated system) for every student, in every learning situation?
3. Robotics Skills, Robotics Careers PC25(d)	There is a particularly large gap between the number of robotics technicians available and the number needed. To begin addressing the gap, the Institute has outlined three promising career pathways: Robotics Technician, Robotics Specialist, and Robotics Integrator.	Explore roboticscareer(g). If you have an education and training program, consider, at the minimum, submitting your program for inclusion in their database. It is free to do so. In addition, there may be real value in your program becoming endorsed.

(a) https://www.preparingtechnicians.org/episode-35-the-emerging-workforce-of-advanced-manufacturing/
(b) https://www.preparingtechnicians.org/episode-13-a-robot-for-every-technician-a-look-at-trends-driving-manufacturing/
(c) https://www.preparingtechnicians.org/episode-22-here-come-the-cobots/
(d) https://www.preparingtechnicians.org/episode-25-robotics-skills-robotics-careers/
(e) https://labmidwest.com/11-ways-artificial-intelligence-will-transform-manufacturing/
(f) https://techedpodcast.com/11-predictions-how-artificial-intelligence-will-transform-manufacturing/
(g) https://www.roboticscareer.org/

Method: Profile of An Enhanced Podcast

The *Preparing Technicians for the Future of Work* podcast series (44 episodes) [13] is a clear example of enhanced podcasts as content acquisition tools. The target audience consists of educators and industry personnel involved in preparing the skilled technical workforce — individuals who use science and engineering skills in their jobs but may not have bachelor's degrees. The podcasts are designed to give educators a deeper understanding of coming changes, the availability of resources, and the strategies necessary to stay up to date. In this way, the podcast series constitutes a cohesive instructional product.

The following represents a scenario that illustrates the design, content discovery, augmentation/enhancement, and additional resources that create the enhanced podcast.

Scenario: Here Come the Cobots

This episode [14] considers the topic of collaborative robots (cobots) as part of the rapid growth in automation that is now occurring throughout the technology industry sector. Cobots are robots that can safely work alongside humans and are intended for direct human-robot interaction. The podcast host establishes the credentials of the guest (an industry expert), who describes the tremendous growth in cobots over the past three to five years. These statistics grab listeners' attention and engage them in a topic that may not be familiar to educators. Skills and competencies identified in the episode prompt listeners to contemplate changes in courses and curricula. A "key learning" is highlighted: *for technicians, knowing how to integrate automation technology is more important than understanding the technology itself*. This can cause fundamental shifts in workforce preparation programs.

The podcast moves into a storytelling stage that illustrates how people without prior knowledge can learn about cobots. The podcast concludes with a call to action: *gain more familiarity with cobots*. Downloadable shownotes identify additional resources and resource links [15], and the transcript provides an alternate means of access. The guide provides a link to instructional cards [16]—scenario-based microlessons for introducing new technology skills in existing courses. As a result, this enhanced podcast provides motivation, a call to action, and resources for self-directed professional development.

Podcast Creation in the Classroom as a Learning Activity

The concept that "you don't really know something until you can explain it to someone else" can be used to encourage students to create their own enhanced podcasts as a method of demonstrating their understanding and competency (i.e., a performance assessment). This approach is a variation of the Feynman technique [17], which involves being able to teach a given topic to someone else. Students can create podcasts using readily available technology for recording, editing, and transcribing. By adding their own resource links, they create an enhanced learning experience for themselves and demonstrate their knowledge. As a teaching tool and strategy [18], learner-created podcasts have been shown to promote active engagement and collaborative learning [19].

Conclusion

Enhanced podcasts increase accessibility and engagement by providing additional resources to help listeners better understand and retain information. In addition, these enhancements reframe podcasts as *content acquisition podcasts* that can be used as a self-directed professional development approach or employed as a student learning activity. Podcast design, the approach to content discovery, and the nature of the enhancements all contribute to the viability of enhanced podcasts as content acquisition tools for professional development.

Acknowledgements. This work was funded by the National Science Foundation under DUE ATE #1839567.

Disclosures. The author declares no conflicts of interest.

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Invited Letter: AEA Advocacy Includes Avionics Technicians

Keywords: Aircraft Electonics Association, aviation, aviation technician training, avionics technicians

I am, first and foremost, a professional aircraft mechanic. I began my career as a line mechanic working on Huey (UH-1N) aircraft, transitioning to Sikorsky HH-52 helicopters, then Lockheed HC130 aircraft. During my military experience, I obtained my Federal Aviation Administration (FAA) mechanic certificate with airframe and powerplant ratings and began working on a wide range of general aviation aircraft. As my maintenance career evolved, I finished the line maintenance chapter as the chief inspector/director of quality.

Following my line maintenance chapter, I progressed into the advocacy activities of the trade association of Washington, representing aviation maintenance individuals and businesses before the FAA. Currently, I work with the Aircraft Electronics Association (AEA) providing regulatory training and counsel, writing a monthly column for Aviation News, and continuing to advocate before the FAA as well as international authorities worldwide. In addition to my position with AEA, I also support individual maintenance technicians as a member of the board of directors of the Professional Aviation Maintenance Association (PAMA).

Founded in 1957, the Aircraft Electronics Association represents nearly 1,300 member companies in more than 40 countries, including approved maintenance organizations specializing in the maintenance, repair, and installation of aircraft electronics systems in general aviation aircraft. The AEA membership also includes manufacturers of aircraft electronics equipment, instrument repair facilities, instrument manufacturers, airframe manufacturers, test equipment manufacturers, major distributors, engineers, and educational institutions.

The association's mission is to educate, communicate, and advocate for aviation businesses worldwide that manufacture, support, and install innovative technologies for flight. The association represents businesses that employ well over 100,000 technicians. Their work ranges from the design and certification of aircraft electronics systems and the manufacturing of these systems to the installation and maintenance of the latest technologies.

An avionics technician is a unique qualification that involves a fundamental understanding of science, technology, engineering, and mathematics. The science and theory of electricity, sound, and movement; the digital technology of the most advanced computer technologies; the engineering design and application of aircraft design and the integration of electronic technologies; and well as the mathematics necessary to install and repair electronic technologies are the working environment of an avionics technician.

Ric Peri
Vice President, Government & Industry Affairs
Aircraft Electronics Association
Washington, DC
Lees Summit, MO

AIRCRAFT ELECTRONICS ASSOCIATION

A Data-Driven Flight Proficiency Benchmark for Small Unmanned Aircraft Systems Curriculum at Two-Year Institutions of Higher Education

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Abstract: To fly an unmanned aircraft system (UAS), commonly referred to as a "drone," the Federal Aviation Administration requires pilots to pass a knowledge test. There is no official requirement at the state or federal level for drone operators to demonstrate the ability to operate a UAS. The National Institute of Science and Technology (NIST) has created an exam for basic UAS flight proficiency. It created this exam for public and private entities to assess basic flight proficiency. However, NIST does not provide a scoring recommendation and leaves it to the exam user to determine the minimum criteria to pass. Hence, there is limited literature on scoring recommendations and none pertaining to institutions of higher education. This paper fills this gap by evaluating the performances of carefully selected UAS pilots who participated in the study. Their performance was divided by percentile and used to provide recommended benchmarks that community colleges can use with their flight skills assessments. This is particularly useful when the NIST exam is used for graded assessments.

Keywords: UAV, UAS, NIST, drone, proficiency

Introduction

Unmanned aerial vehicles (UAVs), commonly referred to as drones, are used in many applications. UAV refers to the drone or the aircraft itself. An unmanned aircraft system (UAS) is the total system that includes the drone, controller, and anything else that is required to keep the drone in flight. Some applications or uses for drones include delivering life-saving medical packages [1], retail deliveries [2], supporting first responders during disasters [3], inspections of critical infrastructure such as bridges and highways [4], monitoring construction projects [5], traffic monitoring [6], and land surveying [7]. As of December 2022, there were 870,389 commercial and recreational drones registered in the US [8].

Pilots are required to obtain a "remote pilot certificate" from the Federal Aviation Administration (FAA) to fly a drone for commercial purposes in the US. This knowledge test is a computerized test conducted at a third-party testing site. A practical examination is not a requirement in order to operate a drone for commercial use and presents a source of risk. Pilots may be licensed without having operated a drone. Without flight proficiency included with the license, there is no federal guidance on the minimum level of flight proficiency before pilots can operate a UAS in the national airspace. The lack of a convenient method of assessing flight proficiency creates a risk for organizations with drone pilots and the drone community as a whole [8]. This is an acute issue for two-year institutions with UAS coursework. Currently, there are no recommendations for what level of flight skills students should have upon completing an effective drone program.

This study addresses this issue by answering these two questions.

1) Can a proficiency exam be created and recommended to two-year institutions?

2) Can a tier level of proficiency with scoring metrics be identified to help train remote pilots?

For this study, the research institution used a sample of 52 pilots selected from a general population of drone pilots primarily working for state and government agencies. The pilots had their part 107 remote pilot certificate but did not have significant experience operating a UAS. These criteria were intentionally chosen for benchmarking because they represented the proficiency of entry-level UAS pilots.

Background and literature review

2.1 Drones as an emerging technology

UASs have become commonplace over the past several years. As a result of the expansion of uses and applications, drones have penetrated a wide range of industries. This growing trend of services and popularity has raised many concerns about drone safety and effectiveness and a growing demand for means to assess pilot competence. As organizations increase their use of UAS technology, it has become incumbent that two-year institutions incorporate this technology into their curriculum.

The FAA considers a UAS and a crewed plane both “aircraft”; however, it treats their licensure differently. It is essential to understand the knowledge requirements for obtaining a manned aircraft license and the required practical assessment. It is important to understand the gap between the extensive practical requirements for a manned aircraft license and the absence of a practical examination requirement for a UAS license. Manned aircraft pilots must demonstrate extensively that they can fly, whereas drones do not have any flight proficiency standards.

To obtain a Title 14 Code of Federal Regulations Part 61 manned aircraft certification, the FAA requires 40 hours of flight time with an instructor and additional flight time solo. After the pilots have completed ground school testing, they can partner with an examiner to complete the practical exam. Even if a pilot receives a private license, it only licenses them to fly that specific type of manned aircraft.

2.2 Advanced Technological Education (ATE)

The National Science Foundation’s (NSF) ATE program was created to support two-year higher education institutions and help fund the education of technicians for high-technology fields [9]. The ATE program supports the education of these technicians, who are critical to economic development and national security. Congress mandated ATE as one of the first congressionally endorsed programs at the NSF in 1992 [10]. The ATE program invites research proposals that advance the body of knowledge concerning technical education. For this paper, we will expand on ATE’s support of technical education with respect to UASs.

Since 2008, ATE has awarded 30 grants to support the development of technicians in the UAS industry, ranging from geospatial data systems to agricultural development, workforce planning, and other autonomous technologies [11]. Figure 1 shows an increase in the number of awards, primarily starting in 2015 and reaching a peak in 2019 at six awards per year. The COVID-19 pandemic most likely significantly impacted the number of awards granted in 2020 and 2021; however, there has been a rebound in 2022, with three awards within the first four months of the year. Monitoring the number of awards by ATE supports this research and shows the importance of two-year institutions educating drone pilots.

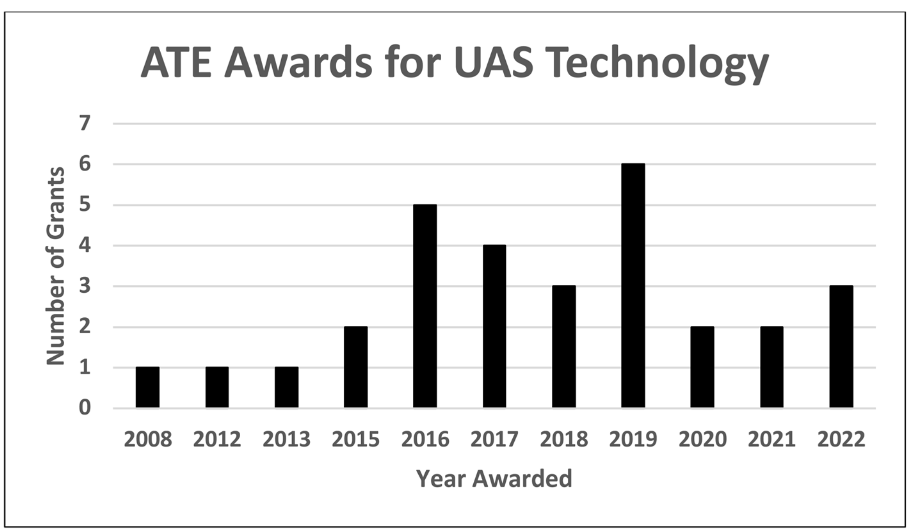

Fig. 1. ATE Awards by Year for Drone Technology

2.3 Two-year institutions supporting this growing industry

Community colleges across the US are developing drone programs to support these growing industries, and ATE has played a large part in funding these initiatives. Since 2008, ATE has awarded funding to 21 different colleges. The Old Dominion University Research Foundation and Northland Community & Technical College have received the most awards to date, with three awards each. For this research, monitoring these awards shows the emphasis these institutions and the NSF place on the UAS industry and the importance of education with respect to the UAS industry.

2.4 What areas are funded by these institutions?

For this research, each award provided by ATE was categorized into five major groups: Geospatial, Drone Workforce, Agri-Drone, Autonomous Tech, and Drone Sensors. As shown in Figure 2, Geospatial is the leading category based on the relevant geospatial data acquisition, analysis, and exploitation with the use of UASs. Other geospatial-related topics focus on creating student opportunities within this technical workforce. The geospatial industry is being fueled by the increasing number of drones being manufactured, registered, and capable of building new ways of applying geospatial technologies.

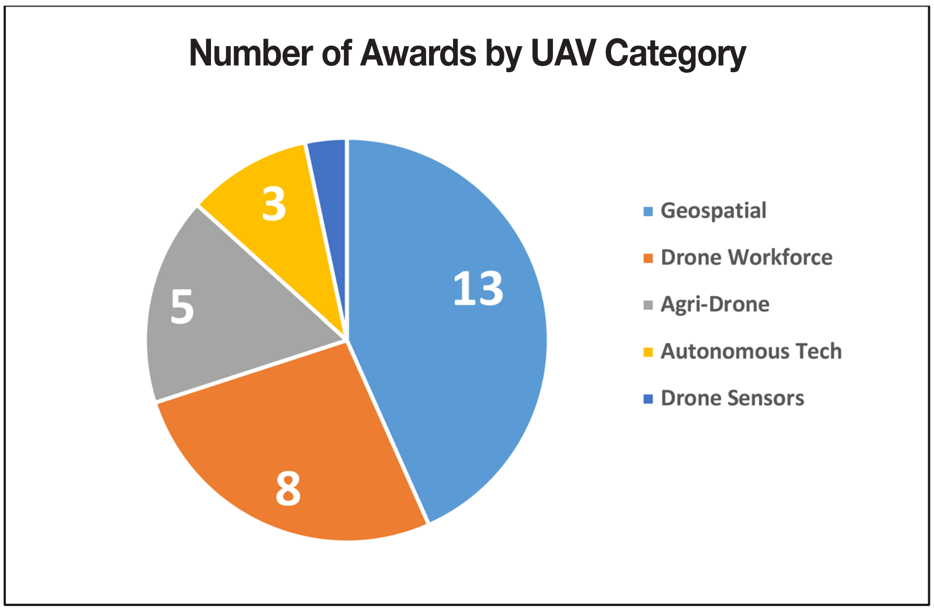

Fig. 2. ATE Awards by Category

2.5 Why does the industry need two-year institutions to have UAS training programs?

In the US, pilots flying a drone for anything other than recreational purposes must earn a Part 107 remote pilot certificate from the FAA. To earn their remote pilot certificate, pilots must take a computerized knowledge test at an FAA-approved testing site. Pilots must also register their drone with the FAA online using the FAA drone zone website before operating their drone commercially. Currently, there is no practical examination to identify flight proficiency, as there is with a manned aircraft license. This creates a potential risk for commercial operators with respect to safety, skill assessment, and risk management if it is not addressed. Owing to the FAA not requiring a minimum level of flight proficiency, employers, organizations, and higher education institutions must develop standards for what constitutes an acceptable level of flight proficiency.

2.6 National Institute of Standards and Testing (NIST)

NIST was founded in 1901 as part of the US Department of Commerce [12]. NIST's mission is to promote innovation and competitiveness by advancing science, standards, and technology in ways that enhance security and improve quality of life [12]. Next, NIST develops the measures and means to quantitatively evaluate robotic systems and UAS pilot proficiency [12].

NIST has created low-cost and simple test methods for UASs that assist in objectively measuring and comparing system capabilities and remote pilot proficiency. Because NIST does not train or certify pilots, it leaves this final task to other standards development organizations, such as the Airborne Public Safety Association (APSA) and National Fire Protection Association, to determine which metrics are appropriate for individuals and organizations to adopt.

In the following sections, examples of the Open Test Lane and Basic Proficiency Evaluation for Remote Pilots (BPERP) are explained with the understanding that NIST recommends no scoring metrics and that this final step is left up to the administrators to determine on their own what an acceptable passing rate is.

2.7 NIST Open Test Lane

The NIST Open Test Lane includes five different maneuvers, as shown in Figure 3. Five bucket stands are constructed in such a way that image targets are created at the bottom of each bucket. The pilots must perform these maneuvers while a proctor calls out different instructions. The image targets must be captured clearly, and the drone should be positioned an "S" distance from the bucket. The distance "S" is a predetermined variable that the proctor can set before the test begins. For example, the "S" distance could be set to 10, 20, or 30 feet from the buckets to be awarded a point.

Maneuver 1: The position test requires the pilot to capture images while moving forward and backward along a center lane. Maneuver 2: The traverse requires pilots to rotate in a pattern around the bucket stands 1, 2, and 3. Maneuver 3: The orbit test requires a rotation around bucket stand 3 clockwise and counterclockwise. Maneuver 4: The spiral test calls for the pilot to fly around all four bucket stands in order, alternating from clockwise to counterclockwise. Maneuver 5: The recon test requires an in-line flight from the launch pad to the last bucket stand.

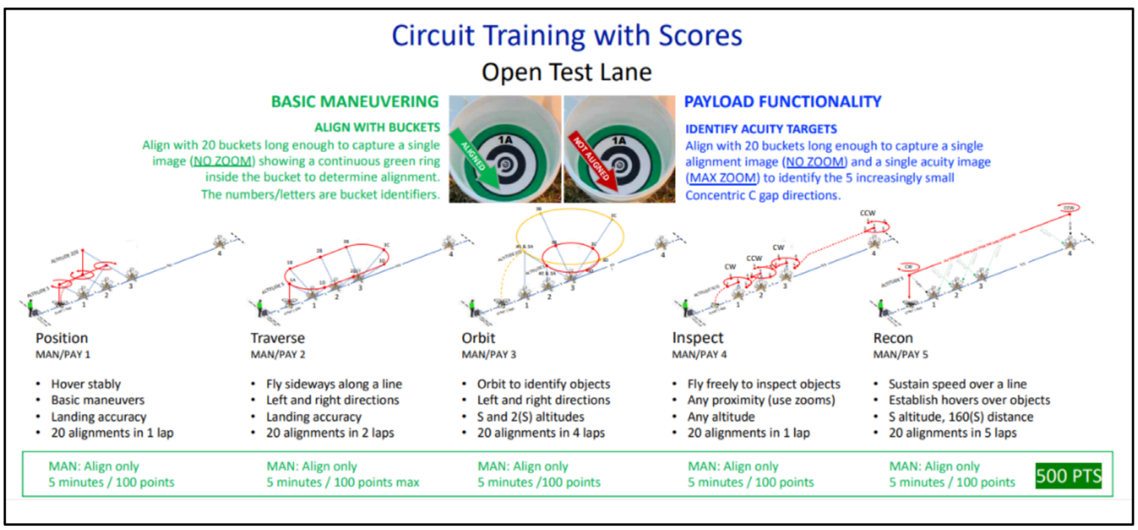

Fig. 3. NIST Open Test Lane Exam [13]

2.8. NIST Basic

Proficiency Evaluation for Remote Pilots (BPERP)

Created by NIST, the BPERP is a combination of the first two maneuvers from the Open Test Lane described in Section 2.7. NIST does not define a scoring or timing criteria, but it can be given in 10 minutes using three bucket stands, a 50-foot tape measure, and a stopwatch. The BPERP takes up an area of 50 feet by 20 feet and can easily be taken indoors or outdoors [14]. The tests are carried administers with a visual observer present. The pilot flies the flight paths in alignment with the buckets. Each alignment requires the pilot to capture a single image of a green ring inside the buckets. Because NIST does not certify pilots or recommend scoring metrics, there have been other nationally recognized and reputable organizations, such as APSA, that can provide a flight certification. APSA recommends that the remote pilot capture 32 out of the 40 image alignments with accurate landings within the designated 10-minute time limit to pass the BPERP exam.

APSA is a nonprofit organization founded in 1968 that supports and encourages the use of aircraft for public safety. APSA's goal is to support, promote, and advance the safe and effective use of manned and unmanned aircraft by governmental agencies in support of public safety operations through training, networking, advocacy, and educational programs [15]. Currently, it has over 3,000 members at both the international and local levels. APSA provides networking systems, educational seminars, and product expositions that members find invaluable [15].

Methodology

Data Collection

Three NIST Open Test Lanes were constructed at a soccer field on the research institution's campus. The soccer field was ideal for the study due to the area being spacious and level. The experiment was given on a sunny day with a light breeze. Each lane was assigned an administrator to help with flight instructions, record the times, and provide any safety precautions. Each pilot was assigned to a test lane, and an additional pilot would record the exam with a secondary drone positioned at an altitude of 250 feet. The research institution provided either a DJI Mavic [16] or a DJI Phantom [17] drone to complete the test. The two drones used in the study have similar characteristics, with any differences considered negligible.

The pilots that participated in the study were Part 107 pilots that predominately worked for state and local government agencies. Most had minimal flight experience but were considered competent to fly a drone by their agency. Considering that the participants were novice pilots, the sample would be comparable to students at two-year institutions.

Once the pilots completed the five maneuvers, they were directed to proceed to a research lab nearby to perform the test using a recently developed simulator. The simulator was programmed to represent the test conditions closely. The pilots were given instructions through the simulator, just as during the outdoor test. Instructions were provided on the simulator screen in addition to the auditory instructions. The script mirrored the text provided on the NIST scoring sheet that was used with the outdoor open lane test. The controller had a standard configuration as the drone controllers. Participants captured images using a button on the controller similar to the actual drone controller. The camera could be pitched up or down with the roll button on the left side of the controller. Once the image was taken, a "camera click" could be heard before the next instruction began. Specific weather conditions could be set, but a clear day with no wind was set for this experiment. These conditions were used in the outdoor open-lane examinations. The research administrators used laptops with appropriate RAM to run the software necessary. Lab assistants were available to assist with logistics, but the simulator was entirely self-administered.

The research institution identified the correlation of specific maneuvers and combinations of maneuvers to measure the strength of the relationship to the overall NIST Open Lane Exam. Using the adjusted R-squared method provided a more accurate understanding of each maneuver or combination of maneuvers by comparing each of them to the overall 5 maneuver NIST Open Lane Exam. RStudio was used to build the multi-linear regression model using a built-in data set using the participant's flight data.

Percentiles were used to determine each maneuver's scoring requirement and flight time requirement and the different groups of maneuvers. In addition, using percentiles for the various maneuvers would help describe how a score compares to other scores from the same set. This would help build the different levels of proficiency and group pilots based on their flight accuracy and expertise.

Results

The first objective was to determine how well the BPERP predicts flight performance compared with the more elaborate open lane suite. The next objective was to understand which of the five maneuvers (individually) or which combination of maneuvers would best estimate the average of all five of the NIST Open Test Lane maneuvers. Finally, we would identify an appropriate pass rate based on the sample of novice practitioners that were examined.

3.1 Statistical Goodness of Fit

A statistical "goodness of fit" analysis from the 90-flight test was conducted. Understanding how each of the five NIST Open Test Lane maneuvers fits the overall five-maneuver (dependent variable) data set would aid in determining which of the five maneuvers instructors could choose from, given a priority list. Providing instructors with a shorter exam saves time, space, and financial resources. In addition, just as importantly, it has a near-equivalent assessment value as compared to the overall NIST Open Test Lane. Each of the five maneuvers has two criteria that should be met: score and time. A proctor reviews the score to determine if the images of the targets meet the scoring criteria as a pass or fail. Next, and more importantly, is the time elapsed during the completion of the maneuver.

Table 1 explains how well each maneuver represented the overall five-maneuver NIST Open Test Lane exam with respect to flight time. We used the score from the overall five-maneuver Open Test Lane exams as the dependent variable. The adjusted R-values indicate the strength of a linear relationship among the overall five maneuver exams and either a single exam or a grouping of exams. Two two-year institutions may choose an individual maneuver or a smaller subset of maneuvers if they have limited time, space, or financial resources. This will assist them in deciding which exam to choose.

Table 1. Adjusted R-Values for Flight Times of Individual Mans and Combinations of Mans

Maneuver #	Adjusted R-Value
Maneuver 1	0.8471
Maneuver 2	0.7399
Maneuver 3	0.8991
Maneuver 4	0.9177
Maneuver 5	0.8654
Maneuver 4 & 5	0.9420
Maneuver 1 & 2	0.9213
Maneuver 2 & 3	0.9175
Maneuver 3 & 5	0.9563
Maneuver 3 & 4	0.9494
Maneuver 2 & 3	0.9364

4.2 Why Is Time More Important?

When analyzing the data from BPERP exams, the study found that 93% of participants passed the image scoring portion of the test, but only 48% met the time requirement. Further, nearly 44% of all flights recorded passed the image scoring portion of the exam with a perfect score. This led the researchers to believe that meeting the time requirement is much more difficult than meeting the image scoring requirement. So, for this research, more weight and significance are placed on the time requirement than the scoring requirement.

4.3 Flight Time Ranked Individually

When evaluating the pilot's time, the research indicated that each maneuver has a close goodness of fit compared to all five maneuvers from the Open Test Lane exam. The researchers then determined how closely correlated the current BPERP test was to the overall five-maneuver Open Test Lane after the maneuvers were prioritized or listed in a way that showed the goodness of fit for each maneuver. Finally, because NIST had already established the BPERP, the researchers focused on this test to determine if another maneuver or combination of maneuvers should be used instead of the BPERP.

After examining the adjusted R-values for flight times, the current BPERP (Man1 + Man2) indicates a good fit to times from the entire open lane suite of maneuvers. Table 2 shows a high adjusted R-value of .9213 for the participants' times compared to the overall NIST Open Test Lane exam. This study identifies the BPERP as a good predictor of flight proficiency compared to the full open lane suite based on the adjusted R-values shown in Table 2. This is important to help validate, based on this research, that the BPERP can be used to create not only a basic proficiency exam but also a multitiered flight proficiency exam with various levels that pilots can achieve.

Table 2. Times for BPERP-Adjusted R-Value (Combination of Man1 + Man2)

Maneuver	Adjusted R-Value
Maneuver 1	0.8471
Maneuver 2	0.7399
BPERP (Maneuver 1 and 2)	0.9213

Discussion

The following flight combinations in Table 3 represent a diverse range of flight patterns, maneuvers, and difficulties. Because there are five different flight maneuvers, this would result in 12 different combinations of flight maneuvers. Still, the researchers selected these based on the criteria of patterns, maneuvers, and difficulty as mentioned before.

Table 3. Adjusted R-Values for Flight Times Across a Sample of Maneuver Combinations

Sample Maneuver Combinations	Adjusted R-value
Maneuver 1 & 2	0.9213
Maneuver 2 & 3	0.9175
Maneuver 4 & 5	0.9420
Maneuver 2 & 4	0.9364
Maneuver 3 & 4	0.9494
Maneuver 3 & 5	0.9563

Institutions can use the following tables (4 and 5) to create a customized training or testing course outline. Using the adjusted R-value for each maneuver for scoring and/or flight times, either using individual or different combinations of maneuvers can be helpful.

Table 4. Recommended Testing Outline for Image Scoring

Adjusted R-value	0.6556	0.7753	0.7642	0.6982	0.7307
Percentiles of Image Scoring	Maneuver 1	Maneuver 2	Maneuver 3	Maneuver 4	Maneuver 5
90.0%	20	20	20	20	20
80.0%	20	20	20	20	20
70.0%	20	20	20	20	20
60.0%	20	20	20	20	20
6.0% (BPERP)	16	16	NA	NA	NA

Table 5. Recommended Testing Outline for Flight Times

Adjusted R-value	0.8471	0.7399	0.8991	0.9177	0.8654
Percentiles of Image Scoring	Maneuver 1	Maneuver 2	Maneuver 3	Maneuver 4	Maneuver 5
90.0%	0:02:40	0:02:34	0:02:58	0:03:12	0:03:29
80.0%	0:03:03	0:02:49	0:03:27	0:03:40	0:03:41
70.0%	0:03:22	0:03:11	0:03:46	0:04:03	0:04:01
60.0%	0:03:57	0:03:35	0:04:25	0:04:26	0:04:15
6.0% (BPERP)	0:05:00	0:05:00	NA	NA	NA

Table 6 breaks down the percentiles and the respective flight times associated with each percentile. When comparing the APSA's current BPERP test, the research shows this test fits in the 50th percentile and helps establish this as a basic or beginner level of proficiency.

Table 6. Percentile of Times for Establishing Different Proficiency Levels

Percentile	Time
90.0%	0:05:09
80.0%	0:06:08
70.0%	0:06:30
60.0%	0:07:29
50.0% (BPERP)	0:10:00 (APSA criteria)

To provide instructors at two-year institutions with a benchmark for flight proficiency, the researchers established the proficiency level and grade recommendation shown in Table 7. The grade recommendation is based on the 10% percentile tiers of the sample data. The times have been rounded for ease of use in the field or classroom setting.

Table 7. Recommended Proficiency Levels Using the BPERP as the Basis

Proficiency	Percentile	Time	Score
Level/Grade (Recommendation)		(minutes)	(Total 40)
A	90.0%	0:05:00	40
B	80.0%	0:06:00	40
C	70.0%	0:07:00	40
D	60.0%	0:08:00	40
BPERP	50.0% (BPERP)	0:10:00 (BPERP)	32 (BPERP)

Conclusion

For instructors at two-year institutions looking to establish their UAS training criteria, the complete NIST Open Test Lane exam may be their initial starting place. However, before doing so, it is necessary to consider that the full five-maneuver open lanes can be time-consuming to build and set up and require additional space beyond what is required with the BPERP.

The good news is that other options available are statistically similar in predicting flight performance and can be used to establish a reputable training program with fewer resources. Going back to the five maneuvers that constitute the NIST Open Test Lane, the researchers present different combinations of maneuvers that can be quicker to set up, are less expensive, and require less space to administer. For example, the first three maneuvers only require three bucket stands, only take up roughly 50 feet in length and 20 feet in width, and can be administered in approximately 10 minutes as opposed to including maneuvers four and five, which require a total of 100 feet in length and require more time and resources.

In conclusion, the flight times for our sample participants have been broken into percentiles to establish a proficiency scoring method. The top 10% of pilots completed the BPERP test in five minutes and nine seconds or less. Continuing with building these levels of proficiency required breaking the dataset into four additional parts and by percentile of the pilots' flying times. This is intended to give instructors at two-year institutions the ability to create different levels of pilot proficiency.

Disclosures. The authors declare no conflicts of interest.

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Design and Development of Mixed Reality (MR) Laboratory Tools to Improve Spatial Cognition, Student Engagement, and Employee Safety

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Abstract: Immersive technologies such as Virtual Reality (VR), Augmented Reality (AR), and Mixed Reality (MR) have become worldwide technological innovations superimposing the computerized simulation with the physical world. The thriving concept of simulating an interaction environment broadens the researchers' competence to design the ideal virtual experimental conditions and sufficiently manipulate the environment's layouts. Researchers are reporting the significant impacts of AR, VR, and MR applications that have led them to investigate potential capability in several areas, including STEM-related fields. Moreover, researchers concluded that AR-assisted courses tend to enhance students' learning and spatial cognition and increase student motivation and engagement in the learning process.

In this study, the researchers explore their previously developed MR applications to assist students in improving spatial cognition and independent/engaged learning. Additionally, the discussed tools provide simulated immersive laboratory experiences for remote learners.

Keywords: virtual reality, augmented reality, student engagement, employee engagement, safety, motivation in education

Introduction

VR has recently developed as a prevalent technique adopted in numerous fields of scientific experiments. The thriving concept of simulating an interaction environment broadens the researchers' competence to design the ideal virtual experimental conditions and sufficiently manipulate the environment's layouts.

VR is a broad term incorporating a wide range of computer simulations [1] that provides an immersive experience to the user via a head-mounted display (HMD). Although the VR technology varies, the common purpose of VR is to enable a human-computer interface that simulates an alternate three-dimensional (3D) environment and augments audio-visual graphics, referred to as AR, in this study. In addition, AR provides on-demand data, thus facilitating and enriching the employees' work [2] in real-time applications. This leads to redesigning the training material for the manufacturing and safety industry [1] and is expected to become more flexible.

The MR, on the other hand, combines both VR and AR technologies and merges real and virtual worlds, where physical and digital objects interact in real-time to provide enhanced 3D information to the users [3,4]. This enables the users to visualize the immersive virtual world and the real world and interact with those objects. A study by Richter, et al. in 2022 discussed the challenges of video materials in education, especially during the Covid-19 pandemic, and proposed VR simulations for immersive experiences for

teachers and students (Richter, et al., 2022). Additionally, the authors argued that VR makes it easy to generate materials from a first-person perspective as opposed to a third-person perspective. However, a systematic literature review [5] discussed the most frequent adverse events after a VR exposition could be disorientation and nausea. Therefore, this study focuses on developing AR/VR/MR simulation tools to limit extended exposure in the virtual environment. These simulated endeavors aim to generate simulated trainers, limiting the simulation use time to 20 minutes or less; or activities to develop muscle memory for students in STEM fields and create potential AR applications for workers frequently exposed to hazardous materials.

This study discusses six case studies with custom-developed AR, VR, and MR tools to improve spatial cognition, student engagement, and employee safety and provide services to the COVID-19-impacted communities as part of relief efforts. This study aims to broaden the emerging technologies and generate discussion on the potential positive outcomes that these novel technologies may offer to STEM fields. The researchers discuss six case studies supporting the conversation with the discovered outcomes from each AR, VR, or MR-related activity. The researchers use IBM's Statistical Package for Social Sciences (SPSS) statistical analysis tool to conduct comparative analyses using t-Tests for dependent and independent groups, multivariate analyses, and Tukey's post-hoc tests [6].

Methods and Results

Case Study 1

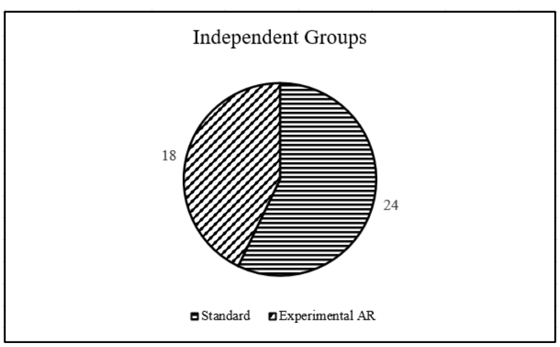
This study involved the introduction of an AR tool in primary school students. It investigated the effectiveness of an AR tool for promoting engaged learning in technological literacy for STEM education [7]. Forty-two children (25 female and 17 male) from three different first-grade classes with diverse socio-ethnic backgrounds participated in the study, as seen in Table 1. One of the classes experienced a conventional teaching method by their class teacher, the second class experienced the integration of the AR tool in their learning, and the third class participated in both modes. This way, the researchers achieved two groups for study and attempted to attain homogenous participation with limited interruptions of the outcomes.

Table 1. Frequency Distribution of Participant Gender

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Male	17	40.5	40.5	40.5
	Female	25	59.5	59.5	100
	Total	42	100	100	

The research team separated the participating students into two groups, a control group (Standard=24) and an experimental group (Experimental AR=18), to explore the developed AR tool's effectiveness in students' learning and engagement, as shown in Figure 1. Both male and female students participated in the standard and experimental groups in a randomized fashion.

Fig. 1. Distribution of Standard and Experimental AR groups



An independent sample t-Test is conducted on the response of the students that participated in the study. The control and experimental groups have a total of 24 and 18 participants, respectively as shown in Table 1. The descriptive statistics table (Table 2) illustrates that the mean value for the Experimental AR group increased by 4.736 points, where the mean value for the standard group was Mean 1 = 11.875 and the mean value for the Experimental AR group was Mean 2 = 16.11.

Table 2. Descriptive Statistics for Participating Groups (Standard & Experimental AR)

Group Statistics					
Response Participants Score	Participant Groups	N	Mean	Std. Deviation	Std. Error Mean
	Standard	24	11.875	4.377	0.893
	Experimental AR	18	16.611	2.524	0.595

The independent sample t-Test (Table 3) showed a significant difference between the two groups, p = 0.001< p = 0.05 alpha level. Therefore, the student's involvement and participation in academic learning with the integration of the AR tool improved significantly.

Table 3. Independent Sample t-Test Analysis for the Standard and Experimental AR Groups

Independent Samples Test										
		Equality of Variances		t-test for Equality of Means						
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Interval of the	
									Lower	Upper
Response Participants Score	Equal variances assumed	7.257	0.010	-4.100	40	0.000	-4.736	1.155	-7.071	-2.402
	Equal variances not assumed			-4.412	37.849	0.000	-4.736	1.073	-6.909	-2.563

Student learning success is highly dependent on the availability and literacy of experiential technological tools provided to them. The researchers introduced the first-grade teachers to the AR tool, as seen in Figure 2, used in this study. Once the teachers became familiar with the application of the AR tool, they provided demonstrative education to their classes. Overall, the investigators observed that cognitive reasoning [4] and interest in learning improved with the integrating of AR tools in the classrooms. Although the first-grade teachers commented that uncertainties of technological devices might hinder technological literacy in students, the AR and VR tools could benefit the student's retention of the newly introduced material at an early age.

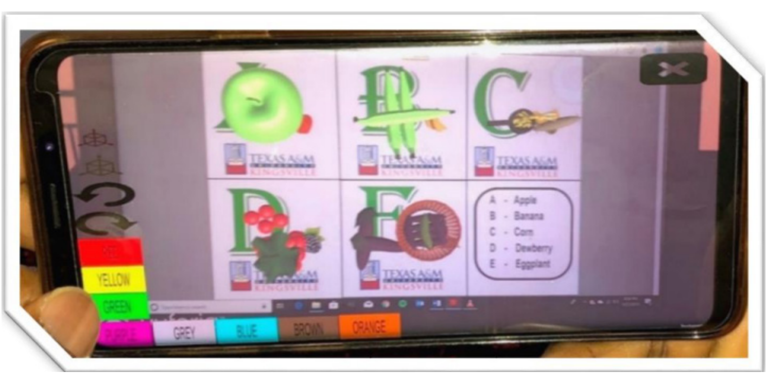


Fig. 2. Augmented Reality Tool, 3D representation of Objects, with the Image Target.

Case Study 2

The effects of disaster training with and without the Augmented Reality Mobile (ARM) tool, as seen in Figure 3, were explored to study the experimental design. The study subjects, Undergraduate Engineering Technology students from first-year to senior year, participated in the disaster response activity by designing and constructing a Mobile Renewable Response Trailer (MRRT).

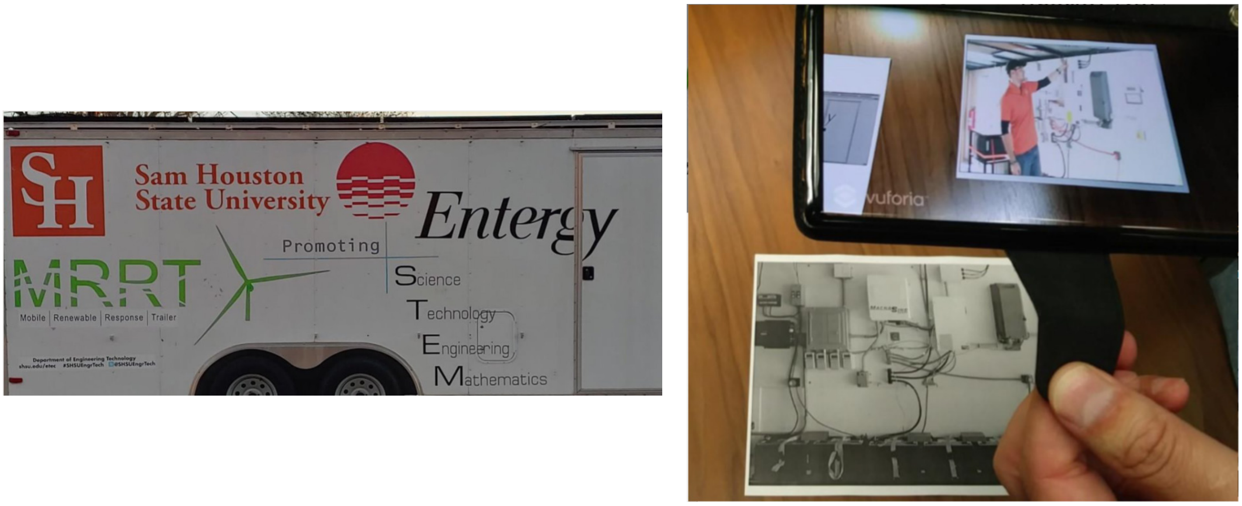


Fig. 3. Right side view of MRRT.

None of the participants previously had any operation in emergency response vehicles; therefore, the control and treatment groups were randomly selected to participate in the study. Two participating control groups (CG1 & CG2) were given a scenario where they needed to operate the MRRT from a non-operational stage to assist the disaster victims and provide power without any assistance from the trained first responders. In contrast, the treatment group (TG) received ARM to repeat the same tasks on the spot. The researchers compared the timeliness of the equipment setup between the three groups, where CG1 was asked to set up the trailer equipment, CG2 was asked to set up the trailer equipment with a step-by-step instructional operation manual, and the TG was asked to set up the trailer using the ARM application on a tablet or phone [4,8].

Case Study 3

The ability to visualize 3D objects and their orthogonal views and manipulate those images is a cognitive skill that is vital to many STEM fields, especially those requiring work with computer-aided design (CAD) tools [9]. In addition, research suggests that well-developed spatial skills of this type are critical to successfully advancing in engineering and many other fields [10]. These spatial skills involve visualizing 3D objects and perceiving their different orthogonal viewpoints if they were rotated in space.

A group of CAD students (freshmen and sophomores) participated in this study. A total number of thirty-five (4 female and 31 male) students completed a spatial orientation test. The spatial orientation test was used to explore students' spatial cognition and was comprised of 10 questions in which the participants must select the correct orientation of a given part. In addition, in each class, instructors provided a 3D representation of a part of the virtual environment for students to analyze before class, as seen in Figure 4.

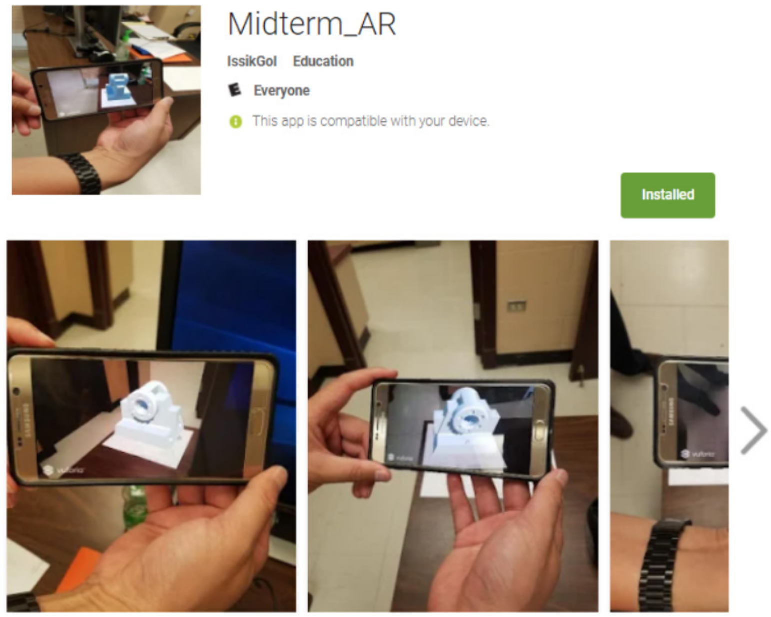


Fig. 4. Analysis of a 3D model for CAD class

Paired sample t-Test resulted in the students finding the correct orientation after they analyzed the part (Pretest Mean = 1.42 < Posttest Mean = 8.58) within the virtual environment, as seen in Table 4.

Table 4. Paired Sample t-Test Descriptives for Freshmen and Sophomore Engineering Students

		Mean	N	Std. Deviation	Std. Error Mean
Pair 1	Pretest	1.42	19.00	0.69	0.16
	Posttest	8.58	19.00	0.84	0.19

Additionally, SPSS t-Test results indicate a significant difference (p value=0.00 < alpha level 0.05) between the test results when the students were exposed to the virtual analysis of the 3D part model with a 95% confidence interval, as reported in Table 5.

Table 5. Paired Sample t-Test Mean Comparison to Compare the Influence of a VR

		Paired Differences					t	df	Sig. (2-tailed)
					99% Confidence Interval of the Difference				
		Mean	Std. Deviation	Std. Error Mean	Lower	Upper			
Pair 1	Pretest & Posttest	-7.16	0.83	0.19	-7.56	-6.76	-37.40	18.00	0.00

Although the t-Test analysis showed significant differences between the pretest and posttest average means of the scores, the correlation table indicates a slight correlation between the two scores, as seen in Table 6.

Table 6. Correlation between the Pretest and Posttest outcomes for Spatial Orientation

		N	Correlation	Sig.
Pair 1	Pretest & Posttest	19	0.418	0.075

Moreover, the researchers needed to investigate more to see if the involvement of a VR tool in the 3D modeling class would improve the spatial orientation skills of freshman and sophomore engineering students, as seen in Table 7.

Table 7. Paired Sample t-Test Descriptives for Freshmen and Sophomore Engineering Students

		Mean	N	Std. Deviation	Std. Error Mean
Pair 1	Pretest	6.06	16.00	2.82	0.70
	Posttest	919	16.00	0.98	0.25

The descriptive statistics in Table 8 show that students' post-test mean values were slightly higher than the pretest, meaning that the interjection of VR into the model analysis improved students' spatial visualizations.

Table 8. Paired Sample t-Test Analysis for the Influence of a VR in Fall 2017 Semester

	Paired Differences							
				95% Confidence Interval of the Difference				
	Mean	Std. Deviation	Std. Error Mean	Lower	Upper	t	df	Sig. (2-tailed)
Pair 1 Pretest - Posttest	-3.13	3.18	0.80	-4.82	-1.43	-3.93	15.00	0.00

The paired sample t-Test between the mean values at the beginning of the semester, with and without the introduction of a VR environment to analyze virtual parts, indicated a significant difference (p value=0.00 < 0.05 alpha level) between the test scores. This result shows that the students understand the structures of the 3D model when they inspect it in the virtual environment. It should also be noted that the descriptive statistics produced a higher mean value for the posttest boxplot as well as one extreme outlier for the posttest for the spring 2017 data points. The reason for this outlier was calculated inaccurately since SPSS multiplied by 1.5 IQR [11]. Therefore, the researchers decided to review the data point and concluded the histogram of the data was normal for the posttest data. The data score of 6 was not an outlier. Therefore, the researchers believe that restructuring an introductory CAD course could help instructors engage and motivate students and train skilled drafters/modelers with less effort.

Case Study 4

The AR_GHS (Augmented Reality Globally Harmonized System) safety tool was developed for employee awareness and training on OSHA-determined nine pictograms, as seen in Figure 5 [8]. Employee awareness of pictograms requires workers to retrieve and understand potential hazards in proximity (OSHA) as they perform janitorial tasks on the premises. The assembly of OSHA determined nine pictograms to be selected since these pictograms are internationalized and exist in almost all manufacturing companies [12].

Fig. 5. Internationally standardized GHS Pictograms.

A total of 21 untrained janitorial and carpentry workers (age 18-45, male=11 and female=10) participated in the study from two countries (Nigeria and Kyrgyzstan). Two independent groups were randomly recruited to participate in the study. The Globally Harmonized System (GHS) pictograms were printed and posted on the wall. The first group was invited to observe and study the pictograms and fill out a brief survey prepared by the researchers. The room where the participants conducted their experimental study was an empty room with a regular table and a chair. A similar setting was practiced in both countries. The second group of participants, who were never exposed to the pictograms, were invited to the room with the pictograms.

Based on the Shapiro-Wilk test, the normality of data frequency was violated for pre- ($p = 0.01$) and post- ($p < 0.01$) data. Therefore, a non-parametric statistical test (Wilcoxon test) was used to analyze the data. The Wilcoxon test results show that the participants' scores significantly increased after using the AR app ($p < 0.01$). However, the independent test shows no significant influence of gender differences ($p = 0.10$) or geographical location ($p = 0.15$).

The preliminary study results show that the innovative AR application can enhance the understanding of the GHS pictograms for non-English speaking employees, contributing to their safety awareness of hazardous materials. However, further data collection is necessary to validate these critical discoveries and study additional variables that AR technology can introduce to improve safety.

The MR-Lab application enables students to visualize the isometric product from its orthogonal views and provides short tutorial clips of how a specific feature was developed and what tools were used [13]. The MR applications have become crucial laboratory pedagogy for STEM fields [14] as conventional lab courses require dedicated equipment. In this regard, the MR applications can provide virtual labs for situational learning and involve the participants with learning tasks. In addition, the students can perform basic modifications on the 3D part in the ARCADE, such as section views, details views, scale, rotation, and explode assembly views. Although this project is a work in progress, the initial pretest and posttest results show a significant improvement in students' spatial cognition when the proposed tool is used to assist the course.

Case Study 5

Firefighters are on the front lines, protecting lives and creating emergency preparedness to ensure our homeland is safe, secure, and resilient against different hazards (Dakeev, et al., 2020). Firefighters respond to a wide range of unexpected incidents, including medical calls, motor vehicle accidents, fires, technical rescues, explosions, hazardous material incidents, terrorism, mass casualty incidents, and anything else involving a call to 911.

A total of 7 subjects participated from student population to be exposed to three VR environments (Figure 6) with three levels of mental challenge activities for each environment: 1- Fighting Fire, 2- Rescue, and 3- Escape the Scene to investigate firefighters' physical behavior represent by the following physiological responses: heart rate, body posture, as well as the respiratory rate during VR simulation. Participants with a history of motion sickness, claustrophobia, anxiety issues, neck issues, elevated blood pressure, or epilepsy were ineligible for participation.

Fig. 6. VR Fire Intensity for Morgue Room

The virtual environment contained three burning facilities with low to high-intensity levels of fire. The researchers visited the local fire station to receive feedback and consultancy on the fire scene development to make the scenes as realistic as possible. The received feedback and suggestions were incorporated into the scenes, where the environments gradually get darker as time progresses within the scene. The researchers initially started with a real burning room fire scene and incorporated it into the VR simulation; however, the rarity of training facilities, resources, and the equipment's heat resistance factors, steered the VR simulation to be developed in animation and game engines. In contrast, the number of VR headsets is increasing [15] as more industries find positive impacts on their business activities.

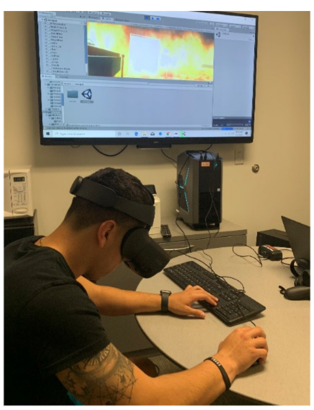


Fig. 7a. Student participant in the morgue VR simulation

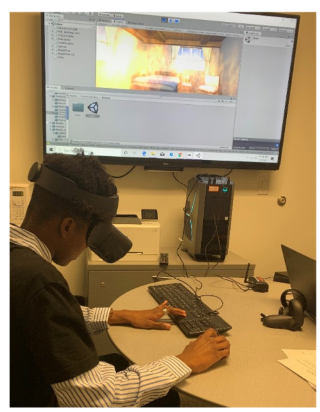


Fig. 7b. Student participants experiencing furnished cabin VR simulation.

A bio harness monitor from BioHarnessTM III, Zephyr Technology Corporation, Annapolis, MD was used to measure physiological responses. The bio harness was strapped to the chest of each participant before starting the experimental session of virtual simulation and was worn until the end of the session.

A total of five students (age: 20.2 ± 1.4, BMI: 25 ± 1.4) participated, from the untrained firefighters' population, in the fire-simulating VR project. Figure 8 shows the heart rate comparison between the fire intensity levels for sixty readings from the bio harness.

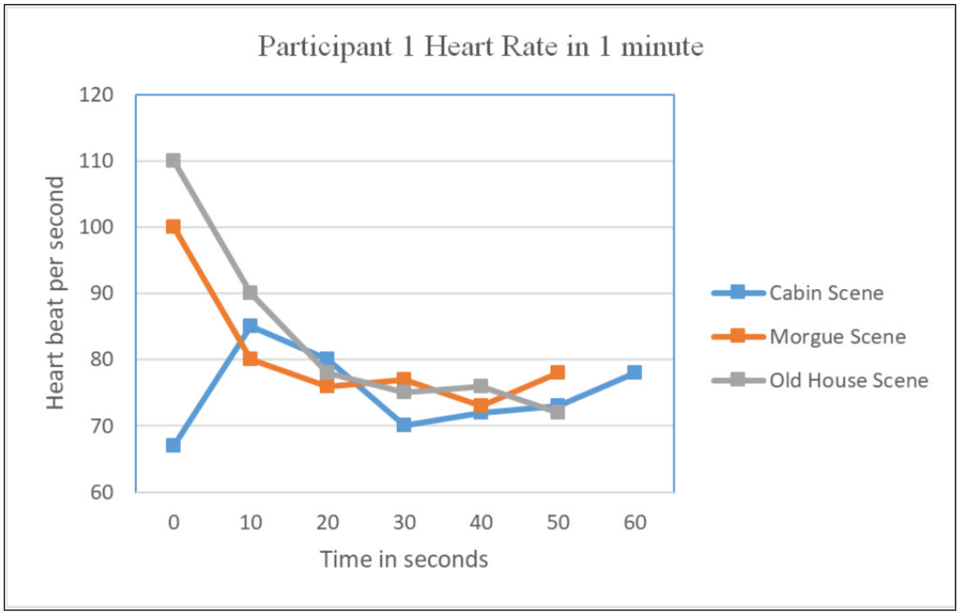


Fig. 8. Heart Rate Comparison based on Fire Intensity Levels

The researchers conducted a One-way Analysis of Variance (ANOVA) in SPSS to compare outcomes from each scene (Cabin, Morgue, and Old House) and to analyze whether there is any significant difference between the scene fire intensity levels' impact on the participants in the virtual environment. The descriptive statistics show that the means were relatively similar for Morgue =82.867 and Old House=82.267, where the Old House scored 0.6 lower average than the Morgue scene, and both greater than the Cabin mean value of 76.371, as shown in Table 9.

Table 9. Paired Sample t-Test Analysis for the Influence of a VR in Fall 2017 Semester

Descriptives								
Observations								
					95% Confidence Interval of the Difference			
	N	Mean	Std. Deviation	Std. Error	Lower Bound	Upper Bound	Minimum	Maximum
Cabin	35	76.371	6.532	1.109	74.117	78.626	66.000	93.000
Morgue	35	82.867	11.907	2.174	78.421	87.313	70.000	111.000
Old House	30	82.267	12.539	2.289	77.584	86.949	70.000	110.000
Total	95	80.284	10.812	1.109	78.082	82.487	66.000	111.000

One-way ANOVA Table 10 shows a significant difference between the fire scenes at $p=0.024< 0.05=$alpha level from 95 total observations, as seen in Table 10.

Table 10. One-way ANOVA report for three intensity level fire scenes in VR

	Observations				
	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	853.822	2	426.911	3.875	0.024
Within Groups	10135.505	92	110.169		
Total	10989.326	94			

To further investigate how the virtual fire scenes impacted participants' physiological conditions, further Tukey post hoc analysis is reported in Table 11.

Table 11. Paired Sample t-Test Analysis for the Influence of a VR in Fall 2017 Semester

					99% Confidence Interval of the Difference	
(I) Group		Mean Difference (I-J)	Std. Error	Sig	Lower Bound	Upper Bound
Cabin	Morgue	-6.49524[a]	2.612	0.039	-12.716	-0.274
	Old House	-5.895	2.612	0.067	-12.116	0.326
Morgue	Cabin	6.49524[a]	2.612	0.039	0.274	12.716
	Old House	0.600	2.710	0.973	-5.856	7.056
Old House	Cabin	5.895	2.612	0.067	-0.326	12.116
Old House	Morgue	-0.600	2.710	0.973	-7.056	5.856

[a]*The mean difference is significant at the 0.05 level*

Table 11 shows that the mean difference is significant at 0.05 alpha level, which indicates that the participants were highly impacted by the Morgue = 6.495 vs Cabin most, followed by the Old House = 5.895 vs. Cabin, and the Cabin impacting the least among the three levels of fire scenes.

Of the three variables: 1-heart rate, 2-respiratory rate, and 3-posture from the participants, the latter two did not yield reportable data due to the limited number of participants. However, the researchers discovered that the intensity of VR fire simulation fire scenes, with variable intensity levels of fire, resulted in a significant heart rate elevation between scenes. A negative reaction of untrained/first-timer firefighters may lead to delays in decision-making during critical times and may lead to injuries during duties.

Case Study 6

The researchers developed an Engineering Building floor plan and an immersive simulation to investigate the effectiveness of safety escape zones as seen in Figure 9. The participants with no prior experience with either the VR simulations or the building itself participated in visualizing the VR environment to locate the exit signs. Similarly, an independent group of participants located the physical exit signs on the experimental floor.

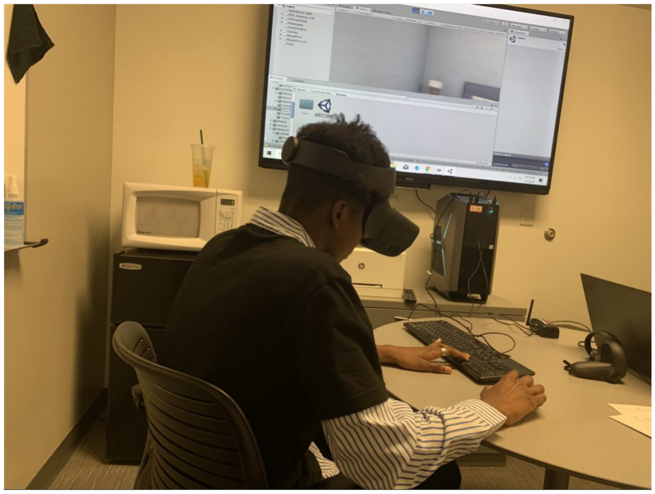


Fig. 9. Immersive search for exit signs in a virtually developed floor

Independent sample t-Test analysis showed that (p-value $0.03 < p=0.05$ for 15 participants) the VR simulation provides a significantly shorter time to locate the exit signs, which could be a matter of life and death.

Discussion

The authors of this study discussed six case studies from their previous findings and publications. Each case study presents generalized outcomes, from kindergarten children to adults at workplaces, to investigate the effectiveness of VR and AR applications to a specific group of participants in this study. Case study 1 started with the provided AR tool's positive impact on kindergarten student learning and engagement compared to the conventional way of teaching styles. In case study two, the college students developed an AR tool for an existing community resilience trailer to support community engagement. Case study three discussed and provided outcomes on the impact of AR tools to support student engagement and spatial cognition improvement in early CAD students in colleges. Case study four examined additional custom-developed AR tools for industry workers, specifically those who do not receive formal safety training on hazardous materials and their labels to prevent major workplace safety accidents. These four AR-related case studies showed that supplementary AR applications can significantly impact various persons from diverse groups and ages in engaging with the content material, learning about safety hazards, retaining information, and staying motivated with the new knowledge they are acquiring. Cases five and six focused on VR applications, where case study five discussed physiological changes in new firefighter trainees when they are exposed to different intensity levels of fire, and case study six discussed muscle memory they are exposed to different intensity levels of fire, and case study six discussed muscle memory development in finding safety exits from unknown premises. Both VR case studies showed significant improvement when a VR tool is used as a simulator.

Conclusion

Generation z is an electronic tycoon due to the abundance of computerized devices available. Therefore, participants who had previously played role-playing games were more enthusiastic about trying VR. Researchers needed to develop measures to deal with motion sickness that the participants would experience during the immersive experiences in VR. VR time was limited to a maximum of 20 minutes as part of those measures. Furthermore, the researchers used smooth locomotion control with a thumb stick instead of teleportation. Motion sickness may be further reduced by using omni pods to enable physical movement.

Further, this study examined the effects of AR applications on student learning, engagement, motivation, and spatial cognition in CAD courses. The paired sample t-tests and independent t-tests showed that AR tools significantly improved understanding of 2D blueprints and spatial cognition skills, regardless of previous 3D modeling experience. A t-test of independent samples showed that students could comprehend 3D models significantly better when using the AR tool. Engaging students in the MR learning process and motivating them can improve their engagement and enthusiasm toward learning.

Acknowledgements. The authors would like to thank the participants of all the research projects discussed in this paper.

Disclosures. The authors declare no conflicts of interest.

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UAS Law Enforcement Technicians in South Carolina: An Exploration of Supply and Demand

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Abstract: Unmanned aircraft systems (UASs), commonly referred to as "drones," are tools used in many industries. Law enforcement, in particular, has leveraged drones for various applications, including search and rescue, surveillance, and accident reconstruction. However, a recent report suggested South Carolina's public safety agencies underutilize the technology. This paper focuses on UASs in law enforcement and examines the issue through the lens of market supply and demand. Market demand was determined by surveying 46 South Carolina police chiefs. The police chiefs were asked about their current and future drone programs. The survey data shows that there is market demand for law enforcement UAS technicians, as 61% of the departments currently use drones, with another 36% expected to in the future. Market supply was partly addressed by searching the course catalogs and criminal justice program websites for drone-related keywords at all SACS-accredited community colleges in South Carolina, Georgia, and North Carolina. The search revealed that market supply was lackluster at best, with only 15 of the 110 community colleges offering drone courses. No UAS courses were tailored to law enforcement, and the program websites did not mention the technology at any level.

Keywords: drone, unmanned aircraft systems, law enforcement, public safety

Introduction

Over the past ten years, the use of small unmanned aircraft systems (UASs) has significantly grown. Where once limited to military applications, UASs, commonly referred to as "drones," have been adapted for many commercial purposes. Commercial drones can generally be grouped into vertical rotor (single or multi), fixed wing, and vertical takeoff fixed-wing hybrid types [1]. Multirotor drones are widespread in commercial applications because they can take off vertically, maintain a hover, and are comparatively easy to fly [2]. U.S. regulations require drones to be less than 55 pounds, have a speed slower than 80 mph, be flown under 400 ft from the ground or ground objects, and operate within the visual line of sight. Lenient regulations and the availability of low-cost equipment have allowed many industries, such as construction, cinematography, agriculture, and real estate, to incorporate drones into their operations [3]. Law enforcement, in particular, has significantly incorporated drones into their operations. UASs have supported the law enforcement community in many ways, including crime scene investigation [4], accident scene documentation [5], bomb threats [6], and search and rescue [7].

The Center for the Study of the Drone at Bard College recently published a report indicating how frequently public safety agencies, including police, fire safety, and emergency management, were using drones to support their missions [8]. The data were collected from news media, FAA drone regulation waivers, and other publicly available data. The report indicated that South Carolina had only 26 public safety agencies using drones. Given the state has more than 350 law enforcement offices, this number seems alarming low. Underscoring this statistics is the Mercatus Center at George Mason University scoring South Carolina 43rd out of 50 for drone commerce [9]. There are many reasons why so few agencies were reportedly using drones; however, two possibilities are that there is not a desire by the agency leadership to use drones or that there are insufficient drone technicians to operate them. This study will focus on law enforcement and evaluate if there is market demand by police chiefs to use drones and if South Carolina and bordering states are supplying a significant number of law enforcement UAS technicians.

Background

The use of UASs has significantly grown over the past several years. One of the drivers behind this was the implementation of the CFR Title 14 Part 107 (Part 107) regulations in 2016. Before Part 107's release, the regulatory environment was prohibitively burdensome for most non-hobby UAS activities. Commercial drone operators were required to apply for a Section 333 exemption, which had requirements that made drones an unviable alternative to traditional workflows. With the release of Part 107, the industry has grown rapidly. As of August 2022, nearly 300,000 people have received their remote pilot certificate [10]. To put this in perspective, that is more than the 266,000 licensed commercial and private pilots in the United States [11].

Law Enforcement UAS Hardware

The two most common drone types are multirotor and fixed-wing. Multirotor UASs are "helicopter" style drones with vertical propellers providing lift. Fixed-wing drones operate like an airplane with horizontal foils providing lift. According to a recent survey, over 90% of public safety agencies using drones operate the multirotor type [12]. Some of the reasons multirotor drones are preferred are their ability to launch and land horizontally, maintain a hover, fly at low altitudes around obstructions, and carry a wide range of payloads. The two most common payloads are RGB cameras with zoom capabilities and infrared imagers. Figure 1 shows two images of a street sign taken at the same location. The image on the right has been enlarged with a 40× optical zoom in real time. This type of zoom sensor allows law enforcement to gather intelligence without impacting scene operations or giving away the position to persons of interest. Still, images are also used in structure-from-motion software to create 3D reconstructions of accident or crime scenes.

Fig. 1. Image of street sign (a) without zoom and (b) with 40× zoom

Thermal imagery is a valuable tool long used by law enforcement. High-resolution 640 × 512 resolution infrared imagers are the UAS industry standard. These imagers allow officers to detect fleeing suspects, see automobiles warmed from recent use, and navigate at night without light that gives away the position of the UAS. Figure 2 provides an example of an infrared thermogram collected with a UAS.

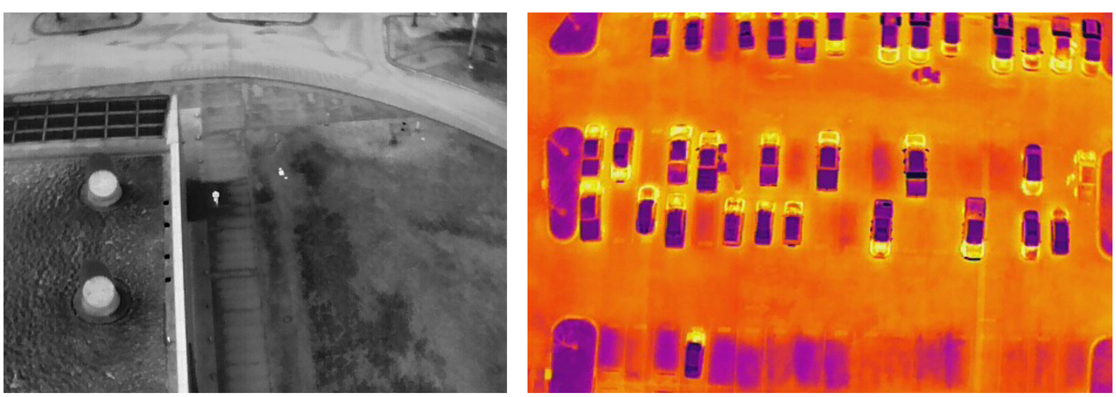

Fig. 2. Infrared image (a) of a person walking with a black and white palette and (b) a parking lot of recently used cars with a rainbow palette

Law Enforcement Drone Uses

DRONERESPONDERS is a 501(c)(3) nonprofit organization whose mission is to support public safety agencies using drones. In early 2019, DRONERESPONDERS published the findings of a national study. One of their key findings was that "most public safety UAS programs are in their infancy" and "bootstrapping their way into the air" [13]. In a follow-up survey, over 300 law enforcement, fire safety, and emergency management professionals completed a survey on various drone topics [12]. One area of interest for this study was how public safety agencies use drones. The most common uses were training/exercises, search and rescue, and incident command and control. Other notable uses were crime scene investigation, mapping, public information, and special event planning. The complete list of mission types ranked in order of frequency is provided in Table 1.

Table 1. Mission Type Frequency from DRONERESPONDERS 2019 Survey[a]

Mission Type	Frequency
Training/Exercise	204
Search and Rescue	139
Incident Command and Control (Live Streaming)	130
Crime Scene Investigation/Forensic Analysis	119
Damage Assessment	114
Mapping (Non-Forensic Related)	114
Security Overwatch (Surveillance)	103
Public Information	102
Structure Fire Response	98
SWAT Related	91
Special Event Planning	81
COVID-19 Support	58
Hazardous Materials (HAZMAT) Response	52
Wildfire Response	47

[a]From DRONERESPONDERS (2019)

A similar study was conducted by a collaborative effort between the Police Executive Research Forum (PERF), the Department of Homeland Security, and the U.S. Department of Justice [14]. Their data came from a quantitative online survey of nearly 300 police departments, 50 interviews with police executives, and a national law enforcement conference roundtable discussion. Their survey and conclusions were similar to the DRONERESPONDERS study. The most common drone use cases were search and rescue, crime scene photography and reconstruction, and investigating armed and dangerous suspects. Table 2 provides a complete list of uses from their study.

Table 2. Common Purposes for Using Drones in Policing[a]

Drone Purpose	Percent-age
Search and Rescue	91%
Crime Scene Photography and Reconstruction	85%
Investigating Armed and Dangerous Suspects	84%
Disaster Response	84%
Traffic Collision Reconstruction	81%
Hazardous Material and Bomb Observation	68%
Fugitive Apprehension	63%
Crowd Monitoring	51%
Surveillance	27%
Other	14%

[a]From PERF (2019)

Bard College Study

Public safety agencies generally operate autonomously with respect to their equipment purchases and activity management. With only a few exceptions, such as Minnesota, they are not required to disclose in detail the number of drones they own or how they are being used. Quantifying how many public safety agencies use drones is difficult because the information comes from publicly available data and the news media. The Center for the Study of the Drone at Bard College maintains the "only comprehensive open-access tally of publicly disclosed public safety agencies that are reported to own at least one drone" [8]. Their data comes from local media, FAA Part 107 waivers, and publicly available annual reports, contracts, and meeting minutes from state and local government offices [8]. The Bard College database contains over 1,500 public safety agencies believed to have drones. Over 70% of these agencies were in law enforcement, with the remaining in emergency management, fire rescue, or another public safety agency. Their database does not include agencies with undisclosed UAS operations or who outsource their drone activities. The center's most recent report states that, because of this limitation, their findings should be used as a "barometer of the growing adoption of drones" and not to quantify specific drone activity in the public safety sector. While acknowledging this limitation, the report indicates that South Carolina has only 26 public safety agencies with drones. South Carolina has over 350 law enforcement offices, making Bard College's finding alarmingly low.

Methodology

There are many possible reasons why Bard College's report indicated drones were being used so infrequently in South Carolina. The acknowledged limitation suggests that the low value could be a function of drone use simply being underreported. However, two other possibilities are the focus of this study. The first possibility is that there is an aversion to using drone technology at the agency leadership level. Leadership may feel there is little benefit to the technology and that it is not worth investing resources in. To address this, an online survey was emailed to 332 South Carolina police department chiefs. This represents over 90% of the police departments in the state. Law enforcement is the largest component in the public safety sector and the focus of this study. The survey contained a mix of Likert-scale, multiple-choice, and text-response questions.

A second possibility for low drone use in South Carolina is the lack of trained UAS technicians. UAS training can be provided at high schools, community-based organizations or at the police academies. Addressing this question comprehensively is beyond the scope of this study. However, an important part of the answer is UAS technician training at community colleges. This study thoroughly evaluated the UAS curriculum at two-year institutions in South Carolina and the bordering states of Georgia and North Carolina. The Southern Association of Colleges and Schools Commission on Colleges (SACS) is the leading regional accreditation body in the southeast. The course catalogs of all 110 SACS-accredited, two-year colleges in South Carolina, Georgia, and North Carolina were searched for the keywords "drone," "UAS," "UAV," and "unmanned." The keywords were searched in the course titles and descriptions. Of the 110 two-year colleges evaluated, 94 had criminal justice (CRJ) degree programs. The CRJ program websites were also searched for the same keywords. The objective was to categorize how many drone courses were offered at the two institutions in South Carolina and the neighboring states supplying South Carolina's labor market.

Results

Of the 332 police department chiefs that were emailed a survey, 46 of them completed it for a 14% response rate. The first group of questions addressed drone use in their department. The first question confronted this topic head-on by asking, "Is there a need for licensed and trained drone operators in law enforcement?" An overwhelming 96% of the chiefs (44 of 46) indicated that there was. In a follow-up question, they were asked if they currently use drones in their department. Only 28 police chiefs (61%) indicated that their department currently uses drones. An important comparison can be made with these responses. Over 96% indicated a need, but only 61% indicated filling that need. A reasonable interpretation of the data is that some barrier is preventing 35% of the population from meeting an acknowledged need in their department. See Table 3 for the questions and responses given.

Table 3. Drone Use in South Carolina Police Departments

Question	Yes	No
1. Is there a need for licensed and trained drone operators in law enforcement?	96%	4%
2. Does your department currently use drones?	61%	39%

Future Drone Use

Several questions were asked to address the departments' drone programs' future and how drone pilots would be trained. Nearly 93% of the departments currently using drones expect to increase their drone use in the future. Of the departments not using drones, 67% indicated that they expect to start using drones in the future. Only 13% of the chiefs surveyed indicated that they were not using drones and had no plans to in the future. The survey asked the chiefs using drones if they had a comprehensive training program giving their employees the skills and knowledge needed to operate drones for their department. Less than half (46%) of the departments using drones had internal training programs. This is consistent with the DRONERESPONDERS report indicating the departments were "bootstrapping their way into the air" [13]. This also shows the need for external training centers, such as community colleges, to train UAS operators in law enforcement. This is reinforced by 35% of the survey respondents indicating that they did not expect their departments to develop a training program within the next five years. See Table 4 for a list of the questions and responses.

Table 4. Expected Use of Drones in South Carolina Police Departments

Department Information	Yes	No
1. Police departments using drones and expecting to increase their drone use in the future.	93%	7%
2. Police departments not currently using drones but expecting to in the future.	67%	33%
3. Police departments using drones that have a comprehensive training program that gives its employees the necessary skills and knowledge to operate a drone for law enforcement purposes.	46%	54%
4. Departments expected to develop a comprehensive drone training program in the next 5 years.	65%	35%

Disconnect Between the Need for Drones and Active Drone Programs

The data show a disconnect between department chiefs' view that there is a need for drones in law enforcement and departments with active drone programs. The data also show that even with departments with active drone programs, there is a lack of comprehensive training. What is particularly concerning is the pessimistic opinion about developing an internal drone training program. In anticipation of this potential finding, the survey asked the department chiefs their opinions about a local community college with a CRJ degree developing a law enforcement UAS certificate program. The chiefs were asked a Likert-scale question on how supportive they were of the proposed certificate program. An overwhelming 76% were either "supportive" or "very supportive." The chiefs were also asked if a new employee that was licensed and trained using drones in law enforcement should earn a higher salary, and 64% of the chiefs indicated that UAS-trained new employees should have a 1%–10% higher base salary. Perhaps the most revealing data gathered from the survey was the written text provided by the chiefs with respect to a new certificate program. A representative sample of the comments is bulleted below.

- “Drones are invaluable in law enforcement response and tactical operations.”
- “Drones have become a vital part of law enforcement.”
- “The use of drones in the law enforcement field is on the rise and will continue to be a critical part of our profession moving forward.”
- “There is a great lapse between having a drone and piloting a drone safely. It is time for agencies to be trained and qualified for safety and liability!”
- “The expanded use of drones in law enforcement will make officers safer and more efficient, and the ethical and lawful use of drones in the day-to-day work of law enforcement professionals is vital to this technology growing.”
- “Due to the fact we do not have any type of program that will provide classroom training for preparing individuals for getting their licensing with drones. I feel this is a much-needed program for individuals and law enforcement agencies wanting to become a licensed drone pilot.”
- “This tool is especially valuable to small rural agencies that do not have access to an air unit.”
- “Drone technology would be extremely important and useful in rural areas to assist with the apprehension of offenders during active criminal incidents.”
- “There is a critical need in law enforcement for new and developing technology. The use of UAS has proven to be very useful. Currently, we have to rely on neighboring agencies to provide such support.”

There are several key takeaways from the chiefs’ statements of support. The chiefs were overwhelmingly supportive of the technology using words such as “vital,” “invaluable,” “needed,” “useful,” “critical,” and “important.” General theme in their comments include the expectation that the technology would continue to grow, the lack of internal training capabilities and concerns about legality, safety, and privacy. Additionally, several indicated that UAS technology would be particularly useful to rural departments that cannot support manned aircraft. The lack of available training was also a recurrent message provided by the chiefs.

UAS Curriculum in 2-year Community Colleges

Half of the surveyed departments that use drones do not have a fully developed training program. While this training can be outsourced to private third-party vendors, an obvious provider for UAS education is community colleges with CRJ programs. Part of this study was to identify if community colleges in South Carolina and the neighboring states had UAS classes and how many had programs to develop law enforcement UAS technicians. The keywords “UAS,” “UAV,” “drone,” and “unmanned” were searched in the course catalogs and CRJ websites of 110 SACS-accredited community colleges. Of the 110 schools included in the study, 94 (85%) had CRJ degree programs. Only 15 schools had one or more courses that included a drone keyword in the title or course description. None of the UAS courses identified in the search were specific to law enforcement. The concerns raised by the police chiefs regarding the lack of UAS education appear to be well-founded. See Table 5 for the results of the keyword search.

Table 5. UAS Course at SACS-Accredited Community Colleges in South Carolina, Georgia, and North Carolina

State	No. of Schools	Schools With CRJ Degrees	Schools With UAS Courses	Schools With CRJ UAS Courses
SC	21	18	1	0
GA	26	20	6	0
NC	63	56	8	0
Total	110	94	15	0

Conclusion

The Bard College's Center for the Study of the Drone at Bard College report indicated that South Carolina had 26 public safety agencies using drones [8]. The center collected its data through publicly available data. It acknowledged that it should be used as a "barometer" of drone use and not as a tool to estimate how many agencies were using drones. Still, the value reported appeared surprisingly low and prompted the research team to evaluate drone use, focusing on law enforcement. It assessed the data through the lens of market demand and supply, where demand was the perceived need for drones by police chiefs and supply was the availability of training outlets for UAS technicians. Nearly two-thirds of the police departments surveyed were currently using drones. Assuming the survey is representative of all South Carolina's police departments, it can be estimated that approximately 210 police law enforcement agencies are currently using drones. This is significantly more than the 26 reported in the Bard College report.

There appears to be ample market demand for UAS technicians. The survey showed that 61% of the police departments in South Carolina are using drones, with 93% of them expecting their program to grow. Of the departments that did not use drones, 67% expected to develop a drone program in the future. Access to training to develop UAS law enforcement technicians appears to be a challenge for South Carolina. Less than half of the police departments using drones have a comprehensive training program. The lack of education was echoed in the police chiefs' written comments. Based on the course catalogs and CRJ department website, it does not appear that community colleges in the tristate area are keeping up with the supply needs of UAS technicians. Only 14% of the SACS-accredited community colleges in South Carolina, Georgia, and North Carolina had drone courses. None of these drone courses were tailored to the specific needs of law enforcement.

This paper explores drone education at South Carolina's community colleges. However, a requirement for South Carolina is that all law enforcement officers attend the state's police academy. Currently, the state's police academy does not include a UAS component. However, this could be an alternative way of improving drone education. Exploring the advantages and challenges associated with providing this additional curriculum is beyond the scope of this study and a recognized limitation worthy of additional research.

Recommendation

The data collected in this study suggests there is a need for law enforcement UAS technicians and a lack of training at the community college level in South Carolina. The ATE program was developed to support community colleges in creating programs to develop technicians for an advanced economy. The authors of this paper recommend that the 2-year institution in this state investigate participating in the ATE program and developing UASs in law enforcement certificate programs. Clemson University is a land grant institution and houses the ATE-supported Center for Aviation and Automotive Technological Education Using Virtual E-Schools (CA2VES). Community college faculty are encouraged to reach out to them as a resource for seeking ATE funding and developing UAS programs.

Disclosures. The authors declare no conflicts of interest.

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Invited Letter: NIIT Broadens the Talent Pipeline for the Semiconductor Industry & Other Advanced Manufacturers

Keywords: NIIT, semiconductor industry workforce, advanced manufacturers, National Talent Hub, apprenticeships, talent pipeline

As the president and CEO of the National Institute for Innovation and Technology (NIIT), I am responsible for executing NIIT's mission to identify and eliminate risks to innovation in strategic industry sectors. My 40-year career in manufacturing policy includes a focus on related education, training, and workforce development, more than a decade of which was within the semiconductor industry.

NIIT is a Maryland-based nonprofit charged with developing and executing a national strategy to build the talent pipeline for strategic industry sectors with a primary focus on the semiconductor industry. NIIT is the U.S. Department of Labor Office of Apprenticeship contractor responsible for establishing and expanding Registered Apprenticeship Programs for the semiconductor and nanotechnology-related supply chains. As part of this strategy, NIIT uses a scalable, programmatic approach in deploying the infrastructure required to sustain and grow the nation's highly skilled semiconductor industry workforce.

As part of NIIT's "National Talent Pipeline Development Initiative," we establish regional workforce hubs to ensure alignment between local employers and education systems and develop effective training programs to support target industries. In addition, NIIT has developed the National Talent Hub to connect job seekers from all walks of life with careers, training to fill skills gaps, and paid Registered Apprenticeship Programs. We also have dedicated programming for veterans looking to leverage existing skills supporting strategic industries.

As part of NIIT's mission to broaden the talent pipeline, we provide a gateway for technicians interested in transitioning to careers in advanced manufacturing. The apprenticeships our partners offer serve as a path to engineering-related careers by providing on-the-job training and employer-sponsored degree programs. In general, more than 50% of the positions at companies in the industries NIIT targets begin at the technician level. Offering training opportunities to technicians in related fields fills talent gaps in industries most crucial to our country's long-term economic health and national security while also providing alternative paths to successful careers for job seekers.

Community colleges play a crucial role in developing the nation's talent pipeline, and in particular, the training and education of the technician workforce. Community colleges are flexible and can readily design programs to meet industry requirements. At NIIT, we collaborate with community colleges throughout the nation to offer Required Technical Instruction to support students and employers utilizing Registered Apprenticeship Programs. In fact, the MNT-EC network of community colleges has access to our unique, state-of-the-art platform, the National Talent Hub. All students in applicable programs can utilize the skills assessment and career mapping tools to match their skills to specific job requirements and connect with employers.

I am proud of NIIT's work with community colleges, which will continue to play an important role in providing job seekers with education pathways into tech-related industries and supporting career development for an ever-broadening workforce.

Mike Russo
President and CEO
National Institute for Innovation and Technology

NIIT
National Institute for Innovation and Technology
MOVING INDUSTRY FORWARD

Semiconductor Resurgence Creates Opportunity at Community Colleges

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Abstract: Newly announced semiconductor fabrication facilities in Ohio, Arizona, Indiana, New York, and Kansas have led to a need to increase the number of semiconductor workers, including technicians and engineers. The recently signed CHIPS and Science Act provides $52 billion of funding to support the semiconductor industry, with over $5 billion allocated for workforce development. This paper focuses on how community colleges can support technician education and prepare a diverse student population for transfer into semiconductor disciplines at four-year universities.

Keywords: semiconductor, technical education, community college, CHIPS and Science Act

Introduction

The resurgence of US semiconductor manufacturing is a national call to action that will require recruiting, educating, and supporting a workforce anticipating adding tens of thousands of new jobs within the next few years [1]. The Micro Nano Technology Education Center (MNT-EC), a nationwide consortium of thirty-eight community colleges, believes authentic partnerships with industry and four-year universities are key to addressing semiconductor workforce needs in both technician training and educating graduate-level engineers. Though the current need is in semiconductor workforce education, MNT-EC supports community college technical education in all MNT-based emerging technologies, all exhibiting need cycles. A strategy must be developed that allows community college technical education programs to quickly and effectively pivot to specific needs when they arise. The current and near-future semiconductor workforce need is great; however, this need can ebb and flow based on past market conditions and cycles. In some years, the need is substantial, yet in others, the need is sparse [2]. Creating broad technical programs that can educate students to meet the requirements in various aspects of electronics, such as semiconductor fabrication, quantum, cybersecurity, and more, will provide long-term stability to community college technical education programs. These workforce programs can thus respond to industry-specific needs when high and not a niche workforce demand when down.

The global semiconductor market grew by 4% in 2022 to $618 billion [3]. Though 2023 market growth is expected to retract by 3.6%, it is anticipated that long-term workforce needs will remain high with the building of new fabrication plants [1]. Semiconductors are essential components in thousands of electronic devices, particularly electric and self-driving vehicles. They are used to manage functions such as navigation and parking and to monitor engine performance. Supporting technologies in semiconductor fabrication, such as vacuum deposition technologies and lithography, also need the support of community college workforce education. Community colleges need to focus on creating broad technical education programs in combination with short "Boot Camps" or training programs that are designed to provide educational experiences tailored to specific industries, such as semiconductor manufacturing, providing access to resources community colleges lack, like working in a cleanroom or using complex and expensive instruments. Industry training programs should commence near the conclusion of students earning a technical education degree focusing on skills community colleges were unable to teach that best prepared them to work for a specific company. These training programs should be industry designed and ideally performed at industry partner sites or with industry-leading experts who can best train workers to enter their fabrication facilities. Ideally, for the semiconductor industry, education centers can be built and resourced across the country with industry support. These education centers should be available for any community college student to utilize and provide the just-in-time education to best prepare students for entering industry-specific semiconductor fabrication plants.

In January 2021, the US Congress passed the Creating Helpful Incentives to Produce Semiconductors (CHIPS) for America Act [4], substantially strengthening domestic semiconductor production and innovation in the years ahead. The CHIPS and Science Act includes $52 billion in chip manufacturing incentives, research investments, and an investment tax credit for semiconductor manufacturing and semiconductor equipment manufacturing. In addition, the CHIPS and Science Act provides funding for semiconductor workforce development education programs at all levels, from Doctorate to Associate of Applied Science technician degrees. These investments will reinvigorate US leadership in chip technology and reinforce America's economy, national security, and supply chains. This significant investment in semiconductor manufacturing means educational institutions must ramp up enrollment and completion at all degree levels. For instance, community colleges must respond to the growing semiconductor technician workforce need, especially in localities where new fabrication facilities are being built, such as Phoenix, Arizona; Columbus, Ohio; West Lafayette, Indiana; Kansas City, Kansas, Clay, New York, and Boise, Idaho, among others [5]. In many instances, these localities do not have enough space in technical education programs to fill the workforce need [6]. As a result, community college students tend to stay where they are educated [7]. A national strategy that incentivizes movement to high industry-need regions must be developed to fill workforce needs. Industry must play an essential role in applying apprenticeships, internships, or providing scholarships to students if they agree to move for work in fabrication plants outside their community college area. Without strong industry support, community colleges cannot fill industry needs. Thus, industry and community colleges must collaborate to develop a strategy that provides them with the essential technicians needed in the semiconductor industry [8].

A.

B.

Fig. 1. A. Semiconductor Industry locations (Data collected from MNT-EC Industry Analysis performed by EMSI) B. Semiconductor Community College Consortium Participants (Green Pins Community Colleges supporting proposed new Semiconductor Fabs)

The CHIPS and Science Act requires the US to have a strong semiconductor workforce pipeline and includes workforce development measures as part of manufacturing incentives and R&D programs [9]. These measures incentivize community colleges to educate a skilled workforce to meet the needs of current and future technician demands. Industry analysis was performed at MNT-EC, which shows semiconductor fabrication facility locations (Figure 1A) and supporting community college technical education programs (Figure 1B) concentrated in these areas. Most importantly, community college partnerships have been formed in regions where the new semiconductor fabrication facilities have been proposed as shown by the green pins in Figure 1B. However, with the expected growth from new semiconductor fabrication facilities and the need to continue supporting small and medium-sized semiconductor companies, a national initiative that educates thousands of semiconductor technicians annually is necessary.

Ohio's economic developments exemplify the semiconductor resurgence. Intel has announced plans for an initial investment of more than $20 billion through constructing two new leading-edge microchip factories in Central Ohio [10]. Manufacturing in Ohio is growing, and along with the jobs created directly as a result of high-profile expansions and new establishments such as Intel, growth in the manufacturing sector will have a ripple effect on suppliers and manufacturing-adjacent companies building on their success in the state, increasing the demand for a skilled workforce.

Intel plans to hire 3,000 individuals in the next three years in semiconductor manufacturing, create work for 7,000 construction employees, and attract a supplier network, with some companies already negotiating on-site locations in Ohio [11]. Semiconductor manufacturing also creates a greater demand for skilled trades and water treatment technicians. In addition, Amgen has broken ground on a new biomanufacturing facility to be operational by 2024 that will employ over 400 Ohioans [12]. Honda also recently announced an increased investment in the state [13], both at their existing plant and a new facility dedicated to electric vehicle battery production. These developments will have a ripple effect on suppliers and manufacturing-adjacent companies, increasing the demand for a skilled technical workforce in a labor market already struggling to meet the demands for skilled technicians. This industry growth will create an exponential impact on Ohio. According to Lightcast LMI Modeling [14], the three announcements at Intel, Amgen, and Honda alone will account for an enormous influx of jobs and increased earnings in the state.

- The estimates for new jobs above will create an additional $1.96 billion in earnings and result in 26,144 new jobs for the region.
- The ripple effect will stretch beyond construction (7,620) and manufacturing (5,560), increasing opportunities in retail (1,554 jobs), healthcare (2,288 jobs), and hospitality and food services (1,196 jobs).
- Management jobs are projected to have a significant increase (2,593 jobs) along with Business and Financial Operations (2,088 jobs), Architecture and Engineering Occupations (958 jobs), and Computer Occupations (595 jobs).

Methods

MNT-EC has partnered with SEMI Foundation and the National Institute of Innovation and Technology to assess the semiconductor workforce needs of the US (Surveys collected from January 15 to March 6, 2023). The survey was designed to be completed in five minutes to increase industry participation. Currently, there is no reliable data on the number of semiconductor workers needed, and no reliable data differentiates between different academic levels. Hence, the MNT-EC survey was created to hear directly from industry what their actual workforce needs are. It is not possible for industry to provide an exact count of the number of workers needed yearly. Consequently, the survey focused on industry needs and level of concern for hiring and provided a rough estimate on the number of yearly hires over the next five years. The survey aims to determine the workforce needs for the semiconductor industry at a regional and national level, focusing on educational needs from Doctorate engineers to technicians earning degrees at community colleges.

Surveys were sent to semiconductor industry representatives through e-mail lists shared by the SEMI Foundation, the National Institute for Innovation and Technology (NIIT), MNT-EC, the Society of Manufacturing Engineers (SME), and the National Society of Advanced Technology Centers.

Survey questions included:

1) Industry location (state and city)
2) Industry role
3) Industry headcount
4) Workforce needs by education level
5) Approximate workforce needs per year for each education level
6) Yearly percent attrition
7) Level of concern hiring for each education level
8) Which education levels industry would consider for apprenticeships.

Results and Discussion

Figure 2 below shows the responses from 39 unique semiconductor industry leaders and companies toward Ph.D. engineers and community college-educated technicians. It is evident that there is a need for both technician-level talent and highly educated engineers. There is a slightly higher level of concern for hiring technicians (40% highly concerned technician versus 22% highly concerned Ph.D.). Educating a technician is expected to be less expensive than educating a Ph.D. engineer because a technician can be educated in one or two years versus eight to ten years for a Ph.D. engineer. Community colleges are also more affordable than four-year universities. In addition, job expectations for a Ph.D. level worker are to oversee the entirety of a project versus a technician who will be responsible for specific project processes. Thus, a focus needs to be on providing support for both the PhD. and technician-seeking students and programs. Community college recruitment strategies must fulfill two purposes. One is to encourage high-achieving STEM students to pursue transfer opportunities at four-year universities in semiconductor-specific programs and increase the number of students in semiconductor-supporting technical education programs that will lead to direct employment in the semiconductor industry. For this to be successful, community colleges must develop strong partnerships with industry, and industry must provide guidance and feedback on community college technical education programs.

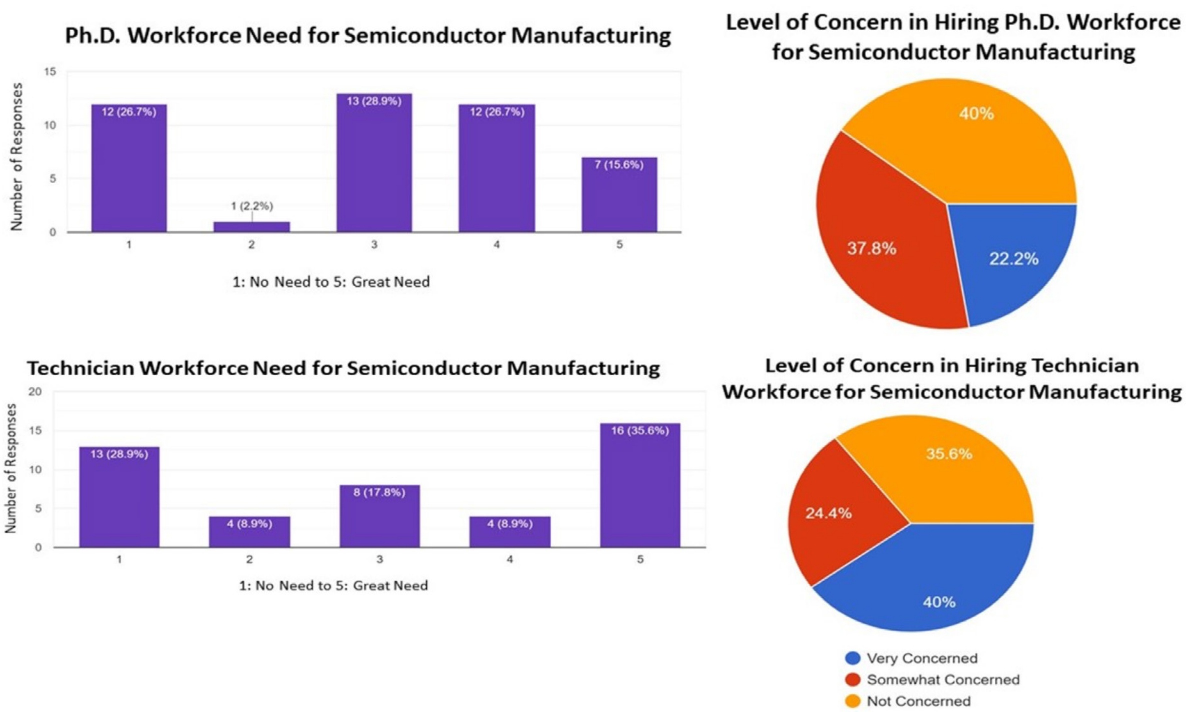

Fig. 2. Semiconductor Industry Workforce Needs and Concern Levels (45 unique Industry Responses)

One effective model to achieve impactful partnerships with industry is through the formation of Business Industry Leadership Teams (BILT) that are organized where industry supports the formulation of Knowledge, Skills, and Abilities (KSAs), needed competencies, and discusses trends with community college educators [15]. MNT-EC has a well-established microsystems BILT, which has developed a comprehensive KSA list that will be shared on the MNT-EC website by Summer 2023. Developing authentic community college-to-industry partnerships is the key to providing a well-prepared semiconductor technician workforce.

Conclusion

Designing and manufacturing the semiconductor devices needed for the future relies on a robust skilled technical workforce. A major concern in training a skilled semiconductor technical workforce is the capacity to educate technicians to work in fabrication facilities and train workers for all the ancillary technical jobs needed to support semiconductor manufacturing. Technical education has always been a strength of community colleges, but current circumstances have led to challenges in educating enough technicians to meet industry needs. Therefore, a nationwide approach is required to support program development to increase academic pathways leading to student outcomes and certifications within the semiconductor manufacturing sphere.

Among community colleges, Pasadena City College (PCC) presently offers a certification and associate degree program in Advanced Materials - Nanotechnology, which is recognized by the Los Angeles Regional Consortium (LARC). An important recent development has been the establishment of the Micro Nano Technology Education Center (MNT-EC) at PCC and the Central Coast Partnership for Regional Industry-focused Micro/nanotechnology Education (CC-PRIME) project at Santa Barbara Community College (SBCC). In addition, the University of New Mexico, University of North Texas, Caltech, and over ten more research universities have partnered with the Micro Nano Technology Collaborative Undergraduate Research Network (MNT-CURN) to provide over 60 community college students year-long internship opportunities to better prepare them for entrance into the skilled technical workforce. All these programs are supported by the National Science Foundation Advanced Technological Education program and are organized whereas community colleges as a collective work in concert to grow a national technician workforce supporting the micro and nano technical education programs. The aim is to increase the number of community college faculty providing certificates and associate's degrees that lead directly to semiconductor industry jobs.

In Ohio, Intel Foundation selected Columbus State Community College to lead the Ohio Semiconductor Collaboration Network in partnership with the Ohio Association of Community Colleges and the 23 community colleges [16]. The project will yield a robust and diverse workforce pipeline serving Intel, its suppliers, and the broader semiconductor industry through key deliverables: 1) enhanced curriculum, 2) faculty development, 3) experiential and project-based learning, 4) the establishment of the Ohio Semiconductor Collaboration Network, under the auspices of an OACC-led steering committee, and 5) wide dissemination of results and best practices.

Despite these developments, serious structural challenges persist. In particular, there is a low number and lack of diversity among students earning degrees or certificates and employment within semiconductor manufacturing [17]. Although semiconductor education requires access to specialized facilities at research universities, there is inconsistent coordination and a lack of formal programs between research universities and community colleges, impeding the facility access, training, and development of educational materials based on industry needs. The existing partnerships are often isolated, decreasing the impact that a nationwide effort could realize. In addition, industry focus frequently neglects community colleges in favor of the highly regarded and established four-year universities, which are perceived by industry as more essential to workforce development. A national partnership between community colleges aims to address these challenges by initiating a unified, coordinated approach through a partnership of all stakeholders, including community colleges, research universities, and industrial partners. In particular, efforts are needed to attract K-14 students from all backgrounds into semiconductor careers; prepare them with the skills needed by industry to pursue an industry career; and connect them with industry professional development opportunities, internships, and ultimately rewarding careers.

Acknowledgements. This project was supported by the Micro Nano Technology Education Center (MNT-EC), NSF ATE DUE #2000281.

Disclosures. The authors declare no conflicts of interest.

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Cell Modeling in Jupyter Notebook using CompuCell3D

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Abstract: CompuCell3D (CC3D) is an open-source software framework for building and executing multi-cell biological virtual-tissue models. It represents cells using the Glazier–Graner–Hogeweg model, also known as Cellular Potts model. The primary CC3D application consists of two separate tools, a smart model editor (Twedit++) and a tool for model execution, visualization and steering (Player). The CompuCell3D version 4.x release introduces support for Jupyter Notebooks, an interactive computational environment, which brings the benefits of reproducibility, portability, and self-documentation. Since model specifications in CC3D are written in Python and CC3DML and Jupyter supports Python and other languages, Jupyter can naturally act as an integrated development environment (IDE) for CC3D users as well as a live document with embedded text and simulations. This update follows the trend in software to move away from monolithic freestanding applications to the distribution of methodologies in the form of libraries that can be used in conjunction with other libraries and packages. With these benefits, CC3D deployed in Jupyter Notebook is a more natural and efficient platform for scientific publishing and education using CC3D.

Keywords: CompuCell3D, Jupyter Notebook, cell modeling, virtual tissue, biology education

Introduction

Computational biological modeling enables scientists to quantitatively describe complex biological systems, test existing biological knowledge and generate new biological hypotheses. Cell-based computational biological modeling describes biological systems on the basis of individual cells [1], and can include dynamic deterministic or stochastic descriptions of cell location and state. Research using computational modeling has produced novel quantitative descriptions of the underlying mechanisms of many developmental processes like somitogenesis [2], vasculogenesis [3, 4] and gastrulation [5], and has provided new biomedical insights in various problems of health and disease such as acetaminophen metabolism [6], autosomal dominant polycystic kidney disease [7], antiviral therapies [8, 9], and influenza infection and host-pathogen interactions [10].

There exist multiple software for cell-based computational biological modeling, each of which employs various numerical methods and provides different features and specializations, including Artistoo [11], Biocellion [12], CHASTE [13], Morpheus [14], PhysiCell [15], Simmune [16], and TissueSimulationToolkit [17] among others. CompuCell3D (CC3D) [18], which implements the Glazier–Graner–Hogeweg model [19], also known as Cellular Potts model, to simulate multicellular systems, has a long legacy as an open-source, cross-platform modeling and simulation environment meant to be accessible to all levels of biologists, from students to veteran researchers. To provide accessibility to a broad user base across multiple disciplines, CC3D is distributed with supporting graphical user interfaces (GUIs) that streamline model and simulation specification (e.g., automated project generators, code snippets and browsable documentation) and project sharing (e.g., well-defined project file structures, built-in project archive import/export) and provide interactive simulation execution and real-time, customizable data visualization.

CC3D version 4.x development added support for Jupyter Notebooks, an interactive computational environment that provides the benefits of reproducibility, portability, and self-documentation in the form of executable, interactive scripts in a web browser. Jupyter Notebook acts as one integrated environment, in which text and graphics can be presented alongside executable code [20]. Jupyter was created in 2013 and is the most widely used computational notebook [21], with more than 2.5 million notebooks in GitHub since September of 2018 [22]. While CC3D was originally developed to support model specifications written in Python and CC3DML (an XML-based language), recent CC3D developments expanded deployment support to include specifications defined purely in Python. Since Jupyter supports Python and other languages, Jupyter can naturally act as an integrated development environment (IDE) for CC3D users as well. This update follows the current trend in software development and distribution to move away from monolithic, freestanding applications and towards the distribution of libraries that can be used in conjunction with other software. With these benefits, CC3D deployed in Jupyter Notebook is a powerful resource to expose students to computational biology as well as for scientists publishing work using CC3D. In this paper, we describe the basic features of CC3D simulation visualization in Jupyter Notebook as relevant to students, educators and scientists interested in integrating Jupyter-based computational biological modeling and simulation into their classrooms and projects.

Software Design

CC3D is written in C++ and provides Python language bindings, including an interface for runtime simulation execution and control in Python. The current distribution of the CC3D software includes two GUIs: Twedit++, a text editor for writing model specification code controlling the simulation (Fig. 1.1), and CC3D Player, a freestanding application to run and interact with a simulation (Fig. 1.2). Twedit++ and CC3D Player are both built on the PyQt framework, and CC3D Player uses the CC3D Python interface for runtime simulation execution. Likewise, the CC3D visualization pipeline employs infrastructure from the Visualization Toolkit (VTK) [23], which also provides Python language bindings and supporting widgets for interactive visualization in a Jupyter Notebook. These important software features permit both control of CC3D simulation execution and real-time rendering and visualization of CC3D simulation data within Jupyter. Furthermore, CC3D Player integrates VTK support for PyQt to provide interactive visualization, while VTK also provides implementations of those same widgets deployed in CC3D Player but for Jupyter Notebook. CC3D support for Jupyter Notebook integrates such features from VTK to provide a comparable user experience between simulation execution and visualization in CC3D Player and a Jupyter Notebook.

Player offers flexible visualization specifically tailored to the needs of CC3D users. While general standard visualization tools exist, they can be cumbersome for non-expert users. Player provides a simple way of representing complex visual data in real time by allowing the user to run/pause/stop execution of the simulation while rendering the graphics in real time. Users can create multiple graphics windows to view different properties, locations and objects of the simulation simultaneously. Rendering settings such as outlines, colors, bounds, and more can be configured to communicate the information the user needs. The view on the frames can be manipulated directly during the simulation with natural controls for pan, tilt, and zoom, switch between two- and three-dimensional views and setting view coordinates for two-dimensional visualization. Player also supports on-demand rendering of visualized simulation data and saving to file, as well as scheduling rendering at regular intervals of simulation time.

The Jupyter Notebook implementation of CC3D includes the rich features provided by Player, but in an interactive environment supporting user-specified visualization along with the implementation of their models, simulation specifications and documentation. Users can specify an arbitrary number of graphics frames, each of which can be individually customized to visualize simulation data in ways that complement, clarify or demonstrate the ideas communicated in their Jupyter Notebook. Each graphics frame can be interactively configured, and each graphics frame configuration can be stored to file during development in a human-readable JSON format and reloaded during subsequent executions of a Jupyter Notebook (e.g., when shared with others). CC3D visualization in Jupyter Notebook supports displaying individual graphics frames or grids of frames that effectively communicate complex simulation data over multiple fields (e.g., reaction-diffusion fields), which are common to models developed in CC3D that target intercellular signaling and/or dynamic environmental conditions. To this end, CC3D promotes deployment of multiple interactive visualization frames through multiprocessing and an application-specific message-passing interface. Visualization of each frame is executed in a separate process and message passing shares serialized simulation data from the computational core to each visualization process, and likewise instructions from user interactions are shared from each visualization process back to the computational core for real-time manipulation of data visualization (Fig. 1.3).

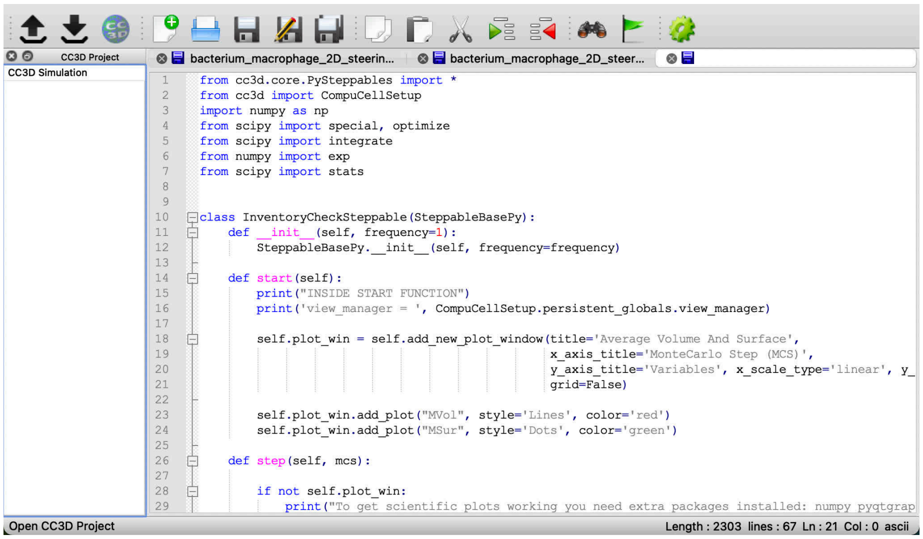


Fig. 1.1. Editing a simulation file using Twedit++ on MacOS

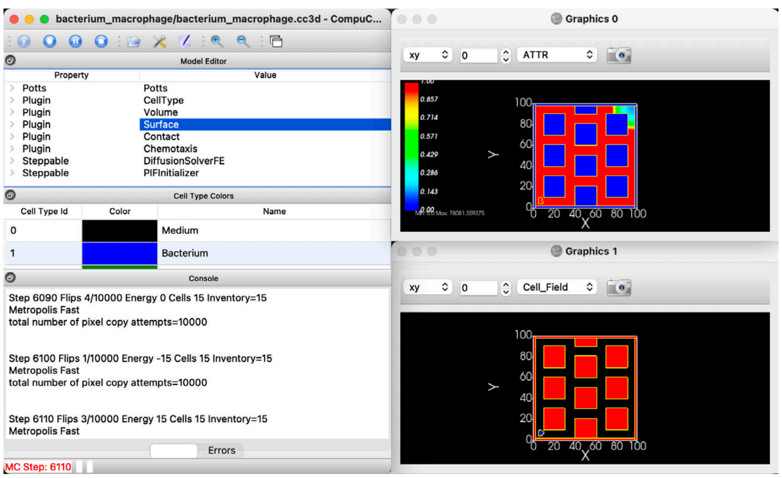


Fig. 1.2. Visualizing a simulation in CompuCell3D Player on MacOS

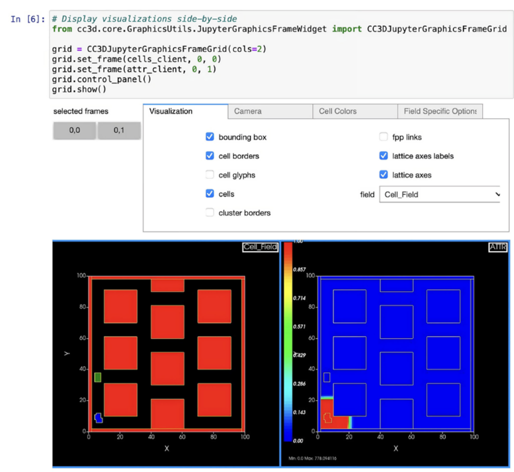


Fig. 1.3. Visualizing a CompuCell3D simulation in a Jupyter Notebook

Previous CompuCell3D releases are primarily designed to run natively on Windows, Mac or Linux operating systems with a GUI. This meets the needs of a majority of users but makes remote client-server computing setups difficult since the remote server needs to render and stream its GUI. For instance, CompuCell3D version 4 is available through nanoHUB [24] and is rendered using the X11 default window manager (Fig. 2). The nanoHUB deployment of CC3D is fully functional and can demonstrate all the capabilities of CC3D, however, there are challenges to using it as a development environment. For one, the simulation execution speed on this platform is slower. In addition, since the remote desktop is an isolated environment, some basic computer functionality including keyboard shortcuts such as copy/paste are not transferable between the client and remote machine.

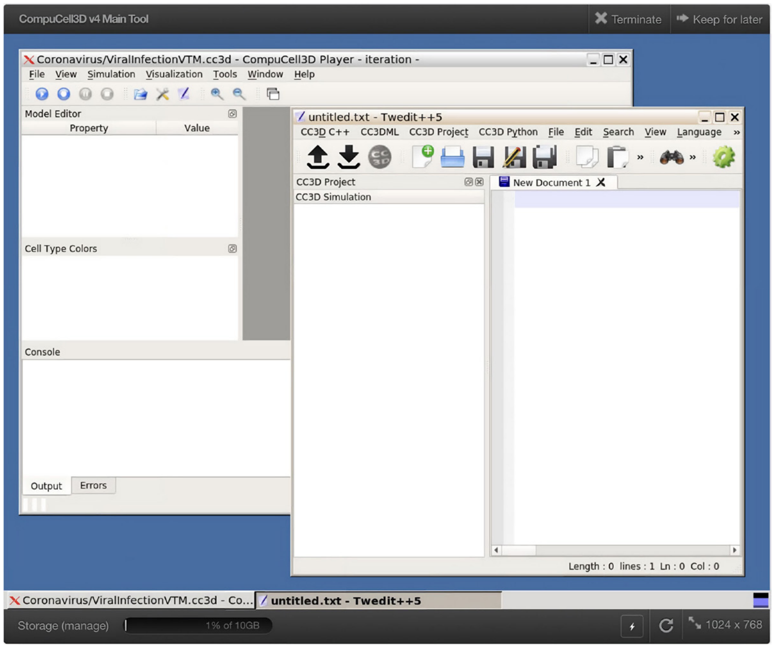


Fig. 2. CompuCell3D Player and Twedit++ running on nanoHUB X11 window manager

On the other hand, a client-server interface is inherent to Jupyter, making Jupyter Notebooks that specify and describe a CC3D simulation easily deployable and efficient on cloud computing systems (Fig. 3). Jupyter can be hosted on a cloud server and accessed using a link by the client user. In such deployments, computations are performed on the server and the graphics are rendered locally, which can significantly improve user experience by increasing the performance of visualization interactivity.

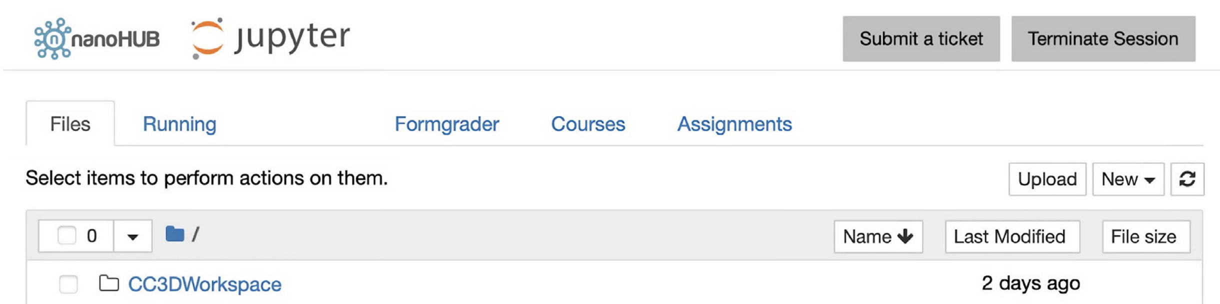


Fig. 3. Jupyter instance of nanoHUB with CompuCell3D files

Discussion

The flexible, portable, and reproducible format of Jupyter Notebook makes it an appealing environment to use as an educational resource and to supplement scientific publications. A single Jupyter Notebook can display instructions, figures, live code and simulations in a single browser window, forming a coherent "computational narrative" [20]. In comparison, working with the native CC3D application would require three different components, where code is written in Twedit++, simulations run in CC3D Player, and instructions are outlined in a separate document. In addition, the Twedit++ and CC3D Player applications have menus and features which may be irrelevant for a particular presentation, while a Jupyter Notebook can selectively load and display relevant components. This customizable and interactive format makes it simpler for audiences to follow and understand the concepts, technical details and overall scope of a CC3D-based project in Jupyter Notebook than with native CC3D (Fig. 4).

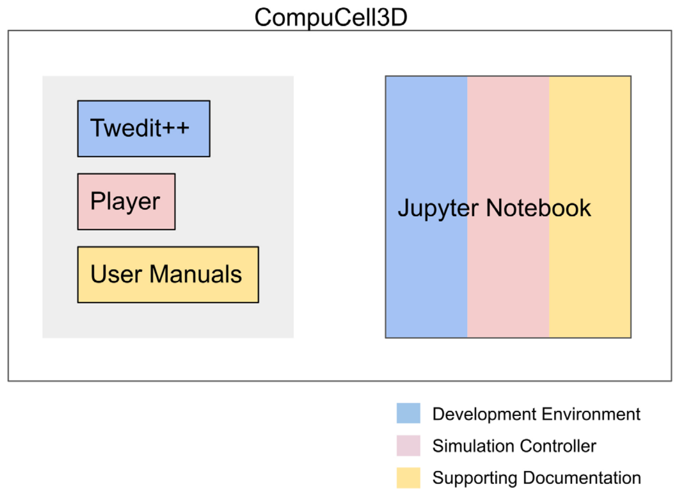


Fig. 4. With the CompuCell3D native applications, the development environment (Twedit++), simulation controller (Player), and supporting documentation (User Manuals) are separate. With Jupyter Notebook, these three aspects are seamlessly integrated as one.

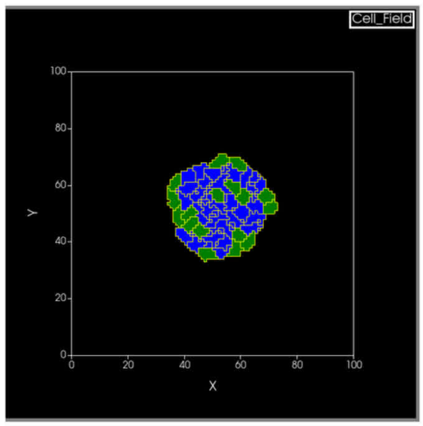
The portability of Jupyter Notebook also makes it easier for teachers to distribute and collect Notebooks as assignments. Jupyter Notebook files may be uploaded onto file-sharing sites such as GitHub or other institutional platforms. In addition, existing online tools for Jupyter Notebooks such as nbviewer [25] allow for more ways to access/view a Notebook. With the flexibility and portability benefits that Jupyter offers, CC3D can be more effectively used in the classroom to demonstrate and reinforce biological concepts to students. Fig. 5. demonstrates an example of CC3D in Jupyter Notebook for educational use, including steps to run CC3D and additional exercises The full example notebook can be found in .pdf and Jupyter Notebook formats in the supplementary materials. In this fashion, a curriculum can be created with interactive Notebooks in place of worksheets. Previously, CC3D would have been difficult to deploy in classrooms because of its device-dependent and multicomponent nature. The development of CC3D for Jupyter Notebook enables a simpler replication and distribution process for instructors. The time to set up the CC3D environment for learning and to create new lesson materials would be reduced because of the streamlined format. The format benefits students as well: a Notebook allows a more focused way of learning rather than having to use and reference multiple applications to operate CC3D, as discussed above. The interactive format also encourages exploration, providing opportunity for a different kind of learning format. Previous research has shown that working with simulated models improves foundational and conceptual skills in biology students [26]. In addition, given the increasing need for online learning, simulations could be an alternative to exercises in a physical laboratory [27].

Step 7: Visualizing the Simulation

However, there is still one more step in order to see the output of our simulation. The cell below is used to show a single frame that visualizes the simulation data as it is generated.

In [7]:
```
from IPython.display import display

cc3d_sim.visualize().show()
display(cc3d_sim.jupyter_run_button())
```



Exercise 1: Reversing Cell Behavior

Run the cell sorting simulation and observe the output. You may notice in some of your simulations that one type of cell tends to form a perimiter around the edge of the blob, wwhile the other cell type forms "pockets" inside this perimeter.

1. Provide an explanation for this behavior. Support your answer by discussing the contact energies provided in the sample simulation above.
2. Modify the contact energies so that the cell types switch behaviors (i.e., perimeter cells become interior cells and vice versa). Document your changes and describe why the new values cause the switch.
3. Modify the contact energy values so that the sorting behavior stops (i.e., cells mix randomly). Document your changes and describe why the new values cause random mixing.

Fig. 5. Excerpts from the SortingDemo_ExtendedContent.ipynb file included in supplementary materials. Instructions for running the simulation and additional exercises are seamlessly integrated into one interactive environment through Jupyter Notebook.

Another beneficial use for CC3D in Jupyter Notebook is to embed CC3D simulations into research publications as supplementary media to help other researchers understand, interrogate and reproduce published work. As reports indicate, a current crisis of reproducibility across published science, especially for the field of computational biology [28], has filled much of the recent literature with works that cannot be reproduced because of factors like insufficient descriptions of methodology. CC3D support for Jupyter Notebook can thus help mitigate the waning reproducibility in computational biological modeling by providing a straightforward way for scientists to publish research in a format that makes it easier for others to trace, understand and reproduce their work. Since Jupyter Notebooks can be shared via accessible file hosting or cloud computing platforms like GitHub and nanoHUB, sharing or accessing a published Notebook is trivial, and many researchers are already familiar with these tools.

One limitation to using CC3D in Jupyter Notebook is that performance can vary depending on how much algorithmic work is done in Python. While the cost of pure backend calculations are unaffected, certain algorithms such as loops implemented in Python are less efficient than the C++ counterpart, which the Jupyter environment does not currently support. As a result, simulations have longer execution time than executed in the native desktop application, which may make Jupyter Notebook unsuitable for larger-scale simulations. For example, a simple benchmark running a 2D cell sorting demo demonstrated an execution time of 35 seconds in a Jupyter Notebook, compared to 2 seconds in Player and 0.5 seconds in a pure Python implementation (see Supporting Materials 1). While simulation performance varies depending on the machine and setup, and there are techniques to improve simulation performance, which is out of the scope of this paper, an implementation of a CC3D simulation may not be appropriate in Jupyter Notebook when developing, testing and applying computationally expensive algorithms specified in Python. However, a CC3D simulation implementation in a Jupyter Notebook still provides value for the purposes of sharing, demonstration and communication, and so CC3D-based research projects that do not primarily use Jupyter Notebook to generate published results should still provide a published implementation in a Jupyter Notebook to support reproducibility, as well as to showcase published work in an accessible and engaging medium.

Conclusion

CC3D is a software tool for computational biologists to develop, test and apply cell-based computational models of biological systems, while Jupyter Notebook is a generic interactive computing environment. Providing support for Jupyter in CC3D pushes computational biological modeling towards modern software practices and better accessibility for more users of different backgrounds. The Jupyter implementation of CC3D preserves the intuitiveness of CC3D Player while also serving as an IDE.

The authors encourage biology educators and student researchers to try using this new feature of CC3D and share any work done using this tool with the community of CC3D developers and users. Engagement and feedback allow the developers to continue improving and adding features which are most useful to users. In addition, learning resources will be continually added to support a growing user base.

Acknowledgments. We thank Hayden Fennell, postdoctoral researcher at Indiana University, for contributing his time and expertise to create an example Jupyter Notebook using CC3D for educational use.

We additionally thank Prof. Jared Ashcroft and the Micro Nano Technology Education Center of Pasadena City College for helping initiate this collaboration and for ongoing support. We acknowledge support from National Science Foundation grants NSF 2120200, NSF 2000281 and NSF 1720625 and National Institutes of Health grants U24 EB028887 and R01 GM122424.

Disclosures. The authors declare no conflicts of interest.

Supporting Materials. Source code for simulation benchmarks using CC3D Player, CC3D Python API and a Jupyter Notebook.

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Results and Discussion from Two Seasons of the Talking Technicians Podcast

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Abstract: This study analyzes the first two seasons of the Talking Technicians Podcast, which consists of 24 episodes with working technicians. The study aims to demonstrate that podcasts featuring working technicians provide unique insights into technological education that other methods cannot easily obtain. The themes that emerged from the interviews include the importance of soft skills, teamwork, and when in a large company environment, it pays to be aware of opportunities for professional advancement. While wage and benefit comparisons were not made between the technicians interviewed, the study found that podcasts offer a powerful tool for sharing knowledge and connecting with audiences, enabling listeners to focus on the content and engage with the ideas of presenters and guests.

Keywords: podcast, talking technicians, technicians, dissemination

Introduction

The Talking Technicians Podcast [1] is a podcast about working technicians. The Micro Nano Technology Education Center (MNT-EC) produces and supports the podcast under the National Science Foundation Advanced Technological Education (ATE) program.

Each podcast episode is an interview with a technician or a panel of multiple technicians. The Talking Technicians Podcast aims to share and promote technician jobs with community college students and faculty to broaden participation in the workforce. In addition, we aspire to drive awareness of technician education and careers. The goal of each episode is to share the life of a working technician: who they are, what they do, and where they come from.

A Brief History of Podcasts

Podcasts have been around in some guise since the 1980s, but with the advent of portable media players such as the iPod, they became increasingly popular by the early 2000s. These digital-only players made it easy for people to listen to podcasts on the go, and the rise of broadband internet made it easy to download and stream [2].

The term podcast itself was coined in 2004 by journalist Ben Hammersley, and it was derived from the words "iPod" and "broadcast." Podcasts continue to grow with the rise of smartphones and other devices, and podcasts remain an increasingly popular way to consume information [3].

Podcasts are typically audio recordings, but some may include video. They cover a wide range of topics, from news and politics to sports and entertainment, and are often created by individuals or small teams. Many podcasts are free, and listeners can subscribe to them to receive new episodes automatically via a web-based podcast player or an app on a mobile device.

Overall, podcasts are a way for people to stay informed and entertained, and the platform has opened up new opportunities for educators to share their ideas with a global audience.

In 2006, only 22 percent of the adult population in the United States was aware of podcasting. By 2022, this figure rose to 79 percent. Podcasting is an increasingly popular pastime in the US, with 79 percent of respondents being aware of the format, while over 82 million people listened to podcasts in 2021. This number is estimated to rise even further, reaching over 100 million listeners in 2024 [4].

Podcasts as Dissemination

For educators, podcasts provide a valuable tool to distribute and disseminate information to their students. In addition, they can be used to supplement traditional classroom instruction, providing additional information and examples for students to learn.

Podcasts are also a flexible and convenient medium for students to access. They can be listened to on various devices, including smartphones and laptops, and downloaded and listened to at the student's convenience. This allows students to learn at their own pace and in their own time, making it an effective way to reach students who may have busy schedules or learn best outside the classroom.

In many niche specialties, in business and education, podcasts have proven to be an effective way to share information [5]. Within ATE, other principal investigators have also found that podcasts are a popular and accessible format for conducting effective and valuable outreach [6]. It allows us to reach students where they are and for them to consume the information when and how they want or are able. Arguably, it is a more engaging and interactive learning experience and format. Another benefit is that they are easy to share via text, email, or Bluetooth, with Apple's easy-to-use "AirDrop" button pushing a file from one iPhone to another.

Platforms and Resources Considered

We considered five major podcasting platforms to disseminate the Talking Technicians podcast. Buzzsprout is the platform we chose for Talking Technicians with benefits as explained below.

- Buzzsprout — Best Podcast Hosting Overall [7]
- Libsyn — For Beginners to Experts [8]
- RSS.com — Best for Beginners & Affordable [9]
- PodBean — Easy to use Podcast Hosting [10]
- Transistor — Podcast hosting for brands & professionals [11]

Buzzsprout offers a range of features and tools for beginners and experienced podcast creators. It has a simple interface that is easy to use and provides a variety of player templates that can be embedded in websites.

In addition to standard distribution through Buzzsprout and across its partner podcast platforms, our second most significant source of traffic is from the Micro Nano Technology Education Center (MNT-EC) website. To take advantage of this platform, we customized and embedded a Buzzsprout podcast player directly on the website, allowing visitors to listen to our podcasts from the web player.

This web player provided two main outreach benefits - listeners spend more time on our website with its dedicated episode page. It also helps us optimize our content for search engines, also known as SEO, so potential listeners can easily find our podcasts via searches they make on relevant keywords around technician education.

In 2023, we plan to promote our podcasts on additional social media platforms, including the MNT-EC LinkedIn page [12] and Twitter accounts [13] which will include shareable content for our partners and allies to use.

In social media testing, we have studied and found widespread, well-trafficked hashtags helpful in driving traffic, and allow us to reach the largest audience possible. We have also found that directly encouraging or inviting our network (partners, professional connections) to "Like, Comment or Share" our posts yields higher engagement. Social media is constantly changing as an entire category and on each individual platform. For example, we adapt methods based on what works on LinkedIn, an image and two paragraphs of text, but we would only post the image and not the text on Instagram. We continue to learn what works on social media and change, adapt as necessary to gain more listeners, and encourage audio content sharing.

In addition, we have a prominent section in the MNT-EC Monthly Update emails, which features our podcasts in each issue. This outreach email is sent to over 3,200 subscribers and is one of our most successful ways of gaining listeners [14].

An audio file of each episode was also uploaded to YouTube.com as a static video (which means it shows one image for the entire episode). Although YouTube is known mainly as a video platform, there is data that shows it is a popular way for people to find and listen to podcasts [15].

One of the standout features, and possibly the most important for our learning and growth as a producer, is Buzzsprout's analytics and tracking capabilities [16]. These analytics provides detailed insights into listener demographics, engagement, and other metrics, allowing the Talking Technicians team to understand our audience, what they like and dislike, and improve/customize our content accordingly.

Methods

Finding Guests

Podcast guests were solicited and selected based on a few criteria. All guests were required to have a degree or certificate from a community or technical college and to work or have worked as a technician in an advanced technology field. Besides these two criteria, guests were selected based on their identities belonging to a group under-represented in technician education and the advanced technological workforce. The identities shown below are not exclusive to each other. We are all unique individuals, and podcast guests could identify intersectionality with multiple identities.

Table 1. Solicited Podcast Guest Identities

Gender	Race	Family Background	Language	Ableness	Nationality
Female	Black College Student	First-Time	ESOL	Differently Abled	US Immigrant
Non-Binary	Latino or Latina	Single Parent			
	Indigenous				

Our goal is to ensure under-represented voices in the technician workforce are shared and heard. When we searched for guests to interview, we outreached to guests with at least one or more of the identities listed in Table 1. We believe we met this goal, but guest self-identification data was not collected or solicited. This work has made us consider a more complete demographic scan of interviewees. We plan to collect this data in future seasons with the guidance of the MNT-EC External Evaluator.

Methods to secure guest contacts included emailing MNT-EC PIs, emailing MNT-EC partners, emailing community college colleagues, asking about guests during online meetings, and seeking out former students. Guests were also solicited from previous guests. We asked each guest after the recording session if they could suggest anyone else for the podcast.

Tech Check

Before recording, each Podcast guest ran through a "tech check" with the Talking Technicians Podcast Program Manager. The guest's audio quality, internet connection speed, and stability during the tech check were evaluated to ensure a high-quality recording. The tech check also provided guests the opportunity to ask questions about the podcast recording before it started. Depending on the guest, tech checks took 10-20 minutes over Zoom. Tech checks were completed a few days to a week before the podcast recording.

Recording

Each episode of the Talking Technicians Podcast was recorded over Zoom with a simultaneous local recording of the host using a handheld audio recorder.

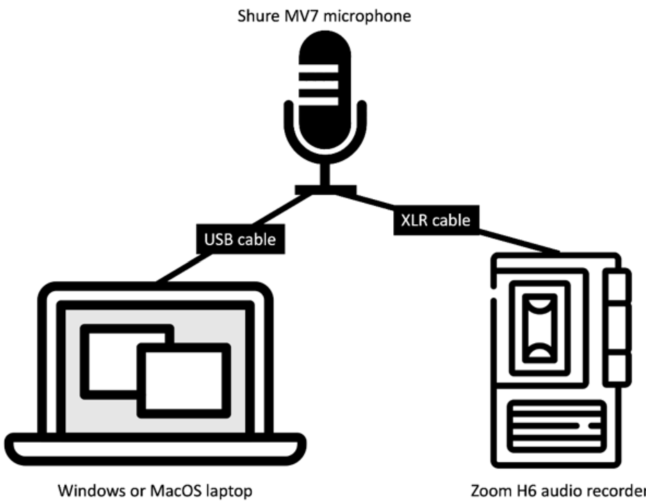

Fig. 1. Audio Signal Chain

The audio signal chain starts with a Shure MV7 USB/XLR dynamic microphone. The microphone was connected to a Windows or MacOS laptop over USB (USB micro-B to USB-C cable). The microphone was simultaneously connected to a Zoom H6 audio recorder using an XLR cable. The Shure MV7 microphone can output a signal over USB and XLR simultaneously. The audio setup produces a clean recording by the host in the Zoom H6 audio recorder and produces a backup recording of the host using Zoom. The guest's audio was recorded using Zoom only. The MV7 USB microphone was selected as the audio input by the host in the Zoom application. A pair of earbuds connected to the computer's audio jack was used as the host's Zoom audio output. This audio setup allows the host to talk with the guest over Zoom. Figure 1 above details the audio signal chain.

Zoom recording settings used when the podcast episodes were recorded shown in Figure 2. A key option to enable when recording podcasts over Zoom is to "Record a separate audio file of each participant."

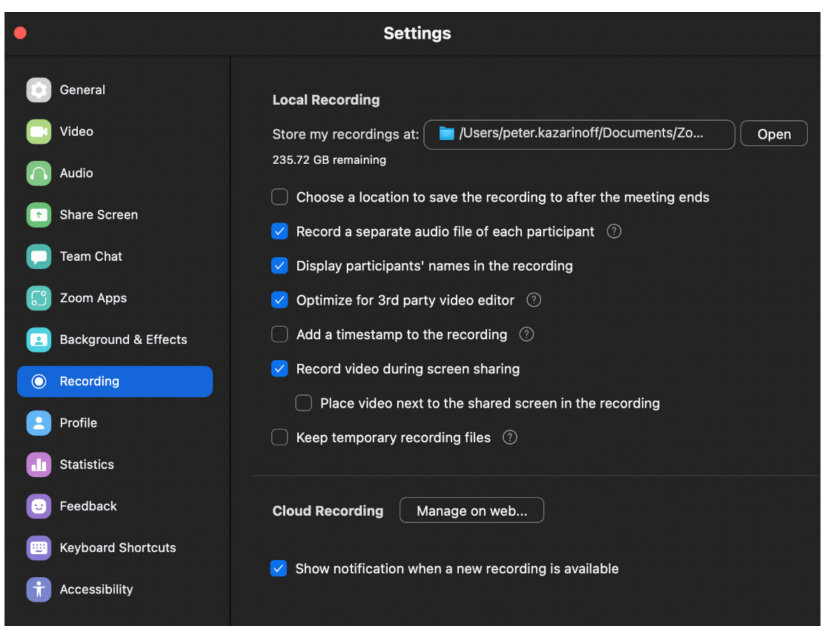

Fig. 2. Zoom Recording Preferences

Zoom audio settings included enabling “Original sound for musicians” and “High-fidelity music mode”. Zoom audio preferences used for podcast recordings are shown in Figure 3.

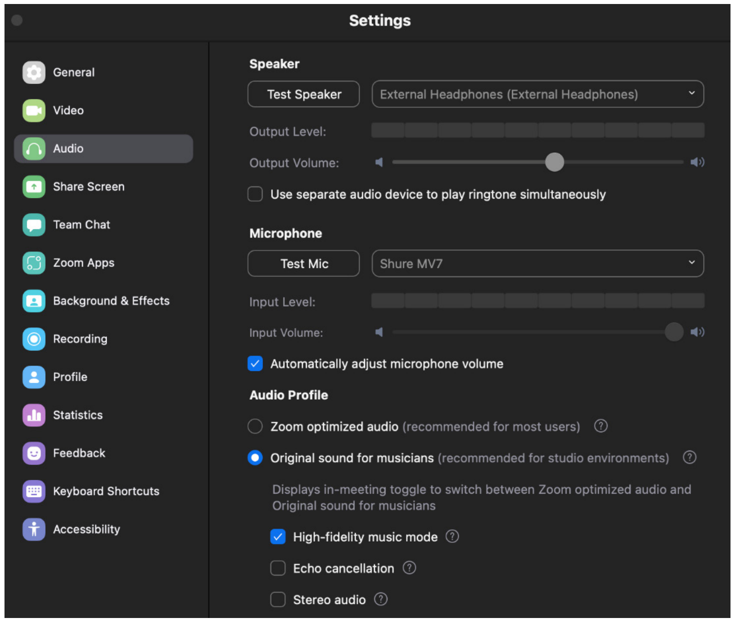

Fig. 3. Zoom Audio Preferences

Each podcast recording took around 20 to 30 minutes, depending on the episode. After recording, the episodes were edited.

Editing

Podcast episodes were edited to clean up the audio and make them easy to listen to and understand on various devices (phone speakers, earbuds, car speakers, etc.). Episodes were not edited for content unless a guest requested to re-do an answer or leave out a portion of the interview. Breaths, coughs, long pauses, “um’s” and “ah’s” were edited out when necessary to increase intelligibility. Podcast episodes were edited with Adobe Audition version 2022 on a MacOS or Windows Laptop. An example Adobe Audition Project is shown in Figure 4. The podcast episodes were edited in multi-track mode at a 44100 Hz sample rate and a 32-bit depth.

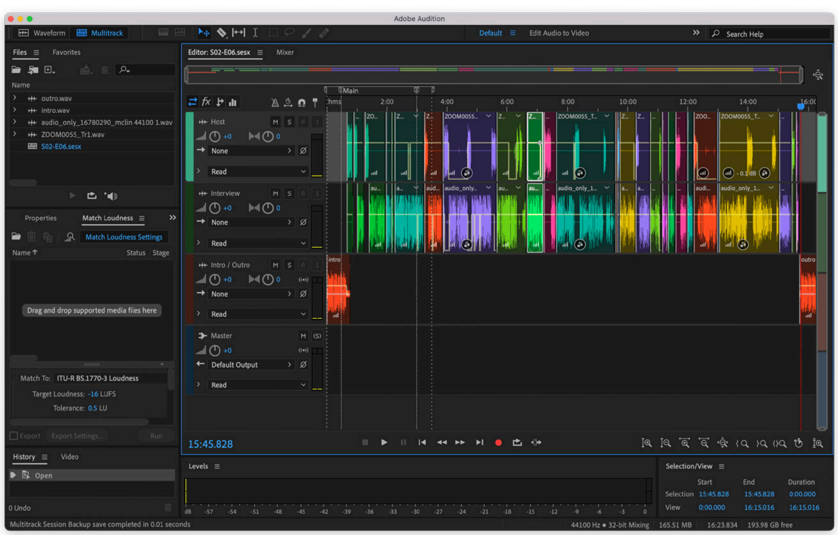

Fig. 4. Adobe Audition Audio Editing Software

The podcast intro and outro were added to the beginning and end of each episode. The intro music is from Stream Beats [17], and the song is called Ambient Gold. The outro message was based on the outro message of the Future of Work podcast [18]. Each podcast audio recording differs slightly based on ambient noise, recording environment, and other variables. A general set of audio effects were applied to increase intelligibility, remove harshness, and ensure the podcast episodes were easy to listen to on a variety of devices.

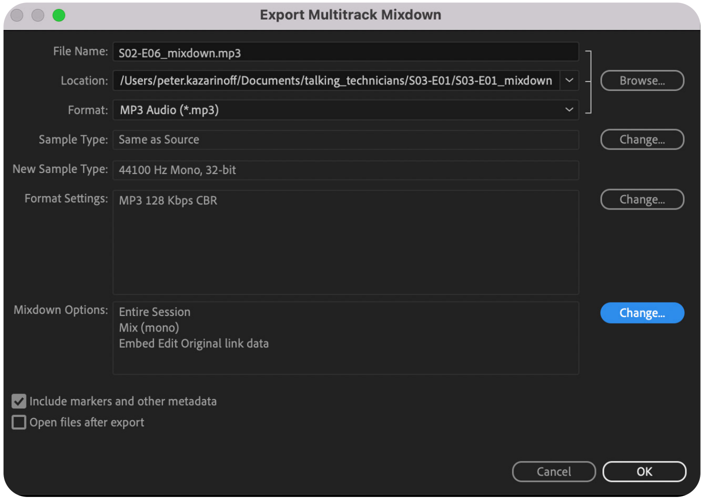

Fig. 5. Adobe Audition Export Settings

Audio Editing Effects Order:

- Noise Gate: -40db Threshold
- Parametric EQ: Adobe Audition 2022 Vocal Enhancement Preset
- De-esser: Frequency 9.2k, Threshold -40db
- Compressor: Threshold -16db, Ratio 3:1, Attack 10ms, Release 100ms, Makeup gain 8db
- Limiter: -1 db

After audio effects were applied, podcast episodes were normalized to a target loudness of -16 LUFS. After editing, each podcast episode was exported from Adobe Audition as a mono .mp3 file. The Adobe Audition export settings are shown in Figure 5.

Publishing

Otter.ai [19] was used to construct text transcripts of each episode. After transcription, manual checking and editing were completed to ensure accurate transcripts of each episode. Finally, transcripts were exported from Otter.ai as .txt files.

Podcast episodes were uploaded and hosted on buzzsprout.com [7]. Buzzsprout's Magic Mastering service [20] was applied to each episode. A description was added to each episode that included links related to the episode.

Video versions of the podcast episodes were converted from .mp3 audio files and a single .png image using a custom Python script [21] and ffmpeg [22]. The single .png image used to create .mp4 videos was 1920 x 1080 pixels. The custom .png image for YouTube export is shown in Figure 6.

Fig. 6. Single .png image used to produce .mp4 video files from podcast .mp3 audio files.

The basic ffmpeg terminal command used to convert .mp3 audio files into .mp4 video files is below:

```
ffmpeg -loop 1 -i image.png -i audio.mp3 -c:a copy -c:v libx264 -shortest video.mp4
```

Ffmpeg, a command line tool, used to modify and convert video files, was installed using the conda package manager [23] into a custom conda virtual environment. Conda is a virtual environment creation and management tool used in the Python and Data Science ecosystem. A virtual environment is a stand-alone isolated collection of software separate from a computers system tools. See the audio-to-video git repository for more information [24].

Results and Discussion

Publishing Platforms

Buzzsprout has distribution agreements with almost every major podcast platform, such as Apple Podcasts, Spotify, Google Podcasts, Stitcher, iHeartRadio, TuneIn, Alexa, Overcast, PocketCasts, Castro, Castbox, and Podchaser. This is an excellent way for us to increase the visibility of our podcast.

The podcast was also published to the Micro Nano Technology Education Center (MNT-EC) YouTube Channel [25] and shared on the MNT-EC website [1].

Website Analytics

As of January 2023, there are 3.02 million podcasts produced with 150 million episodes, with an average of 50 episodes per podcast. We use these data points to help us estimate what constitutes success and, frankly, survival rates for podcasts [26].

Education podcasts are the second most popular genre, with approximately 450,000 unique podcasts (not episodes) in existence. Although we were not able to segment down into the STEM niche and find specific data for comparison, we know that overall podcasting is growing in popularity, with 82 million people reporting they listen to or are aware of podcasting. We aim to continue growing our download count and track how many people listen to our episodes. We are also interested in where listeners are enjoying the Talking Technicians podcast in the US or globally. For example, we know international students return to their native countries but continue to have ties to the US in various ways. Some of those listeners may also be US citizens now residing abroad and working for a multinational corporation [26].

Since launching the Talking Technicians Podcast on December 31, 2020, the podcast has had 626 "views" from 415 unique visitors on the MNT-EC Website [27]. Google Analytics reports clicks on various parts of the site as "views" and not listens as most podcast platforms. The overall listening time for podcast episodes via the website is only 30 seconds, but between views and listen time, the podcast is at number nine of the most visited pages on the site. It also is helpful to the overall mission of the site and delivers other engagements, and has driven over 2,100 "events" or actions/clicks to other areas of the site, again part of why it is consistently in the top ten list of valuable pages for the site.

Traffic (User) data on the MNT-EC website begins December 2020; however, MNT-EC started publishing static videos with audio only to YouTube.com. Therefore, Seasons One and Two of YouTube Data are reflected from May 2021 to July 2022.

YouTube Analytics

Overall, we have 24 episodes uploaded to YouTube as audio-only files with a total of 549 views. The view count data point, however, does not tell the whole story as they resulted in almost 27 hours of total listening time impact. Of those hours, the average listen time per episode is only two minutes (with a range of listens from just under one minute to over 7 minutes average per episode) [25]. But, again, this does not provide a complete picture as those 24 episodes received nearly 12,000 impressions on the YouTube platform (for people who searched for us or found us in suggested video lists) and contributed 60 clicks through to the MNT-EC Website from May 2021 to July 2022.

Podcast Analytics

As mentioned above, the Talking Technicians podcast was made available on the listening platform, BuzzSprout, starting in December 2020. In addition, BuzzSprout also cross-lists the podcast on several other listening platforms, including Apple Podcasts, Spotify, iHeartRadio, etc. [28]. In the first two seasons, the podcast was downloaded over 1,160 times across various platforms. The graph below shows the top five listening platforms plus an accumulation of all other platforms available to BuzzSprout.

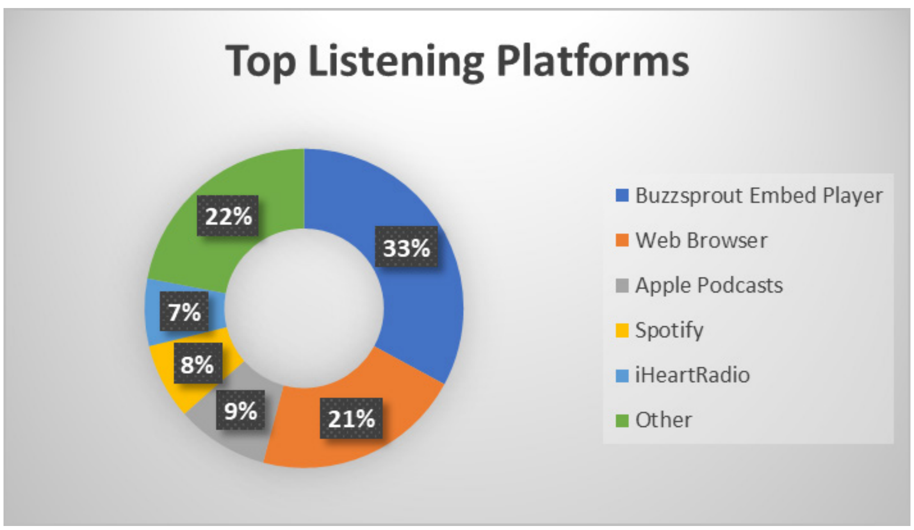

Fig. 7. Top Podcast Listening Platforms

The web browser data could be accounted for by the fact that the podcast is listened to through the MNT-EC website embedded player and in other countries outside the United States. MNT-EC has the BuzzSprout player embedded into its website, where people can listen to the podcast. The top five Talking Technicians episodes on BuzzSprout provide us with early data for later comparison and evaluation when we connect with other STEM Podcast producers. The top five episodes downloaded are shown in Table 2 on the following page.

Table 2. Most Popular Podcast Episodes by Number of Downloads

Episode Number	Episode Title	Number of Downloads
S01-E01	Laser Technicians at Lawrence Livermore National Lab	114
S02-E02	Antonio is a technician at Lawrence Livermore National Lab	85
S02-E03	Cristian is an electron microscopist	81
S02-E06	Linzee is a technician at Intel	67
S01-E12	Welcome back Geovana, Amalia, and Danil!	66

The total number of downloads for each episode is shown in Figure 8 below. Most of the downloads for each episode happen within the first seven days of publication. After the first week, download activity for each episode decreases. This decreasing trend is something that appears to happen naturally with other podcasts and online media like YouTube videos (Looking at Nano-Link YouTube [29] and MNT-EC YouTube pages [30]).

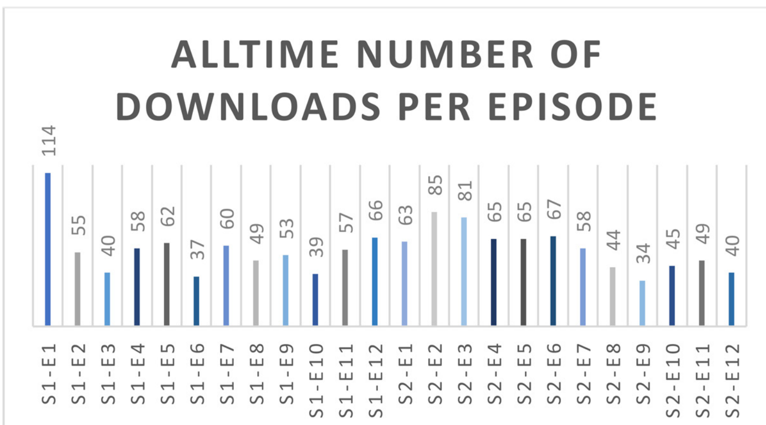

Fig. 8. Podcast Downloads Per Episode

Guest Demographics

A core value of the Talking Technicians Podcast is sharing voices from diverse working technicians. Table 3 below shows the identities of the podcast guests during the first two seasons.

Table 3. Podcast Guest Gender Identity

	Number of Guests
Male	17
Female	11
Non-Binary	0

In season one, we interviewed five technicians who were immigrants. Listening to their stories of what they had to go through to become technicians was of interest to the authors. One story stands out, a woman from Brazil came to the United States with her husband. They came because he had gotten a job with a US-based company. In her home country, she was a pharmacist. When she came here, she had to start all over with her schooling. However, she loved being a pharmacist back home and was doing HIV research. She didn't speak much English, so she went to school to learn and also took some other classes so she could apply for pharmacy school. She gave up on pharmacy school, and she chose to pursue an AAS degree in Bioscience Technology. She then got a job at Intel and now loves her job. She explains in the episode how nervous she was and how she wasn't sure if she could do it. Sometimes we forget just how different things are for other people and listening to that episode can put things into perspective for us.

Technician Responsibility Trends

By reviewing the text transcripts of the 24 podcast episodes, themes, trends, and contrasts emerge. For example, some technicians were recent graduates, and only a few were in the workforce for 30 years or more. When the podcast guests were asked what kinds of things they did at their jobs, there were quite a few recurring topics with some key differences between large companies, those with 1000+ employees, and small companies, those with less than 100 employees. Small company technicians did everything the large company technicians did, plus other responsibilities as outlined in Figure 9. Some top items that emerged were preventative maintenance, communication, and teamwork.

We don't have the data to compare wages, but we do know that those working for a company in a higher cost-of-living area tended to start with higher wages than those who lived in a lower cost-of-living location. Benefits were another thing that kept coming up for the technicians at the larger companies. Again – we don't have the data to compare wages or benefits between the two groups; however, the technicians that did tell us about benefits said they were a huge plus for them and their families if they had one.

Nonetheless, all the technicians we interviewed talked about continuous learning opportunities and supportive environments at work.

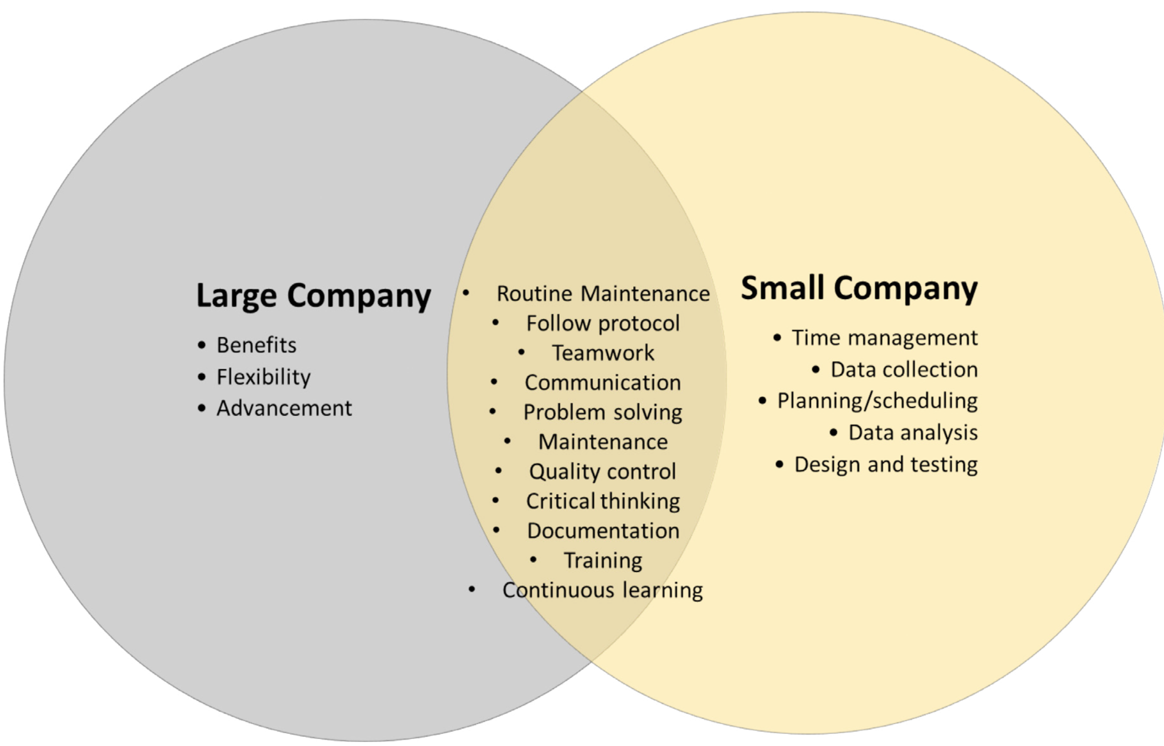

Fig. 9. Venn diagram showing the responsibilities that technicians at a small company have compared to technicians at a large company.

Takeaways for Community College Students and Faculty

Over the course of two seasons and 24 episodes of the Talking Technicians Podcast, we find five takeaways for community college faculty and students:

- Working as a technician is a rewarding career that can help people in direct and indirect ways
- Technician jobs are living wage jobs. Most jobs included benefits such as health insurance and retirement.
- Working as a technician can be a life-long career or the start of a career that can lead to more advanced roles.
- Becoming a technician can be a transformational experience. It allowed some guests to buy a house, send their kids to better schools, go on vacation, or not have to worry about how to pay the next bill.
- All technicians noted that future students or career changers should consider starting a community college program and encouraged others to just dive in and get started.

Conclusion

The Talking Technicians podcast is driving awareness of technician education and technician careers. The podcast has seen growth for MNT-EC's dissemination in audio and video compared to plain text on a webpage. Podcasts are more compelling as an audio stream. Generally, it is a great format that drives how you can share information and the people you can reach. This work shows people listen to podcasts on YouTube as well as podcast players on mobile devices. The Talking Technicians podcast goes where people are: listening to audio or watching/listening video. Podcasts allow us to hear and feel the emotion of the presenter and the guest. We can focus on the words better and are not distracted by looks, body movement, or the environment around the individual or group. As a result, we are more in tune with what is being said and more likely to be fully engaged with the person speaking.

Further study could include if and how partners have integrated the podcast in the classroom, either in their lesson plans or by teaching students to make their own podcast. In addition, it would be interesting to survey the MNT-EC partners to see who is using podcasts; and to record more demographic data from each podcast interviewee.

Acknowledgements. This work was funded by the National Science Foundation under DUE ATE #2000281. The Talking Technicians Podcast would not be possible without the hard work, dedication, and support of Janet Pinhorn, Program Manager for the podcast. Reaching out to guests, scheduling tech checks and recording times, following up with guests, and answering email questions were all part of Janet's essential work. The Talking Technicians Podcast would not be possible without Janet.

Disclosures. The authors declare no conflicts of interest.

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Invited Letter: Highly Skilled Technical Workforce Helps Advance Regenerative Medicine Research & Scale Biomanufacturing

Keywords: Wake Forest Institute, WFIRM, InnovATEBIO, Forsyth Technical Community College, regenerative medicine, biomanufacturing technicians, biotechnicians industry-education partnerships

As the chief workforce development officer for the Wake Forest Institute for Regenerative Medicine and chief operating officer for the non-profit RegenMed Development Organization, I see every day the need for a highly skilled technical workforce to advance regenerative medicine and ensure that the United States remains the global leader in research, clinical translation, and scaled biomanufacturing. As a former community college president and currently co-chair of the National Industry and Workforce Advisory Council of InnovATEBIO, the NSF ATE-sponsored national center for biotechnology education, I know that community colleges, with their employer and higher education partners, can produce this skilled workforce.

The Wake Forest Institute for Regenerative Medicine (WFIRM), located in Winston-Salem, NC, is a recognized global leader in regenerative medicine, bringing together over 450 scientists, physicians, technologists, technicians, and support personnel to translate scientific and technological advances into engineered tissue and organs and cell therapies. Interdisciplinary teams work with over 400 industry, academic, and government partners to address patient needs. The RegenMed Development Organization serves as the nexus connecting academia and business, creating an economic engine for regional development – the RegenMed Hub.

While regenerative medicine research has been underway for decades, the field has reached a level of maturity where the work is often focused on production for clinical translation and ultimately scaled biomanufacturing. With this evolution comes a change in the workforce needs as skilled technicians undertake more and more of the work. While basic research at WFIRM requires creativity and problem-solving at an advanced scientific level, production for clinical translation and biomanufacturing generally requires the ability to follow established protocols and procedures without variation in a highly regulated environment. These abilities are developed in skilled technicians. WFIRM currently has approximately 50 technicians assigned to 15 core research and translation laboratories and production facilities. The growth of the Institute has resulted in a continuing need for these technicians.

The Institute's 20-year relationship with its local community college – Forsyth Technical Community College – and other community colleges with biotechnology and bioprocessing programs has resulted in a pipeline of skilled technicians for entry-level lab and production positions. In addition to serving WFIRM, these programs provide the skilled workforce needed for large and small companies that are developing in and migrating to the RegenMed Hub. The success of the partnership with the community college is grounded in continuous communication among key leaders, employer support for faculty and curriculum development, work-based learning opportunities for students, and articulation relationships with universities supporting long-term career pathways. The community college relationship is central to advancing science and technology, serving patients, and enhancing national competitiveness in regenerative medicine.

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WFIRM

Wake Forest Institute for Regenerative Medicine

Biotech-Careers.org: A Resource for Building Career Awareness in Biotechnology

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Abstract: Biotech-Careers.org is a comprehensive career information resource used in college and high school classrooms nationwide. The site combines education materials and job search capabilities with an extensive employer database. We describe four paths for exploring Biotech-Careers.org–People, Places, Things, and Jobs and describe the impacts of using the site on multiple cohorts of college students. The students reported an increased interest in pursuing biotechnology-related careers and an increase in cognitive factors (awareness, belonging, self-efficacy, and identity) known to be important in career choice.

Keywords: biotechnology, career, awareness

Introduction

Biotechnology companies have a wide variety of positions, pay well, provide good benefits, and offer opportunities for advancement and job satisfaction. Yet, despite these advantages, industry reports highlight the challenges companies face with finding enough qualified employees [1, 2].

Two factors contributing to this problem are a lack of awareness of what people do in biotechnology and an absence of clear pathways for embarking on biotechnology careers. When it comes to biology-oriented professions, most students know what doctors and nurses do. Many can even guess what a medical technician's job might be like. But when it comes to biotechnology, the job titles are mysterious, the work responsibilities unclear, and the pathways for learning the required skills and embarking on those careers are invisible. For example, how would a student know the difference between a Research Assistant, Research Associate, and Scientist? How could they know what kinds of tasks are performed by Process Development Associates, Quality Control Associates, Manufacturing Technicians, Data Managers, Validation Engineers, and Project Managers and what the educational pathways might entail?

Biotech-Careers.org was designed to address the challenge of describing entry-level biotechnology careers. We describe educational materials at the site, discuss four pathways for student exploration, and present student data demonstrating increased career awareness and other cognitive factors related to career choice after students have used the site.

1.1 Biotech-Careers.org

Biotech-Careers.org is a multi-media online resource where students can learn about different industry sectors and find position titles, career descriptions, maps, companies, job postings, videos, and programs that can prepare them to enter the biotechnology workforce (Table 1).

The site was created by Digital World Biology (DWB) as part of the National Bio-Link Center for Biotechnology Education [3] and launched in June 2012. Since the end of Bio-Link in 2018, DWB has continued adding features and content through a grant (DUE 1764225) from the National Science Foundation's Advanced Technological Education (ATE) program. DWB also collaborates with the current National ATE Center for Biotechnology, InnovATEBIO, as a leader for the Biotech-Careers.org and Entrepreneurship Hub [4].

The site addresses a common misperception that biotechnology careers require advanced degrees by including profiles from community college alumni and hiring data from InnovATEBIO. Alumni from biotechnology programs nationwide contributed descriptions of their educational journeys and daily routines along with photos showing what their work is like [5]. In addition, 96 InnovATEBIO community college programs contributed hiring data [6]. These stories and data demonstrate that a wide variety of people at multiple education levels work in biotechnology companies and that the industry values community college certificates and degrees.

Table 1. Career education resources at Biotech-Careers.org

Link Title	Career Education Resource	Number
Career Descriptions	Descriptions of entry-level positions in biotechnology – include average salary, education, degrees, colleges	33
Job Areas	Job descriptions in different business sectors	36
People	Profiles of community college alumni working in industry	35
Blogs	Articles on the biotechnology industry and new careers	59
Videos	Videos about working biotechnology	70
Biotech Companies	Interactive maps show a global view of company locations, companies in the United States, or company locations organized by state. Company profiles contain a short description, a link to the company's website, and indicate whether the company has hired a student from a two-year college. In addition, direct links to company career and internship pages are included.	>8828[a] companies in >12,488 locations
Biotech Jobs	Links to two job board databases allow visitors to search job posts. Searchable lists of employer career pages and internship pages are also provided.	>3963 US employer career pages >99 US employer internship pages in 191 locations
Business Areas	A word cloud displays terms companies use to describe their activities. Each term is linked to a page with an interactive map of the company locations and table with companies working in one area.	>507

[a]The number of companies and business areas is dynamic and changes almost daily.

1.2 The Biotech-Careers Industry Database

DWB added a biotechnology industry database to Biotech-Careers.org in 2016. The database represents a wide variety of employers worldwide that produce biotech and biopharma-related products, technology, and services. We use Google (Google.com) to search for company names and gather data from company websites to add companies to the database. For each company, we enter locations, a description, URL, the company's business areas, and whether they have hired a community college student. We enter most of the data manually, averaging 100 companies per month. Tabular data are imported using the Drupal Feeds module [7].

We use automated tools to check company URLs once a year to maintain and curate the database. Automated tools are also used more frequently to obtain and add links to career and internship pages. Companies with problem URLs are reviewed and either unpublished or updated. Since 2016, we have unpublished 1786 companies that either went out of business, were purchased, or merged with another company.

We obtain company names from multiple sources. These include CrunchBase [8], the Biotechnology Innovation Organization (BIO) membership list (BIO.org), and trade association websites [9-12]. In addition, we use scientific journals such as Nature (Nature.com), Science (Science.org), and Nature Biotechnology (Nature.com/nbt); newsletters: 360Dx (360dx.com), GenomeWeb (GenomeWeb.com), STAT news (STATnews.com), Fierce Biotech (FierceBiotech.com), Endpoints news (Endpts.com), Genetic Engineering & Biotechnology News (genengnews.com), Geekwire (Geekwire.com), BioBuzz (Biobuzz.io), SynBioBeta (Synbiobeta.com); and newspapers: the Seattle Times (Seattletimes.com), and the New York Times (nytimes.com). Companies also fill out forms on our website requesting to be added.

InnovATEBIO programs are an essential data source [13]. These data are used to identify companies that have hired community college students. As of February 2023, at least 732 of the 6639 U.S.-based employers (11%) hired students from InnovATEBIO community college programs [14]. The map of companies that have hired community college students illustrates that students from InnovATEBIO programs are being hired by large and small companies throughout the US.

1.3 Insights from the Industry Database

Biotech-Careers.org does not claim to include every biotechnology company in the world or even in the U.S. With 8,828 employers, Biotech-Careers' database is larger than the BIO membership list (1473) [15], smaller than BiotechGate (21,565 companies) [16] and close in size to the IBIS World report (11,076 businesses worldwide) [17]. Two outliers are CrunchBase (41,855) and the TEConomy/BIO report (127,000) [18]. These values are higher because CrunchBase includes companies that have gone out of business, and the TEConcomy/BIO report derives company numbers from NAICS codes. NAICS codes are a standard used by the government for classifying businesses. These codes have well-documented problems when it comes to biotechnology [19].

No database is perfect. Even so, the company database provides insights into the biotech industry. Interactive maps visually demonstrate that biotechnology is a worldwide industry and that companies cluster in specific locations. In addition, business terms show that biotech-related companies work on a wide range of topics.

The top ten business areas in the database are shown in Table 2. Except for COVID-19, the top six, from Small Molecules to Antibodies, are well-known topics in biopharma. Newer technologies such as Cell and Gene Therapy and Synthetic Biology are also represented.

Table 2. Top Business areas Represented in Biotech-Careers.org

Business Area	Number of Companies	Locations Worldwide
Small Molecules	697	1151
COVID-19	620	1207
Therapeutics	533	821
Diagnostics	512	750
Medical Devices	474	776
Antibodies	476	928
Cell and Gene Therapy	422	681
Synthetic Biology	401	507
Bioinformatics	328	409
Cancer Therapeutics	291	473

Choosing a topic from the Business Areas page shows a further breakdown of areas that describe company activities (Fig. 1). For example, companies that work on Small Molecules also work on other Therapeutics (Biologics, Cancer, Antibodies, Immunotherapy), and related areas such as Drug Discovery and Vaccines.

Companies Working with Small Molecules also Work in 153 Other Areas:

Therapeutics (57) | Biologics (50) | Cancer Therapeutics (47) | Drug Discovery (36) | Antibodies (29) | COVID-19 (29) | Cancer (25) | Immunotherapy (19) | Neurobiology (18) | Vaccines (17) | Immunology (16) | Rare Diseases (16) | Cell and Gene Therapy (15) | Generics (13) | Diagnostics (12) | Epigenetics (12) | Metabolism (12) | Inflammation (11) | Alzheimer's (10) | Microbiome (10) | Oncology (10) | Cardiovascular (9) | Pharmaceuticals (9) | RNA (9) | Antivirals (8) | Drug Delivery (8) | Infectious Disease (8) | Pain Management (8) | Protein Degradation (8) | Artificial Intelligence (7) | Autoimmunity (6) | Parkinson's Disease (6) | Protein Kinase (6) | Vision (6) | Antibiotics (5) | Biomarkers (5) | Chemistry (5) | Contract Research (5) | Liver Disease (5) | Medical Devices (5) | Peptides (5) | T-Cells (5) | Biopharmaceuticals (4) |

Figure 1. Subdivisions of business areas in Biotech-Careers.org. These data are from 697 companies that work on small molecules. The numbers in parentheses show the number of small molecule companies working in each business area.

1.4 Pathways for Exploration

Students who visit Biotech-Careers.org are likely to have different goals and interests depending on where they are in their educational careers. To reach students of different ages and interests, we developed four pathways for exploring the site: People, Places, Things, and Jobs (Fig. 2).

College students, who are already interested in biotechnology, might prefer starting with Jobs or Places to quickly learn about companies in their area, what they do, and the kinds of jobs available. Students at an earlier stage, such as high school students, might prefer reading about the People working in different careers or learning about the kinds of Things that companies make or the topics they work on.

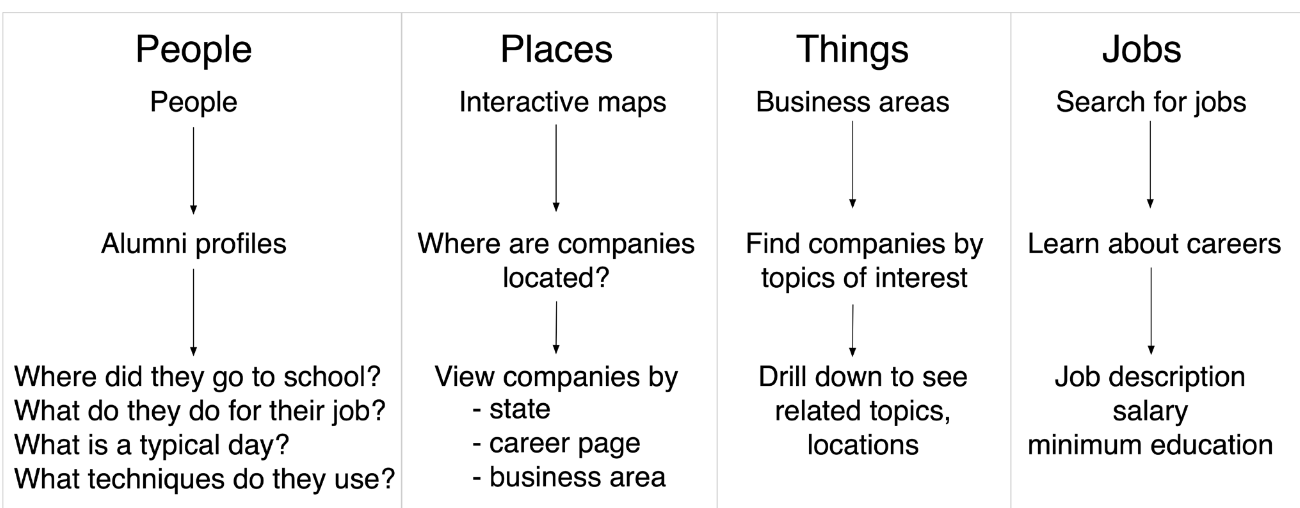

Fig. 2. Four paths for exploring Biotech-Careers.org.

To learn about people working in biotech (Fig. 3), students select People to view profiles of community college graduates working in biotechnology. They choose a person to read about, learn where they went to college, what a typical day on the job is like, and see the kinds of degrees or certificates they obtained. They can follow links to job areas or career descriptions from an alumni profile. Job areas organize content around different business sectors, such as genomics or synthetic biotechnology. This section contains links to videos, articles, profiles, careers, and more. Visiting the Careers page displays cards linked to descriptions of different jobs. These include the average salary across the US, the minimum education needed, a job description, links to view available positions, and links to InnovATEBIO programs that prepare students for these careers.

The Biotech Companies link opens a page for exploring biotechnology through Places (Fig. 4). There are links to explore companies worldwide, the entire United States, or specific states. Interactive maps show over 12,000 company locations, 8,341 in the US.

Individual state maps show students, through word clouds of the top business areas (Fig.4, right side), that the distribution of companies working in different business areas varies from state to state. Students can use the buttons under Career Information and Internship Information as filters to select companies that provide this information on their websites. Companies with career information on their websites are more likely to be hiring.

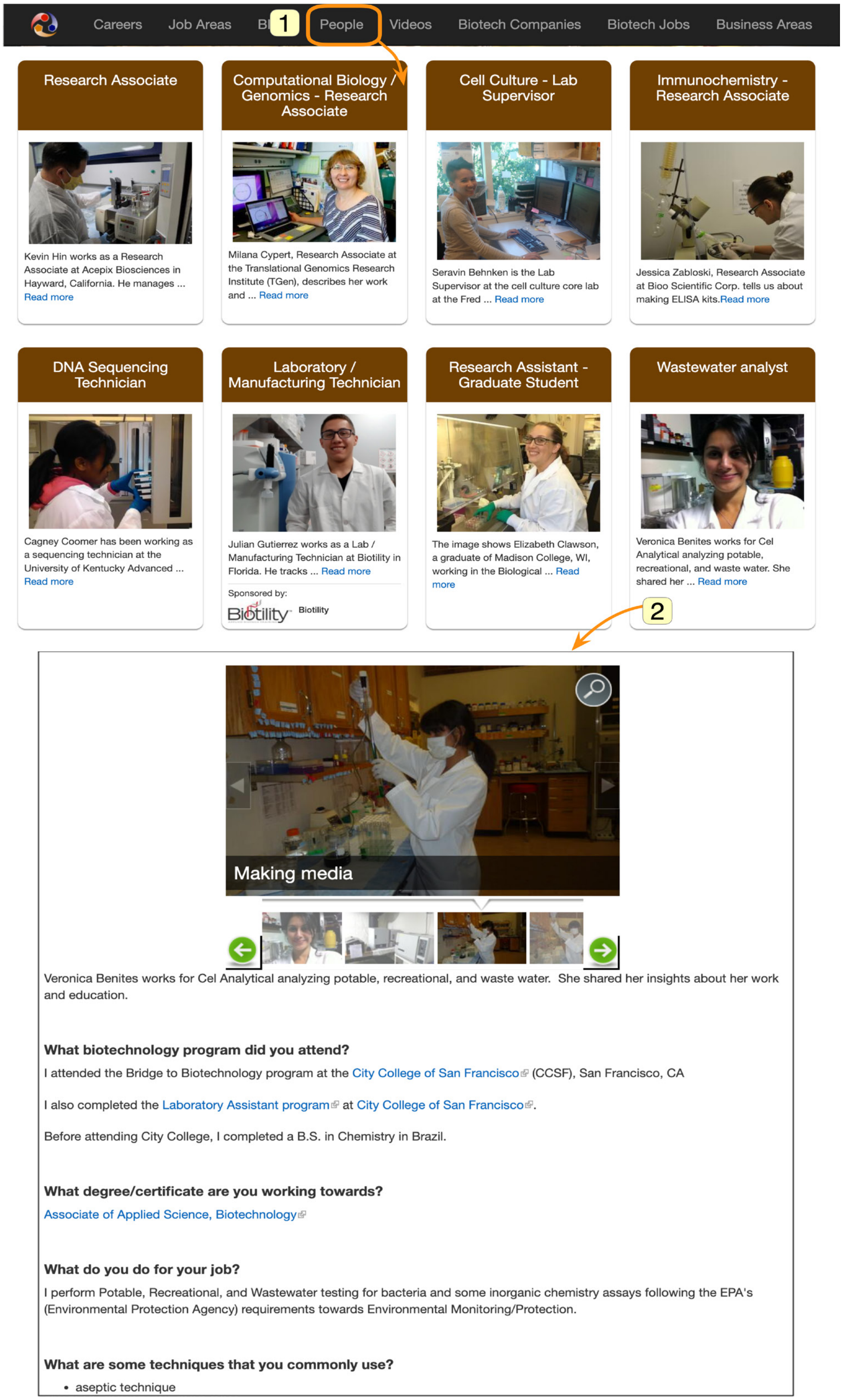

Fig. 3. Exploring careers through People. Students begin by selecting an alumni profile and reading about that person's educational journey. From there, students can choose from multiple resources such as videos, articles, profiles, and career descriptions.

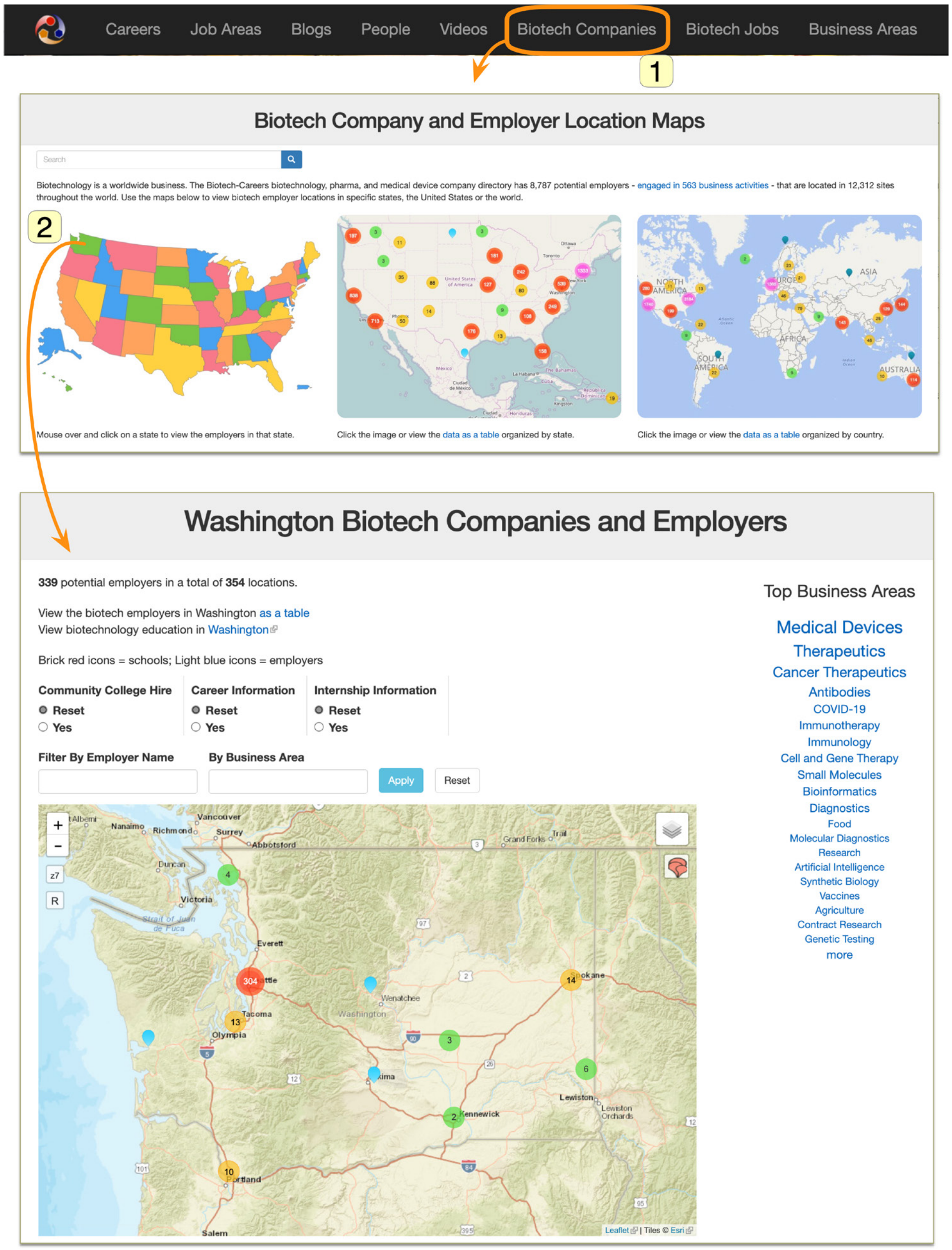

Fig. 4. To explore careers by the Place path a student can look at companies on a US map or choose a state. Zooming in shows if there are companies in areas of interest to students.

For the Things path (Fig. 5), we recommend asking students to spend a few minutes jotting down topics of interest. Then, for the next five minutes, they can share those items with the class if they choose. At this point, students can choose Business Areas to see a page with columns showing links to Business Areas, Job Areas, and a list of Entry-level Jobs.

The Business Areas word cloud in the far-left column is derived from over 507 business activities companies use to describe themselves. In each case, the size of a word corresponds to the number of database companies that work in that area. The list is long, but students will likely find terms connected to topics of interest. Some examples are Biofuels, Cancer, Climate tech, Cosmetics, Fashion, Food, Pets, Regenerative medicine, Sporting goods, and Women's Health.

Selecting a Business Area leads to a page with a map and directory of all the companies in the database that work in that area. They can see where those companies are located, look at individual company descriptions, and visit company web pages to learn what they do and whether they are hiring.

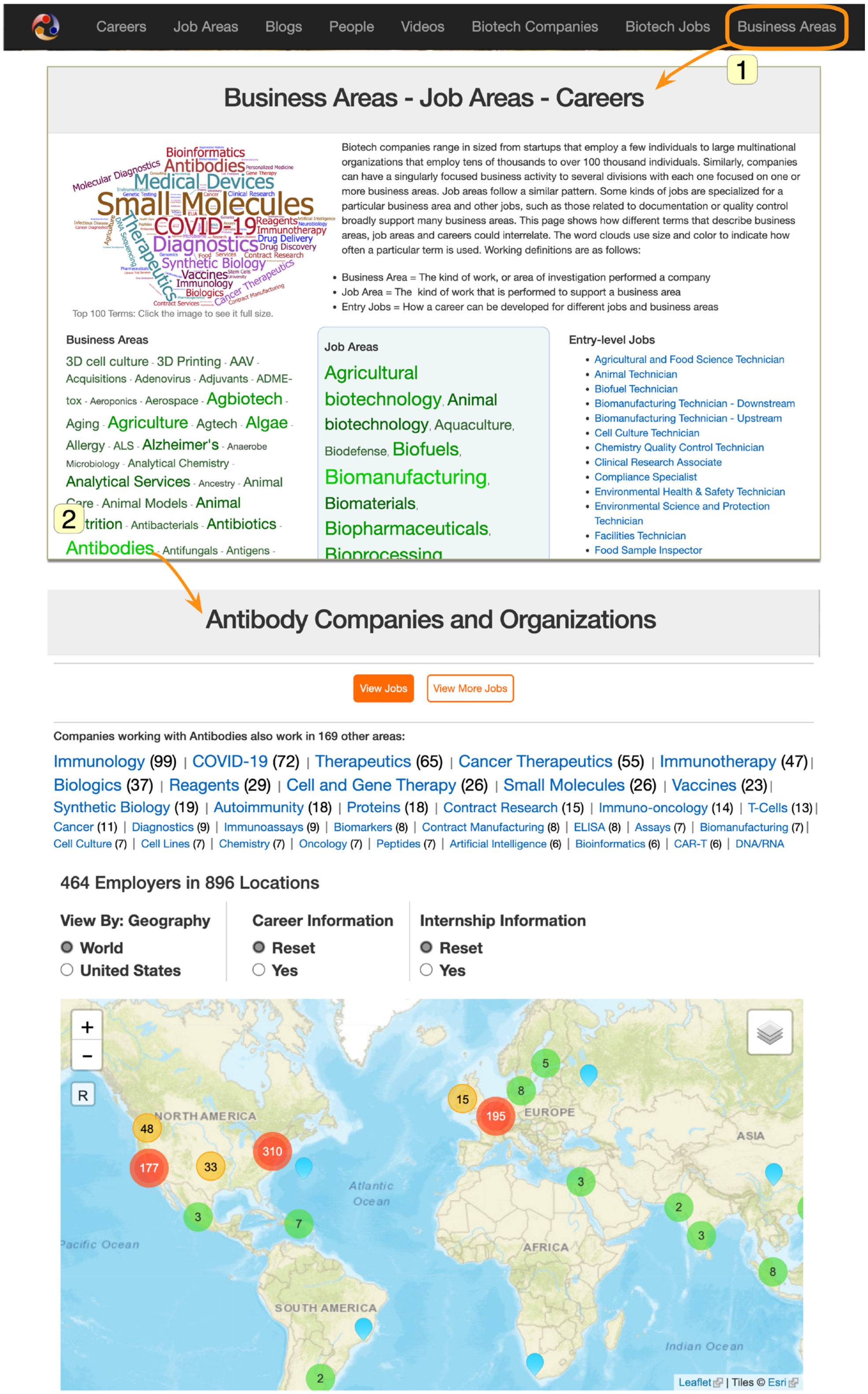

Fig. 5. The Business Areas path enables students to explore biotechnology companies by the things they make and the business areas they focus on.

The Jobs path begins at the Biotech Jobs link (Fig. 6). Selecting the orange “Search for Jobs” button shows the current number of biotechnology jobs within 25 miles of the user’s location. The location, search terms, and distance can all be changed. For example, changing the location to the US on June 6th, 2022, showed 11,802 biotechnology jobs.

In presentations, we stress that these job postings are one example and are supplied by a third-party company that updates data daily. Every job board from LinkedIn (Linkedin.com) to Monster (Monster.com), Indeed (Indeed.com), and Glassdoor (Glassdoor.com) will have a different data set and provide different results. We recommend students use a variety of sites when they begin a serious job search.

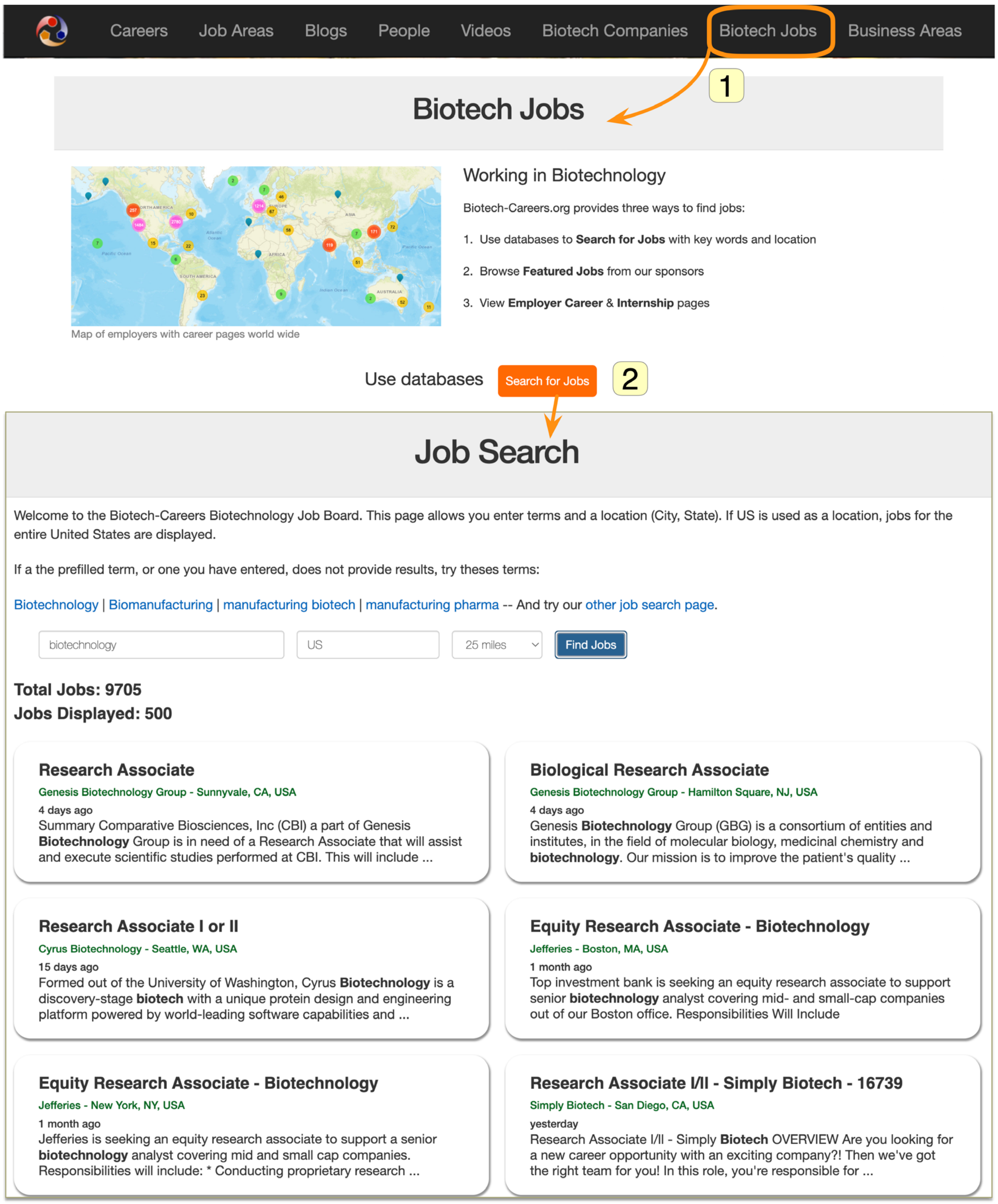

Fig. 6 The Jobs path allows students to search for available jobs by industry sector and location.

Results from students

The many resources at Biotech-Careers.org have made the site popular with both high school and community college educators. We use StatCounter (statcounter.com) and Google Analytics (analytics.google.com) to obtain and analyze statistics from our weblogs. In 2021 and 2022, the site had over 400,000 unique visits annually.

We determined that 20-25% of these visits came from classrooms by looking at referrals, IP addresses, and usage patterns. Referrals from learning management systems often include names that indicate they came from Canvas, Blackboard, Google Classroom, Schoology, or a school district. A typical classroom visit will appear in the weblogs as several independent visits within a short time from the exact location, with a referrer that contains the word “assignment” or a URL such as “classroom.google.com.”

We should note that the number of classes using Biotech-Careers.org has most likely resulted from our work since 2012 in promoting the site and giving presentations for teachers at national conferences such as the Bio-Link Summer Fellows Forum (2012-2018), the National Association for Biology Teachers (NABT), and in online webinars organized by NABT and InnovATEBIO. These events were attended by college instructors and high school teachers, giving us a unique opportunity to inform teachers about the site.

The realization that approximately 100,000 students use Biotech-Careers.org annually made us interested in learning whether using the site influences students’ perceptions of biotechnology careers. To address this question, we gave virtual demonstrations of Biotech-Careers.org to four cohorts of students from a Hispanic Serving Institution (HSI), City College of San Francisco (CCSF), during 2020-2023, as part of CCSF’s Career Exploration in Bioscience course. All the presentations and class sessions were synchronous through Zoom.

For each presentation, we followed the outline below:

- 15 minutes - Walkthrough the four paths for exploring Biotech-Careers.org (People, Places, Things, Jobs).
- 15 minutes – Students chose a path and explored the site independently. Each student was assigned to identify at least one career on the site related to an area of biotechnology that interests them.
- 15 minutes – Students met in Zoom breakout rooms (2-4 students per room) and discussed careers they found interesting.
- 15 minutes – Whole class questions and discussion.

Students were asked to complete a short survey after working with the site. The survey included questions designed to measure changes in awareness, self-efficacy, sense of belonging, and identity. Examining cognitive factors related to career choice helps educators better understand why students might choose one path over another. Awareness is essential since it would be difficult to consider a career without knowing it exists. Self-efficacy, outcome expectations, and student goals have been identified as other important factors [20, 21]. Self-efficacy describes a student’s perceived ability to be successful. Outcome expectations are related to a sense of belonging and identity [22].

After using the site, 97% (64/66) of the students were more aware of the variety of careers in biotechnology (Fig. 7).

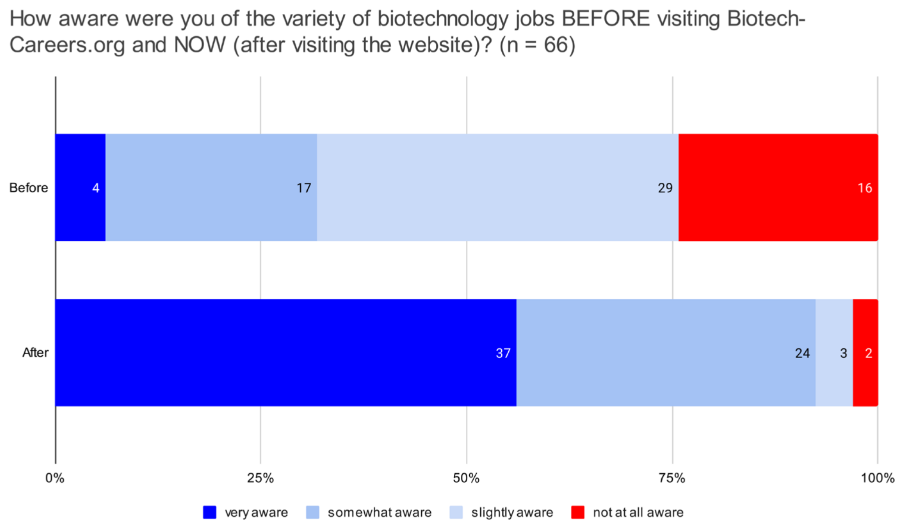

Fig. 7. Student awareness of biotechnology jobs before and after using Biotech-Careers.org.

Most students (51/55) agreed that using Biotech-Careers.org increased the likelihood of pursuing biotechnology as a career (self-efficacy). Students also agreed that they were better able to picture themselves in a biotechnology career (55/57) (belonging) and that visiting the site broadened their ideas about who can be successful in a biotechnology career (56/58) (identity).

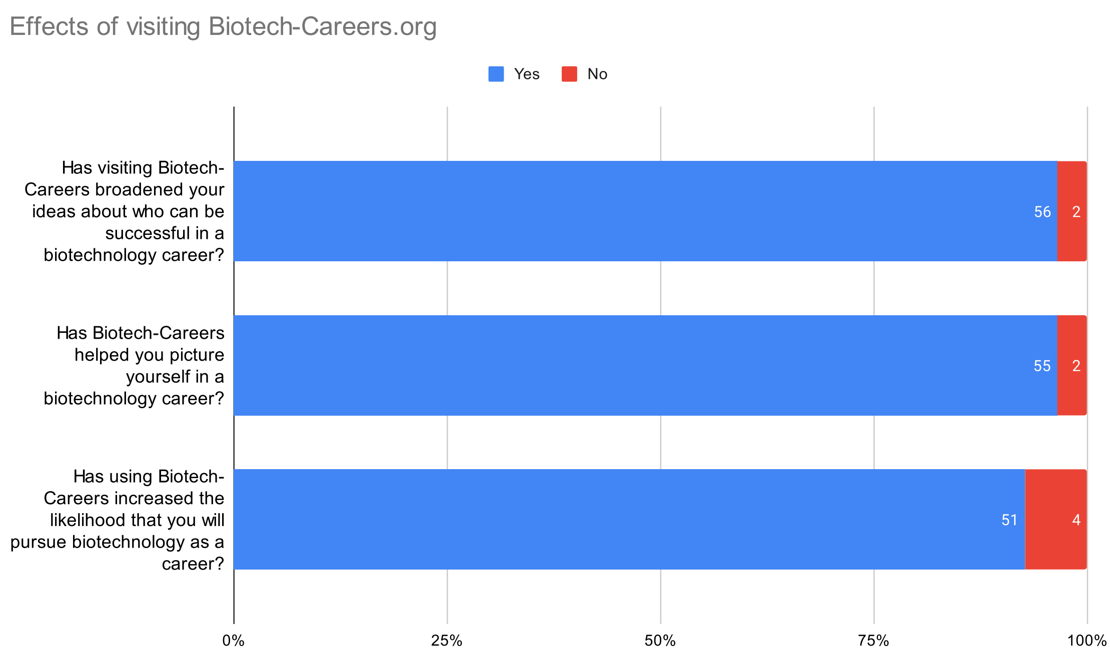

Fig. 8. Student attitudes after using Biotech-Careers.org <http://biotech-careers.org/>

Discussion

We launched Biotech-Careers.org in 2012 in response to requests from members of the Bio-Link community. At that time, most career websites made it seem like all biotechnology jobs required a Ph.D. Even now, three of the top four results from a Google search for biotech career information are sites where the information is inaccurate or incomplete [23-25]. One site [23] stated that a bachelor's degree is the minimum requirement for a biotechnology job. Two of the sites [23, 25] obtained misleading data from the US Bureau of Labor Statistics (BLS.gov), causing them to categorize job titles such as Biochemist/Biophysicist, Biomedical Engineer, Agricultural Engineer, Epidemiologist, Animal Scientist, and Soil and Plant Scientist as technicians. While biotechnology companies may employ people in these roles, these scientists in these roles often have a PhD or Master's degree and are not considered technicians. All three sites missed common positions such as jobs in bioprocessing, kitting, or validation.

Unlike the other sites in the top four Google results, Biotech-Careers.org is unique in that the career descriptions and the information come from people who have worked in the biotech industry. Biotech-Careers.org focuses on entry-level technical positions, many of which can be filled by a person with an associate degree. Many of the original career descriptions were based on a publication [26], co-sponsored by Bio-Link, that is still relevant today. Other descriptions have come from industry contacts and job postings. The site is maintained and updated by subject matter experts with thirty years of experience who are active in the industry.

We have presented an overview of the Biotech-Careers.org website, described how the site might be used in education, and presented results from students who have used the site in class. The website is easy to use and a free resource for students from high school through college. It can be used in synchronous and asynchronous formats to enhance awareness and understanding of the breadth of available biotechnology careers. For example, Michael Fuller, an InnovATEBIO team member from BABEC, uses the site as part of an introduction to biotech activity with high school students. Fuller's approach and slides are available at Biotech-Careers.org [27].

One of us [Dr. Leung (CCSF)] uses an assignment where students research different entry-level jobs and discuss them with each other. Alternatively, a jigsaw activity can be used (either in person or in virtual breakout rooms), where students research one career through the website and then interview each other to learn about those positions. One of our favorite activities is a cocktail party. Students research careers and then participate in a "cocktail" party (with non-alcoholic drinks). They are tasked with making small talk and describing their careers to other students at the party. Other instructors have had students make posters describing different types of biotech jobs. Materials and guidelines for these activities can be downloaded from Biotech-Careers.org [28].

Our studies thus far have focused on college students. In the future, we will present the site to high school students to learn more about the impact of Biotech-Careers.org on career choice in this demographic. Some of us remember being advised against biology as a study topic in college because it was common knowledge that there "were no jobs in biology." As a result, students may stay away from subject areas unless they believe there are attainable jobs. Conducting real-time job searches in an assignment demonstrates that jobs are there and that entry-level jobs don't all require a bachelor's degree or a Ph.D. Convincing students that jobs exist and are attainable may be an essential part of the message.

We are also exploring methods for demystifying career paths. For example, we are currently building a database of skills and linking that information to college programs and jobs to help students better understand what they need to know and where to acquire the appropriate knowledge and skills.

Conclusion

Biotech-Careers.org is a comprehensive resource for career education that can launch many career exploration activities. We found that using the site positively impacted students' awareness and interest in biotechnology careers and their ability to picture themselves working in a biotechnology career. Including an industry database shows where students are likely to find positions working in the industry. The job search feature provides additional, timely information about the skills and knowledge that employers seek.

Acknowledgments. We thank Candiya Mann and Adam McKee for their evaluation services and data analysis. This work was funded by a grant from the National Science Foundation (DUE 1764225). Grants from the National Science Foundation's Advanced Technological Education program (DUE 0903307, DUE 1400721, DUE 1764225) provided the initial funding for developing, maintaining, and adding content to the site. Any opinions, findings, conclusions, or recommendations expressed in this material are those of the author(s) and do not necessarily reflect the views of the National Science Foundation.

Disclosures. The authors declare no conflicts of interest.

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EvaluateUR: Helping Students to Acquire the Knowledge and Skills Needed for Success in the Workplace

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Abstract: The EvaluateUR Method supports the assessment of undergraduate research programs in different educational settings, from independent undergraduate research ("EvaluateUR") to classroom-based research ("EvaluateUR-CURE") and robotics design competitions ("Evaluate Compete"). The method provides statistically reliable assessments of student growth in a wide variety of outcome categories identified as essential to success in the workplace. It differs from traditional approaches to assessing student outcomes because it is integrated directly into the research experience. A unique feature of the method is its emphasis on metacognition. Thus, it also serves as a learning tool for students, helping them to become more aware of their academic and professional strengths and weaknesses while supporting their efforts to identify strategies for expanding their knowledge and improving their metacognitive skills.

Keywords: EvaluateUR method, Assessment, Undergraduate Research, Metacognition, Workplace Skills

Introduction

Industries and businesses across the country have identified technical and professional competencies and skills they consider essential in today's workplace [1,2,3]. These skills include communication, problem-solving, time management, and teamwork. Above all, industries and businesses want employees who can identify and think through problems and determine how to solve them. If students are to succeed as employees (or as entrepreneurs), they will have to master these and related skills, be aware of what they know and don't know, and understand how best to overcome any weaknesses in their knowledge and skills.

Undergraduate research programs have proven their value over many years at colleges and universities nationwide [4-7]. These experiences provide students with many important insights and skills related to their academic interests and the process of systematic inquiry.

We developed a method [8,9,10] that provided reliable data on the value of undergraduate research across a wide range of desirable skills. Faculty representing both STEM and non-STEM disciplines identified a list of undergraduate research outcome categories of interest and contributed to developing the components used to define each outcome category. We were particularly interested not only in how well students did on research projects, but in student knowledge, skills, and abilities desired in the workplace. The method - known as EvaluateUR - was designed to gather statistically reliable empirical data on student outcomes and also to ensure student awareness of the range of skills that employers value, sharpen student insight into their strengths and weaknesses, and provide students with the self-reflective and analytic tools they will need to succeed. To accomplish these goals, the evaluation employs an assessment instrument that is completed by both the student researchers and their research mentors at different times during the students' research projects. The instrument covers a wide range of student skills – including many "soft" skills valued by employers – and becomes the basis for student-mentor conversations to discuss reasons for their respective assessment scores, critically examine the degree of student insight into their academic strengths and weakness and consider potential student strategies for leveraging strengths and overcoming weaknesses. EvaluateUR encourages students to be aware of what learning strategies they employ and why and use that awareness to make adjustments that help them learn more effectively. This cycle of self-awareness, adjustment, and renewed self-evaluation – widely known as ***metacognition*** – is an essential element in the EvaluateUR method. It is reinforced by a set of separate exercises that provide students with additional opportunities to develop their metacognitive skills. Acquiring the habit of metacognition is perhaps the single most important benefit that students take away from their EvaluateUR experience.

EvaluateUR was shown to be effective [9], and with funding from the NSF WIDER program was scaled up and pilot tested with undergraduate research programs at over 40 colleges and universities across the country [9,10]. Our evaluation found that EvaluateUR introduced students to a wide range of competencies and skills that are valuable in education and the workplace; measured student growth in mastering those competencies and skills; contributed to the development and enhancement of metacognitive skills; enabled mentors to focus their efforts on areas where students were weak; and helped students gain new insights into their academic strengths and weaknesses. EvaluateUR is now available by subscription and provides undergraduate research program directors with reliable evidence to document the benefits of their programs.

Since its introduction and with funding from the NSF ATE program, the method has seen two adaptations: EvaluateUR-CURE (E-CURE) supports students enrolled in course-based undergraduate research experiences (CUREs), and Evaluate-Compete (E-Compete) supports students participating in remotely operated vehicle (ROV) regional and international competitions created by the Marine Advanced Technology (MATE) Center and now organized and administered through MATE Inspiration for Innovation (MATE II). While E-Compete's initial design is intended for ROV competitions, it can be adapted to other student team efforts under the direction and mentoring of an advisor, including other robotics competitions and events such as the Community College Innovation Challenge. The need for variants stems primarily from the differences in student-advisor/mentor ratios, the duration of the research experiences, and the need to align outcomes to rubrics used by competition judges. Thus, while the three variants of the method support a broad range of research experiences, they are more alike than different. The underlying approach is the same and embeds metacognition, encouraging students to self-reflect on their strengths and weaknesses. Differences in implementation steps and the number of outcomes recognize differences in research settings but do not compromise the method's original intent or basic design.

Description of the EvaluateUR Method

All three variants of the EvaluateUR method include a set of outcome categories (Table 1), and each outcome category is defined by several components. Examples of outcome categories and defining components are included in Table 2, with a complete list of the outcome categories and components found at https://serc.carleton.edu/evaluateur/methods/outcomes. All three variants of the method share common key features. These include: 10 or 11 student outcome categories with options to add several additional outcomes; each outcome category is delineated by several components that measure specific outcome objectives; repeated assessments at the beginning, middle, and end of the research so that students' progress can be followed; independent faculty/mentor assessments and student self-assessments using identical instruments and a 5-point rubric based on how often the student has exhibited the behavior described by a particular component (1=Not Yet to 5=Always); and student-faculty/mentor conversations to improve students' metacognitive insights into their strengths and weaknesses. In addition to the outcome categories and components listed in Table 1, E-Compete includes a set of ROV-specific outcome categories and components that align with the scoring rubric used by judges during the competition, such as: vehicle design, buoyancy, and propulsion; control and electrical system; sensors, payload, and tools; safety; project management; and entrepreneurship.

Table 1. List of Outcome Categories for the Three EvaluateUR Variants

Outcome Categories	EvaluateUR	EvaluateUR-CURE	Evaluate-Compete
Communication	✓	✓	✓
Creativity	✓	✓	✓
Autonomy	✓	✓	✓
Ability to Deal with Obstacles	✓	✓	✓
Intellectual Development	✓	✓	✓
Critical Thinking and Problem Solving	✓	✓	✓
Practice and Process of Inquiry	✓	✓	
Nature of Disciplinary Knowledge	✓	✓	
Project Knowledge and Skills	✓	✓	✓
Teamwork / Collaboration		✓	✓
Ethical Conduct	✓	✓	

Table 2. Examples of Outcome Components for Three Outcome Categories

	Outcome Components for each Variant		
Outcome Categories	**EvaluateUR**	**EvaluateUR-CURE**	**Evaluate-Compete**
Ability to Deal with Obstacles	Is not discouraged by setbacks or unforeseen events and perseveres when encountering challenges.		
	Shows flexibility and a willingness to take risks and try again.		
	Trouble-shoots problems and searches for ways to do things more effectively.		Demonstrates ability to quickly improvise & implement a solution to fix a design or equipment problem
Critical Thinking & Problem Solving	Looks for the root causes of problems and develops or recognizes the most appropriate corrective actions.		
	Recognizes flaws, assumptions, and missing elements in arguments		**This outcome component is not used in Evaluate-Compete**
	This outcome component is not used in EvaluateUR or EvaluateUR-CURE		Demonstrates the ability to evaluate alternative designs and/or operational solutions
Project Knowledge & Skills	Displays knowledge of key facts and concepts.		Displays an understanding of the engineering and scientific principles and practices relevant to vehicle design and operation

2.1 Steps in the Implementation of the EvaluateUR method

To illustrate the implementation sequence for the EvaluateUR method, Figure 1 shows the four stages of EvaluateUR and the steps that take place during each stage. E-CURE and E-Compete both follow the same sequence, as explained below.

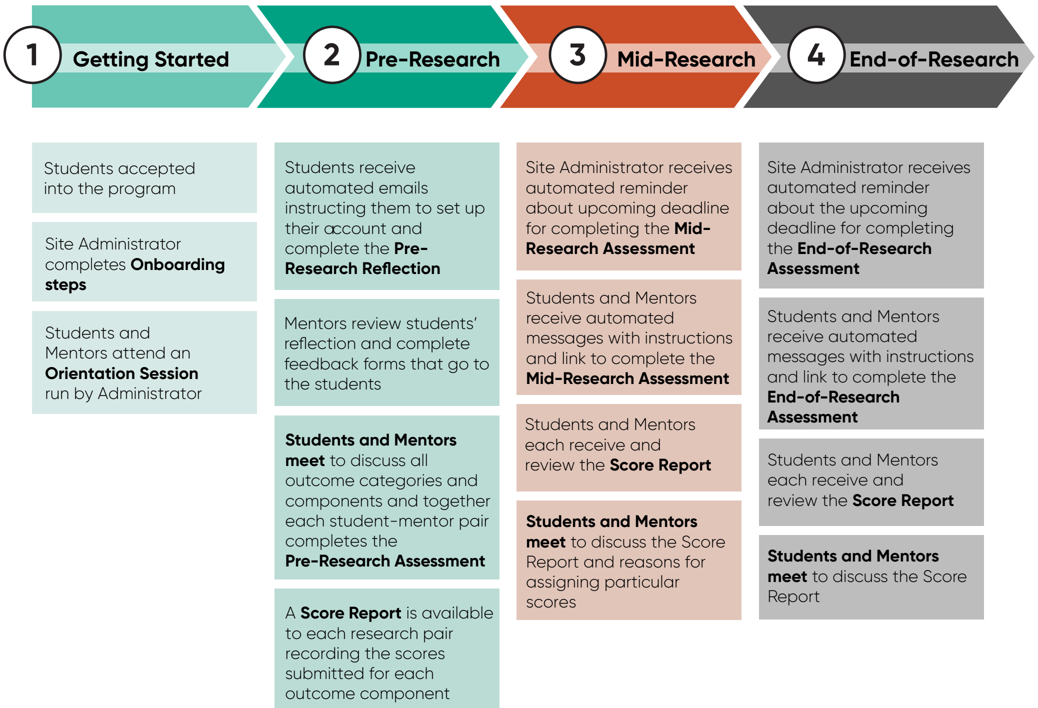

Figure 1. Four stages of EvaluateUR

1.) Getting Started

Site administrators (usually program directors or coordinators) learn how to use the EvaluateUR method by completing the **onboarding** steps that illustrate and explain how to configure their program dashboard (e.g., setting assessment completion dates, adding student-mentor pairs, adding optional outcomes or questions). Once it is set up, the dashboard shows all the student-mentor pairs and the sequence of steps to be completed by each pair. Clicking inside the box for any student-mentor pair expands the box and lists what actions happen at each step of the process. As steps are completed, they change color from gray to orange to green, making it easy to see what steps are completed (green), what action is required to complete the current step (orange), and steps that have not yet been started (gray). This helps the administrator track the progress of each student-mentor pair. The last activity is running an **orientation session** to help students and mentors understand the purposes and advantages of EvaluateUR. For E-CURE and E-Compete, the CURE instructor or ROV team advisor completes the onboarding process to learn how to set up the dashboard and introduce the method to their students. For all variants, selecting the 'activate' option on the dashboard results in an automated message alerting students to begin the Pre-Research steps.

2.) Pre-Research

Students record their ideas about the research process by answering a set of open-ended questions called a **pre-research reflection**. This is intended to provide mentors with more information about their students, and the student responses can highlight any concerns the students might have about the research they are about to begin. After mentors review the responses, the students and mentors complete the **pre-research assessment** for the list of student outcomes (see Table 1). The outcome scores allow students and mentors the opportunity to exchange ideas about the importance of the various outcomes. To facilitate these conversations, score reports are automatically generated and provide a side-by-side comparison of the scores assigned by the students and mentors for each outcome component. This makes it easy to identify outcome components with score differences of 2 or more (based on the 5-point rubric).

Depending on the variant, the pre-research assessment is done when the student-mentor pair meets to discuss each outcome category and its components (EvaluateUR), or is completed only by the student (E-CURE and E-Compete). The different approaches to completing this pre-research assessment reflect the diverse research environments for the three variants. For example, the one-to-one student-mentor ratio in EvaluateUR makes it feasible for the student-mentor pair to complete the pre-research assessment together. In contrast, the larger number of students enrolled in a CURE or a member of an ROV team makes this impractical. In E-CURE, students are reminded that the assessment scores are not considered in their grades but provide an independent picture of student growth on the outcome measures. For E-CURE and E-Compete, the course instructor or team advisor, respectively, have access to a data summary of all the students' scores for each outcome category.

3.) Mid-Research

Mid-research assessments are completed independently by students and mentors about halfway through the research. Following this, automated messages are sent with a link to a score report that provides the scores for pre- and mid-research assessments. Each student-mentor pair then meets to discuss the reasons for assigning particular scores. This provides an opportunity for students to consider how they might leverage their strengths and adopt strategies to help them tackle areas of weakness as they continue their research. For E-CURE and E-Compete, these meetings might involve a class-wide discussion, meetings with research groups, and/or meetings with individual students. There also is an option in E-CURE and E-Compete to select a sub-set of outcome categories to be used on the mid-research assessments. This sub-set can be selected at the same time the CURE instructor or ROV team advisor sets up their dashboards and can be modified at any time before releasing the mid-research assessment. This option accounts for the higher number of students CURE instructors/ROV team advisors are mentoring and help them concentrate on observing fewer outcomes as they interact with all the students.

4.) End-of-Research

This stage in the process is very similar to what happens at the mid-point. For EvaluateUR, students and mentors complete the **end-of-research assessments** and schedule the final conversations. For E-CURE and E-Compete, students answer a set of open-ended questions following the completion of the end-of-research assessments. These questions help students reflect on their experiences and provide CURE instructors and ROV team advisors with another way to assess student learning. This can help them consider how they might modify their pedagogical strategies. In addition, E-Compete includes an optional de-brief exercise that ROV team advisors can use soon after the students return from the ROV competition.

2.2 Impacts of the EvaluateUR Method

Based on statistical analyses of data and responses to student and mentor surveys, a number of findings about the impacts of the method are clear. A key result is that the method's structure supports meaningful dialogues between students and mentors/instructors/ROV team advisors. For a great majority of the students using the three variants of the method, most outcome scores improved over time. A summary report from the final year of the NSF WIDER project collected data on 799 student-mentor pairs representing STEM and non-STEM disciplines. For all outcome components, there was a statistically significant increase in student growth in assessment scores given by students and mentors when analyzed by a paired sample t test (alpha =.05). An analysis of effect size (Cohen's d) showed medium and large magnitudes of effect for almost all components. The medium and large effect sizes suggest that the significance was not due to chance or large sample size but to actual impacts on student outcomes. Student and mentor survey responses confirmed that the repeated conversations contributed to developing and enhancing student metacognitive skills. This is characterized by learners becoming aware of what learning strategies they are pursuing and why, and then using that awareness to make intentional adjustments to those strategies to learn more effectively. The conversations also helped most students confirm their plans for continuing their education at the graduate level or seeking employment in their discipline. Research mentors found it easier to identify the academic strengths and weaknesses of their students, enabling the mentors to better focus their guidance. The mentors could also more easily identify areas where students might be over- or under-estimating their abilities and were able to help students gain new insights into their academic strengths and weaknesses and the relative efficacy of their learning strategies. Research mentors also reported that using EvaluateUR contributed to changing their attitudes about what students are capable of doing, leading them to rethink their pedagogical practices.

Findings from a two-semester-long CURE taken by engineering technology students confirm that E-CURE outcome categories and components correspond to ABET ETAC performance indicators [4]. Integrating E-CURE into this design course has provided regular and structured feedback to the students, including serving as an early warning system should individual students or a team of students fall behind in meeting project deadlines. E-CURE also supports the generation of individual and whole-class assessment scores that align with ABET performance indicators. According to E-CURE instructors teaching other STEM courses, this variant promotes a positive learning environment and helps students become more resilient in overcoming research obstacles. E-CURE also provides data that help instructors revise their CUREs to improve student learning.

Student survey feedback from all three variants indicates that the key project design features – introduction to outcomes important to employers, independent student/mentor assessments, follow-up conversations, and metacognitive exercises – have introduced students to new ideas and have helped them to think strategically about skills they need to sharpen or acquire. In addition, faculty survey responses have indicated that EvaluateUR and its variants have encouraged them to make changes to their courses to incorporate more intentional metacognitive growth activities and discussions about the skills employers value.

3. Metacognition and the EvaluateUR Method

The EvaluateUR method encourages students to be aware of what learning strategies they employ and why [11]. Then, they can use that awareness to make adjustments that enable them to learn more effectively [12, 13, 14]. As noted above, this cycle of self-awareness, adjustment, and renewed self-evaluation, or metacognition, is perhaps the most important benefits students can take away from their EvaluateUR experience.

To further support the development of metacognition, a collection of 12 exercises has been developed. These exercises provide additional practice that supports the metacognitive benefits of the method. Table 3 provides a brief description of each exercise with downloadable full versions found at https://serc.carleton.edu/evaluateur/methods/outcomes.html.

Table 3. Metacognition Exercises

Title of Exercise	Brief Description
Learning From Past Projects	Students reflect on how they've navigated past projects and assignments. The goal is to help students learn from those experiences and develop the independence necessary for a research project.
Building Project Management Skills	Students reflect on how they are currently navigating their research project.
Thinking About How to Ask Good Questions	Students reflect on how they formulate questions as well as how they generate answers. The aim is to prompt students to think about disciplinary modes of thinking and what constitutes appropriate evidence.
Thinking About How to Ask Good Research Questions	Students reflect on how they formulate questions central to their research and what counts as adequate evidence. The aim is to prompt students to connect disciplinary modes of thinking with research projects.
Building Resilience	Help students reflect on how they can overcome obstacles. It asks them to think back to a prior experience and draw out lessons that might help them succeed in their research projects.
Building Research Resilience	Students reflect on how they're coping with setbacks related to the research process.
Reading with a Purpose	This activity is designed to be used in conjunction with a reading assignment. The aim is to prompt students to read more intentionally and draw out lessons that might help them succeed in their research projects.
Reading for Research	Students reflect on how they're doing the reading related to their research project.
Thinking About Self-Assessment Process	Encourages students to reflect on how they completed the self-assessment to consider whether it was fair and accurate.
Better Together: Teamwork and Collaboration	Asks students to reflect on how teams can function effectively and get collaborations back on track when they run into trouble. The aim is to prompt students to think about how to have a good research team experience.
Thinking About How You Communicate	Asks students to reflect on how to effectively express their work to a disciplinary audience. The aim is to encourage students to develop clear, concise, and organized modes of communication.
Thinking About How You Communicate Across Audiences	Asks students to reflect on how they communicate with others about their research project. The aim is to prompt students to express ideas in a clear and concise manner using discipline-specific language.

Each exercise is short and follows a format that includes an introduction to students about the purpose of the exercise. This is followed by several questions intended to help the student reflect on strategies they have used in the past that might be useful in assessing a particular situation and identifying how they might tackle that situation. Metacognition exercises are not intended to be graded. Instead, they are designed to help the students think about strategies in their 'toolbox' and how to use them effectively. A user guide for the exercises is available on the website and is intended to provide adopters of the EvaluateUR method with an overview of metacognition and how to help their students build and apply their metacognitive skills. Because E-Compete is likely used for students participating on an ROV or equivalent team, a metacognition card game has been developed to replace the more traditional exercises developed for E-CURE and used for EvaluateUR. The card game has 30 cards divided into three major categories: People, Problem-Solving, and Persistence. Each card poses a situation that is intended to help students think about how they approach a particular situation or express their thoughts. The card game can be used as an 'icebreaker' for ROV team members to get to know each other better, and to introduce metacognition into break time when the team members are not focused on tasks related to designing, building, and testing their vehicle.

Conclusions

The EvaluateUR method differs from other undergraduate research assessments because it provides a framework for student-mentor conversations that are aimed at helping students understand their strengths and areas where improvements are needed. By including measures of outcomes valued in the technical workplace the method assesses a diverse range of student knowledge and skills that go beyond those of immediate interest to specific research projects. The three variants of the method serve specific research settings (e.g., independent research, course-based research, and robotic competitions). Each variant is integrated directly into the research experience, thereby providing assessments of student outcomes that serve as measures of student success and as learning tools for the student. A primary benefit of the method is that it encourages students to become more aware of what learning strategies they employ to analyze and solve problems. It also strengthens their ability to recognize situations where they need to learn new skills and/or seek assistance from others. For mentors, adopting and implementing the EvaluateUR method has contributed to a greater awareness of the value of structured feedback. In some cases, it has resulted in changes to their pedagogical strategies.

Acknowledgments. This material is based upon work supported by the National Science Foundation under Grants No. 1347681, 1347727, 1836033, 1932929, and 1932940. Any opinions, findings, conclusions, or recommendations expressed in this material are those of the author(s) and do not necessarily reflect the views of the National Science Foundation.

Disclosures. The authors declare no conflicts of interest.

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