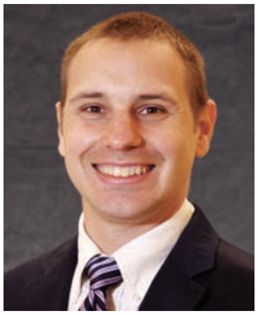

Letter from the Editor

Peter D. Kazarinoff

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Keywords: J ATE, Journal of Advanced Technological Education

Dear Technician Education Community:

Welcome to the Journal of Advanced Technological Education! Or, as we like to call it, J ATE. On behalf of our editors, we are pleased to launch the inaugural issue of J ATE.

J ATE is a peer-reviewed technical journal focused on community college faculty and staff who work primarily with technician education. J ATE is a platform for dissemination of peer-reviewed work that furthers the development of technician education.

J ATE is cross-disciplinary, encompassing all technologies under the National Science Foundation (NSF) Advanced Technological Education (ATE) Program. An incomplete list of disciplines covered by J ATE is below:

- Micro Nano
- Biotechnology
- Autonomous Technology
- Cyber Security
- Advanced Manufacturing
- Earth Sciences
- Agriculture Technology
- Energy
- Welding

In addition, J ATE publishes articles on topics that cut across all technician education disciplines, such as:

- Evaluation
- Mentoring
- Undergraduate Research
- Applied Technician Education Research

This first issue of J ATE features three articles that highlight some of the sub-disciplines in our community. One of the articles is on Unmanned Aerial Systems, while Micro Nano Technology is the theme of the second article, and the third article is on student recruitment. We want to thank the authors, reviewers, editors, and journal staff for their hard work bringing these articles to the publication.

As Editor-in-Chief of J ATE, I want to introduce you to the J ATE Editorial Board. Please reach out to Editorial Board members with your J ATE article ideas, journal questions, or collaboration opportunities.

J ATE began at the National Micro Nano Technology Education Center (MNT-EC) in late 2019 and became a multi-discipline, peer-reviewed journal as a collaboration with six National ATE Centers.

Table 1. National ATE Centers Supporting the Journal of Advanced Technological Education

Technology	Center	Principal Investigator
Micro Nano Technology	**MNT-EC**	**Jared Ashcroft**
Biotechnology	**InnovATEBIO**	**Linnea Fletcher**
Autonomous Technology	**NCAT**	**Jonathon Beck**
Cyber Security	**NCyTE**	**Corrine Sande**
Advanced Manufacturing	**NCNGM**	**Karen Wosczyna-Birch**
Earth and Energy Technology	**EARTh Center**	**Ellen Bluth**

As new ATE National Centers are launched, J ATE will incorporate their expertise into its Editorial Board.

I invite you to participate in our J ATE Community. We are looking for new authors to publish their work. We strive to build a cohort of reviewers from all the sub-disciplines represented in technician education. We need your help as readers and networkers to share J ATE with your colleagues and students. We hope to work with you soon.

In Teaching and Learning,

Peter

Peter D. Kazarinoff
Editor-in-Chief

Invited Letter: Welcome to the Journal of Advanced Technological Education

V. Celeste Carter

Lead Program Officer, ATE Program, The National Science Foundation, 2415 Eisenhower Avenue, Alexandria, Virginia, USA

Keywords: NSF, ATE, Technician Education

Welcome to the Journal of Advanced Technological Education!

As the Lead Program Director of the National Science Foundation's Advanced Technological Education Program (ATE), I am pleased to introduce the Journal of Advanced Technological Education (J ATE) to the technician education community. Technician Education programs at two-year community and technical colleges across the United States now have a peer-reviewed journal to learn about the newest advancements in technician education produced and reviewed by their peers.

J ATE covers two-year community and technical colleges with technician education programs in advanced technology industries. These industries include: Micro and Nano Technologies, Biotechnologies, Autonomous Technologies, Advanced Manufacturing, Cyber Security, Environmental Technologies, Energy, Engineering and the shared technician education space such as mentoring and evaluation. J ATE is a peer-reviewed journal for all Advanced Technological Education (ATE) faculty.

The leaders of the Micro Nano Technology Education Center (MNT-EC), the national Center for Micro and Nano Technician Education, proposed a peer-reviewed journal as one of their activities. Since then, the Journal has grown to encompass all sub-disciplines under the ATE umbrella. In addition to community college faculty and staff, the Journal welcomes submissions from students doing undergraduate research and industry members involved with community colleges and K-12 teachers and administrators.

My publishing journey started when I was a technician and was given the opportunity to lead and carry out a research project characterizing viral mutations. I continued publishing as a graduate student, post-doctoral fellow, and published during my tenure as a community college faculty. Publishing provides a way for the greater STEM community to be aware of advances made both in research and teaching. The advances made at two-year community and technical colleges often remain either at the institution or, at best, within the region where the institution is located.

I highly recommend two-year faculty, staff, and students publish in J ATE for multiple reasons. These include knowledge sharing, professional advancement, collaboration opportunities, and dissemination of results that can impact faculty and students at community and technical colleges across the United States.

I am proud to support technician education, the ATE grant program and J ATE. You can support J ATE by submitting articles, serving as a peer reviewer and reading and sharing articles with your colleagues.

Dr. V. Celeste Carter
Lead Program Officer, ATE Program
National Science Foundation

Initial Observations of a Community College Microsystem Fabrication-Focused Undergraduate Research Experience

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Abstract: Providing hands-on learning experiences increases student understanding of theory and practices in STEM (science, technology, engineering, and mathematics) fields. The experience gives students motivation and allows them to focus their career path towards completing a degree in a STEM field. This paper provides initial observations on the learning impact of community college students and their instructors participating in the Support Center for Microsystems Education 2021 Undergraduate Research Experience. Twenty undergraduate community college students and their instructors participated in a week-long, hands-on, project-based course in a cleanroom environment. Both students and instructors showed an increase in the level of knowledge regarding microfabricating based on the collected survey results after completing the program. Survey results and observations of participating mentors are presented.

Keywords: undergraduate education, microfabrication, cleanroom, MEMS, community college

1. Introduction

Hands-on approaches to learning are beneficial to students, maximizing students' academic completion potential and better preparing them for success in the workforce. This can be especially true in STEM fields, where the development of "real-world" skills through practice is beneficial to not only the learners, but to future employers [1,2].

While theoretical ("book") learning holds powerful value, the next generation of STEM practitioners needs to strive at putting theory into practice [3]. This is especially true while working in a technology-oriented career, where hands-on learning contributes to students' enhanced interests in education continuation and core class attentiveness (i.e., engagement) [4]. Focusing on the microfabrication manufacturing field, previous undergraduate class curriculums have demonstrated success in student semiconductor manufacturing training and in making these students sought after by industrial employers [5]. The current semiconductor industry requires a wide variety of skilled workforce, from technicians to design engineers, with a high demand for skilled and trained workers in the relevant areas [6,7].

Finally, a hands-on education approach will also address the growing concerns of industry recruiters regarding a skill gap between the existing workforce and the incoming technician graduates [8]. Therefore increasing job-readiness is of high importance to the semiconductor industry, as it leads to decreased training time and costs. There is a wide range of application fields of typical micro-fabricated devices from the semiconductor industry, including communications, healthcare, computing, transportation, aerospace, among others [9]. Therefore, there is a need for highly skilled microfabrication technicians to fulfill these workforce demands [7]. Community college students can pursue technician jobs upon graduation or continue at the university towards an engineering career. Nonetheless, with a microsystems fabrication hands-on project-based experience added to their curriculum, both types of students benefit greatly, providing valuable and relevant cleanroom and microfabrication experience for the micro-nanotechnology (MNT) industry. This paper presents the initial observations of community college students' and instructors' learning impact in a microsystem fabrication-focused research experience based on their survey responses as presented in the following pages.

2. Methodology

A total of twenty participants, including at least five instructors, and twelve students from three community colleges, participated in the Microsystem fabrication-focused Undergraduate Research Experience (URE). The course consisted of the participants receiving online preparatory materials and lectures in the microfabrication area weeks before arriving at the laboratory, followed by a week-long hands-on cleanroom experience at the University of New Mexico (UNM). Two graduate teaching assistants and two UNM faculty members educated and mentored the participants in using multiple fabrications and metrology tools and processes. This classroom experience allowed students to work inside a class 1000 cleanroom at the UNM Manufacturing Training and Technology Center (MTTC), as seen in Fig. 1.

During the week, students participated in several microfabrication projects and received training on various cleanroom equipment, followed by completing the survey to analyze the experience's impact. There were three main types of microdevices fabricated, namely i) a micro pressure sensor ii) microneedles and iii) microfluidic channels. An initial "Art Wafer" project was undertaken to introduce students to basic cleanroom processing and safety protocols. The Art Wafer Project included a photolithography step and wet chemical etch resulting in a pattern of the students' choosing onto a 4-inch silicon dioxide coated silicon wafer. This initial project introduced the students to wafer cleaning procedures (i.e., solvent resist stripping and spin rinse dry (SRD) methods). They also gained training on the spin coater, mask aligner/exposure instrument, chemical fume hoods (including solvent and caustic wet materials), and wafer handling.

Fig. 1. Students with the teaching assistants prepare samples inside the UNM MTTC Cleanroom.

2.1 Microfabrication Methods: Making of a Micro Pressure Sensor

The micropressure sensor process is a simple two mask process that consists of multiple steps that expose students and faculty to many of the processes used in micro nanofabrication: 1) photolithography with positive and negative resists, 2) dry anisotropic etching, 3) wet anisotropic silicon crystal etching, 4) sputter deposition, 5) thin-film measurement, 6) wafer dicing, 7) optical microscopy, 8) scanning electron microscopy, and 9) electrical probe characterization of the Wheatstone bridge circuit.

The purpose of the photolithography process is to transfer a pattern to the wafer. Spin coating is the first step and is a technique used to deposit uniform thin films upon a substrate dispensing liquid material followed by spinning of the substrate (wafer). The centrifugal forces induced by the spinning, spread out the material, leaving behind a uniform thin film [10]. This is a standard method to deposit photoresists in photolithography procedures. Photolithography is a process where a photoresist, a photosensitive polymer, is exposed to light via a photomask using a contact or projection illumination system. This light exposure makes certain parts of the photoresist soluble (positive resist) or insoluble (negative resist) to the subsequent development step. After developing the photoresist, selective areas are covered with photoresist, and other areas are not. The photoresist protects what is underneath in the subsequent etching step or allows the selective deposition of material to the open areas (metal in the case of the pressure sensor process). In other words, the step following photolithography allows for different microfabrication techniques such as etching (removal of material) or material sputter (deposition or material) to transfer the photomask pattern into different material layers [10,11].

By the end of the week of cleanroom activities, the students learned how to fabricate and characterize a fully functional micro-pressure sensor. This completed device consists of a chrome-gold (CrAu) bi-layer or a single layer nichrome (NiCr) alloy piezoresistive Wheatstone bridge circuit on top of a thin film silicon nitride membrane. To create the device, there are two patterning steps. The first step is to create the opening for the sensor chamber, and the second is to create the actual bridge circuit. Fig. 2 shows the pressure sensor device; note the chamber viewed from the backside of the wafer and the Wheatstone bridge as seen from the top.

To create the chamber, one must first transfer the pattern to the backside of the wafer via photolithography and subsequent reactive ion etching of the silicon nitride film. The first step is to coat both sides of the wafer with a thick positive photoresist: AZ 10XT. Next, the front side is coated to protect the one-micron thin silicon nitride film from being damaged while processing the backside. Next, a series of open areas are patterned in the photoresist allowing for the selective removal of the silicon nitride using reactive ion etching (RIE). The photoresist is then removed. The patterned silicon nitride is now a "hard mask" for the subsequent etching of the crystal silicon wafer substrate resulting in the pressure sensor chamber. The RIE process uses a carbon tetrafluoride and oxygen (CF4/O2) gas combination with a plasma to open SiN windows. Next, the photoresist is stripped with acetone followed by an alcohol and deionized water quick dump rinse (QDR) and spin rinse dry (SRD).

To create the frontside Wheatstone bridge pattern, the front side of the wafer is patterned using one of two lift-offs resist processes, either LOR5B and AZ1518 or NLOF2070, a positive and negative resist process, respectively. This photolithography process step results in open areas on the wafer, which defined the Wheatstone bridge circuit. Once the pattern is defined, metal for the circuit is deposited into open areas on the SiN and on top of the photoresist. After sputter deposition, the photoresist is stripped and the wafer cleaned, resulting in the metal on top of it also being lifted off, leaving only the Wheatstone bridge circuit on top of the silicon nitride, which will become the flexible membrane of the pressure sensor.

The last step of the fabrication process is to etch the chamber. The wafer is submerged in a heated potassium hydroxide (KOH) bath. KOH selectively etches the exposed silicon crystal wafer substrate. The SiN does not etch in KOH; hence, only the open areas of the backside chamber pattern are exposed, and the exposed silicon is removed until the etch reaches the frontside SiN layer. Upon completion of the KOH etching, the Wheatstone bridge circuit is on top of a released SiN membrane which can now flex along with the circuit.

The students and faculty also were exposed to wafer dicing, the separation of the individual devices from the wafer, scanning electron microscope (SEM) inspection, and electrical probe testing of the device under varying pressure difference conditions. The probe station also includes an interferometer whereby the participants can determine the degree of membrane deflection, determine the change in the circuit resistor length and compare theoretical with actual voltage output.

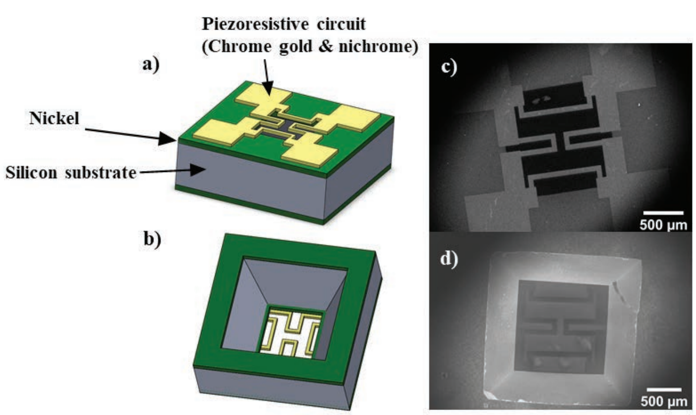

Fig. 2.
Topside Wheatstone bridge circuit (a) and bottom side chamber opening (b) 3D models with the corresponding scanning electron microscope images of the actual device (c) and (d), respectively.

2.2 Microfabrication Methods: Micro Fluidic and Needle Fabrication

Additionally, students learned how to fabricate micro-needles, focusing on three types of fabrication: i) cavity-based needles for soft-lithography ii) protruding silicon microneedles, and iii) 3D pillar needles. The process flow for the different types of needles is shown in Fig. 3. SU8 is a negative photoresist used in the process. When the cavity-based microneedles were patterned, polydimethylsiloxane (PDMS) was used as a flexible cast for the soft lithography of the cavity needles in order to produce replicas of the protruding microneedles by pouring the PDMS on top of the wafer and allowing it to cure. Once cured, the PDMS can be peeled away, leaving a soft-lithography mold. These PDMS needles can be seen in Fig. 4.

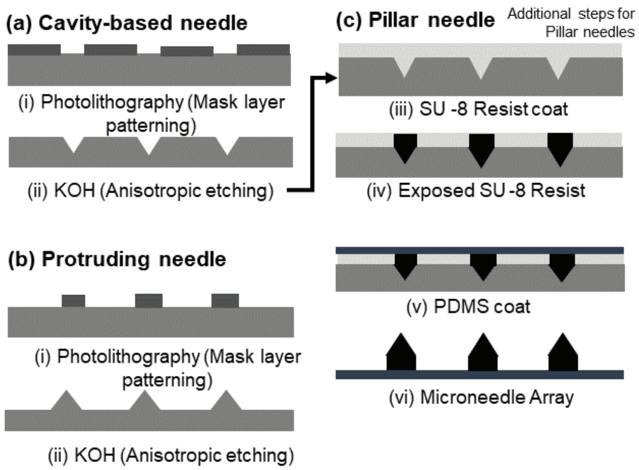

Fig. 3.
Fabrication process flow diagrams for a) cavity-based needles, b) protruding needles, and c) pillar needles.

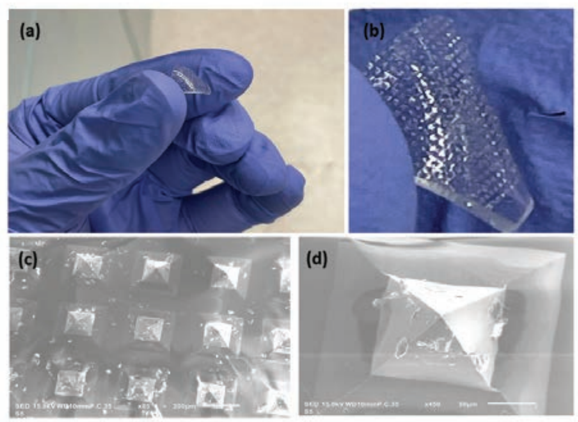

Fig. 4.
a) and b) PDMS microneedles c) and d) corresponding SEM images of the PDMS microneedles.

Similarly, students learned how to make traditional micro-fluidic channels utilizing similar soft-lithography methods. Surface micromachining methods (i.e., additive manufacturing) were demonstrated for microfluidics channels using negative photoresist SU8 on a Si Wafer. A photolithography process was used to pattern different microfluidic geometries. PDMS was used again for the soft-lithography mold. In Fig. 5a, a student can be seen peeling the PDMS mold away from the patterned SU8 profiles on the Si wafer. The final mold is shown in Fig. 5c. In this case, the mold was dyed red for visual purposes. Lastly, students and faculty were exposed to different methods to characterize these microdevices and structures using an electrical probe mechanical and optical-based metrology methods.

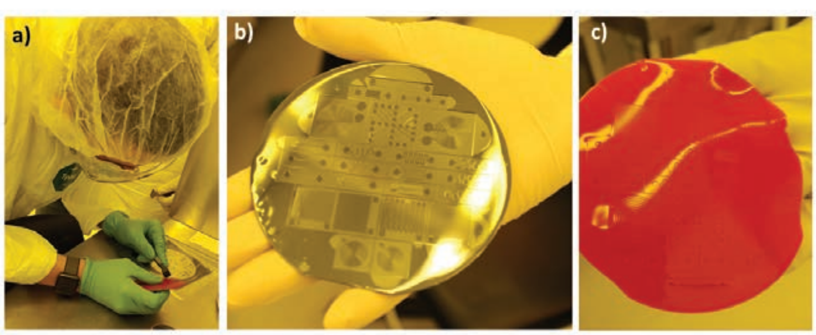

Fig. 5.
a) A student removing PDMS mold from the patterned SU8 on a wafer b) Patterned microfluidic channels on SU8 c) soft lithography PDMS mold

3. Survey Methods

Out of 20 participants in the program, 17 participated in a survey to rate their experience in this program. The online survey was shared on the last day of the cleanroom research experience, which included questions using the Likert scale (1-5) and short answer options.

The survey items included questions such as the following:

- How satisfied were you with the experience?
- Did you have any prior experience with hands-on microfabrication inside a cleanroom?
- What was your level of knowledge regarding microfabrication *before* and *after* starting the program?
- What is your field of study background? (i.e., degree currently seeking, previous experience)
- Which part of the hands-on experience did you learn the most? Explain why and what parts helped you bring your understanding to a higher level.
- Do you feel that you were introduced to new scientific concepts? Please Explain
- Please describe your familiarity with the different processes *before* and *after* the accelerated course.
- How likely are you to participate in a similar experience like this in the future?
- How likely are you to recommend it to your peers?

Similarly, when answering the question regarding their current field of study, the participants had the option of selecting multiple fields. The respective backgrounds are summarized in Fig. 6.

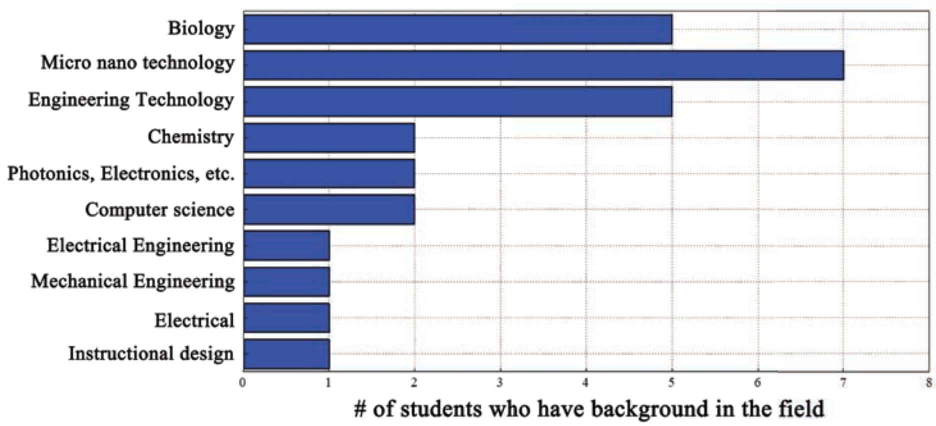

Fig. 6.
The current field of studies of the participating students was remarkably diverse

4. Survey Results

Instructors and students were asked to rank their familiarity with a number of microfabrication processes on a Likert scale from 1-5 before and after the course, with 1 meaning "You were not at all familiar" and 5 meaning "You were very familiar." Fig. 7a and Fig. 7b show the responses to this question from the instructors and students for different processes, respectively.

For both the instructors and the students, there was a positive increase in the level of familiarity with each aspect of microfabrication. As seen in Fig. 7a, in the case of the instructors, there was an increase in familiarity for all of the microfabrication processes listed. The largest positive difference (+1) with a standard deviation of 0.44, was in Soft Lithography, which involved creating a mold of the microfluidic and microneedle structures by pouring and curing PDMS on top of the wafer substrate and then peeling it off. The smallest increase was in the Exposure section, with an increase of only (+0.2) and a standard deviation of 0.44. Exposure is one of the basic steps in the photolithography process and is an essential part of transferring a pattern to the wafer using a photoresist.

In the case of the students, the levels of familiarity, as seen in Fig. 7b, had a positive increase in each microfabrication category as well. The category which showed the highest student self-assessed knowledge was the Lift-Off process with an increase of +2.42 and a standard deviation of 0.96. This process involves patterning thin metal film deposited on top of developed photoresist profiles and subsequently removing the metal-on-photoresist surfaces with solvents baths producing the Wheatstone bridge circuit. The area with the smallest increase (+1.78) with a standard deviation of 0.67 was interestingly in the area of soft lithography, which was a new exercise for most students.

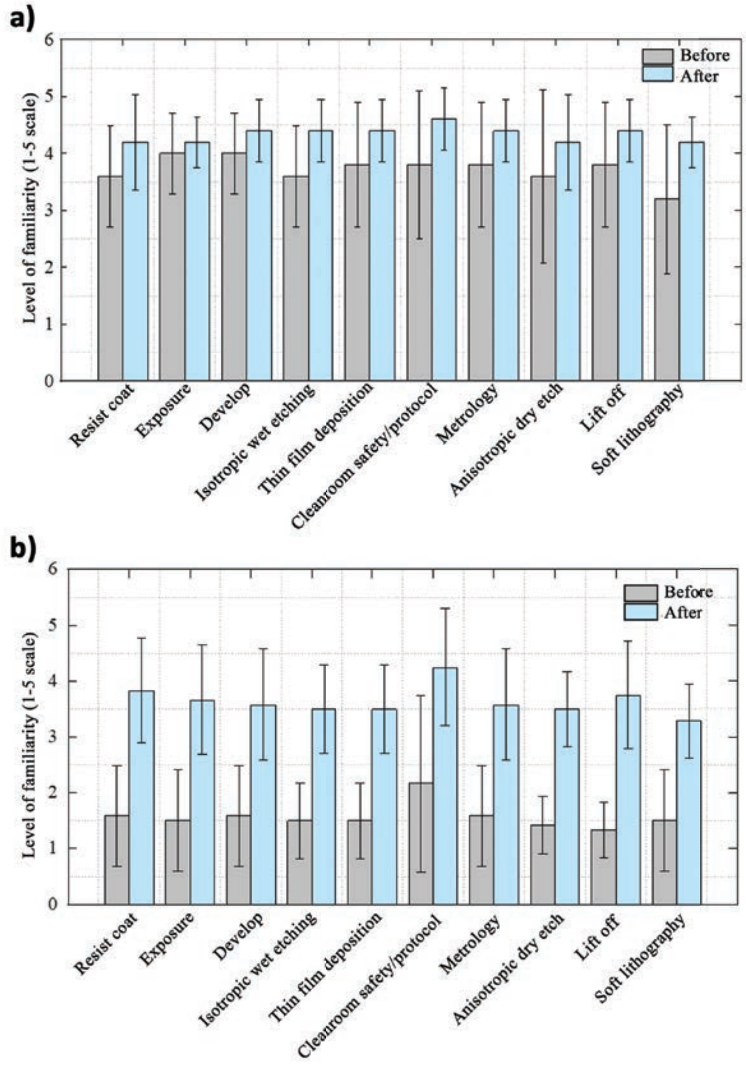

Fig. 7. Self-assessed level of knowledge before and after the experience for the various fabrication methods covered in the URE experience for a) instructors and b) students.

When asked a general statement regarding their knowledge before and after the class, the participants reported an increased level of knowledge corresponding to microfabrication processes. Table 1 summarizes this data, highlighting an overall improvement in a general understanding of microfabrication. After completing the program, the average instructor familiarity increased 11%, and students increased by 61% in terms of familiarity measured via a 1-5 Likert Scale.

Participant	What was your level of knowledge regarding microfabrication <u>before</u> starting the program? (1-lowest, 5-highest)	What was your level of knowledge regarding microfabrication <u>after</u> completing the program? (1-lowest, 5-highest)
Instructors	3.4 ± 0.55	3.8 ± 0.44
Students	2.1 ± 0.99	3.4 ± 1.16

The values are presented as average +/- STD, with 12 students and 5 instructor participants.

Table 1. Likert Scale self-assessed impact on student and instructor learning

When asked how likely the participants are to recommend it to their peers, 88.2% of the total participants selected "Highly Likely," and the remaining 11.8% selected "Likely," showing a positive assessment of the course. Responses to how likely the participants wou participate in a course like this in the future was similar, with 76.5% selecting "Highly Likely" and 23.5% selecting "Likely." This is not a first-time event; however, it is the first time a survey has been presented to participants.

The following are direct quotes from instructor responses:

- *"The equipment required (wet bench, fume hood, exposure tool, etc) is not only much more expensive than our Community College department budget could afford, but even could we find grant funding, our space limitations are considerable."*
- *"Much of the SCME material is already very remote-friendly, however I think the hands-on cleanroom experience is invaluable."*

In their responses, the instructors noted how this was a valuable experience and beneficial to their learning. Instructors stated that from a pedagogy perspective, it might be difficult to create more lecture materials leveraging the recently covered topics; however, they intend to use the resources from this experience such as modified lecture slides, and adapt these into the delivery methods used in their courses.

5. Discussion

Given that this was a short online, week-long, hands-on research experience, the apparent trend of gained knowledge is vital. It increases microfabrication and cleanroom knowledge, skills, and familiarity for both students and instructors. These initial observations have shown that a hands-on microfabrication course is significantly beneficial for both instructors and students in STEM fields looking to gain practical cleanroom process experience, especially in the semiconductor/microfabrication fields. This has the potential to grow student employment in the semiconductor fields by giving them real-life experiences inside a cleanroom and exposure and familiarity with surface and bulk microfabrication techniques.

Hands-on learning has been shown to improve abstract concepts into a more concrete context and directly lead students to a higher chance of succeeding in STEM fields [12]. We can see this in the positive trend of results; considering this is primarily a one-week experience, the familiarity of the accelerated teaching is effective and beneficial.

Having students go through the entire process of fabricating a two-mask micro pressure sensor allowed them to see the complete process from the bare silicon wafer substrate through patterning, etching, and thin film deposition, and finally, device characterization. This permitted the participants to acquire the knowledge and skills needed to understand microfabrication and the ability to work in a clean-room setting.

When fabricating the microneedles, the students were exposed to creating similar structures through different methods, which contributes to understanding the process designs and how to modify these processes for different applications and geometries. For example, how to obtain longer microneedles or create a sharper needle tip from the different etching techniques applied.

Further, in fabricating a soft lithography mask for microfluidic applications, the students were able to apply MEMS fabrication techniques to create flexible final samples. These have a wide variety of bio-applications, such as wearable sensors or sensors for different types of bio-detection; this is of interest to many students. In addition, there is a wide range of applications of fabricated microdevices. For example, micro pressure sensors are used in technologies including biomedical applications, automotive industries, aerospace, among others [13,14]. Furthermore, microneedles can be used in areas such as transdermal drug delivery, biotherapeutics, and monitoring purposes [15,16]. Lastly, microfluidic channels have applications in the area of analytical processing of biological and chemical samples [17].

Students learning microfabrication through hands-on approaches have previously mentioned how hands-on teaching methods have engaged their interest [5,18,19]. Moreover, the area of MEMS (micro-electro-mechanical systems) is fundamentally centered on creating a device/system or can be thought of as product-oriented, so hands-on learning is appropriate. In the students' case, this experience also introduced new fields of study, which helped students discover an interest in the semiconductor/microfabrication fields. As there is a vast number of STEM careers, it is essential to allow students to explore a variety of career paths, including process, equipment, quality control technical roles. Here are some comments from students:

- *"As a student who knew nothing about MEMS before the UNM experience, this experience was extremely beneficial and gave me new insight into MEMS technology."*
- *"I did not know anything about MEMS and their applications before participating in this experience. I learned more about possible careers that I could go into in the future."*
- *"This experience not only expanded my scientific knowledge by introducing me to MEMS and the techniques needed to make MEMS but allowed me to better determine what I want my career path to look like."*

Similarly, some feedback provided by the instructors was received:

- *"This is an unparalleled opportunity for whoever is new to nanotechnology."*
- *"[Microfabrication is an] informative and useful research field that is prospering and growing which makes it beneficial for students to learn more about and potentially immerse oneself into this field."*
- *"[I have] already suggested it to future students."*

Furthermore, we should note that most participants (64.7%) had never been inside a cleanroom before as most of them were community college students. In fact, 83.3% of students had no prior experience with hands-on microfabrication inside a cleanroom; in the case of the instructors, this was only 20%. The program introduced most students to the cleanroom for the first time, which was a valuable experience.

From the instructors' feedback, it can be very costly to translate all hands-on teaching experiences to a community college that does not possess a cleanroom. Not only in terms of equipment and material costs but also in terms of laboratory space. This experience might be difficult to emulate in a non-cleanroom environment. This gained experience can be insightful for students who have never done hands-on microfabrication and have only studied microfabrication theories previously in their classes. Further, since most of these students are in an engineering technology program, this experience can pave the way for careers in the semiconductor industry.

6. Conclusions

The participants of a week-long, hands-on microfabrication course were comprised of instructors and students. Both surface and bulk micromachining methods were taught, with the participants completing a micro pressure sensor, different types of microneedles, and fabricating a soft lithography mold for microfluidic applications. Valuable and relevant knowledge was gained for both the instructors and students based on the feedback received at the end of the program. The students showed a significant increase in familiarity and understanding of the different fabrication methods: photolithography, isotropic and anisotropic wet etching, reactive ion etching, thin-film sputter deposition, cleanroom safety/protocol, photoresist development, measurement, and characterization methods, among others. This experience further introduced students to new possible career paths within the microsystems and semiconductor fields, both academic and industry options. Overall, initial observations of a community college hands-on microfabrication course proved beneficial and valuable for the participants.

Acknowledgments. We thank the members of UNM's MTTC cleanroom staff for all their help. This material is based upon work supported by the National Science Foundation under DUE Grant No. 1700678.

Disclosures. The authors declare no conflicts of interest.

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Workforce Development Strategies in Additive Manufacturing

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Abstract: Additive Manufacturing (AM), also known as 3D Printing (3DP), is one of the newest manufacturing technologies with growing utilization in our daily life. Parallel to this growth, new materials, machines, and specific processes are being developed to produce parts in better-finished quality, at lower cost, and with shorter production time. However, workforce education in this evolving field has not advanced at the same pace as the technology, lacking proven curriculums, high-quality/accredited degree programs, and specialized advanced degrees. In this paper, some best practices established by the authors are introduced. The list is far from exhaustive but is proven to be effective in practice.

Keywords: Additive Manufacturing, 3D Printing, Workforce Development, Innovation, Training

1. Introduction

The products fabricated using AM technologies are usually geometrically complex with superior properties such as lighter weight and higher strength. It is clear that the trend will continue in this direction; new products will be manufactured with improved properties without being restricted by their geometric shapes.

Today, there are many technological advancements reported about the unique developments of the AM in every sector, from medicine to aerospace. For instance, a new AM method has been developed to produce nanoscale-level metal parts such as copper objects as small as 25 nanometers in diameter [1]. This new technique has great potential in electronics, automotive, sensor, and battery technologies. Scientists have also developed a number of new edible plant-based gel materials that can be used to 3D print meat-like foods [2]. These gels ingredients, such as soy protein and wheat gluten, are as nutritious as real meat. It is believed that such a solution will be very effective for high volume food production for hotels and army sites. In addition, AM has been used to build houses, bridges, and storage units. Engineers have worked with construction specialists to print substantial buildings with real concrete, such as a 2,100 sq. ft home with three bedrooms and three bathrooms [3]. Scientists have also developed a low-cost wire arc additive manufacturing (WAAM) machine that can be constructed with a $1,000 budget [4]. Their beta-testing results with carbon steel and Inconel 718 presented some excellent successes. In health care, researchers have also created smart health monitoring devices that could operate without being manually recharged [5]. Wearable biosensors were precisely designed and fabricated using AM to address the personalized monitoring applications [6].

Although there are significant needs, no well-established workforce development strategy prepares engineers and technicians for these new and challenging technologies. The development of AM workforce is an important priority for several funding agencies, too [7,8,9]. Some funded projects are dedicated to developing AM-related curricular materials, MOOCs (Massive Open Online Courses), and training workshops. Specific course modules developed for AM instruction have been implemented in a number of design and manufacturing courses [10]. It was shown that the courses offered in Flipped Classroom (FC) model received a high satisfaction rating [11]. Hands-on AM training programs offered in-studio formats have shown higher learner satisfaction than the traditional in-person training formats [12]. During the COVID-19 pandemic, several remote training solutions have been developed and successfully delivered [13,14]. Institutions sharing their capabilities in teaching remotely have presented higher student success rates, especially during the pandemic [15].

This unique paper will present the latest AM workforce advancement strategies reported and delivered in various higher education institutions.

2. Delivery Strategies

2.1. Strategy 1 - MOOCs: MOOC is one of the latest models for delivering instructional content online without attendance requirements to the learners [16]. Some organizations like *CourseRA* [17] and *LinkedIn Learning* [18] have adopted this innovative learning method to offer several curricular contents for their participants. The instructional modules available on *YouTube* also fall into this strategy. Some of the commonly used proven examples in this category are given below:

- Additive Manufacturing developed by John Hart, Massachusetts Institute of Technology [19]
- MOOC AM Resources developed by Ismail Fidan, Tennessee Technological University [20]
- Introduction to Additive Manufacturing, David Bourell, ASM International [21]
- Introduction to the Digital Manufacturing and Design Technology Series, Kemper Lewis, The University at Buffalo [22]
- Additive Manufacturing 101, Siemens Software [23]

2.2. Strategy 2 - Textbooks and Reports: Many AM books and reports have been written and are currently available. It was shown that *Additive Manufacturing Technologies* textbook published by *Springer* (3rd edition) is one such resource that has been highly adopted and used in higher education institutions [24]. This book has been downloaded more than 101,000 times and used by thousands of institutions in higher education. The other most popular book is *Fabricated*, published by *Wiley*. This nine-year-old book has been widely used by many institutions in higher education and translated into several other languages [25].

The authority in reporting the annual AM innovations, trends, and technologies is the *Wohlers Report* [26]. This prestigious annual collection has been authored by many subject matter experts in the AM field and provides cutting-edge advancements in industry, higher education, research, and development. The report will continue providing the same level of cutting-edge information, although the international standardization society, *ASTM International*, announced the acquisition of *Wohlers Associates* at late 2021. It is expected that the quality and prestige of the report will even increase due to the acquisition [27].

2.3. Strategy 3 - Studios: Compared to the standard lecture format, studio-type learning and teaching pedagogy have become popular in courses requiring hands-on practice [28]. An appropriately managed studio classroom provides an active and cooperative learning environment in all subject matters. In AM, the training activities in studio format have shown high satisfaction rates in several AM workforce training practices [12,29].

The majority of the studio-type innovative AM workforce activities are reported in Maker Space practices. Some papers reported the innovations made in home institutions' maker spaces in providing an efficient and effective learning environment [30,31]. Figure 1 shows a team of participants building a 3D Printer in an AM Studio organized by Tennessee Technological University and Edmonds College.

Fig. 1. A diverse group of AM studio participants builds a 3D Printer

2.4. Strategy 4 - Virtual Lecture Series: One of the best ways to learn a specific subject matter is to learn from its expert. However, it is not always possible to conveniently find that expert. With the help of video conferencing solutions, in the last six years, additively innovative virtual lecture series has been developed and implemented by Tennessee Technological University. Several AM topics have been presented to hundreds of participants via this strategy [32,33]. Figure 2 presents the AM Virtual Lecture Series held in Spring 2021. The lectures were recorded and may be accessed from the event's archive [34].

Some technical companies, such as *Solidprofessor* [35], developed a series of interactive video courses in different areas of AM supported by certification exams where students have to pass with a score of 80% to receive a certificate of achievement and complete the course. Massachusetts Institute of Technology has also developed a virtual course to help attendees learn the AM knowledge blocks from design to production in three months [36].

Fig. 2. Virtual AM Lecture Series held by Tennessee Technological University in Spring 2021

2.5. Strategy 5 - The Technician Education in Additive Manufacturing & Materials: The Technician Education in Additive Manufacturing & Materials (TEAMM) project established a unique coordination network of public and private sector stakeholders on AM [37]. This network addresses a critical gap in supporting a new direction of technician education, including identifying and adapting *ASTM skills standards* that keep pace with advances in research and development. TEAMM is supported by utilizing social networking technologies, proactive identification and expansion of key stakeholders, and improved access to workforce development.

AM News, published by the TEAMM project, highlights the latest developments and innovations in AM education workforce development efforts [38]. Subject matters and institutional affiliations tag news items. This news site has been proven to be a good and accessible resource for several institutions to read and learn the latest best practices in AM workforce.

2.6. Strategy 6 - FC: FC is one of several educators' new course delivery techniques. In FC, educators prepare educational materials via video conferencing tools and are released for students' convenient access 24/7. This way, educators spend more time answering students' questions than developing the course materials. The FC in AM instruction has shown some success [11,39].

The AM technologies have successfully supported the FC teaching model in several cases. It was proven that the students and participants of the classroom environment leave the learning activities with high satisfaction rates. Educators not only in engineering but also in medicine have reported their success stories [40]. Figure 3 shows the students' satisfaction with core learning outcomes collected from a *Computer-Aided Design* course in Fall 2020. This course was offered in FC format and enhanced with AM practices.

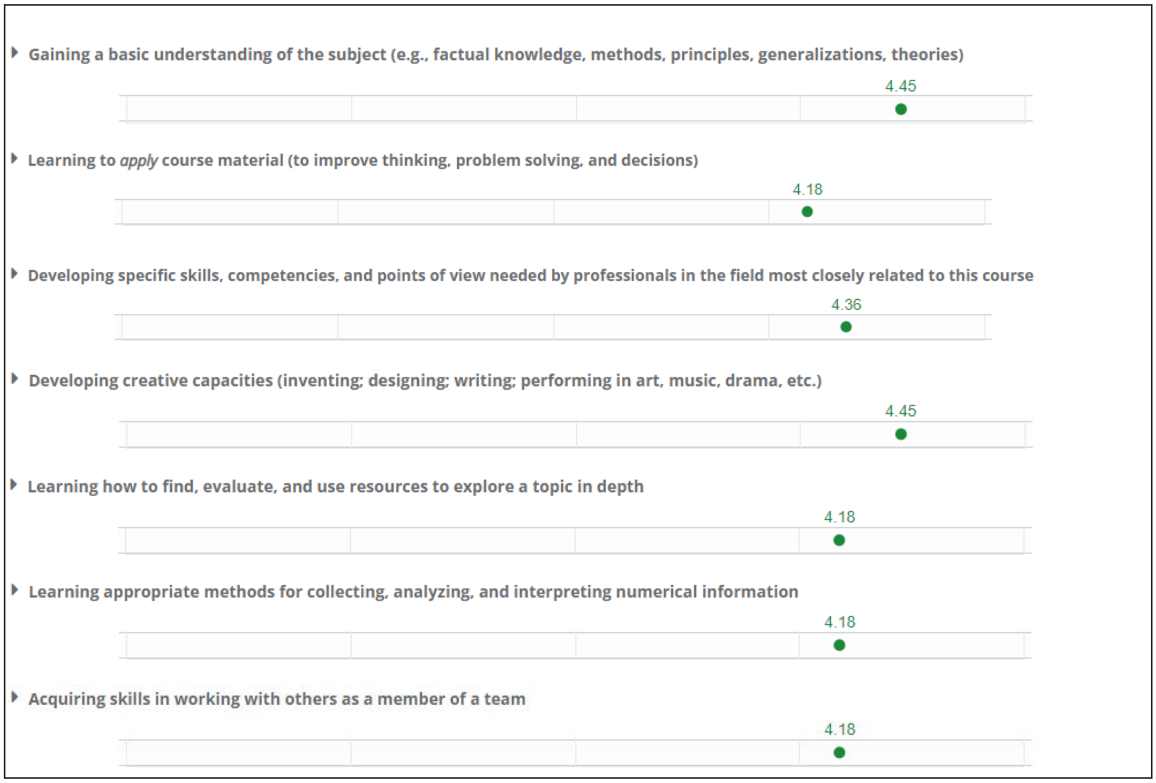

Fig. 3. Student Satisfaction Survey of Computer-Aided Design course offered in FC model in Fall 2020 over a 5.0 scale

2.7. Strategy 7 - Academic Centers of AM: Many universities established centers through funding from public and private sectors, which provide students with opportunities to practice and learn and do collaborative projects with the industry. A constantly increasing number of universities, colleges, and community colleges have adopted this strategy in the last few years. Among these academic institutions, Somerset Community College [41], Calhoun Community College [42], North Carolina State University [43], New York City College of Technology [44], and New York University [45] are the ones presenting some tangible workforce development activities.

2.8. Strategy 8 - Resources Developed by the 3DP Companies: Companies like Formlabs, Ultimaker, Desktop Metal, and Markforged have high-quality education and workforce development materials with videos and infographics on their website. Those informative materials are product-based, hands-on orientated, and up-to-date resources. Anyone interested can easily find information about maintenance, design guide, orientation analysis, and more in their documents. Some of the well-known AM Resources in this category are given below:

- 3D Systems [46]
- Stratasys [47]
- Markforged [48]
- Formlabs [49]
- Ultimaker [50]
- Desktop Metal [51]

3. Discussion

The growing trend of AM will continue with the advancements in new machines, materials, and technologies every day. It is also clear that the demand for training the workforce who could efficiently utilize these advancements will be a significant concern for many companies and institutions. The strategies highlighted in this paper will provide new opportunities for institutions and industries and students and workers.

The summaries of the eight strategies provide brief details about the specifics of each AM workforce training. These available strategies also have specific costs, timeframe requirements, and eligibility details. However, it was shown that each of them has a number of success stories provided by trained or educated individuals.

The manufacturing industry has progressed beyond traditional processes such as CNC, casting and injection molding, etc. AM technologies are emerging as critical enabling practices for modern design and end product development, revolutionizing manufacturing processes. In both consumer and commercial markets, the advancement of AM is highly dependent upon innovations that improve 3D printer capabilities, speed, and materials. As new materials are developed, and 3D printers are increasingly capable of utilizing multiple materials, it is imperative that technicians understand these materials' properties both individually and as they are combined during the AM process.

One of the challenges to AM is that most of the technology now is either FFF (Fused Filament Fabrication) or SLA (Stereolithography) since they are both affordable. Thus, most educational institutions provide training to students in these two areas. Other AM technologies are still far from academia, even though they can be used to fabricate good-quality components. Metal AM is still very expensive, and most schools cannot afford it. It is anticipated that its cost may drop down but not in the near future.

4. Conclusion

Conventional training methodologies of AM have been reported in many papers and reports. For example, hands-on training activities were conducted in a laboratory environment or train-the-trainer workshop. However, technological advancements in AM, distance learning tools, learning pedagogies have provided several more unique and flexible training solutions. This paper has shared some of them. Authors believe that the number of these training solutions will parallelly grow with the advancement of AM.

Acknowledgments. This material is based upon work supported by the National Science Foundation's Advanced Technological Education program under Grant Numbers:

- 1501251: Technician Education in Additive Manufacturing & Materials (TEAMM)
- 1601587: Additive Manufacturing - Workforce Advancement Training Coalition and Hub (AM-WATCH)
- 1601522: Advanced Design and Fabrication of Prosthetic and Medical Devices

Any opinions, findings, conclusions, or recommendations expressed in this material are those of the authors and do not necessarily reflect the views of the National Science Foundation.

Disclosures. The authors declare no conflicts of interest.

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Investigation of the Post-Pandemic STEM Education (STEM 3.0)

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Abstract: In this work, we analyze the lessons learned from the COVID-19 pandemic and the prospects of the science education that evolved as a result of the pandemic. The two primary shortcomings that arose during the pandemic include: the poor presence of cross-boundary and interdisciplinary research as evidenced by the urgency in establishing cross-boundary research groups in the early days of the pandemic, and the lack of understanding of the scientific method in the general public as evidenced, for example, by the worldwide Hydroxychloroquine events of 2020. An effective approach to solving these shortcomings is increasing innovative research at the two-year tertiary education level. The focus of continuing technical education will shift towards technologies that provide self-sufficiency, such as artificial intelligence, intelligent robotics, augmented reality, digital twins, and additive manufacturing. These features likely constitute the cornerstone of the upcoming science education paradigm, which we denominate “STEM 3.0”.

Keywords: STEM 3.0, COVID-19 Pandemic, Post-Pandemic Education, Junior Tertiary Education

Introduction

The COVID-19 pandemic has resulted in shockwaves that have reverberated in almost every aspect of human civilization. As a result of the pandemic, severe supply chain disruptions have occurred throughout manufacturing industries. As a result, the global economy has been hit hard with a loss of $28 trillion; an aviation industry was virtually paralyzed for months, and crippled services and tourism sector comprising restaurants to hotels, and retail commerce. It also exposed the need to develop local, regional, and national self-sufficiency after supply chains had been severed by the initial wave of the pandemic [1].

However, COVID-19 will not be the last pandemic nor the most lethal. It is estimated that there are between 650,000 and 840,000 unknown virus species in the wildlife that can infect humans [2]. Some of the viruses that have jumped from wildlife to humans (a process referred to as Zoonotic Spillover [3]) include very deadly ones such as Rabies (from bats), incurable ones such as HIV (from primates), and very contagious and deadly ones such as Smallpox (from rodents). Eventually, with the exponential increase in human population and the reduction in natural habitat for wildlife, new Zoonotic virus infections will be inevitable, and it is just a matter of time before the next pandemic hits [4].

In a study that was published recently, researchers suggested that the threat of a viral spillover from wildlife will be a “daily reality” and identified some of the newly discovered viruses that are very likely to spill over to humans [5]. For example, the Lassa virus, which is naturally found in rats and has a higher risk factor than the SARS-CoV-2 virus (which causes COVID-19), despite the potential, has not yet emerged at an epidemic level. Other viruses with a high spillover potential include the Bat strain 229E, CoV-35, and others, as shown in Table 1.

Risk Score	Virus	Symptoms if contracted by humans	Natural Host
91	Lassa Virus*	Affects Organs: Kidneys, liver	Rats
87	SARS-CoV-2*	Causes COVID-19	Bats
84.8	Simian immunodeficiency virus*	Causes AIDS-like symptoms	Primates
81	Bat strain 229E	Common cold symptoms	Bats
80	Rousettus Bat HKU9	Symptoms are thought to be similar to the Middle East Respiratory Syndrome (MERS): severe respiratory illness, shortness of breath.	Bats
80	Beta Coronavirus RP3	Thought to be Similar to COVID-19	Bats
79	Murine virus	Causes cancer in mice, unknown effect in humans	Mice
72.5	Bombali virus	Similar to Ebola With a fatality rate ~ 40% in bats. Unknown effect in humans	Bats
Astrick (*) indicates that spillover of the virus had already been documented.			

Table 1. Recently discovered viruses in wildlife and their risk factor discovered between 2009 and 2019 [5,6].

From the above discussion, it is evident that more preparedness is needed on the academic level to counter future health crises and/or pandemics. In this work, we evaluate the impact of the COVID-19 pandemic on Science, Technology, Engineering, and Mathematics (STEM) education, and we discuss the lessons learned and present a post-pandemic paradigm for STEM education that has emerged as a result.

Shortcomings in the Science and Technology Education Exposed by the Pandemic

The COVID-19 pandemic exposed two primary shortcomings in science and technology education: poor interdisciplinary and cross-boundaries research; and the lack of understanding of the evidence-based scientific method for public policy and societal decision making.

Poor interdisciplinary and cross-boundaries research: Before the pandemic, many warning signs arose, anticipating a gap in interdisciplinary research on the undergraduate level. In 2018 a study led by Dalhousie University found that undergraduate level interdisciplinary scientific research is very poor (standing at only 28%) [7]. During the pandemic, the need for collaborative border-crossing research intensified to the point of forming consortia such as the COVID-19 R&D group [8]. After all, according to the famous mathematician and astronomer Laplace, "to discover is to bring together two ideas that were previously unlinked" [9]. Some of the challenges that were uncovered by the pandemic and effectively slowed down international collaborations were the lack of cross-boundary funding agency agreements and the lengthy procedures needed for visa and scientific work permits across boundaries [10].

Consequently, scientists found themselves unable to fund research beyond the political boundaries or get foreign talents timely. The CEO of the American Society for Microbiology stated in a joint publication with its president that in the post-COVID-19 world, there is a need for a new scientific system that gets rid of scientific isolationism [10].

Lack of understanding of the evidence-based scientific method in public policy and societal decision making [10]: the initial response to the spread of COVID-19 was characterized by a desperate need in the world, and people were "jumping to conclusion without any rigorous scientific evidence" [11]. For example, results from an initial study conducted in March 2020 on Hydroxychloroquine in test tubes led to what came to be known as the "hydroxychloroquine roller coaster" [12]. Nevertheless, by mid-April, almost every country in the world approved the drug for the treatment of COVID-19 despite that no study had been conducted on animals or humans.

Although the scientific method is taught in grades K-12 and at post-secondary levels, the dramatic events that unfolded around hydroxychloroquine during the pandemic could highlight the need for a different approach. Particularly, students do not usually engage in an actual implementation of the scientific method until entering a graduate degree program, when they participate in innovative research.

Moreover, recent studies show that in 2019, about 50% of adults in the U.S. aged 25-32 attained at least a 2-year degree, while the rate drops to about 40% for adults that attained at least a bachelor's degree [13]. Therefore, the vast majority of the adult population in the U.S. likely has not engaged in an actual implementation of the scientific method. At a minimum, an effective approach to enhance understanding of the scientific method should target that 50% of the adult population that does pursue higher education starting at the 2-year degree level. This should be initiated by including research at two-year post-secondary institutions such as community and technical colleges.

Broader Societal Shortcomings Exposed by the Pandemic: The Supply Chain

On the technological level, the pandemic exposed the urgent need for more preparedness in developing self-sufficiency in the supply chain [1]. The supply chain disruptions seen during the pandemic have abruptly accelerated the use of next-generation intelligent robotics [14,15] and additive manufacturing [16] (Fig.1) as well as a shift from the two-decade-long trend of having complex benchtop Point-of-Need instruments towards simplicity and portability. This shift is expected to last into the next decade, as shown in Fig. 2 below [17].

Fig. 1. Next-generation intelligent robots are highly portable, can work collaboratively with human operators and have the ability to self-learn.

Despite the sharp fall in the global economic activity brought about by the pandemic and resulting supply chain jams, some industries experienced surges in demand, including the BioMEMS (Micro-Electro-Mechanical Systems for Biomedical applications) [18,19] and the Telecommunications MEMS industries [20].

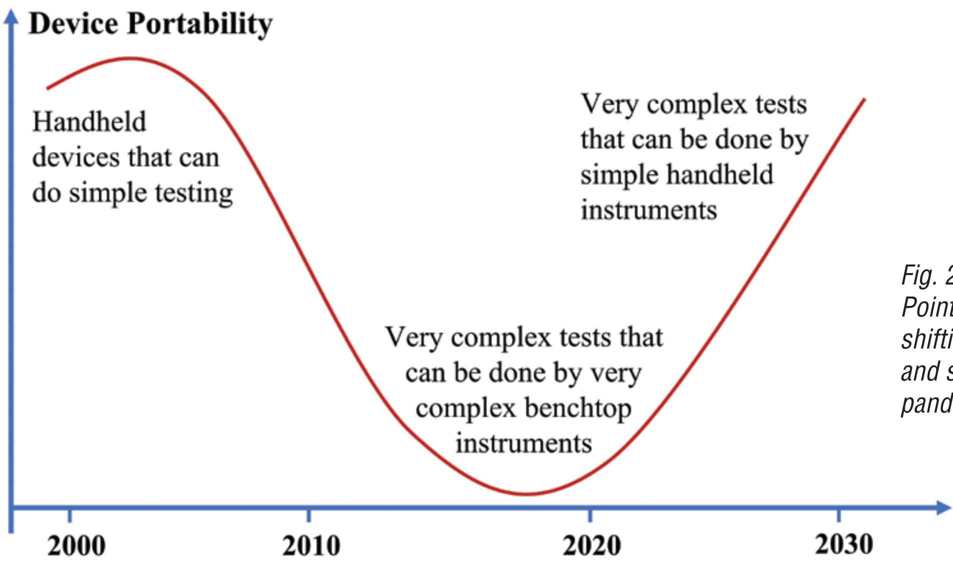

Fig. 2.
Point-of-Need Instruments are shifting gears towards portability and simplicity as a result of the pandemic [17].

The STEM 3.0 Paradigm

With the start of the 21st century, a new approach in science evolved that is characterized by collaboration and openness and has been referred to by Schneiderman [21], Waldrop [22], and others as “Science 2.0”.

However, just like the older classical science, labeled “Science 1.0”, the second paradigm targeted mainly the scientific research community. Therefore, it had little or no impact on scientific education, particularly in junior tertiary education (community and technical colleges).

From the above discussion, a new generation of science, technology, engineering, and math (STEM) education paradigm, STEM 3.0 is evolving in the wake of the pandemic. The main characteristics of this paradigm include cross-boundary collaboration and increasing knowledge of the scientific method in the general adult population. This is accomplished through practical innovative research that targets secondary and junior tertiary education. Furthermore, its implementation is greatly enhanced by reliance on smart technologies. The main features of each of the three paradigms (Science 1.0, Science 2.0, and STEM 3.0) are outlined in Table 2.

Characteristics	Science 1.0	Science 2.0	STEM 3.0
Involvement of secondary and tertiary education	Classical Classroom learning. No involvement in research	Classical Classroom learning, limited involvement in research	Engagement in innovative research as a cornerstone in education
Main features	• Rise of copyrights • Data safeguarding	• Networkization • Data sharing	• Intelligentization • Involvement of the community (Citizen Science) • Self-sufficiency
Scientific research	Multi-disciplinary	Inter-disciplinary	Cross-boundary

Table 2. The characteristics of the post-pandemic STEM 3.0 paradigm compared to the classical Science 1.0 and the 21st-century pre-pandemic Science 2.0 paradigms.

Project-Based Learning as a Model to Integrate Research into Junior Tertiary STEM Education: Capstone and end-of-study projects are known to constitute one of the high-impact educational practices [23], the importance of capstone projects in undergraduate education was acknowledged in the Boyer Commission report of 1999. The 2009 National Survey of Student Engagement reports that 75% of a randomly selected sample size of 360,000 students from universities and four-year colleges indicated a substantial impact of capstone projects in developing their intellectual curiosity and critical thinking [24].

However, the studies mentioned above primarily targeted four-year colleges. Furthermore, none of them considered the impact of the innovation aspect in the capstone projects on both the students and society.

In the STEM 3.0 paradigm, the two primary characteristics of the project-based learning model are that it is carried out in the junior tertiary level (two-year colleges) and the requirement of an innovative approach in the project.

Technologies that Emerged During the Pandemic and their Role in the Next Educational Paradigm: In the technical maintenance sector, the need for virtual technologies, augmented reality, and remote accessibility intensified, particularly in the first few months of the pandemic, when person-to-person interactions were curtailed, air transportation was virtually shut down, and cross-border travel was heavily restricted.

Manufacturing sites that created virtual models of their plant floors before the pandemic suffered far less from these disruptions, as technicians could conduct many troubleshooting tasks remotely utilizing augmented reality technologies.

Virtual classrooms, scientific conferences and workshops, and even engineering labs that are controlled remotely have emerged as a result of the pandemic [25]. In fact, STEM 3.0 appears at some level to be emerging organically due to the innovations that have allowed research, development, and manufacturing to continue.

Therefore, to be prepared for the next pandemic, educational systems will need to incorporate and stay current with up-to-date technologies that can provide the needed flexibility and ability in three primary routes:

1. Virtual conferencing and lecture tools.
2. Contactless laboratories: This is achieved with digital twinning of lab equipment and institutional facilities, Internet of Things (IoT), utilizing augmented and virtual reality, and intelligent robotics for equipment handling and conducting experiments remotely.
3. Self-sufficiency and portability: this is achieved by enhancing the use and education of technologies that enable self-sufficiency and portability, such as additive manufacturing with 3D [26] and 4D printing [27] (3D printing with smart materials that adjust their final shape with time), laser material processing, and following the trend of favoring portable over benchtop instruments, as well as robotized equipment handling with intelligent robots and drones to counter any possible supply-chain disruptions in the future.

This incorporation of smart technologies is coupled with a project-based learning approach; where students are required to apply the scientific method, critically assessing their approach, and arrive at effective solutions.

The increased demand for highly automated and intelligent systems further emphasizes the need for training programs on intelligent technologies and systems in the STEM 3.0 era. The term “Intelligentization” was first introduced by the Chinese State Council in its National Artificial Intelligence Strategy [28] translated as “ Next Generation Artificial Intelligence Development Plan” to refer to the next generation of intelligent systems that include decision making, as opposed to the current generation “advanced autonomous” systems, which lack the ability to make decisions. This concept is integral to A.I. The importance of A.I. technology and the gradual presence of the technology in almost every industry and every application will result in a shortage of the skilled A.I. workforce on two levels: the applied technology-handling level and on the research level, and it has been rapidly widening, and is starting to have a tangible effect [29]. Furthermore, the demand for A.I. increased during the pandemic with the increased dependence on technologies that rely on artificial intelligence.

Discussion and Conclusion

Scientific studies show that future pandemics are inevitable, and more preparedness is needed academically. Recent studies indicate that more than 50% of the adult population in the U.S. holds at least a two-year tertiary education degree, which means that preparedness will be most effective starting at that level. Here we propose a science education paradigm that we refer to as STEM 3.0 that addresses the two major scientific concerns that arose during the COVID-19 pandemic: Lack of interdisciplinary cross-boundary research, in this case at the 2-year undergraduate level, and the poor understanding of the scientific method among the adult population. In this paradigm, the approach for teaching the scientific method will shift to increased incorporation of innovative interdisciplinary and cross-boundary research in community and technical colleges.

Finally, to be more prepared for the next pandemic or other societal disruption, academic institutions will need to continuously consider contactless laboratories and self-sufficiency. This is achieved by creating digital twins of laboratories, incorporating remote machine-assisted labs with intelligent robotics and augmented reality. Knowledge of using additive manufacturing tools and integrated A.I. will be integral in all educational fields to ensure self-sufficiency.

Acknowledgments. Author K. Tantawi acknowledges NSF Awards DUE #1801120 and DUE # 2000685. Authors M. Cossette, G. Kepner, and J. Ashcroft acknowledge NSF Award DUE #2000281.

Disclosures. The authors declare no conflicts of interest.

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Strategies to Increase Awareness, Recruitment, and Success in Community College Advanced Technical Education Programs

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Abstract: Community College Advanced Technological Education programs are prime sources for educating students for employment into the Skilled Technical Workforce, such as micro nanotechnology, biotechnology, and autonomous technologies. However, community college technical education programs struggle to make students aware of program availability, recruitment, and graduate students into the workforce. Recruitment and retention are fundamental to any workforce pipeline. Therefore, programs in biotechnology, nanotechnology, advanced manufacturing, autonomous technologies, and other Skilled Technical Workforce certificate and associate degree programs must increase awareness and recruitment strategies or continue with low enrollment and eventual discontinuation of programs. Strategies used to increase awareness of technical education programs to the public, community college students, administrators, and industry partners will be described in this manuscript.

Keywords: Recruitment, Success, Program Completion

Introduction

It is expected that 3.4 million skilled technical jobs will need to be filled by 2022 [1]. Many of these jobs are filled through community college technical workforce programs, which recruit and prepare students with the knowledge, skills, and abilities vital for successful employment in these advanced technological industries. The National Science Board (NSB) therefore recommended the following to increase Skilled Technical Workforce (STW) opportunities [2].

1. **"Change the Message"**: The NSB, National Science Foundation (NSF), and national leadership in science and engineering will communicate the importance of the STW and raise awareness of STW careers and educational pathways to parents, educators, and students. The keys to increasing awareness among education stakeholders are to demonstrate how crucial the STW is to science and industry, advertise the multiple educational pathways into today's knowledge-and-technology-intensive world and publicize the variety of career opportunities within the STW.
2. **"Focus on the Data"**: NSF will promote partnerships among industry/academic stakeholders within STW training institutions to collect, share, and analyze data leading to the development of STW education practices.
3. **"Leverage the Portfolios of Federal Investments"**: The NSF will analyze its STW investments across education, research, infrastructure, data collection, and analysis to determine optimal strategies to build awareness of funding opportunities and leverage these investments to maximize impact.

4. **“Build Partnerships”**: NSF will foster a community of partnership among K-12, two-year colleges, four-year universities, workforce development programs, and industry leaders to grow an STW program tailored to the needs of local communities.

These NSB recommendations are ideal to be implemented in community college technical education programs. However, current recruitment and success in many technical education disciplines, such as micro nanotechnology, biotechnology, advanced manufacturing, and autonomous technologies, among others, has three major challenges:

1. The overemphasis and recruitment of four-year research university baccalaureate and doctorate students into STEM Skilled Technical Workforce positions.
2. The low enrollment and understanding of students to opportunities provided through community college technical education programs.
3. General awareness and connection with new and emerging technologies.

One example that demonstrates these challenges was displayed at community meetings with Biotechnology Program Department Chairs and faculty at community colleges. The number one challenge for the Biotechnology programs was recruiting students [3]. The consensus was that community college workforce programs, such as Biotechnology, suffer from the wrong brand identity. Parents, even many parents who work at the community college, do not support their children attending a community college to gain a well-paying job. The idea that a person would need to attend a baccalaureate-granting university to gain a well-paying job is challenging, especially in fields where industry also feels they should hire students from universities granting higher degrees. Biotechnology is one of these industries. So, community colleges have developed biotechnology certificates for post baccalaureates and now are starting to offer four-year biotechnology degrees. But there is a place for the biotechnology associate’s or technical certificate degree in industry and therefore for the student who earns this degree. In fact, a study done by Genentech showed increased persistence of community college students in entry-level technician jobs compared to four-year students [3]. Students in the Genentech study from technical education programs were more likely to stay in their jobs longer than four-year university students. It is essential to match the student with the job to ensure expectations both on the student and the employer sides are properly matched to retain the workforce.

In addition, emerging or breakthrough technologies often disrupt a defined degree pathway to a career. The Massachusetts Institute of Technology recently defined emerging or breakthrough technologies as “a technology, or perhaps even a collection of technologies, that will have a profound effect on our lives” [4]. Autonomous Technologies are proving to be precisely that. According to the Rocky Mountain Institute, the rise of automated mobility services could be one of the most interesting and complex disruptions of the modern era [5]. The personal mobility market is a $1 trillion market, with 41% of users indicating that they would use autonomous vehicles. The managing director of one of Silicon Valley’s leading venture capital firms sees it like this:

> *“The PC revolution gave us major computer manufacturers, big disk drives, and memory companies. So with the internet companies like Google, and already from mobile phones, we have seen breakout successes from a new breed of mobile-focused companies. Expect the same from the transportation revolution. Somewhere out there, in garages and dorm rooms, entrepreneurs are beginning work on the company that will do for autonomous vehicles what companies like Intel did for PC processing, what companies like AT&T did for mobile phone networks, and what companies like Norton and McAfee did for PC security”* [4].

The PC revolution created new occupations and demanded skills unheard of even 15 years ago. Think app developer, podcast producer, cloud architect, and social media manager, to name a few. In just that way, Autonomous Technologies are innovative, transformative, and need skilled technicians for job titles that are just being created and those that do not yet exist. Advancing technician education in all the different careers that the ubiquity of autonomous technologies will create is rapidly evolving and critical to maintaining the role of the United States as a competitive global leader in this fast-moving field.

Technical education educators within the Advanced Technological Education (ATE) program must identify strategies to increase awareness, recruitment, and completion of technical education programs. In addition, partnerships must be built with industry to provide graduating technical education students placement in industry jobs.

Strategies to Increase Awareness

Recently, Pasadena City College surveyed 645 community college students enrolled in lower-division chemistry courses to determine awareness and interest in technical education as an academic and career choice. Over 94% of students selected transfer as one possible outcome compared to 41% who aim to earn an Associate's Degree and only 11% who desire to obtain a Certificate of Achievement or Occupational Certificate (Figure 1). The overall transfer rate for California Community Colleges is less than 10%. There is an obnoxious disconnect between the expectations and availability of opportunities for STEM students at community colleges to transfer to baccalaureate-granting institutions. Many Associate's Degrees earned at Pasadena City College are Associate's to Transfer degrees, not necessarily degrees used to apply for employment in the STW. Students must be made aware of the limited transfer options and guided to more available technical education degree programs that can lead to employment directly from community colleges.

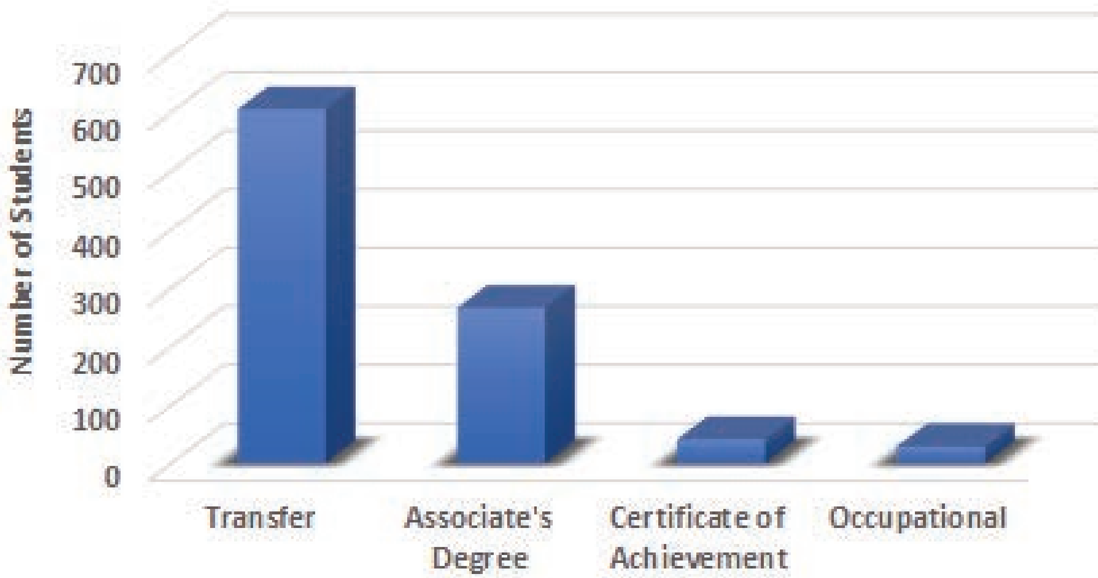

Fig. 1. Outcomes Students Have Considered at Pasadena City College

Pasadena City College has 141 Associate Degrees and 99 Certificate of Achievement Degree programs. Certificates of Achievement include Biotechnology, Laser Technology, Geotech, and Computer Information Systems. A total of 155 students had considered earning a degree in one of these programs (24%), with the majority 107 indicating that biotechnology was a degree pathway of interest (Figure 2). Over the last 20 years, biotechnology has developed into a robust technical education program with opportunities across the country. It is vital that additional technical education programs develop sustainable models like biotechnology to build a foundation of advanced technological education degrees that can increase degree and employment opportunities.

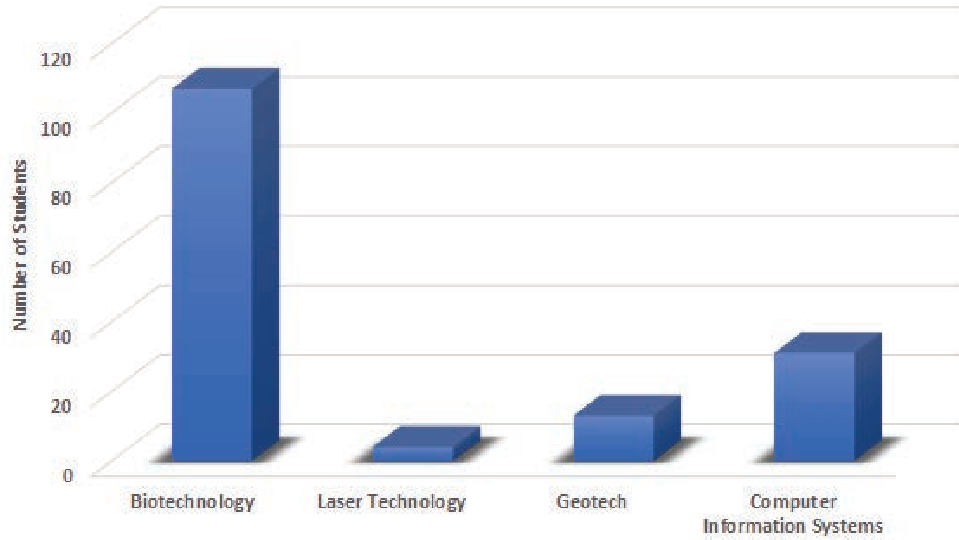

Fig. 2. Technical education pathways that community college students are interested in at Pasadena City College

Surveys conducted by the supplemental instruction program in chemistry asked students if they were aware of any other technical education pathways at community colleges that lead to STW jobs. Out of 620 students, only 33, or just over 5%, were aware of different technical education programs. However, in a follow-up question, if students would be interested in a Nanotechnology degree program at community college, 223 or 35% said they would be interested. The challenge is not the interest students have in advanced technological education programs. Instead, students are not aware that these programs exist.

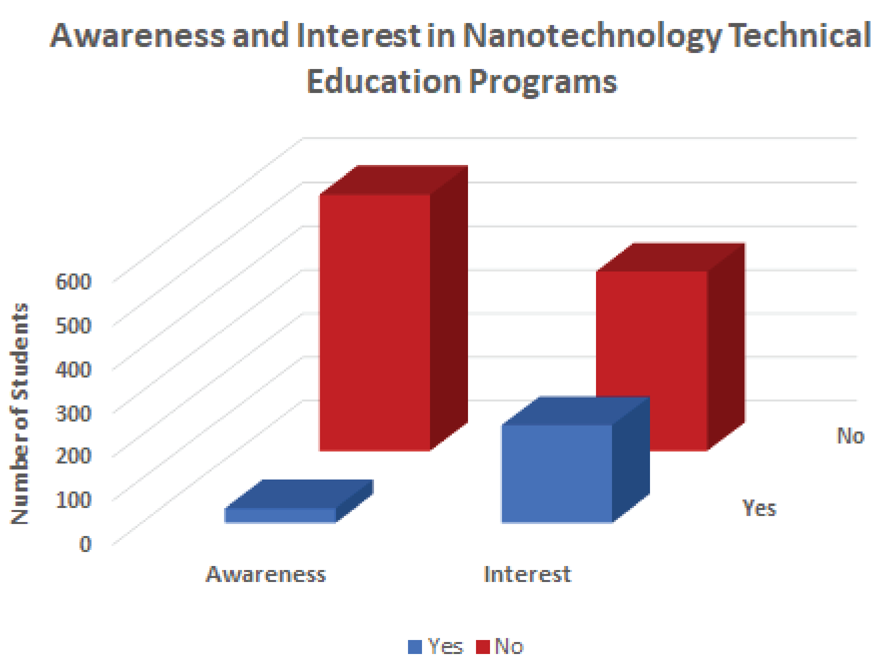

Fig. 3. Awareness and interest in a Nanotechnology technical education program at Pasadena City College

The advanced technological community should focus on creating outreach and dissemination programs tailored to increase awareness of community college students into certificate and associate's degrees that lead to jobs. Three focus areas on increasing awareness can be:

- **Better use of Social Media:** Work with social media experts to create content on social media platforms students currently use, such as Tik Tok, not on platforms such as Facebook that students do not commonly use at community college.
- **Increase buy-in from the administration:** Work with community college administrations to create programs and recruit newly hired faculty to organize and lead technical education programs at community colleges. Focused professional development on these new faculty, who are are more likely to implement the strategies shared at professional development workshops.
- **Increase engagement from industry:** Develop Business and Industry Leadership Teams to provide industry a strong voice in determining optimal pedagogy and share the future trends needed to be taught by technical education programs.

An additional NSF ATE program in autonomous technologies, the National Center for Autonomous Technologies, was launched in 2019. In the second year of operation, NCAT's primary focus on outreach has strengthened communities, promoted engagement, and created partnerships with educators, industry, and government agencies. Over a year, NCAT delivered 45 events, engaging more than 5,200 individuals through in-person and virtual workshops, presentations, webinars, and STEM events. The events ranged from workshops, webinars, presentations, and conferences, to STEM/AT specific events and numerous professional development experiences. In addition, through targeted social media outreach, NCAT had over 300,000 interactions, drawing more than 15,000 users to the robust library of education resources on NCAT's website.

Success in using social media as a means of communication and outreach is expanding to reach a more diverse audience. Social media channels (LinkedIn, Twitter, Instagram, and YouTube) offer a way to build relationships and connect with the AT community, increasing visibility and credibility by sharing expertise and thought-leadership in autonomous technologies technical education. In addition, the use of social media as a connection, collaboration, and engagement tool expand beyond the physical classroom or office. It allows a platform to create a better public understanding of the emerging technology.

NCAT has also partnered with government organizations such as the Federal Aviation Administration (FAA) to bring together communities of educators with certificate and degree programs in unmanned aircraft systems technology. NCAT has taken a significant leadership role in the FAA Unmanned Aircraft Systems Collegiate Training Initiative (UAS-CTI). Since 2020 this initiative has had a significant coast-to-coast impact, reaching more than 84 member organizations across 39 states. Most of the organizations are community colleges. The UAS-CTI mission is to collaborate with selected colleges and other organizations to deliver up-to-date UAS training tools, resources, and guidelines to prepare students for UAS careers. As the designated repository and resource hub for the UAS-CTI community, NCAT provides access to its extensive collection of interactive educational content, curriculum, workshops, presentations, and other resources. The website has become a forum for exchanging ideas and launching new initiatives. This type of relationship with the FAA is a model for how academia and government organizations can work together to create resilient partnerships that prepare the nation's workforce for the future.

Forming a collaborative environment that includes industry leaders, technical education community college faculty, community college administrators, and current and former technical education students will provide the best chance to increase awareness in community college technical education programs.

Strategies to Increase Recruitment

Community college STEM programs have typically focused on transfer over earning a degree that leads to employment. The minimization of certificate degrees vested by industry, leading to Skilled Technical Workforce jobs, is a disservice to students. This trend is especially true since the number of transfer opportunities for community college students is limited. Focus on recruiting students into Associate or Certificate degree programs that lead straight to employment would benefit an abundance of students when completed at community college. To increase the recruitment of students into these degree pathways industry needs to provide mechanisms to support the learning of technical education students. Industry can get actively involved in recruitment through:

- Partnering with technical education programs through Business Industry Leadership Teams where industry assists in curriculum guidance to improve technical education curriculum to current trends in industry will make programs more engaging and lead to current jobs within the technical education community. It is essential in the recruitment phase to provide possible outcomes from technical education programs.
- Recruit students through course-based undergraduate research experiences (CUREs) embedded within the introductory STEM courses at the start of a student's STEM academic pursuit. Use CURE's within the course to introduce students to technical education pathways and outcomes available through this path.
- Utilize informal supplemental instruction sessions to expose students to everyday life applications of Nanotechnology, Biotechnology, Autonomous Technology, and more and the availability of the related technical education programs.
- Highlight technical education as an attractive path through "Careers in STEM" summits and series, which can be provided through campus affiliations, such as clubs, Veteran's resource centers, or campus organizations like the Mathematics, Engineering, Science Achievement Program (MESA).
- Utilize social media in outreach and organize a website that shows each technical education program, discipline, and campus across the United States.
- Provide faculty-mentored undergraduate research experiences and industry apprenticeships that provide advanced experiences in preparation for employment into the STW.
- Have program alumni participate in speed networking sessions with potential students to share their job experiences with potential candidates. Students listen to previous students (now alumni and on the job) because they identify with them.

Recruiting students into careers rapidly impacted by technology can create challenges in defining a clear path. In some cases, the technology, industry application, and career titles move so quickly that educational programs lag in catching up. NCAT views extracurricular activities such as student competitions as a way to engage students in thinking about a variety of tracks that support developing the 21st-century workplace skills desired by industry partners. For example, the MATE ROV Competition challenges students worldwide to engineer Remotely Operated Vehicles (ROV) to complete a set of mission tasks based on real-world workplace scenarios. Students transform their teams into start-up companies that, in addition to their robots, prepare technical reports, create marketing displays, and deliver engineering presentations.

A 2020 report [6] discusses the competition's impact on developing skills critical to the future of work. Eighty-nine percent (89%) of the alumni credited the ROV competition with having at least a little influence on their educational or career path. Roughly one-third (34%) indicated that the competition influenced them to a great extent, and 38% marked that the competition influenced them somewhat. Students engaged in competitions learn skills, explore technology applications, and see the landscape of career opportunities, which can help inform their educational pathways.

Strategies to Increase Completion

The last component of a successful technical education program is student completion. According to the American Association of Community Colleges Voluntary Framework of Accountability, only 59% of community college students successfully complete an outcome in six years. More worrisome is using the Integrated Postsecondary Education Data System measure only 25% of community college students have a successful outcome within three years of beginning their academic journey. Technical education degrees provide a less time-consuming opportunity to earn a satisfactory outcome within two years of enrollment. The majority of technical education programs can be completed within two years. More importantly, programs can develop class strategies and program opportunities to increase successful completion.

Technical education programs can increase success and completion by implementing active learning strategies within program design. For example, course-based undergraduate research experiences and industry-derived projects have been shown to increase success by providing students with in-class research projects focusing on critical thinking, communication, and teamwork skills. These skills are beneficial to the technical education jobs students pursue and provide opportunities to develop essential STW knowledge, skills, and abilities. In addition, partnering with industry and research universities to provide paid internships or apprenticeships will foster greater engagement with industry and begin networking within technical education industries. These two components will significantly increase success and completion among technical education pathway students.

Discussion and Conclusion

Technical education programs provide excellent opportunities to community college students to earn a degree and directly enter the workforce. Obviously, this message is not being heard as many programs, especially micro nanotechnology, biotechnology, and autonomous technologies, suffer from low enrollment and are often discontinued. Therefore, the message concerning what community college technical workforce programs can provide needs to be changed. Approaches to change this message are as follows: (1) Provide students with direct examples and role models of individuals working in the field from various backgrounds to strengthen their scientific identity and shift stereotypes around who works in science for community college students [7]. (2) Produce outreach materials, such as the *Talking Technicians* podcast, to provide stories from working technicians to share with community college students interested in obtaining a technical education degree. (3) Establish an alumni network for the purpose of setting up speed networking events where alumni talk with potential or existing students sharing their experiences. Most importantly, partner with industry leaders in creating recruitment strategies and developing an engaging curriculum that focuses on the current needs of industry.

The message needs to be based on data. Programs, industries, and others need to collect data to demonstrate the effectiveness of these workforce programs. One example of a data-driven organization is based on a Pew Research Center saying that social media is an effective tool for raising awareness and creating sustained movements [8]. Utilizing data, outreach, and decimation strategies can be planned and implemented through partnerships among NSF ATE Centers and programs. Leverage the federal portfolio and build partnerships with other federally funded initiatives that intersect with the ATE portfolio, such as the Manufacturing Institutes. For example, InnovATEBIO partners with both BioMADE and NIIMBL manufacturing institutes to help spread the message that community college biotechnology workforce programs are doing an excellent job of producing the technicians needed by industry. Finally, building partnerships with industry, policymakers, and others are also the way to change the message. Community College technical education programs cannot be the choir for their success. Industry partners outside of the community college arena need to promote us. Community College technical education programs cannot only rely on promoting themselves.

It is imperative that technical education programs actively recruit and support community college technical education students. Industries need workers, students need jobs, and advanced technical education can provide the support and opportunities to satisfy both.

Acknowledgments. This material is based in part upon work supported by the NSF (DUE 1902574, 2000281, and 1901984). Any opinions, findings, and conclusions or recommendations expressed in this material are those of the author(s) and do not necessarily reflect the views of the NSF.

Disclosures. The authors declare no conflicts of interest.

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Considerations for Unmanned Aircraft Systems Maintenance and Reliability

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Abstract: The proliferation of unmanned aircraft systems has introduced exciting new ways to conduct aviation operations. Much focus has been dedicated to best practices, mitigating human factors, and human-to-machine interface considerations while the aircraft is in one of the phases of flight. Far fewer resources have been dedicated to those topics regarding the maintenance of these systems. Unmanned aircraft systems have some unique challenges associated with their maintenance that must be accounted for and mitigated. On top of the challenges related to introducing personnel to new concepts and skills, we are also introducing new and very different equipment to our maintenance personnel while removing haptic and audio cues typically used to narrow system faults. Additional thought and foresight must be put into the engineering, specifically how maintenance personnel interact with these systems. Properly designed systems will lead to an improvement in system readiness and operational safety.

Keywords: unmanned, maintenance, training, aviation

1. Introduction

Human factors play an essential role in all aviation disciplines but may affect unmanned aircraft (UA) personnel much more significantly than traditional manned aviation. The top three issues with unmanned system operations, that I chose to focus on, are the pace of changing technology, exacerbated imprecise fault symptoms from pilots, and a lack of engineering with maintenance in mind.

Anyone in the unmanned aircraft systems industry knows quite well that the technology is changing at an accelerated pace and has been for the last 20 plus years. While this is inherently a good thing, it also leaves gaps that must be filled to continue to conduct safe operations within the National Airspace System (NAS). While pilot training is continuously stressed, maintenance training does not always garner the same attention. Aviation maintenance personnel are a specific group that comes out of regulatory mandated training well behind the industry [1]. The Federal Aviation Administration regulates aviation maintenance training through 14 CFR Part 147. The topic areas and knowledge, skills, and abilities spelled out within Part 147 were last given a complete update nearly 50 years ago. The required curriculum still teaches component-level troubleshooting and does not address technology that has been ubiquitous for some time now. While there is an industry-led push to adopt new standards put together by the Aviation Technician Education Council (ATEC), the Mechanic Airman Certification Standard (ACS) has yet to be adopted. This new certification standard would allow wider latitude in training by Part 147 organizations, ensuring that students are trained to the standard that we have come to know and allow for the curriculum to shift to mirror current industry practices more closely. It will also help usher in a Competency-Based Education model (CBE) as hour requirements and static curriculum will be removed from the regulation.

Another problem that many in the maintenance world joke about is imprecise symptoms from pilots. An imprecise symptom is a symptom that is not well defined, for instance, "radio inoperative" or "funny sound coming from beneath the seat. "These maintenance write-ups leave room for interpretation or do not clarify the problem. Imprecise symptoms lead to prolonged maintenance actions, as the maintainer struggles to reproduce and fully define the problem. This can lead to aircraft being released for operations with the fault still in place, as a maintainer may find a problem and assume that the problem encountered was the same one that the pilot was referring to.

Finally, we will discuss the need for engineering to happen in close cooperation with maintenance personnel. Engineers typically work within tight budgets and requirements. Meeting some of those requirements sometimes means that maintenance on those products can be challenging. Maintainability tends to be considered, in a passing manner, during later stages of the manufacturing cycle. This can lead to unnecessary costs and missed faults.

2. Discussion

2.1 Keeping Up

Human error accounts for more than 50 percent of aviation accidents, with most of those incidents occurring in the early morning or evening hours during the start of a shift. Of that, nearly 12 percent cite maintenance as a factor and 50 percent of engine-related delays [2]. Human factors in maintenance are of growing interest [3] to the aviation community. Maintainers are more likely to commit a skill-based error in the early morning hours [4]. Unfortunately, newer concepts for operations are ensuring aircraft routing through the day to allow for maintenance at night [5]. From 1994 to 2004, maintenance factors were cited as a contributing factor to 42 percent of fatal airline accidents within the United States [6]. While awareness of the crucial role maintenance plays in keeping aircraft safely operating is expanding, training still lags. Maintenance personnel, straight out of their initial training, must be upskilled before becoming productive members of an aviation maintenance team. While there is some precedent, maintenance technicians are sometimes required to get system-specific training. This training has increased because technicians are missing foundational concepts that must be taught before the system-specific training even begins. This is where the introduction of the new 14 CFR Part 147 standard will come into play. The foreword of the Proposed Mechanic Airmen Certification Standard describes the Federal Aviation Administration's view of the ACS:

> *"The FAA views the ACS as the foundation of its transition to a more integrated and systematic approach to airman certification. The ACS is part of the Safety Management System (SMS) framework that the FAA uses to mitigate risks associated with airman certification training and testing. Specifically, the ACS, associated guidance, and test question components of the airman certification system are constructed around the four functional components of an SMS."*
>
> **-Mechanic Airmen Certification Standards, Foreword [7]**

The new Part 147 will reference the Mechanic Airmen Certification standard [8]. This is a consensus standard document that can be a living document that changes in a way that does not necessitate Federal Aviation Administration (FAA) level action. While the FAA has a core mission of safety and is a great organization, large government regulatory bodies have always been slow to move and adapt. In addition, the pace of technological advancement in the last 30 years has increased, particularly in the previous ten years, leaving the regulatory language woefully behind the curve.

Further changes may be coming to how we train unmanned aircraft maintenance technicians. ASTM's F46 Aerospace Personnel Committee is working on a consensus standard to outline a pathway for unmanned aircraft technician training (expected Q1 2022). This will help standardize training for maintenance personnel working on unmanned aircraft systems. This will be an international standard that can easily be adapted to whichever regulatory agency has jurisdiction based on one's location. As more UAS and their manufacturers go through the type certification process, this standard will help them develop a qualified maintenance team.

By using the ACS [7] and the pending UAS Maintenance Technician standard, educational organizations, manufacturers, and repair stations will benefit by producing high quality and keeping up with the rapid changes we have seen in aviation technology.

2.2 Imprecise Symptoms

There are many running jokes in the aviation maintenance field. Most of them center around the descriptions by pilots of the faults they see within their aircraft during operations. Here are a few examples:

Pilot: Aircraft handles funny.

Maintainer: Aircraft warned to straighten up, fly right, and be serious.

Pilot: Target radar hums.

Maintainer: Reprogrammed target radar with lyrics

Pilot: Something loose in cockpit.


PLANE OF
ROTATION

While these write-ups are, in my opinion, hilarious, they tend to be funny because they contain a grain of truth. Pilots are not being properly trained on how to write up faults or oddities within the aircraft or understand the fundamental interconnectivity of their systems, allowing for more thorough write-ups for the associated maintenance personnel. This gets further exacerbated as we look at unmanned aircraft. Many faults on manned aircraft are something heard or felt by the pilot that was different than the last time they flew a specific aircraft. This lack of auditory and haptic cues limits the pilot's ability to understand what is happening in their aircraft [10].

Engine malfunctions are one example where sensory information plays a significant part. Visually, they may see the propellor stop spinning or slow down. At the same time, auditory cues tell the pilot that the sound has decreased or even stopped altogether [11]. Haptic feedback may come in the form of a reduction in vibration [12]. Unfortunately, these cues are denied to the pilot when flying from a control station on the ground.

Flight surface fluttering, landing gear movement, sudden changes in the cockpit smell, all these things provide signals to the pilot, sometimes even before the installed warning systems register the change and sound an alarm. Unfortunately, the effects of this run downhill to the maintainers responsible for keeping the unmanned aircraft system in a condition for safe operation.

This further complicates the maintainer's work, as the reported symptoms do not include any of the additional sensory input from the pilots. Coupled with the incidents of imprecise symptom reporting, this could lead to further failures during flight or additional time and resources to isolate and repair faults.

2.3 Engineering for Maintenance

During my career in the UAS industry, I have seen many examples of great ideas that are implemented that restrict maintenance or make it much harder for them to do their job. For instance, small access holes make getting your hand into or out difficult. Add in the need to clutch an object within that hole and the maintainer's hand is more difficult to remove from the hole, or the tools cannot be used in a way that allows for visibility of the component being adjusted, installed, or removed.

While this type of thing may seem trivial, the increased cost of man-hours will be exacerbated over the product's lifecycle. Maintenance is typically 10 to 20 percent of an aircraft's overall operating costs [13], so designing for maintainability can save a significant sum of money during the operational life of an aircraft. For example, a Boeing 787-8 has an hourly operating cost of nearly $10,200. At 10 to 20 percent, this means maintenance costs range from $1,024 to $2,040 per hour of operation [14]. This is more than $100,000 per 100 flight hours. If the initial design could reduce maintenance costs by 10 percent, this would be $10,000 savings over 100 flight hours. Typical aircraft may see more than 450 hours of operation through a year, making a potential savings of over $45,000 per year, per aircraft, a significant sum. Structures and systems should be built in a way that places critical items in a position to be rapidly accessible and easily replaceable [15]. Systems should have redundancy for essential parts. Built structures should allow for proper inspection, both inside and out.

Further consideration should be taken with access doors to compartments, making a single larger access door that easily opens and seals closed and placing it in a position that allows the best range of access. In addition, flanges or grommets should be built around the door to help with sealing and to minimize injury to maintenance personnel as they reach in and remove their hands and arms.

Routed cables and lines should allow for inspection and replacement of not just the connectors, but the cable lines themselves. Maintenance loops should be utilized for all installations. When a connector or wire termination fails, there should be enough slack left in the cable to provide the maintainer with enough cable to replace the connector and still provide slack for proper movement.

Test points should be provided [15], allowing measurements near the door rather than on the equipment itself. Wherever possible, automated, internal testing should be built into individual components, and this testing should also be able to isolate faults to specific components. Design products with the entire lifecycle in mind, and personnel from multiple departments, including maintenance, should be consulted early and often in the design phase of a project.

3. Conclusion

Adopting the new Mechanic Airmen Certification Standard [7] will go a long way towards bringing maintenance requirements up to date. Industry groups would influence the subject matter to keep it relevant and updated. Still, the Federal Aviation Administration will have to adopt the standards and a new bank of questions that reflect the norm. Keeping the exam questions and the practical, hands-on exams up to date may be a bit of a challenge. Still, even if they were updated every five years, it would be a significant improvement as the current regulations have not seen an important update in a much longer period. Hands-on examinations will likely be the biggest challenge where new technology is concerned. New technology, particularly in the aviation industry, tends to be expensive to acquire and maintain. A significant buy-in from the aviation community will be necessary to provide equipment to partner schools and training organizations to keep them relevant. The theory is relatively cheap and easy to teach. Practical applications require equipment and enough of it so that every student can train on the equipment.

Manufacturers and maintenance organizations will have to step up and provide this to have a workforce for the future of their business. The good news for them is that by partnering with a state school, their donations can be a write-off on their taxes, allowing them to recoup some of the associated costs.

Imprecise symptoms from pilots can be partially improved by incorporating more systems training on their aircraft. A pilot should not only understand how to use a piece of equipment in their aircraft, but they should also have a good sense of how that equipment works and how the systems work together. If the pilot better understood how the DME functioned and how their aircraft receives and processes the signal, they would be able to explain better what the system is doing or not doing. This will reduce maintenance costs as maintainers will have to spend less time trying to recreate an error on the ground to troubleshoot it. They may also have a better idea of what type of tools they may need before getting to the aircraft in question. Again, this will not likely save a lot of time on each job, but if each job can be completed one minute faster by each maintainer, a shop with 30 mechanics could see a significant change in throughput.

Finally, all aviation design teams should either have a qualified maintainer or at least have a skilled maintenance person to consult on the project during critical phases of the design process. This has the potential to reduce the number of times a concept must be refined before producing it. It would also lead to better, more accurate, and more easily accomplished maintenance tasks. All of which can show significant savings to an organization. Designing for maintenance has been shown to significantly reduce the time spent maintaining the airworthiness of an aircraft. This, in turn, leads to less downtime, sitting in the shop, and more time producing revenue for the organization.

Acknowledgments. The author acknowledges NSF Award DUE 1902574.

Disclosures. The author declares no conflicts of interest.

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Micro Nano Technology Education Center (MNT-EC)

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Abstract: The Micro Nano Technology Education Center is a community college led National Science Foundation Advanced Technological Education Center founded on the idea that by working together to evolve and improve community college micro and nanotechnology technical education programs, we will enhance the quality of education for MNT students who then become higher quality technicians for the MNT industry and skilled technical workforce.

Keywords: Micro Nano Technology

1. Introduction

Micro and Nanotechnologies have been around for thousands of years. For example, the ancient Egyptians used nano-based silica (sand) in their paints and coatings to get a sheen that has lasted to this very day. Stained glass in the south rose window of Notre Dame Cathedral is infused with gold nanoparticles, giving the glass its vibrant color. Although the recipes have been lost over time, the glass crafters of their time knew that if they manipulated certain metals that they could produce beautiful colors. Analysis of these materials from the past, show that nanomaterials have always been prevalent in society and led to modern bottom up fabrication and synthesis techniques to develop new properties of materials. These discoveries have led to advancements in medicine, materials engineering, optics and photonics and a myriad of other areas and provide a framework of modern-day nanotechnology knowledge and applications.

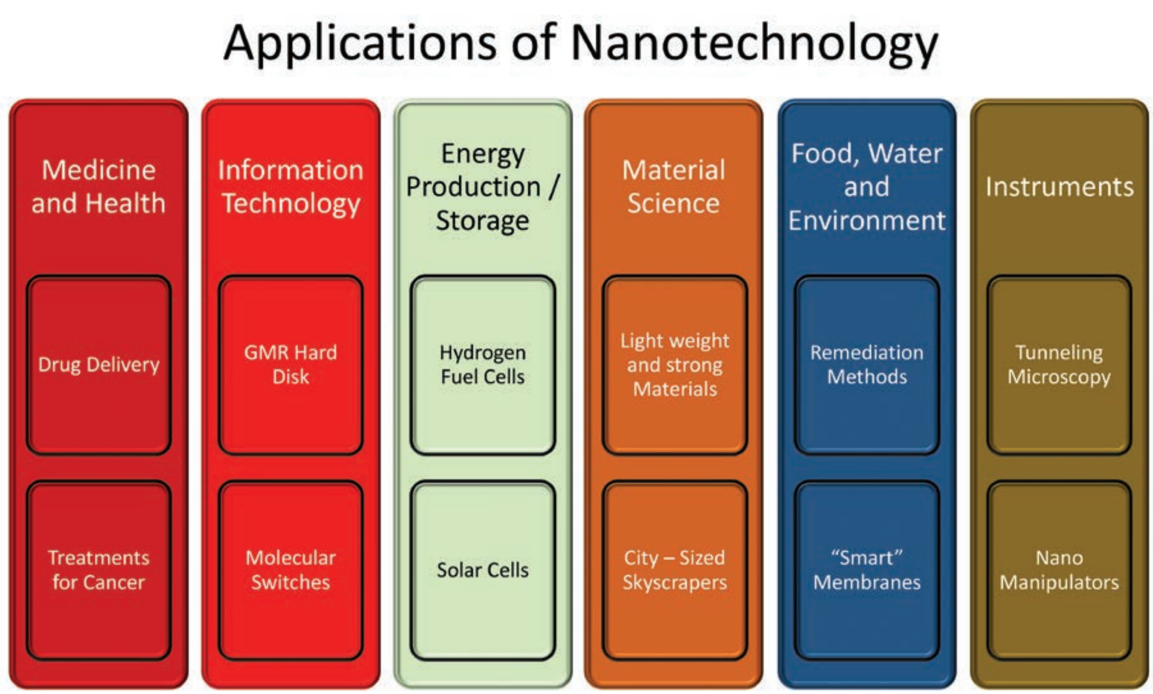

Fig. 1. Applications of Nanotechnology

Micro and Nanotechnology is an advanced technology field specifically identified by the National Science Foundation Advanced Technological Education (NSF-ATE) program as one of the key fields that drives our nation's economy. Micro and Nanotechnology are rapidly developing fields that have revolutionized important technologies in medicine, electronics, biomaterials, nanomaterials, integrated photonics, and semiconductor manufacturing. Micro and Nanotechnologists and technicians work in a wide range of industries such as medicine, engineering, photonics, food science, aerospace, defense, materials science, energy, advanced manufacturing and more.

The Micro Nano Technology Education Center (MNT-EC) was conceptualized in 2019 by educators, who specialize in micro and nano education, and was awarded a grant by the NSF ATE program in 2020. The MNT-EC was founded on the idea that working together to accomplish a greater goal enhances the quality of education for students so they may become higher quality technicians. The MNT-EC has four primary objectives including: 1) Developing a coordinated national approach to advance Micro Nano Education (MNT) education; 2) Delivering professional development to enhance knowledge, skills, and abilities; 3) Conducting strategic outreach, recruitment, and retention of traditional and underrepresented faculty/students; and 4) Creating a deep Industry/Education Alliance that supports student success.

In 2020, the MNT-EC began working with the Micro Nano Technology education Special Interest Group (MNTeSIG) to bring together MNT faculty, industry, and the general public with the goal of getting a cohesive, dedicated community of individuals, business leaders and higher education facilities together to work on a common goal. That goal is to advance micro and nano education through community college led technician education. As part of the mission, the MNT-EC works collaboratively with MNT industry partners through the formation of a Business Industry Leadership Team (BILT), a model developed by the National Convergence Technology Center, that asks active industry engagement in the creation of knowledge, skills, and abilities to be taught in MNT technical education programs. MNT-EC has worked with industry to structure a comprehensive BILT team of members who understand current MNT industry needs across the nation and can assist in guiding curriculum development to match future technology and education advancements. The BILT will allow industry representatives to shape the future of MNT technical training and secure access to the pipeline of highly skilled technicians from community colleges across the country. It will also connect industry directly with educators who are working in MNT technician education. The BILT team is responsible for advocating for the industry needs that will elevate the effectiveness and sustainability of MNT education programs and will work hand-in-hand with members of the MNT-EC to build the vision for the future of MNT education together.

The MNT-EC focuses on educator professional development opportunities in order to grow community college MNT programs and increase the number of community college faculty leading these programs. Professional development covers the wide array of categories included in MNT education, such as micro health and safety, photonics, vacuum technology systems, imaging and characterization, and ancillary topics, such as increasing diversity and equity in MNT. Professional development and outreach are a vital part of creating the cohesive community needed to advance micro and nano technical education.

Partnerships are a vital component within the MNT-EC. Partnerships include other NSF ATE projects and resource centers, educational institutions, nano related organizations, professional associations, and nano related industries.

InnovATEBIO National Biotechnology Education Center

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Abstract: InnovATEBIO Education Center is a community college-led National Science Foundation Advanced Technological Education Center built on the network of the previous national center Bio-Link, to increase industry collaboration, bringing visibility for the 169 currently existing 2-year biotechnology programs, documentation, and meeting emerging workforce technology trends. InnovATEBIO fosters the high school to college workforce program pipeline, provides professional development for faculty, and mentors the Advanced Technological Education (ATE) Biotechnology Community. InnovATEBIO also builds partnerships with trade organizations and other workforce education programs such as the Manufacturing Institutes to produce a quality technician workforce for the biotechnology industry.

Keywords: biotechnology

1. Introduction

Biotechnology has been around since the beginning of civilization. Examples are ancient civilizations that used yeast and bacteria for making bread, alcoholic beverages, and vinegar, while in Central America, the Aztecs made cakes from blue-green algae. Modern industrial biotechnology started with Genentech. It was the first company to use a cloned enzyme in E. coli to produce a human protein, somatostatin, in 1977. The company went on to produce recombinant insulin, which transformed how diabetes was treated.

Modern biotechnology is defined as the "use of the biology to make products and other purposes to improve life. "Life is in the oceans, in the soil, beneath the soil surface, on and in organisms, in water, and in the air," all of which could be exploited by biotechnology. Examples are medical such as bacterial viruses or phages to kill pathogenic bacteria, recombinant drugs such as insulin or vaccines; bio-industrial for making enzymes used in detergents, biofuels; agriculture for making fertilizers, plants resistant to pests and disease; environmental such as cleaning up waste or hazardous materials, and food such as Kombucha, cheese, and alcohol beverages. It is now even being used to make plant-based foods such as Impossible burgers or fungi to make synthetic leathers.

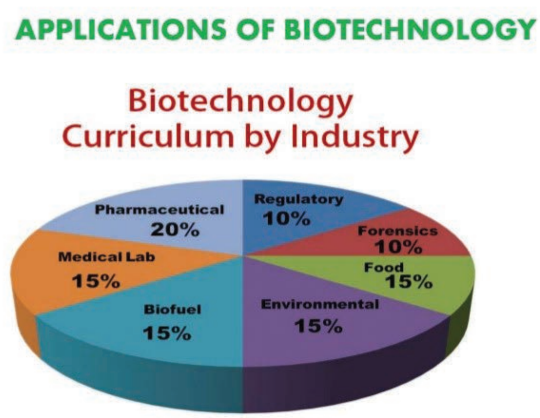

Fig. 1. Applications of Biotechnology [1]

Education Center: The InnovATEBIO National Center for Biotechnology Education. The Center is located at Austin Community College, Texas. Partnering organizations and institutions are Madison College, Wisconsin; Forsyth Technical Community College, North Carolina; DNA Learning Center, New York; Finger Lakes Community College, New York; Digital World Biology, Washington; and BABEC in California. InnovATEBIO is supported by a five-year ATE national center grant (NSF DUE 1901984). The InnovATEBIO National Biotechnology Education Center will address the need to educate highly skilled technicians for the nation's biotechnology workforce. Toward this goal, InnovATEBIO will provide leadership in biotechnology technician education, including support for developing and sharing best practices and emerging technologies in biotechnology workforce development.

Brief History: From 1998 to 2018, Bio-Link was the Next Generation National Advanced Technological Education (ATE) Center of Excellence for Biotechnology and Life Sciences, an NSF ATE grant.

InnovATEBIO will support the expansion of these resources. InnovATEBIO will continue to offer a platform to host the nation's Biotechnology Programs and Affiliate pages for its members, along with Courses in a Box and other content. Members will also continue to be able to provide content via blogs, conference presentations, publications, and event postings. In addition, members will be alerted to new content and community activities via the Center's newsletter, Facebook page, and LinkedIn site.

The InnovATEBIO community enhances biotechnology education programs by providing cutting edge professional development for instructors, by improving curriculum, by members making use of technologies, and by creating a system for sharing information among its targeted audiences of community college biotechnology programs, faculty, administrators, students, alumni, trade organizations, and industry.

Most importantly, InnovATEBIO continues to support a cadre of well-educated instructors to increase the number and quality of biotechnology education programs. InnovATEBIO helps introduce a wide range of underrepresented students to biotechnology by providing opportunities to acquire the knowledge and skills essential to the field and advance their education in math, science, and engineering.

Goals and related activities of the Center:

- **Develop a collaborative infrastructure that supports innovation and promptly addresses the needs of the biotechnology community.** Every Fall, the Center hosts a series of Community Meetings for Biotechnology Program faculty and their trade organization partners to discover their challenges and victories. For the past two years, the main challenge remains unchanged, low student enrollment and industry not being willing to hire 2-year students as technicians. Hubs focusing on emerging technology trends and concentrated expertise are being developed and implemented as part of the infrastructure to address the community's needs.
- **Develop a hub concept as an antidote to a traditional center.** Each Hub is a "go-to" place for specific expertise to create and support biotech programs in high schools and community colleges. Our decentralized infrastructure shares leadership among a unique team of biotechnology educators with a range of experience. We are a service organization ready to help the community with extensive resources.
- **Coordinate and leverage outputs from ATE-funded biotechnology projects identifying opportunities to generate partnerships and collaborations that accelerate innovation in biotechnology education.** Every Spring, the Center hosts a webinar for each funded ATE project. Annually, Jim Hewlett, Finger Lakes Community College, hosts a workshop for ATE projects who want to expand on the research generated by their project.

- **Here, we monitor and address emerging biotechnology industry and technician workforce trends.** In addition, the Center supports a National Advisory Industry Board composed of the industry leaders. Some of the topics discussed are how to convince the industry to hire 2-year students as technicians and the importance of DEI initiatives both at educational institutions and industry. The Center also helps to produce a National Workforce Report every two years with the Coalition of State Bioscience Associations (CSBI). As reported in 2021, the growth of the biotechnology industry continues to accelerate.
- **Develop a regional outreach and mentoring infrastructure to broadly engage underserved populations in biotech labs and emerging technologies.** The Center has hosted numerous workshops and webinars over the past 2-1/2 years. First, starting with a month-long series on online resources for high school teachers, progressing to a webinar series for college faculty, a concentrated series on biomanufacturing, and then this past Summer, on PCR technologies. A very popular one is the Leadership Institute which has teams of faculty working on real-world, industry-based product development. This series lasted several months and is ending with a face-to-face meeting in North Carolina at the end of May 2022.

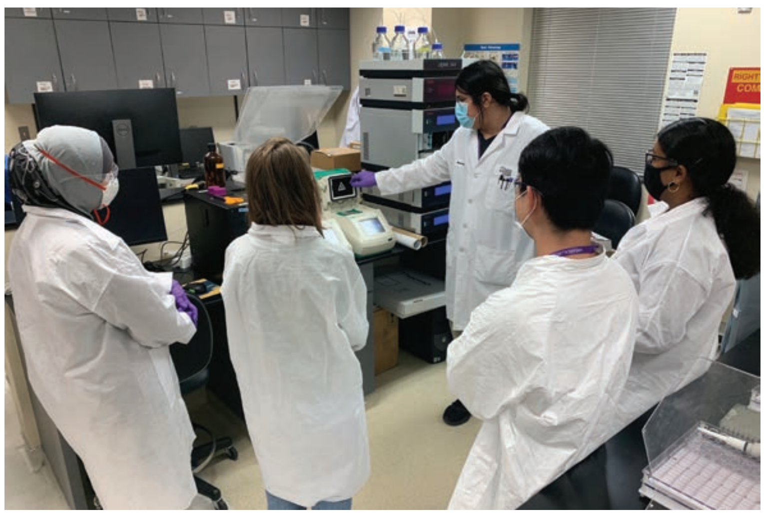

Fig. 2. Student technicians learning the functions of thermocycler equipment for PCR

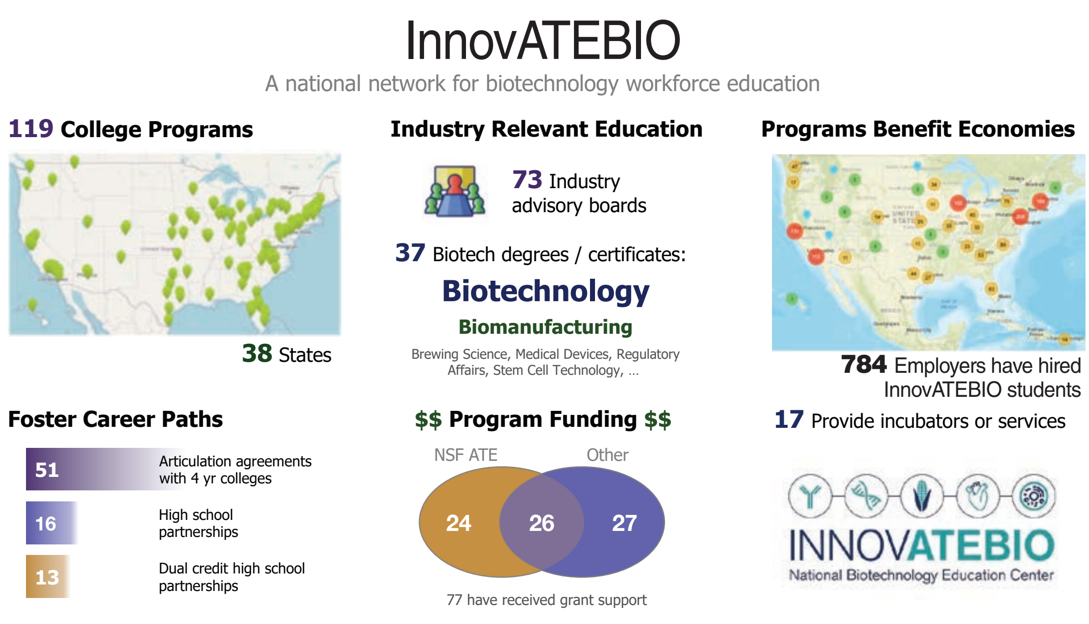

Fig. 3. Fast Facts about InnovATEBIO [2]


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2. The Future

Future activities are defined by the needs of biotechnology programs, students, faculty, industry, and trade organizations. Based on community feedback, the number one challenge continues to be STUDENT RECRUITMENT. This challenge indirectly matches the number one recommendation made by the Science Board Report, "The Skilled Technical Workforce," which is "change the message." What needs to happen is a change in the message about community college biotechnology workforce programs. The public needs to learn that these programs prepare students for employment in high-tech jobs with excellent salaries.

Also, this means the industry needs to advertise technician jobs that require 2-year degrees, not 4-year degrees. Industry needs to recognize the value of skill mastery, not just a degree. A degree alone does not mean a graduate is ready for work. The degree needs to come with documentation showing what "performance outcomes" the graduate has mastered.

Another concern of the community is professional development and support for faculty. InnovATEBIO will continue to provide virtual and face-to-face professional development that reflects the changes in technology and how to gain support from their administration and local industry.

The answers to the questions "what is biotechnology?" and "what careers in biotechnology need to be readily available to students, parents, and the public. The public has known what a nurse does since Florence Nightingale in 1860, but the majority still do not know what biotechnology is and what are the possible careers in this field.

References

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National Center for Autonomous Technologies (NCAT)

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Abstract: The National Center for Autonomous Technologies (NCAT) was formulated through the National Science Foundation's Advanced Technological Education (NSF ATE) program in 2019. As the first national ATE center in autonomous technologies, NCAT is crafting, adapting, and implementing educational resources to support K-12 educators, and two-year college faculty in numerous disciplines to meet workforce demands while increasing the quality and diversity of the highly skilled technical workforce.

Keywords: Autonomous Systems, Unmanned Aircraft Systems, Connected and Automated Vehicles, Remotely Operated Vehicles, Unmanned Underwater Vehicles

1. Introduction

NCAT's first mission is to foster public understanding of three autonomous technologies (ATs): unmanned aircraft systems (UASs), connected automated vehicles (CAVs), and unmanned underwater vehicles (UUVs). All three types of autonomous technologies require highly skilled, agile technicians who can design, monitor, utilize, repair, and control them. Explaining what autonomous technologies do and the career opportunities they generate are part of the center's effort to expand educational programs about these emerging technologies.

NCAT's foundation is to expand and grow autonomous technologies knowledge among secondary and post-secondary faculty, instructors, and administrators through mentorship and coordination of collaborations. By engaging one-on-one with K-12 and post-secondary educators, NCAT provides guidance and recommendations for setting up degrees in autonomous technologies through curriculum development support, access to resources, equipment selection based on program needs and budget, and identification of workforce requirements.

Fig. 1. Autonomous Technologies Students and Instructor


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NCAT leaders draw on their extensive experience developing replicable instructional models and utilize best practices to recruit underrepresented populations and support their entry to STEM careers. Through ongoing support and encouragement for STEM engagement through workshops, camps, and student competitions in autonomous technologies, NCAT works to remove barriers to underserved and underrepresented populations and provide access for all.

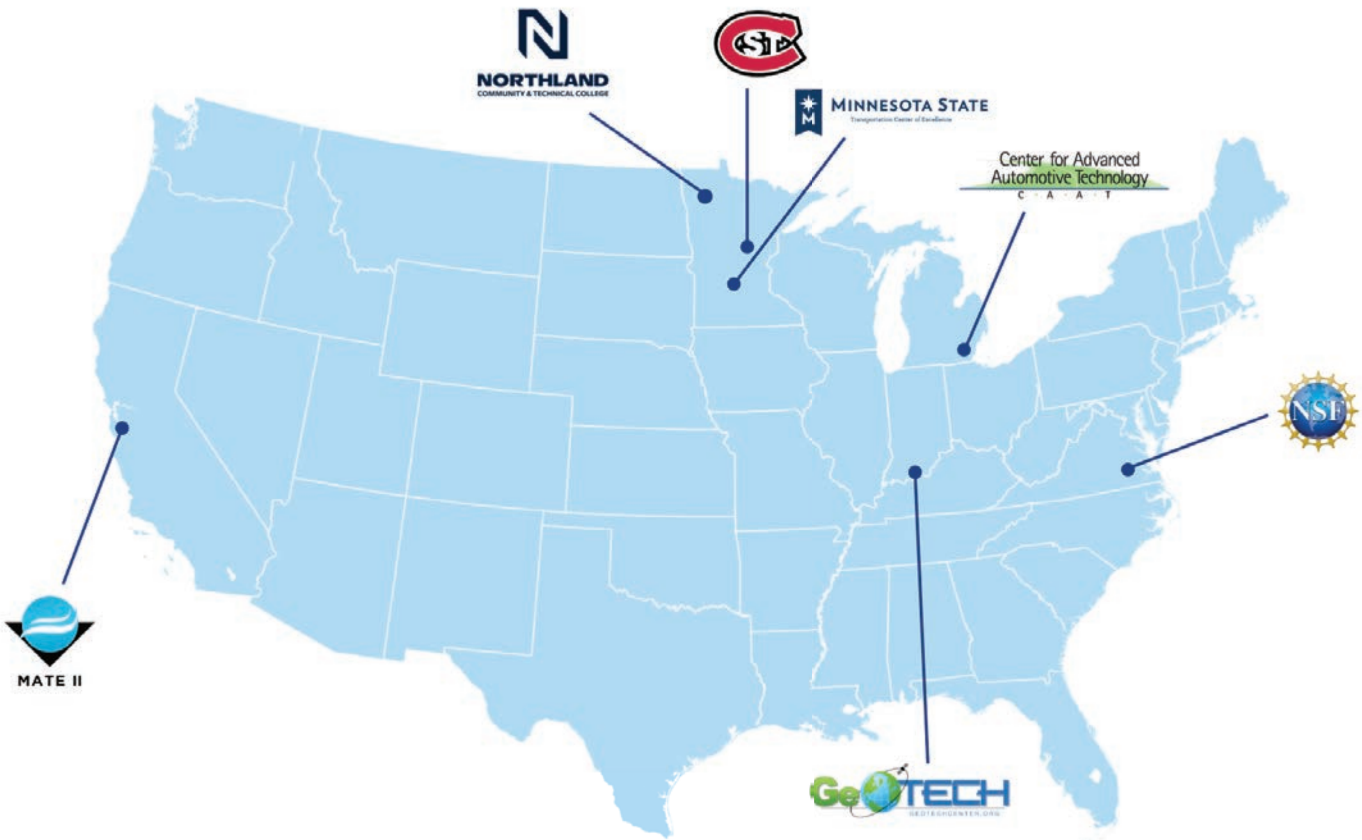

Fig. 2. National Center for Autonomous Technologies Leadership Team

To accomplish the center's goals NCAT leaders have engaged stakeholders from industry and government as well as colleagues from ATE centers and projects. Their shared priority is preparing the nation's technical workforce to use autonomous technologies that are changing how people live, work, and learn. By collaborating with industry to stay informed on technology trends and employer needs, NCAT ensures graduates of ATE-affiliated programs have the complex skills needed and the capacity to learn as the technical field evolves. These same leaders provide influence to help shape the future environments of autonomous technology by serving on various advisory committees for organizations that support policy, standards, and regulations.

NCAT is proud to support the Journal of Advanced Technological Education (J ATE). We are committed to working with the autonomous systems community to increase awareness though J ATE about the amazing work in our nation's community and technical colleges preparing the skilled technical workforce for an exciting future. NCAT serves as a resource hub for the AT community, providing a vast collection of resources for educators, students, administrators, industry professionals, and Federal Aviation Administration (FAA) groups.

National Cybersecurity Training and Education Center (NCyTE)

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Abstract: Across the United States, there are approximately 598,000 unfilled cybersecurity positions. The National Cybersecurity Training and Education Center (NCyTE), hosted at Whatcom Community College (WCC), is a National Science Foundation (NSF) Advanced Technological Education Center working to bridge this gap by providing educational resources and development opportunities for faculty and students.

Keywords: cybersecurity

1. Introduction

From hospitals and school systems to public utilities and agriculture, this country's ability to function increasingly depends on the information systems that support these structures. As technology has become more integrated into every aspect of our lives, the prospect of widespread disruption from cyberattacks has also increased.

Across the United States, roughly 1 million cybersecurity professionals are working to protect our nation against cyber threats. This seemingly impressive number belies a more sobering truth — there are approximately 598,000 cybersecurity positions currently waiting to be filled in the U.S., including 1,700 within the Department of Homeland Security.

The number of qualified cybersecurity professionals graduating from educational programs in the U.S. is being outpaced by the growing number of open jobs. The National Cybersecurity Training and Education Center (NCyTE) seeks to bridge this gap through several programs, with an emphasis on:

- Outreach to communities that have been historically underrepresented in the cybersecurity field.
- Collaborating with national leaders in cybersecurity education to develop and disseminate leading-edge curriculum – such as the College Board-endorsed Advanced Placement (AP) Computer Science Principles (CSP): Cybersecurity course developed in collaboration with CodeHS.
- Providing professional development opportunities nationally to faculty members, high school teachers, and graduate students – giving them new tools and skills for teaching cybersecurity in their classrooms.
- Offering program development workshops to help institutions develop new – or enhance existing – cybersecurity programs.
- Leveraging partnerships with industry leaders to connect graduating students with hiring employers via NCyTE hosted events such as virtual career fairs and industry nights.

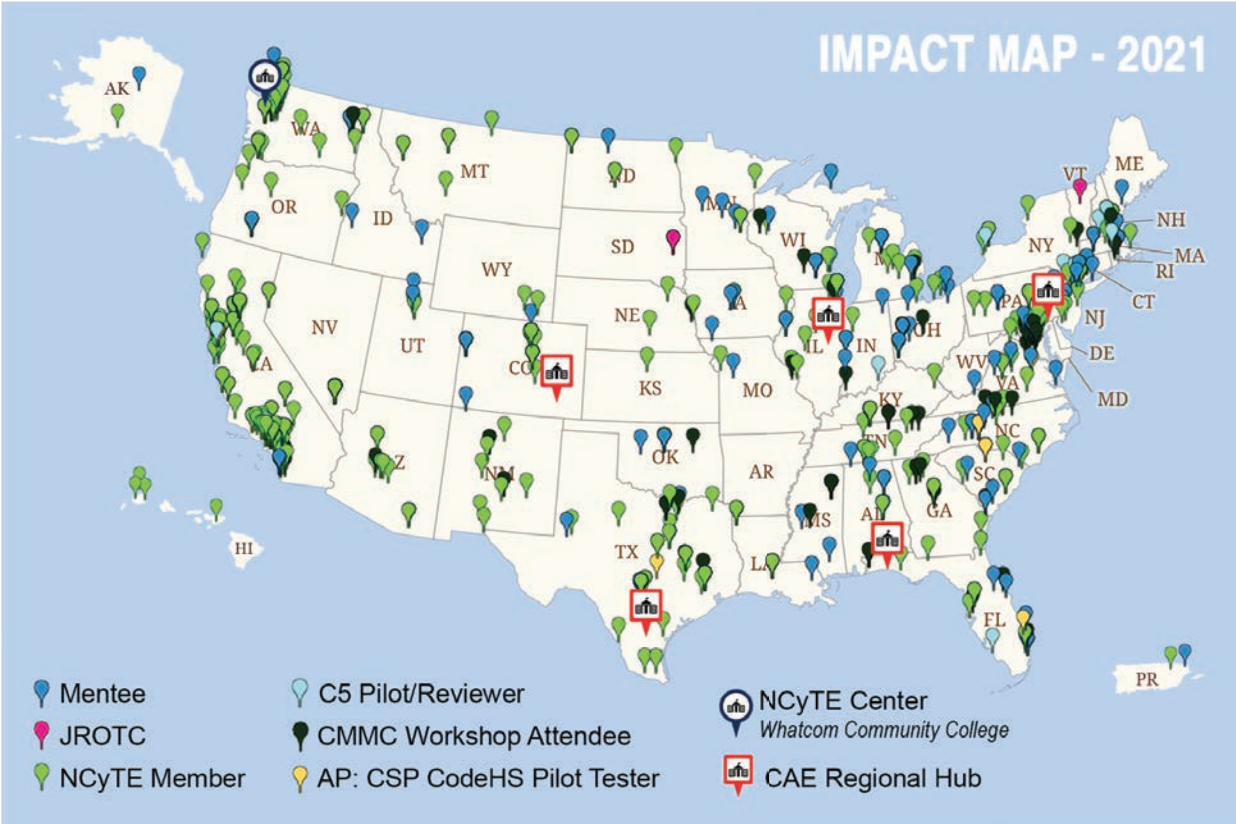

Fig. 1. All institutions NCyTE has collaborated with, reflecting total national cybersecurity efforts associated with NCyTE and WCC

The NCyTE Center began as an NSF ATE Regional Center in October 2011 and became a National Center in October 2021. This growth has enabled NCyTE to expand its services and membership base significantly and reach a broader audience. Some of NCyTE's current initiatives include:

- Organizing and hosting a two-day summit in June 2022, in collaboration with the Center for Systems Security & Information Assurance (CSSIA), where leaders and stakeholders in cybersecurity education will discuss the progress and impacts of community colleges on workforce development and contribute to recommendations for the future.
- Accelerating Community College Cybersecurity Excellence (ACCCE) — a project funded by Microsoft, focused on increasing the number of cybersecurity faculty from underrepresented communities.
- An Industrial Control Systems (ICS) Cyber Range being developed in collaboration with Anvil Corporation that will be located at Anvil's Bellingham campus and available for use by WCC students and Anvil and NCyTE employees.
- A new partnership between Whatcom Community College and the U.S. Cyber Command Academic Engagement Network. The network was developed to build a more robust cybersecurity workforce, increase cyber applied research and innovation, expand cyber-focused analytic partnerships, and enrich strategic cyber dialogue.

As recent cybersecurity threats have shown – from Solarwinds to Log4j – the need for cybersecurity professionals will continue to grow and become more complex. NCyTE is addressing these demands by supporting educators and students as they build a strong, responsive workforce to meet cyber challenges today and in the future. NCyTE is honored by our inclusion in the Journal of Advanced Technological Education (J ATE) and is proud to be a member of the incredible community of institutions taking on the task of preparing the future technical workforce of our nation.

The National Center for Next Generation Manufacturing (NCNGM)

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Keywords: manufacturing

1. Introduction

The National Center for Next Generation Manufacturing (NCNGM) is led by the Connecticut College of Technology (COT) housed at Tunxis Community College, CT, with the following community college partners; College of the Canyons, CA; Central Community College, NE; Columbus State Community College, OH; and Indian River State College, FL. The COT, a seamless career pathway for technician and engineering education, includes all 12 public CT community colleges and 10 universities. It has received National Science Foundation funding, creating the Regional Center for Next Generation Manufacturing (RCNGM) in 2004-2021 and the Next Generation Manufacturing Resource Center in 2018-present. This Resource Center nationally disseminates the best practices of the RCNGM, and other NSF ATE grantees to prepare the future advanced manufacturing workforce.

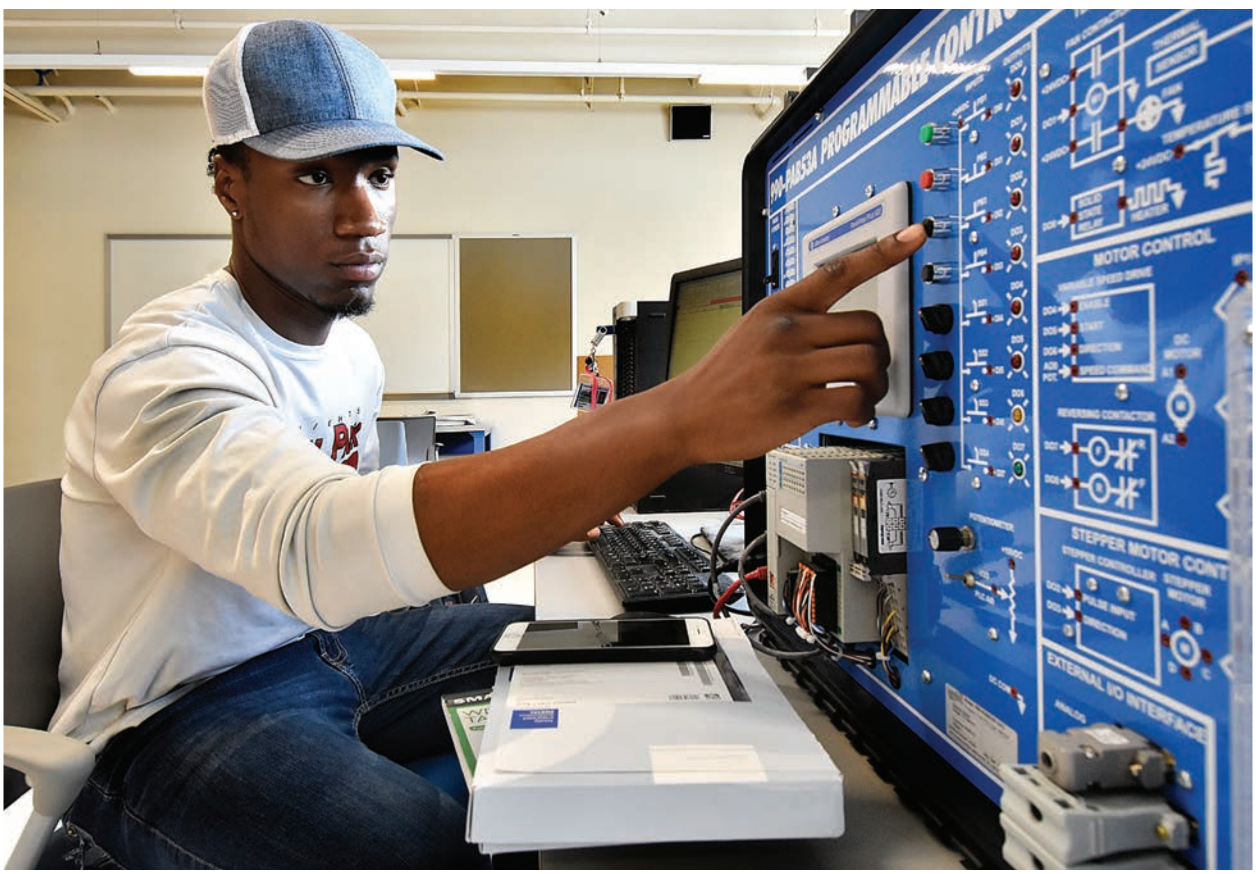

Fig. 1. Manufacturing Technician Student

In 2021, the NCNGM was funded and implemented and includes stakeholders from throughout the United States. The primary goals are to facilitate partnerships between the educational community and industry and disseminate the best practices required to address the need for a more highly-skilled, diverse workforce in the current and future advanced manufacturing environment. The NCNGM provides resources for students and educators in today's high-tech manufacturing companies that address Industry 4.0. The NCNGM also offers access to industry-driven curriculum, professional development, and resources in next-generation manufacturing and career outreach materials that support the recruitment and retention of students in advanced manufacturing programs.

Fig. 2. Manufacturing Technician Student

The NCNGM leadership strongly supports the Journal of Advanced Technological Education (J ATE) and the dissemination of exemplary programs and best practices from our community colleges. The NGNGM will work with the staff of J ATE to help address the need for a journal focused on technician education that will allow educators to publish their findings and seek out best practices discovered by their peers. In addition, the NCNGM stakeholders will feature papers published in J ATE in its own dissemination efforts, such as its website, social media platforms, and newsletter.

We encourage you, our colleagues at community colleges across the United States, to submit articles on how you have created or enhanced advanced manufacturing programs on your campus. The NCNGM leadership team looks forward to learning more about your successful programs.

National Environmental and Natural Resources Technology Center (EARTh Center)

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Keywords: environmental technology, natural resources

1. Introduction

The goal of the EARTh (Environmental and nAtural Resources Technology) Center is to leverage the extensive work of the consortium partners who are leaders in environmental technologies (ET) and natural resources to create a national ATE Center. This Center synthesizes the cross-disciplinary efforts of ET-related sectors and collaborates with industries, government and public agencies, professional organizations, 2- and 4-year colleges and high schools to define and disseminate the critical knowledge and skills required in ET education and support the environmental advanced technology industry. To meet this goal, the Center has created a Leadership Network to support the development and sharing of best practices in environmental technology; establish collaborations between existing, new and potential ATE projects in ET fields to mentor new and prospective PIs and broaden the impact of ATE; provide models and leadership for collaborations between secondary, 2- and 4-year institutions, business and industry, economic development agencies and government; promote ET careers; educate highly skilled technicians and provide faculty professional development; and develop institutionalization of Center functions to sustain activities after the grant.

The Center actively connects with students, including women and underrepresented minorities, economically challenged, first generation, indigenous and those from rural backgrounds. The Consortium making up the Center includes the Advanced Technology Environmental Education Center (ATEEC), the national Partnership for Environmental Technology Education (PETE) and the Nahant Marsh Educational Center (NMEC). Each of these organizations bring essential strengths to the Center. Operated through Eastern Iowa Community Colleges (EICC), ATEEC became an inaugural NSF ATE Center of Excellence in 1994 to support community colleges across the nation and train ET educators to meet current and projected workforce needs.

PETE is a national non-profit organization established in 1993 to facilitate partnerships with educational institutions, industry, and governments in the environmental area. PETE serves 50 states, Tribal Nations, US Territories and insular areas including more than 400 community, Tribal and technical colleges.

NMEC is a nonprofit organization for education and research of natural resources and ecology. Nahant Marsh Preserve is one of the largest urban wetlands on the Upper Mississippi River. After years as a sportman's club, EPA declared the marsh a Superfund Site and cleaned up 243 tons of lead, arsenic, antimony and Polynuclear Aromatic Hydrocarbons. Today the nature preserve is home to over 650 different plant species, birds, mammals, reptiles and amphibians and provides programming on ecosystems, conservation and stewardship to 20,000 individuals each year including K-12 students, college students and adults, undergraduate student researchers, graduate level research students and Ph.D. researchers.

The EARTh Center provides the J ATE community opportunities to utilize resources for further environmental technology research, collaboration and educational reference.

Fig. 1. Blandings Turtle Release Day June 2021