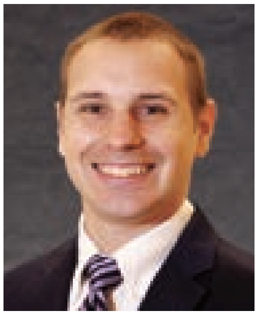


Letter from the Editor

PETER D. KAZARINOFF

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

Keywords: J ATE, technician education, undergraduate research

Community and Technical College Education Community,

I'm pleased to present the Journal of Advanced Technological Education (J ATE), Volume 3, Issue 1, on behalf of the J ATE Editorial Board and staff. The theme for this issue features the great work and research of our community college faculty.

This year, J ATE produced a professional development project called J ATE Connect, funded through a special project grant from the National Science Foundation (NSF). Teams, consisting of a coach and participant writers, crafted manuscripts to be submitted to a peer-reviewed journal. J ATE Connect culminated with an in-person meeting in New Orleans in January 2024. This event welcomed writers, coaches, and additional mentors who met in person with J ATE editors and staff to discuss and advise authors on moving their manuscripts forward through the publication process. We are excited to share that 11 of the 11 writing groups submitted manuscripts by J ATE's January 31, 2024 deadline. J ATE Connect was a huge success, and kudos go out to all the writers, coaches, and, in particular, Karen Leung, who led the program. We hope you enjoy reading the exciting research and information shared by our J ATE Connect authors.

We are all very proud of the growth and development of J ATE over the past three years. Our first issue, Vol 1, Issue 1, contained only five articles, while Vol 3, Issue 1, features 17 articles. We feel that this clearly demonstrates J ATE's commitment to developing a network of community college faculty authors, reviewers, and editors as well as undergraduate authors and J ATE staff members. We are passionate about sharing your hard work and research with all stakeholders. Acknowledging this evolution and the need to serve our community effectively and efficiently, J ATE has transitioned to a new review platform, Scholastica. Through growth and change, J ATE is dedicated to being your peer-reviewed academic journal focused on technician education at community and technical colleges. As we continue to grow, we are committed to being a journal that does not charge authors to submit articles and it is open-access to readers.

In other news, J ATE is embarking on an ambitious sustainability plan this year. We will become a business entity and be entirely supported financially by our community. This is an exciting time! J ATE's sustainability plan includes soliciting and incorporating advertisements from your colleges, programs, and projects into our future volumes. You will find our first advertisement in this issue. Make sure you check it out.

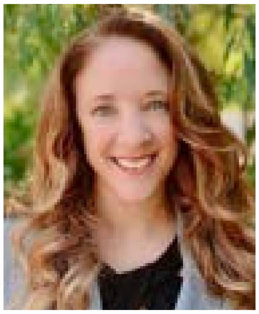
Please help us to continue moving forward and becoming even more relevant to our community by reading J ATE, submitting your manuscript, and serving as a co-author or reviewer. J ATE is your journal serving our community.

In Teaching and Learning,

Peter

Peter D. Kazarinoff

Editor-in-Chief



Invited Letter: Greetings from the National Science Foundation

Keywords: NSF, ATE, technician Education

On behalf of the National Science Foundation (NSF) and as a program director with NSF's Advanced Technological Education Program (ATE), I extend heartfelt greetings to all who contribute to and benefit from the invaluable platform provided by the Journal of Advanced Technological Education (J ATE). As stewards of innovation and champions of inclusivity, I am delighted to recognize the journal's commitment to a peer-reviewed process for disseminating knowledge, ensuring that more voices are heard and valued in the pursuit of progress and equity.

Serving as a program director for the ATE program team is an extraordinary privilege that I value deeply. ATE is one of the longest-standing core programs within the Division of Undergraduate Education and is celebrated for its legacy of outstanding leadership and a vibrant and devoted community. At present, it actively supports the efforts of twenty-three centers and hundreds of unique projects across the country, each focused on transforming and expanding technical education in emerging technology fields. The endeavors of J ATE stand as an essential cornerstone of the ATE community, exemplifying a deep commitment to accelerating research and innovation that yields numerous benefits for society.

At the center of the ATE community's success lies the exceptional and dedicated STEM faculty of two-year colleges, a group I am honored to be a part of. My path to becoming a program director at NSF has been shaped by nearly two decades as chemistry faculty in the two-year college realm, complemented by a background in chemical education research. As passionate educators, we strive to foster supportive learning environments, cultivate equitable opportunities, and engage in meaningful change initiatives that address societal needs while simultaneously transforming the lives of our students.

I am thrilled to see the spotlight shine on this inspiring group of educators throughout this issue of J ATE. This issue's theme highlights the invaluable contributions and unique challenges faced by STEM faculty in our diverse and dynamic educational environments. Likewise, the ATE program acknowledges the vital role of STEM faculty by mandating that they hold leadership positions on all ATE projects. I applaud J ATE for recognizing the significance of this work and offering a venue to amplify faculty voices and exchange ideas that will undoubtedly galvanize colleagues nationwide.

In closing, I urge each member of the technical education community to recognize the impact of publishing their work and disseminating their research findings. By sharing insights, practices, and innovative approaches, we not only enrich our collective knowledge base but also drive regional economic growth. I extend a warm invitation to all to submit their work to J ATE, where it will find a forum to reach a wide audience and contribute to the ongoing dialogue within our community. Together, let us continue to advance the field of technical education and foster a culture of collaboration, innovation, and excellence.

Kalyn Owens
Program Director, ATE Program
The National Science Foundation

Flow Cytometry - A Specialized Analytical Skill for the Cell and Gene Therapy Industry

KATHI GROOVER[1], VALERIE COUSINS[2], BRYAN PELKEY[2], SAVITA PRABHAKAR[3]*

[1]Program Manager, Career & Technical Training, Workforce Development, Frederick Community College, Frederick, MD, 21702, USA

[2]Adjunct Faculty, Biotechnology, Frederick Community College, Frederick MD, 21702, USA

[3]Assistant Professor, Program Manager Biotechnology, Frederick Community College, Frederick, MD 21702 USA

**SPrabhakar@frederick.edu*

Abstract: Cell and gene therapy is one of the fastest-growing fields in the biopharmaceutical industry, and Maryland is witnessing the impact of this growth first-hand. Flow cytometry, a crucial analytical tool for ensuring the quality and purity of cell and gene therapy products, has become a highly sought-after skill. However, access to flow cytometry training is often limited and expensive. Recognizing this gap, Frederick Community College (FCC) has developed an innovative Cell Therapy and Flow Cytometry course, validated by industry, to make this training accessible and affordable to local students, particularly those from underserved communities. This specialized training in cell culture and flow cytometry offers students a competitive edge in the regional job market. Integrated into various program pathways, such as the new Cell and Gene Therapy Certificate, Letter of Recognition (LOR) for Cell Therapy, digital badges, and non-credit options. Flow cytometry training caters to a diverse range of learners, including traditional degree-seeking students and incumbent workers seeking to enhance their skills. In the successful pilot run during Spring 2023, the FCC Cell Therapy and Flow Cytometry course attracted ten students from the Biotechnology Associates program and six others eager to acquire new technical skills. This initiative aims to enable employers to recruit highly qualified and diverse candidates from the local talent pool, thereby supporting the biotechnology workforce in the region. FCC anticipates that this Cell Therapy and Flow Cytometry Workforce Project will serve as a model to enable other community college biotechnology programs to meet similar workforce demands as the cell therapy industry continues to expand across the country.

Keywords: Flow Cytometry, workforce, Cell Therapy, industry-validated, Gene Therapy

Introduction

Cell and gene therapy is the latest innovation in personalized medicine, and it holds the potential for revolutionizing patient care [1, 2]. Cell and gene therapy are related but distinct fields of practice that may be combined, e.g., to treat cancer. Cell therapy involves injecting or transplanting healthy cells into patients to trigger a medical effect. Gene therapy seeks to modify or manipulate the expression of a gene to alter the biological properties of living cells for therapeutic use. In cell therapy, cells – rather than medication or another type of therapeutic intervention – are used to treat patients. Cell and gene therapy are often combined. One example is the production of cells with Chimeric Antigen Receptors (CARs). A CAR gene contains the receptor-binding portion that binds to a protein on the surface of cancer cells fused to the signaling portion from another gene. CAR cells are made by putting these chimeric genes into cells from the immune system, such as T cells. When a cell makes the chimeric protein, the receptor portion sticks outside of the cell and the signaling portion stays inside. When the receptor binds to a molecule on a cancer cell, it triggers the signal and tells the cell it's time to attack the cancer cell. Most clinically evaluated CAR cell products are derived from a patient's immune cells. These are called "autologous" immune cells. The possibility of engineering cells from healthy donors (allogeneic cells) is also currently being explored [3].

Flow cytometry is a crucial analytical tool for the cell therapy industry. It ensures the quality and purity of engineered cells. Flow cytometry is also used to determine if cells possess the qualities needed to help a given patient. As it is one of the primary methods of ensuring quality control, it is indispensable in the manufacturing and release of cell therapy products [4]. As noted above, many cell therapies are made by putting CAR genes inside a cell. Flow cytometry identifies the cells that produce CARs by using fluorescent antibodies to tag receptors on the cell surface. Fluorescently labeled cells are counted as they flow past single or multiple lasers [5]. FCC's Cell Therapy and Flow Cytometry course teaches students about the cell therapy manufacturing process and gives them practice in preparing and analyzing samples using the flow cytometer. Understanding how flow cytometry works and is used to determine if cells are expressing chimeric receptors equips students with the knowledge and skills needed to enter the local workforce.

The value of the global cell therapy market is currently estimated at $9.5 billion and is projected to grow to $23 billion by 2030 [6]. About 900 firms globally are working on these advanced therapies, and approximately 1,000 cell and gene therapy clinical trials are currently underway [7]. By 2030, the U.S. Food and Drug Administration expects to approve 30-60 cell and gene therapy products [8]. The BioHealth Capital Region, encompassing Maryland, Virginia, and Washington, DC, is one of the top three bio-health clusters in the United States. With the National Institutes of Health, the National Cancer Institute's Frederick National Laboratory for Cancer Research, and the Amyotrophic Lateral Sclerosis Center for Cell Therapy and Regeneration Research at Johns Hopkins, the most advanced scientific research and advancement in the field is taking place in the local region. Maryland is home to approximately 2,700 life science companies and over 500 biotech companies. The I-270 biotech corridor, where 140 life science companies are located, is within the FCC's service area [9]. Numerous well-known clinical-stage cell therapy and gene therapy companies are located within a 40-mile radius of FCC, including Arcellx, American Gene Technologies, TCR2, REGENXBIO, Vigene Biosciences, Autolus, RoosterBio, and MaxCyte [10] (Figure 1). In April 2021, Kite, a Gilead Company, one of the top 10 CAR T cell therapy companies, finished construction on a new state-of-the-art facility in Frederick to manufacture FDA-approved products YESCARTA and TECARTUS [11]. With the increase in the number of ongoing clinical trials, the establishment of commercial manufacturing sites by major companies in the field, and the need to ensure the quality of cell therapy products, the demand for technicians skilled in flow cytometry will continue to grow.

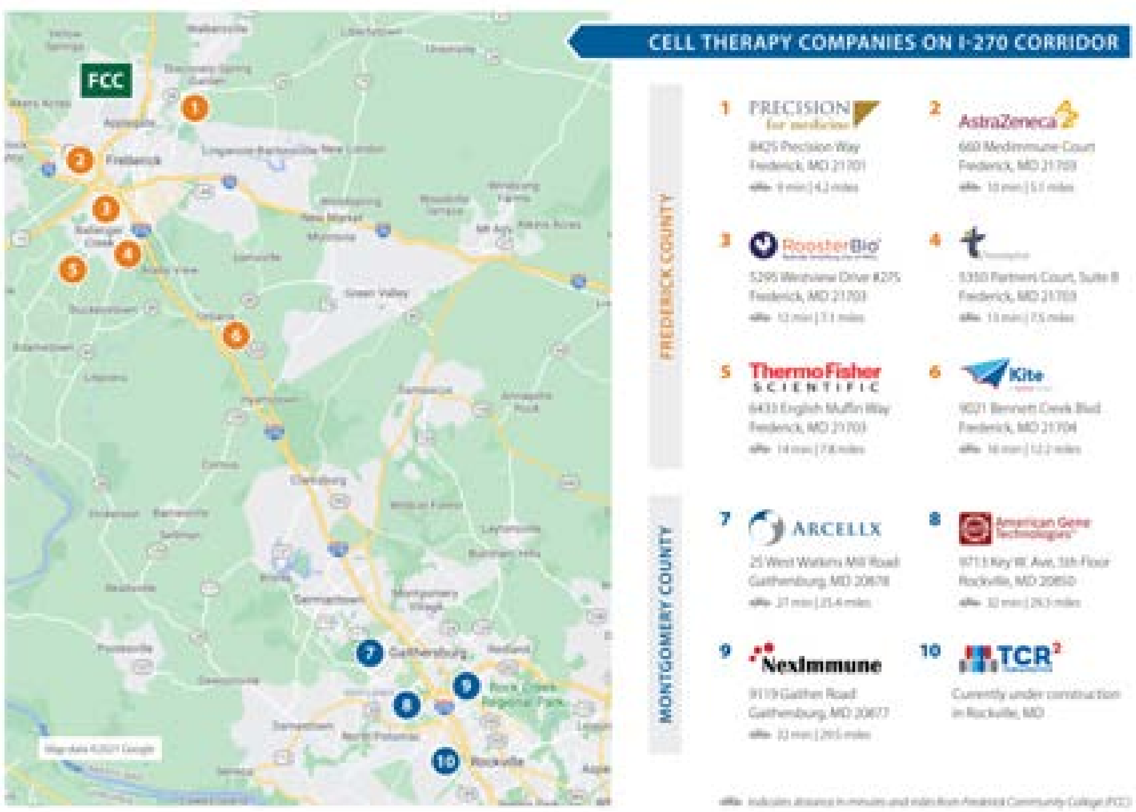


Figure. 1. Cell and gene therapy companies in the FCC service area.

Across the country, technician education programs broadly address biotechnology and cell therapy but do not focus on critical flow cytometry techniques. Aseptic technique, a set of standard procedures that prevent microorganisms in the environment from contaminating sterile cell cultures, is an important skill set for cell therapy that is commonly taught in community college biotechnology programs. Entities developing new cell and gene therapy curricula include NSF-funded projects at Shoreline Community College in Washington, Montgomery County Community College in Pennsylvania, and Montgomery College in Maryland, as well as college and industry collaboratives funded by the National Institute for Innovation in Manufacturing Biopharmaceuticals [12]. However, none of the programs focus on flow cytometry the context of the cell and gene therapy industry, nor do they offer certificates in applied flow cytometry [13-14]. A review of existing biotechnology technician education programs, compiled by InnovATEBIO, the NSF-funded National Advanced Technological Center for Biotechnology Education, indicates that flow cytometry skills are typically taught via on-the-job training in industry and research labs in specialized four-year biotechnology programs like those offered by Solano Community College and MiraCosta College (both in California) and in postgraduate level workshops [15-18]. FCC's project fills a gap in biotechnology technician education by developing a course focusing on flow cytometry as a key component of cell and gene therapy. The course complements and builds upon course currently in the FCC biotechnology program and has been developed in collaboration with industry partners. The course has become part of the FCC Biotechnology Associates degree, a new Cell and Gene Therapy Certificate, a registered apprenticeship, digital badging, and Letter of Recognition for Cell Therapy pathways.

Methods

FCC biotechnology program staff have long been aware of the growing demand for biotechnology workers with skills needed to operate a flow cytometer in central Maryland and had a vision to find a way to affordably offer a flow cytometry course as part of the biotechnology program. Intentional engagement with the local biotechnology industry from the project's inception ensured that industry needs and insights shaped the curriculum design. Following the published business and industry leadership team or BILT model [19], FCC staff recruited a group of industry representatives to serve on the BILT. Members of the BILT represent a mix of local, national, and global employers with a presence in the FCC service area: Kite Pharma, BioNTech, American Gene Technologies, Precision for Medicine, and Frederick National Laboratories Flow Cytometry Core Laboratory. The BILT also had academic biotechnology program representatives with prior experience in developing cell and gene therapy skills standards and curriculum from Montgomery County Community College and Solano Community College. FCC program staff met with the BILT twice to obtain an industry perspective on outcomes they desired from the cell therapy and flow cytometry course including feedback on the course outline and curriculum.

FCC hired an instructor with an extensive flow cytometry training background, giving him the autonomy to devise and teach a workforce-aligned curriculum. FCC procured a BD Accuri C6 flow cytometer and lab reagents. Laboratory materials for flow cytometry were obtained from a variety of sources. Human embryonic kidney cells (HEK293) and Jurkat cells (a CD4+/CD8- T cell line) were purchased from the American Type Culture Collection (atcc.org). AAV/DJ-CMV-eGFP, an Adeno Associated Virus (AAV) vector that expresses Green Fluorescent Protein (GFP) was purchased from Vector BioLabs (Vectorbiolabs.com). The details of the fluorescence-labeled antibodies purchased from BioLegend (BioLegend.com) can be found on ATE Central [20].

The initial flow cytometry course ran as a 7.5-week class (May-March 2023) and utilized multiple modes of instruction, with online course lectures and seven 2.5 hour in-person labs (Tuesdays and Thurdays). Because only one flow cytometer was available, students were paired up for labs, with one leading the Tuesday activities and the other leading the Thursday activities. Students therefore experienced each lab twice, once as a performer and once as a verifier.

Results and Discussion

FCC has developed an industry-relevant curriculum for the Cell Therapy and Flow Cytometry course with input from its BILT. The BILT provided valuable feedback on the curriculum after the lecture and labs were developed. Marketing for the course was accomplished through BioBuzz, a local newsletter that connects the workforce and employers [21].

Overview of the Curriculum

The course emphasized the following skills:

- Aseptic technique, mammalian cell culture, and sample preparation for the flow cytometer (Figure. 2-4).
- Calibration and maintenance of the instrument.
- Sample acquisition and gating.
- Data analysis of the results using FlowJo (Figure. 5).

The general steps in the experiments, as depicted in Figures 2-5, are:

Culture and maintain HEK or Jurkat cells

↓

Prepare cells for either transduction or antibody staining

↓

Calibrating the Flow Cytometer and acquiring the sample

↓

Gating the samples and collecting the sample acquisition data

↓

Analyzing the samples in FlowJo

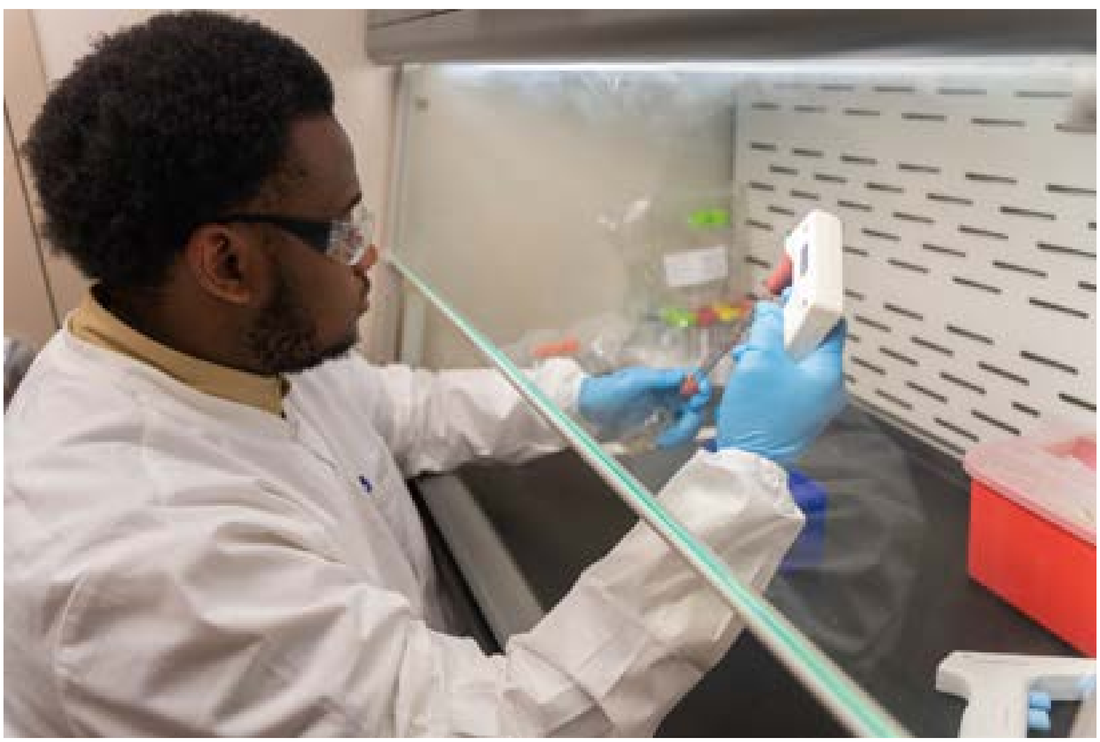


Figure. 2. Student working maintaining the Jurkat cells (T-cell line) aseptically in the Biological Safety Cabinet II A2 (BSC).

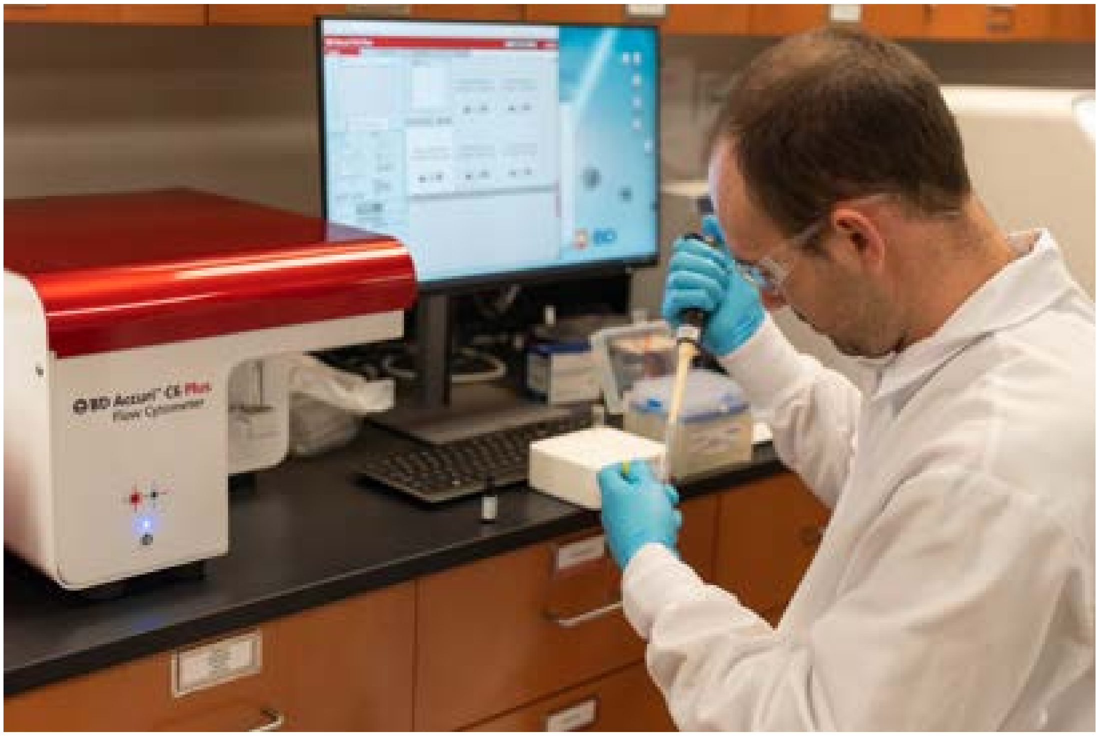


Figure. 3. Instructor demonstrating how to prepare the sample for loading on the Flow cytometer.

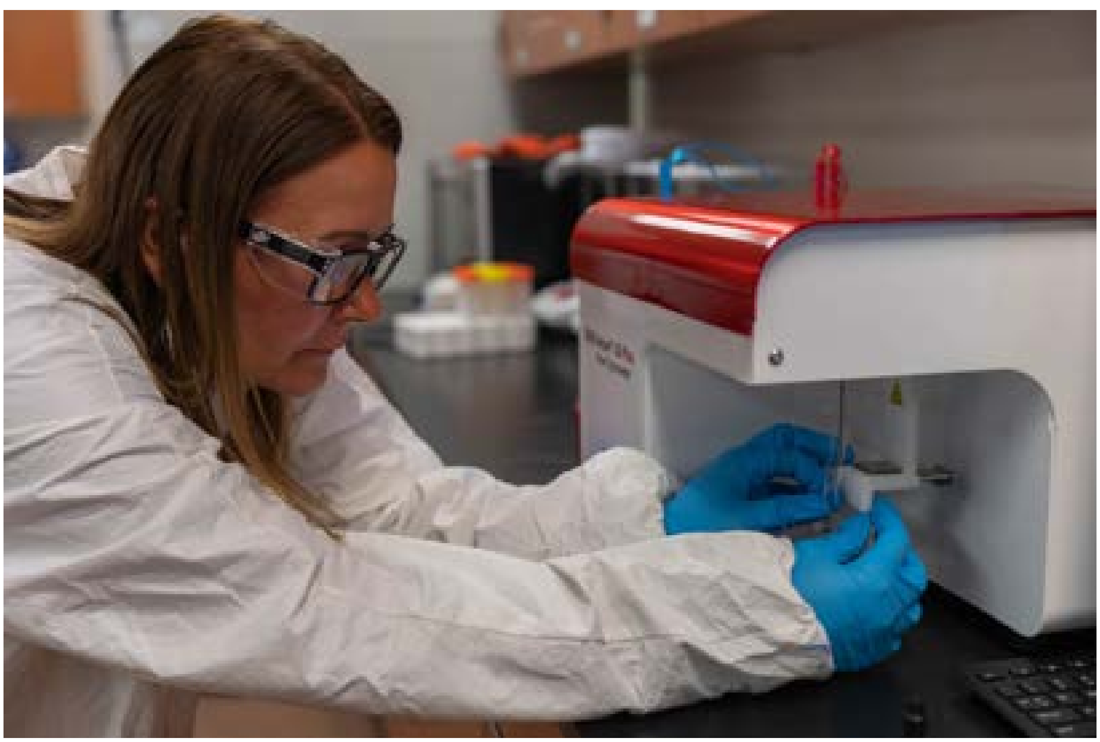


Figure. 4. A student loading a sample on the flow cytometer.

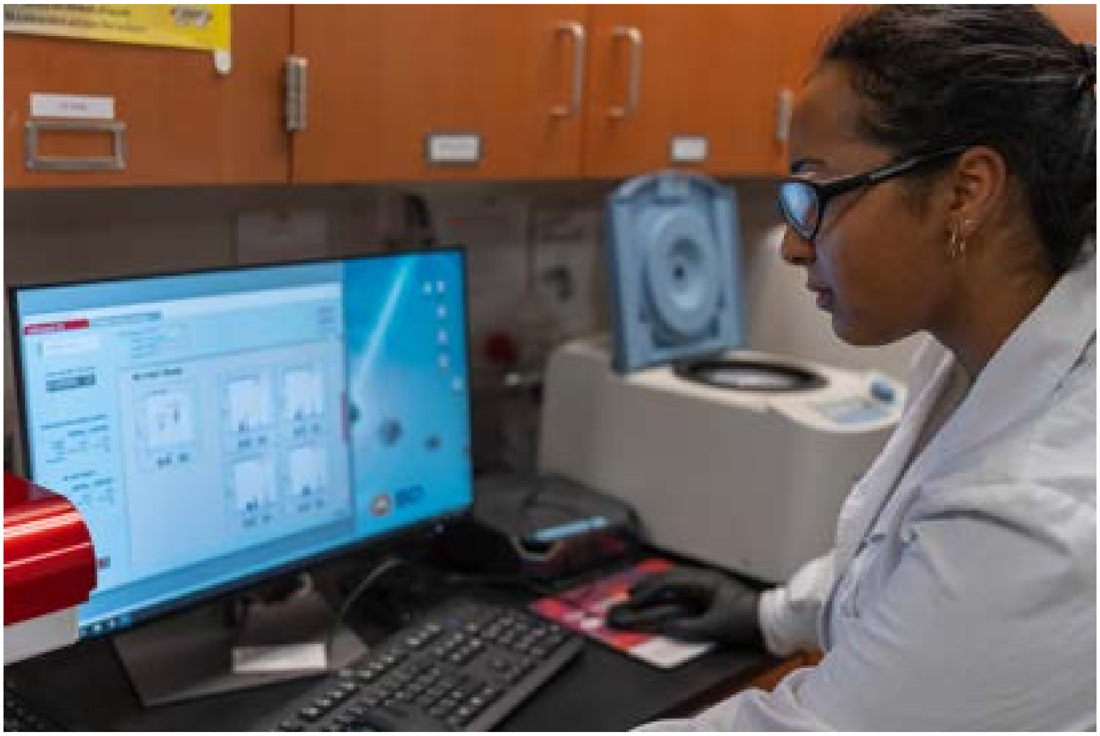


Figure. 5. Student analyzing data on the flow cytometer.

During the course, students used techniques that would be employed in manufacturing cell and gene therapies. To help studentsunderstand the application of flow cytometry in gene therapy product development, curriculum was developed to use flow cytometry to determine the effect of increasing AAV GFP viral particles, the multiplicity of infection (MOI), on transduction efficiency by evaluating the number of fluorescent cells. This experiment is described in Figure. 6B where the increase in GFP-positive cells correlates with the increase in the MOI. Details of the transduction of the HEK cells and the preparation of cells for analysis can be accessed through ATE Central [22].

To help students understand the utilization of flow cytometry for analyzing the cell therapy products, curriculum was developed using a small panel of basic T cell markers to examine the baseline characteristics of non-activated Jurkat cells which express CD3 & CD4 receptor/marker but not CD8 nor CD45RO receptors/ markers. These experiments gave students the opportunity to assess multiple characteristics of the cells at once, test out a beginner-level gating strategy, and understand the variety of expression levels of different receptors.

Student data from these procedures are presented in Figures 6 and 7. Figures 6A and 7A show data from gating. In flow cytometry, gates are regions that are placed around populations of cells that share characteristics such as size. Figures 6A and 7A show oval gates in the left-hand plot that identify cells. In the left-hand plots, the gates show the Forward Scatter Area (FSC-A) plotted against the side scatter area (SSC-A) which allows debris and cell clumps to appear in the bottom left portion of the density plot. On the right, the plot shows the height of the Forward Scatter (FSC-H) plotted against the area (FSC-A). The cells in the tilted rectangle distinguish individual cells from clumps of cells. This gating process helps students identify the cells to analyze to 1) assess GFP expression levels (Figure. 6B) and 2) the presence of Jurkat cell surface markers (Figure. 7B).

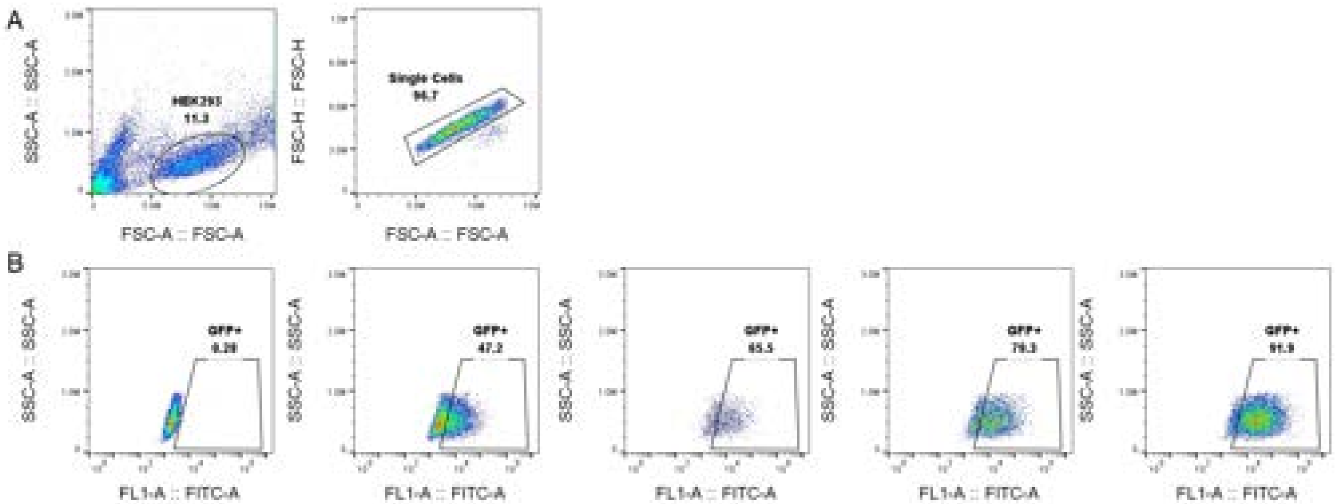


Figure 6. Shows the effect of increased AAV GFP viral particle number on the transduction of HEK293 cells.

Cells were transduced with increasing amounts of AAV GFP virus (expressed as Multiplicity of Infection or MOI) for 48 hours. Figure 6A shows the initial gating strategy for identifying transduced cells based on forward (FSC) and side scatter (SSC). Figure 6B demonstrates increased GFP positive cells correlating with transduction with increased AAV GFP viral particles. On the BD Accuri C6 Plus, Channel FITC was used for the GFP signal. From left to right, MOI 0, 100, 200, 300, and 400, respectively.

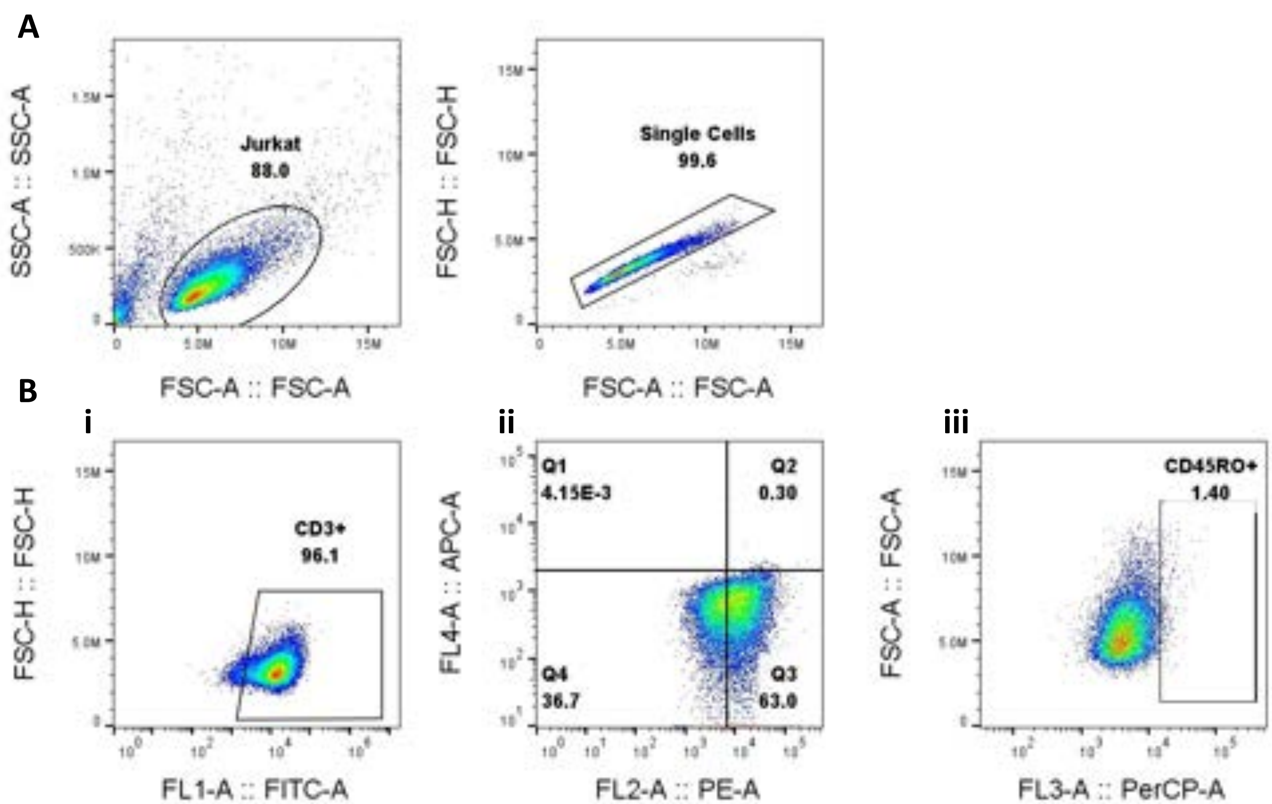


Figure 7. Multi-color panel staining of Jurkat cells.

Jurkat cells classically express high levels of TCR (CD3) with low levels of CD4 and no CD8. Jurkats in culture were counted and stained with the antibody panel (CD3-FITC, CD4-PE, CD8-APC, CD45RO-PE-Cy7). Figure 7A: Cells and single cells were identified using forward and side scatters. Figure 7B: (i) CD3+ cells labeled with FITC were gated, (ii) CD4+ cells (labeled with PE were plotted against CD8 cells (labeled with APC). Jurkat cells do not express the CD8 marker, so no staining is seen in the upper left Q1 quadrant. (iii) CD4+ cells were checked for activation marker CD45RO. Cells did not express the CD45RO marker either, as they were not activated. Gates were determined using Fluorescence Minus One (FMO) control and adjusted for spillover via compensation.

Course Outcomes

The course was initially offered in Spring 2023, and ten students successfully completed it. Seven of the ten were enrolled in the Biotechnology AAS degree program. The other three students already had associate or bachelor's degrees and took the course to gain new relevant skills.

Due to demand, FCC also offered the course as a four-week non-credit course in the Summer of 2023. The same instructor taught the class. The students met three times a week for two and a half hours; of the five students who successfully completed the non-credit course, two enrolled in the Biotechnology AAS degree program and received articulated credits towards their degree. The other three students had bachelor's or master's degrees and took the course to gain cell culture and flow cytometry skills. These three were awarded the Flow Cytometry Basics digital badge. One student did not complete the course. The assignments, labs, and final exams were the same for the credit and non-credit programs.

Table 1. Student outcomes

Course	Students in AAS program	Students with Associates or Bachelors	Total students enrolled	Course Completion	Outcomes
Cell Therapy and Flow Cytometry (credit)	7	3	10	10	2 hired 1 interviewed
Basics of Flow Cytometry (non-credit)	3	3	6	5*	1 promoted
Total	10	6	16		

* One student did not meet the completion requirements.

All students received the Cell Therapy and Flow Cytometry LOR digital badge (credit) or the Flow Cytometry Basics digital badge (non-credit). Two students were hired for research jobs that involved cell culture skills and another was promoted in her job and is now utilizing her cell culture skills at the Frederick National Cancer Laboratory for Cancer Research. One student was interviewed at the National Cancer Institute Flow Cytometry Core and received positive feedback.

Student feedback regarding the course, obtained by the evaluators via phone interviews, was overwhelmingly positive, with one saying I "loved it." Program staff designed the course with the student experience in mind and were excited to receive this feedback. The primary challenge noted by all interviewees was lab space and the amount of equipment. The lab was equipped with one flow cytometer and two biological safety cabinets. The ideal number of enrolled students was 8, but 10 students enrolled in the course. Students were therefore paired up, and they traded off who was the primary operator of the instrument on each lab day. All students received hands-on experience with the machine for each lab, and interviewees noted that the repetition was possibly beneficial for students to learn the procedures. One student highlighted this benefit, saying that being able to "both see and do" facilitated learning instrument skills. Students felt very confident in their ability to use the flow cytometer by the end of the course. The students were assessed both for theoretical knowledge of the principle of flow cytometry as well as hands-on instrument operation and sample preparation skills. Students benefited from receiving in-demand skills and being prepared to succeed in a professional cell therapy and flow cytometry environment. Due to the small number of students in class, only qualitative data was collected.

Feedback from third-party evaluator interviews with select members of the BILT noted that the program met the local employers' needs and the students' outcome expectations. Skills of interest to employers and mastered during the program included aseptic technique, cell culture, calibration and maintenance of the equipment, sample acquisition, and data analysis. The grant Co-PI, trained by the flow course instructor during the program, will continue teaching in the program.

Conclusion

The flow cytometry instructor and students reported that every student had sufficient time to work with the flow cytometer. However, the need to pair students during labs highlights a need to add more flow cytometers in the future. This project made significant progress toward enrollment goals for the Cell Therapy and Flow Cytometry class. In the project's first year, FCC enrolled 16 students in the class. The course has been popular with older individuals working in the biotechnology industry. A future goal is to increase enrollment of 18- to 24-year-olds in the flow cytometry course. FCC's foundational work in local high schools will support higher enrollment of younger students over the next two project years.

It is rare for undergraduates to gain hands-on flow cytometry experience, especially in an affordable setting like a community college ($700 for a 7.5-week course with the possibility of student loans vs. $995 for a 3-day Flow cytometry workshop, https://biotrac.com/). FCC provided several complementary on-ramps into the biotechnology program (including flow cytometry) to meet student needs across varied backgrounds: a high school dual enrollment course and other programs offering lab visits, a for-credit biotechnology course, and a non-credit articulated and shortened summer course. The summer flow cytometry course demonstrates the capacity for coordination and collaboration between credit and non-credit departments to provide program offerings at various levels seamlessly. Employers frequently turn to non-credit divisions of colleges for training needs, so leveraging FCC's non-credit opportunities helps ensure a broader reach for the ATE grant investment. The Synexa Life Sciences Company and Frederick National Labs Flow Cytometry Core scientific staff have contacted us and reviewed our curriculum. The feedback indicated that the curriculum is relevant to their workforce needs, and they subsequently requested resumes from students to determine if they wanted to interview them.

In conclusion, the NSF ATE grant awarded to FCC focused on building a cell therapy and flow cytometry workforce to respond directly to local workforce needs and provide career opportunities to individuals with low incomes and marginalized communities. FCC is sharing the curriculum, lab SOPs, and batch records through the Northeast Biomanufacturing Center & Collaborative (NBC2) (Biomanufacturing.org) to facilitate the introduction of hands-on flow cytometry curriculum in other biotech programs nationwide.

Acknowledgments. This work was supported by the National Science Foundation (NSF) under award 2201621.

Disclosures. The authors declare no conflicts of interest.

References

[1] "The Unprecedented Growth of Cell and Gene Therapy." Accessed: Jan. 12, 2024. [Online]. Available: https://www.cloudbyz.com/resources/clinical-operations/cell-and-gene-therapy/

[2] PharmaNewsIntelligence, "Key Strategies for Advancing Gene and Cell Therapy Development." Accessed: Jan. 12, 2024. [Online]. Available: https://pharmanewsintel.com/news/key-strategies-for-advancing-gene-and-cell-therapy-development

[3] K. J. Caldwell, S. Gottschalk, and A. C. Talleur, "Allogeneic CAR Cell Therapy—More Than a Pipe Dream," *Front. Immunol.*, vol. 11, p. 618427, Jan. 2021, doi: 10.3389/fimmu.2020.618427.

[4] J. D. M. Campbell and A. R. Fraser, "Flow cytometric assays for identity, safety and potency of cellular therapies," *Cytometry Part B: Clinical Cytometry*, vol. 94, no. 5, pp. 725–735, 2018, doi: 10.1002/cyto.b.21735.

[5] K. M. McKinnon, "Flow Cytometry: An Overview," *CP in Immunology*, vol. 120, no. 1, Jan. 2018, doi: 10.1002/cpim.40.

[6] "Cell Therapy Market Size, Share And Growth Report, 2030." Grand View Research, GVR-2-68038-701-8. Accessed: Jan. 12, 2024. [Online]. Available: https://www.grandviewresearch.com/industry-analysis/cell-therapy-market

[7] "Cell and gene therapies," Deloitte Insights. Accessed: Jan. 12, 2024. [Online]. Available: https://www2.deloitte.com/us/en/insights/industry/life-sciences/operating-models-for-gene-cell-therapy-manufacturing-process.html

[8] "Statement from FDA Commissioner Scott Gottlieb, M.D. and Peter Marks, M.D., Ph.D., Director of the Center for Biologics Evaluation and Research on new policies to advance development of safe and effective cell and gene therapies," FDA. Accessed: Jan. 12, 2024. [Online]. Available: https://www.fda.gov/news-events/press-announcements/statement-fda-commissioner-scott-gottlieb-md-and-peter-marks-md-phd-director-center-biologics

[9] M. R. Rey, "Maryland's I-270 Biotech Corridor: A Hub Within A Hub." Accessed: Jan. 12, 2024. [Online]. Available: https://www.qgdigitalpublishing.com/publication/?i=540489&article_id=3231845&view=articleBrowser&ver=html5

[10] S. Surdez, "Cell and Gene Therapy's Future a Complex Mix of Promise and Pitfalls," BioBuzz. Accessed: Jan. 12, 2024. [Online]. Available: https://biobuzz.io/cell-and-gene-therapys-future-a-complex-mix-of-promise-and-pitfalls/

[11] "Kite Expands Cell Therapy Manufacturing Operations in Maryland." Accessed: Jan. 12, 2024. [Online]. Available: http://www.kitepharma.com/news/company-statements/kite-expands-cell-therapy-manufacturing-operations-in-maryland

[12] "NIIMBL Current Projects." Accessed: Jan. 12, 2024. [Online]. Available: https://niimbl.my.site.com/s/current-projects

[13] M. Bryans, J. DeKloe, J. Carrese, "Skill Standards and Curriculum for Cell and Gene Therapy Technicians," National Insitute for Innovation in Manufacturing Biopharmaceuticals, 2022. [Online]. Available: https://biomanufacturing.org/uploads/files/162181136761177190-cgt-technician-skill-standards-2022-on-line-booklet-optimized.pdf

[14] "Training," Flow Cytometry Core Facility. Accessed: Jan. 12, 2024. [Online]. Available: https://med.virginia.edu/flow-cytometry-facility/resources/training/

[15] "Curriculum, Internships and Articulation," Solano Biotechnology. Accessed: Jan. 12, 2024. [Online]. Available: https://www.solano.edu/biotech/students/curriculum.shtml

[16] "Biotechnology," MiraCosta College. Accessed: Jan. 12, 2024. [Online]. Available: https://catalog.miracosta.edu/disciplines/biotechnology/

[17] "Cell and Immunotherapy Hub," InnovATEBIO. Accessed: Jan. 12, 2024. [Online]. Available: https://innovatebio.org/

[18] "UCSF Flow Cytometry Training Program," Parnassus Flow Cytometry CoLab. Accessed: Jan. 12, 2024. [Online]. Available: https://flow.ucsf.edu/ucsf-flow-cytometry-course

[19] "Business & Industry Leadership Team," National Convergence Technology Center. Accessed: Jan. 12, 2024. [Online]. Available: https://connectedtech.org/business-industry-leadership-team/

[20] "Multicolor Antibody Staining of T Cells," Frederick Community College, *ATE Central*, 2023. Accessed 13 Mar. 2024. [Online]. Available: https://atecentral.net/r45044/multicolor_antibody_staining_of_t_cells. Accessed 13 Mar. 2024

[21] "About BioBuzz," BioBuzz. Accessed: Jan. 12, 2024. [Online]. Available: https://biobuzz.io/about/ https://biobuzz.io/about

[22] "Viral Gene Delivery and Evaluation by Flow Cytometry," *Frederick Community College, ATE Central*, Accessed 13 Mar. 2024. Available: https://atecentral.net/r45043/viral_gene_delivery_and_evaluation_by_flow_cytometry .

Bridging the Gap: Identification of Critical Knowledge, Skills, and Abilities (KSAs) to Fill Entry-level Bioprocess Technician Positions Using the BILT Model

BRENDA GRUBB[1]*, LISA SMELSER[1], DREW GOODSON[2], KRISTI SHORT[3], MARGARET ROBERTON[4]

[1]*Biotechnology Department, Central Carolina Community College, Sanford, NC United States*

[2]*Financial Services Office, Central Carolina Community College, Sanford, NC, United States*

[3]*Office of Vice President/Chief Academic Officer, Central Carolina Community College, Sanford, NC, United States*

[4]*Office of Vice President/Chief of Staff, Workforce Development and Continuing Education, Central Carolina Community College, Sanford, NC, United States*

**bgrubb@cccc.edu*

Abstract: Bioprocess manufacturing has grown tremendously, creating a shortage of skilled technicians to fill entry-level positions. The Business & Industry Leadership Team (BILT) model was used to bridge the gap between what students learn in college and what employers need from newly hired technicians. The active involvement of industry partners as co-leads provided insight to identify knowledge, skills, and abilities (KSAs) that have the highest priority for these jobs. Faculty used this information to analyze courses and align the curriculum to meet the industrial trends for future jobs. This report outlines how identifying critical KSAs has allowed us to bridge instructional gaps by implementing changes to the curriculum. Exchanging feedback and networking with the industry increased faculty and students' exposure to thoroughly enrich the Bioprocess Manufacturing program at Central Carolina Community College. The BILT model is also used to align curriculum in other departments to facilitate improvements across the college for different industries. This work can guide other institutions in developing programs and building a more diverse and inclusive workforce of highly skilled technicians.

Keywords: Bioprocess technician, Biomanufacturing, BILT Model, skilled technical workforce development, knowledge, skills, abilities, curriculum alignment, North Carolina

Introduction

Need for a Skilled Workforce in Biomanufacturing

The journey towards establishing national standards for roles within bioprocess manufacturing has been a collaborative effort spanning several decades. It began in Washington state in the early 1990s and gained momentum with initiatives by leaders such as Dr. Sonia Wallman at Great Bay Community College in the late 1990s. Bio-Link, now known as InnovateBIO, continued this work in Indianapolis in 2009. Additionally, the Northeast Biomanufacturing Center and Collaborative (NBC2) played a significant role in the 2000s, culminating in the efforts of the Department of Labor's Trade Adjustment Assistance Community College and Career Training (TAACCCT) grant-funded Community College Consortium for Bioscience Credentials. The consortium was led by the National Center for the Biotechnology Workforce, led by Russ Read, and an affiliate of NC BioNetwork based at Forsyth Technical Community College in Winston-Salem, NC.[1-3].

The increased growth of creating products by biomanufacturing has created a need for a workforce with a specific skill set for the jobs. In North Carolina, the industry has grown by close to 40% over the past decade, with the production of vaccines, biologics, new gene therapy products, traditional pharmaceuticals, other drug substances, food products, supplements, and bioplastics, according to the Economic Development Partnership of North Carolina (EDPNC) quarterly report [4-6]. Between January 2020 and December 2022, biopharmaceutical manufacturing companies have invested nearly $7.6 billion and nearly 6,200 new jobs in North Carolina [5]. Since 2022, North Carolina has invested over $2.1 billion and created over 2,700 new jobs to support the industry [7].

In 2022, a statewide coalition led by the North Carolina Biotechnology Center was awarded $25 million as part of the Build Back Better Regional Challenge. These funds promote training and career opportunities in the biomanufacturing industry and give greater access to more North Carolinians [5]. The infusion of funding from industry investments and federal grants has created a golden opportunity to bridge the gaps in employment by helping historically excluded groups access programs through community colleges. There are many community colleges across North Carolina that teach the BioWork Biopharma manufacturing training program, and the number is growing [5-6, 8].

The BioWork training program represents a culmination of efforts at both state and national levels to provide training for highly skilled, in-demand technicians in bioprocess manufacturing. It has a history of collaborative endeavors with community colleges, the North Carolina Biotechnology Center, and industry. BioWork training involves a variety of topics such as safety, quality, current good manufacturing techniques (cGMP), aseptic techniques, and other topics aimed at establishing robust standards and training protocols, ensuring that the workforce remains competitive in the evolving landscape of the life sciences industry [9]. The entry requirements allow for a vast range of students of all educational backgrounds. Funding for the program comes from the non-profit North Carolina Gold Leaf Foundation, which was created in 1999 to disperse tobacco settlement funds in financially distressed counties that had depended on tobacco for financial stability [6]. Currently 13 of the 58 North Carolina Community Colleges now offer the course to the general public in the form of continuing education and to newly hired biomanufacturing employees in the form of customized training. The BioNetwork is a life science training initiative of the North Carolina Community College System that connects and supports colleges, companies, and students to provide professional growth and network opportunities to facilitate successful career paths [6, 9].

In 2020, under the leadership of Dr. Lisa Smelser, CCCC restarted the Bioprocess Technology program in Lee and Harnett counties. The program encompasses stackable credentials starting with the BioWork Certificate, building to the Bioprocess Technology Certificate, and culminating with the Bioprocess Technology Associate in Applied Science Degree (AAS) [10]. In 2021, Dr. Brenda Grubb joined the department, taking the BioWork program to Chatham County. The program went from zero students at the start of 2020 to serving over 370 BioWork students through 2023, and currently, 50 Bioprocess technology students are enrolled in the AAS degree program. Developing a more robust training program improves the employability of students. Strengthening relationships with industry increases the capacity to reach underserved populations by increasing awareness of biomanufacturing careers and providing opportunities for students to be seen by employers who might not otherwise have connected with this untapped source of talent.

This paper focuses on the KSAs needed for entry-level bioprocess technician positions. These jobs would include process technicians in manufacturing preparation, formulation, or fill and finish, with a minimum education requirement of a high school diploma or GED plus relevant work experience and training. Other entry-level positions, such as quality control and lab technicians, would require a minimum of an Associate's degree. While a bachelor's degree is traditionally required for process engineer positions, those in research and development may require an MS with industry experience or a Ph.D. [6] and are not the focus of this paper.

Improving Industry Workforce Training using the BILT Model

The Business & Industry Leadership Team (BILT) model created by Dr. Ann Beheler from the National Science Foundation (NSF) Center of Excellence in Convergence Technology at Collin College was first used for Information Technology (IT) programs [11]. This model can be applied to any technical program using this process. The BILT model was established through work with business leaders from across the nation to determine the knowledge, skills, and abilities (KSAs) that "workforce ready" graduates would need to be competent in to meet the needs of the industry one to three years into the future. The model has been implemented at over 60 colleges in multiple disciplines [11-12].

The Biotechnology Department at CCCC also strives to reduce instructional gaps between what students learn in the classroom and the KSAs required to fill in-demand technical positions. CCCC has followed the BILT model and enlisted local industry partners to prioritize KSAs. This has allowed the development of a practice of aligning the curriculum at CCCC with the requirement for an entry-level bioprocess manufacturing technician. This iterative process can also be used to develop curricula for technicians in other industries. The BILT model is composed of local industry partners with a vested interest in actively playing a role in developing and training a workforce in collaboration with the educational institution. This is an innovative approach because, unlike an advisory board, the BILT meets more often and feels ownership of the training improvements by their commitment to contribute applied advice. The focus of this publication is to cover the use of the BILT model by CCCC and local biopharmaceutical industry partners to develop a skilled technical workforce. This model puts employers in a co-leadership role, significantly increasing their engagement with the program [11-12].

Methods

Essential Roles in the BILT Model

The BILT program quarterly meetings are conducted with the co-leadership of faculty and industry leaders. Using a structured, repeatable voting process, KSAs are prioritized annually according to employers' predicted needs 12-36 months into the future [13]. This way, the training can produce the expected performance in graduates to meet the predicted labor market demand identified by industry trends [14]. The role of the faculty is to cross-reference KSAs to the existing curriculum and update the curriculum to address KSAs prioritized by industry members of the BILT. Stakeholders are provided with feedback from faculty regarding the implementation.

Fig 1. Annual Cycle of the BILT process [12]

Timeline and Process

First Quarter: The BILT model has a 12-month meeting cycle process [Fig 1, 12]. The first assembly of the BILT was an Orientation meeting to explain the process in January 2022. Once the KSAs needed for an entry-level bioprocess manufacturing technician were determined, a spreadsheet was created to use as a ballot [Table 1], and the first quarterly in-person meeting was scheduled for the voting process.

National standards were used to create the foundation for KSAs based on the Biopharmaceutical Manufacturing Industry Skill Standards, the Bioscience Skill Standards [1-2] and "Window on the Workplace 2023, Workforce Training Needs for North Carolina's Biopharma Manufacturing Industry," 2023, North Carolina Biotechnology Center [5]. The KSAs were validated in the context of local industries, allowing the curriculum to be aligned with continuous improvements based on future trends.

Second Quarter: The KSA Analysis meeting in May 2022 allowed industry partners to vote on KSAs. The meeting was in person and recorded by Zoom. All ratings were captured, and comments were added to the spreadsheet based on the discussion. The discussion was just as important as voting. Employer input at this stage is helpful when faculty later determine how the KSA will be addressed in the curriculum. Meeting participants included seven industry Subject Matter Experts participating in ratings and discussion, 1 Faculty Subject Matter Expert as an active listener, and 2 facilitating processed experts responsible for the efficiency and effectiveness of the meeting, including the creator of the BILT model, who attended via Zoom to facilitate the initial KSA vote ensuring that everything went smoothly.

Third Quarter: In the Fall quarterly, virtual meeting held in September 2022, the faculty shared results after the crosswalk of KSAs to the existing curriculum and the updates to address KSAs prioritized by businesses. Further feedback was requested from employers regarding implementation. Emphasis was also on growing a pipeline of right-skilled job candidates. Building and maintaining a thriving BILT is a high-touch activity with two-way communication. BILT members were encouraged to invite other colleagues in the industry to become a part of the team.

Fourth Quarter: The Trends meeting in November 2022 was a one-hour virtual meeting discussing future directions and innovations reported by Industry Partners. Implementation of the recommended changes to the curriculum began in the Fall 2022 semester was reported.

End of First Quarter Year Two: The established BILT team meeting in March 2023 introduced new members added to the team and gave an overview of the model and updates on the direction of the program and the industry. A mid-year meeting was held in July 2023. There was an in-person discussion of the training facility design and input from the industry on the flow pattern of the new building. Further information was shared about equipment for training necessary for a state-of-the-art curriculum to meet the coming needs.

Fourth Quarter Year Two: The virtual trends meeting was held in November 2023 to discuss KSAs for Quality Control (QC) positions.

Vote to prioritize Knowledge, Skills, and Abilities (KSAs)

The KSA priority vote is ranked from 1-4. One is the lowest, and four is the highest. Ranking criteria consider the following parameters together: Importance, level of proficiency, time spent doing the skill, difficulty, and how complicated the skill is to learn [12-13].

4 = The KSA **must be included** in the curriculum

3 = The KSA **really should be included** in the curriculum

2 = It would be **nice to have** the KSA included in the curriculum

1 = The KSA **can be left out** of the curriculum entirely

Table 1. Ballot Design with KSAs and Priority Levels

KSA#	Bioprocess Technology KSA	Priority Level (1-lowest, 4-highest)				
K-1 K-2	Knowledge Good documentation practices (GDP) Current good manufacturing practices (cGMP)	4	3	2	1	Avg
S-1 S-2	Skill Gowning, PPE, and hygiene at appropriate level/grade. Consistently following written and verbal instructions.					
A-1 A-1	Ability Monitor process or indicators of system performance. Operate electronic communication systems and methods					

Cross-reference KSAs to existing curriculum

After reviewing the vote results, faculty compiled data to recommend changes in the course content. The course objectives and the syllabus content were cross-referenced and reviewed for each course to determine if each KSA was covered. Biotechnology faculty ranked coverage levels as Exposure (E) or Thorough (T) to indicate the level of coverage for each of the courses they teach. This was followed by highlighting the area of focus in the KSAs based on the voting of industry stakeholders and coverage by the instructors. Table 3 provides examples of the updates in the curriculum to address the prioritized KSAs. This subset of the faculty KSA cross-reference data focuses on the areas slated for change.

Results and Discussion

It was determined that changes would be focused on KSAs with an average score above 2.60. Votes from seven industry BILT team members were averaged to determine the priority of each KSA. A detailed description of each KSA can be found for the BILT KSA Voting Results in the Appendix [Table 2], with the average of priority rankings for each KSA. Results shown in Table 2A report knowledge (K) defined as subjects, topics, and items of information that employees should know. Table 2B reports (S) Skills defined as technical or manual proficiencies demonstrated by competency and skills checks. Table 2C reports (A) Abilities, described as the capacity to simultaneously apply several skills and knowledge to perform an observable task or behavior. Table 2D reports Certificates such as the BioWork Certificate and cGMP Quality Systems Certification.

Faculty determined that line items with an average priority above 2.60 were reviewed to ensure thorough coverage or multiple places of exposure in the curriculum. The goal is to elevate KSAs with no exposure to "E" (Exposure) and those that are providing exposure only to "T" (Thorough). Any line item with an average priority that falls below 2.00 was considered an area where the focus may remain the same or be reduced to allow for expansion in coverage of other materials. KSA areas slated for improvements are highlighted in green [Table 3].

Table 2. KSA Voting Results

Table 2A. KSA Vote for Knowledge:

KSA'S	KSA Task Name and Description	Number of Votes (4 = most important)				
K1-37	**Knowledge: subjects, topics, and items of information that employees should know**	**4**	**3**	**2**	**1**	**Avg**
K-1	Good documentation practices (GDP)	6	1	0	0	3.86
K-2	Current good manufacturing practices (cGMP)	6	1	0	0	3.86
K-3	Standard operating procedure (SOP) use and revision process	0	7	0	0	3.00
K-4	Aseptic technique to avoid contamination	4	2	1	0	3.43
K-5	Environmental monitoring	2	2	3	0	2.86
K-6	Mathematical principles, including the metric system and conversations	1	2	4	0	2.57
K-7	Identifying, selecting, and operating tools, equipment, or technological solutions with established operating procedures and safety standards	2	2	2	1	2.71
K-8	Potential hazards related to the use of tools, equipment, and materials	1	5	0	1	2.86
K-9	Data integrity and computer applications for gathering, storage, manipulation, and transfer of information	4	2	1	0	3.43
K-10	Methods to check, examine, and record by entering information, transcribing, storing, and maintaining in written or electronic/magnetic format like batch records	5	2	0	0	3.71
K-11	Foundational science principles like microbiology, genetics, and chemistry	0	5	2	0	2.71
K-12	Major technologies and historical development of biotechnology	0	3	4	0	2.43
K-13	Legal and ethical issues affecting the application of biotechnology	0	1	5	1	2.00
K-14	Emerging and future applications of biotechnology, like cell and gene therapy and regenerative medicine	0	3	3	1	2.29
K-15	Method to clean, sterilize, troubleshoot, calibrate, operate, and maintain instruments and equipment	4	2	1	0	3.43
K-16	Upstream and downstream process implementation and monitoring	4	2	1	0	3.43
K-17	Monitoring gauges and recording instruments to ensure that specified conditions are maintained using control systems	2	3	2	0	3.00
K-18	Obtaining, weighing, measuring, and checking raw materials	3	1	3	0	3.00
K-19	Cleaning methods for manual, Clean in Place (CIP), autoclave sterilization, and Sterilize in Place (SIP)	2	1	4	0	2.71
K-20	Preparing buffers and solutions	0	5	2	0	2.71
K-21	Inspecting materials at all stages of process to determine quality or condition	3	0	4	0	2.86
K-22	Operating reactors and recovering products	0	5	2	0	2.71
K-23	Purification techniques	3	2	2	0	3.14
K-24	Formulating, filling, and inspecting product	2	2	3	0	2.86
K-25	Controlling and maintaining documentation about qualification and validation	2	2	2	1	2.71
K-26	Calibrate and validate equipment systems and assess equipment performance using control systems	1	3	3	0	2.71
K-27	Documenting and taking corrective and preventive action according to Standard Operating Procedures	1	6	0	0	3.14
K-28	Safety mindset to anticipate and prevent work-related injuries and illnesses	3	3	1	0	3.29
K-29	How to properly handle, store, and dispose of hazardous materials	2	2	3	0	2.86
K-30	Safety symbols and signs	2	2	2	1	2.71
K-31	Best practices for maintaining a safe, clean, contamination-free, clutter-free environment	3	3	1	0	3.29
K-32	Standards for selecting appropriate PPE based on biological, chemical, and physical hazards	3	3	1	0	3.29
K-33	Calibration standards and traceability	0	0	4	3	1.57
K-34	Clean room classifications	0	5	0	2	2.43
K-35	Importance of task consistency	3	2	2	0	3.14
K-36	The importance of inventory control and material traceability	0	3	3	1	2.29
K-37	Single-use technologies and the importance of closed systems	4	1	2	0	3.29

Table 2B. KSA Vote for Skills

KSA'S	KSA Task Name and Description	Number of Votes (4 = most important)				
S1-29	**Skills: technical or manual proficiencies- demonstrated by competency and skills checks**	**4**	**3**	**2**	**1**	**Avg**
S-1	Gowning, PPE, and hygiene at appropriate level/grade	4	2	1	0	3.43
S-2	Consistently following written and verbal instructions	6	1	0	0	3.86
S-3	Aseptic technique and environmental monitoring	2	3	1	1	2.86
S-4	Documenting process measurements like time, temperature, volume, pressure, pH, conductivity	3	3	1	0	3.29
S-5	Process variable monitoring and corrective actions	0	4	2	1	2.43
S-6	Identifying potential hazards related to the use of tools, equipment, and materials	2	4	0	1	3.00
S-7	Checking, examining, and recording by entering information, transcribing, storing, and maintaining in written or electronic/magnetic format like batch records	4	2	1	0	3.43
S-8	Clean, sterilize, troubleshoot, calibrate, operate, and maintain instruments and equipment	2	5	0	0	3.29
S-9	Upstream and downstream process implementation and monitoring	1	5	1	0	3.00
S-10	Using SOPs to maintain cGMPs, including good documentation practices like batch records	5	2	0	0	3.71
S-11	Monitoring gauges and recording instruments to ensure that specified conditions are maintained using control systems	1	5	1	0	3.00
S-12	Obtaining, weighing, measuring, and checking raw materials	1	4	2	0	2.86
S-13	Cleaning (manual and Clean in Place (CIP)) and sterilization (autoclave and Sterilize in Place (SIP))	1	4	2	0	2.86
S-14	Preparing buffers and solutions.	0	5	2	0	2.71
S-15	Inspecting materials at all stages of process to determine quality or condition	2	1	4	0	2.71
S-16*	Operating reactors and recovering products (Moved to Knowledge K-22, Skill not required for entry-level)	0	4	3	0	2.57
S-17	Purification techniques	2	3	2	0	3.00
S-18	Formulating, filling, and inspecting product	2	4	1	0	3.14
S-19	Labeling, packaging, and distributing final product	3	1	3	0	3.00
S-20	Recognizing common hazards and unsafe conditions that occur at work, their risks, and appropriate controls to address them	3	3	0	1	3.14
S-21	Documenting and acting upon corrective and preventive action according to Standard Operating Procedures or as directed	2	5	0	0	3.29
S-22	Maintaining compliance with current federal, state, local, and industry regulations	3	2	2	0	3.14
S-23	Properly handling, storing, and disposing of hazardous materials	1	3	2	1	2.57
S-24	Properly handling, storing, and disposing of hazardous materials	1	3	2	1	2.57
S-25	Maintaining a safe, clean, contamination-free, clutter-free environment	3	3	1	0	3.29
S-26	Demonstrate task consistency	4	2	1	0	3.43
S-27	Selecting appropriate PPE based on biological, chemical, and physical hazards	2	3	1	1	2.86
S-28	Documenting and acting upon corrective and preventive action according to Standard Operating Procedures or as directed	2	5	0	0	3.29
S-29	Performing complex QC lab techniques required in the GT industry (e.g., HPLC, ddPCR, etc.)	4	0	2	1	3.00

Table 2C. KSA Vote for Abilities

KSA'S	KSA Task Name and Description	Number of Votes (4 = most important)				
A1-15	**Abilities: the capacity to simultaneously apply several skills and knowledge to perform an observable task or behavior.**	**4**	**3**	**2**	**1**	**Avg**
A-1	Monitor measures or indicators of system performance	1	2	4	0	2.57
A-2	Operate electronic communication systems and methods (e.g., e-mail, PLCs, DCS, LIMS, DeltaV, SAP)	1	3	3	0	2.71
A-3	Communicate with team members, give and receive feedback constructively, and collaborate with others	3	4	0	0	3.43
A-4	Ask questions, report problems/concerns to supervisors when information or procedures are unclear or need improvement, or when feeling unsafe or threatened in the workplace	4	3	0	0	3.57
A-5	Interpret and clarify incidents, problems, and events.	4	3	0	0	3.57
A-6	Collaborate effectively with others, especially to solve problems	3	4	0	0	3.43
A-7	Reduce variability in tasks	3	2	2	0	3.14
A-8	Read, interpret, and use technical documents, diagrams, and SOPs	4	2	1	0	3.43
A-9	Open to considering new ways of doing things and the merits of new approaches to work	3	3	1	0	3.29
A-10	Demonstrate self-control by maintaining composure and dealing calmly with stressful situations	2	4	1	0	3.14
A-11	Anticipate, recognize, and report the existence of a problem https://portal.cccc.edu/sso/default.aspx	3	3	1	0	3.29
A-12	Work in a regulated environment	4	2	0	0	3.67
A-13	Take actions to ensure the safety of self and others in accordance with established personal and job site safety practices	2	3	2	0	3.00
A-14	Report injuries, incidents, and workplace hazards to a supervisor as soon as safely possible	3	2	2	0	3.14
A-15	Engage in safety, security, and compliance training and emergency drills	2	3	2	0	3.00

Table 2D. Certificates

KSA'S	KSA Task Name and Description	Number of Votes (4 = most important)				
C1-8	**Certificate Name**	**4**	**3**	**2**	**1**	**Avg**
C-1	BioWork	4	3	0	0	3.57
C-2	Validation Fundamentals	2	0	4	1	2.43
C-3	cGMP Quality Systems	1	5	1	0	3.00
C-4	QA Fundamentals	1	4	2	0	2.86
C-5	OSHA	2	2	2	1	2.71
C-6	ASQ	1	3	2	1	2.57
C-7	Lean Six Sigma	0	1	4	2	1.86
C-8	Cell and Gene Therapy	0	5	2	0	2.71

Table 3. Updates in Curriculum to Address Prioritized KSAs

KSA#	Priority Average	Course Number and Name					
		BioWork Bioprocess Practices & Industrial Env	**BPM 111** Bioprocess Measurements	**BPM 112** Upstream Bioprocessing	**BPM 113** Downstream Bioprocessing	**PTE 116** Pathway to Employment	**PTC 228** Pharmaceutical Issues
K4	3.43			E to T			
K5	2.86			E to T			
K9	3.43			NC to E			NC to E
K16	3.43			E to T	E to T		
K22	2.71			E to T			
K24	2.86		NC to E	NC to E	E to T		
K37	3.29			E to T			
S4	3.29			E to T			
S5*	2.43						
S8	3.29			E to T			
S9	3			E to T			
S16*	2.57			E*			
S18	3.14	E to T			E to T		
S19	3				*		
S29	3		*				

A subset of the Biotech Faculty KSA Cross Reference data focused on the areas slated for change and further discussion. Green indicates KSAs to be improved with an average priority score greater than 2.60. NC = No Coverage, E = Exposure only, T = Thorough coverage. Red indicates warrants discussion for future consideration of improvements, Blank = No coverage.

Abbreviations: BPM-Bioprocess Manufacturing Technology, PTC-Pharmaceutical Technology, PTE-Pathway to Employment

*(*indicates skill competencies for future improvements, currently prioritized at knowledge level)*

Changes implemented in course content

A list of course numbers and titles are shown in [Table 4]. Specific areas of knowledge were increased in several courses. K24: knowledge of formulating, filling, and inspecting product coverage was slated for increased exposure. The Bioprocess Practices / Industrial Environment (BioWork) Course added an article and video to Unit 8, saline solution, and I V bags. For the Bioprocess Measurements Course, manual inspection was improved in the Unit 1 lab, where vials are measured with digital Vernier calipers. Recommendations were suggested for the Downstream Bioprocessing course, to require coverage of formulating, filling, and inspecting products in the course project.

With further discussion, additional changes to increase coverage and achieve improvements in knowledge were made in multiple courses. K4: knowledge of aseptic technique to avoid contamination, and K5: knowledge of environmental monitoring exposure were elevated from “E” to “T” in the Upstream course.

Thorough coverage “T” will be implemented by student articulation of various plates used, responses to Environmental Monitoring (EM) failure, knowledge of particle counts, and identification of types of microorganisms that are potential contaminants.

Implementing the shake flask cell growth quantifier (CGQ) technology [15] for real-time monitoring in the Upstream Course and data analysis in the Bioprocess Measurements Course elevated K9: knowledge of data integrity and computer applications as they support the gathering, storage, manipulation, and transfer of data and information. Guest speaker lectures in the Pharmaceutical Issues Course produce further exposure to this knowledge. Hands-on activities in the Upstream Course using the shake flask system promote thorough coverage "T" of S4: skills needed for documenting process measurements like time, temperature, volume, pressure, pH, and conductivity.

Improvements in K37: knowledge of single-use technologies and the importance of closed systems by including industry tours and demonstrations, as well as related training in the Capstone Center at the Biomanufacturing Training and Education Center (BTEC) [8], in the Upstream Bioprocessing and Downstream Bioprocessing courses. Field trips also increase K16: student knowledge of upstream and downstream process implementation and monitoring.

Coverage increased from "E" to "T" for several skills with hands-on training in the Upstream Bioprocessing course using the shake flask system. Students perform bacterial cultures and monitor growth curves using the integrated computer software for the Cell Growth Quantifier (CGQ) system [15]. The addition of this equipment to the Upstream Course curriculum elevated several skills, including S4: documenting process measurements like time, temperature, volume, pressure, pH, and conductivity; S6: identifying potential hazards related to the use of tools, equipment, and materials; S7: checking, examining, recording, entering, transcribing, storing, or maintaining information in written or electronic formats; S8: clean, sterilize, troubleshoot, calibrate, operate, and maintain instruments and equipment. Instruction for these skills was increased from "E" to "T".

Recommendations from Discussions

K10, gathering, recording, and maintaining records, was voted a high priority but was not slated for improvements because there is ample exposure coverage in 7 classes. Likewise, K11, foundational knowledge of science principles in microbiology, genetics, and chemistry, was voted a high priority but not slated for improvements because there is sufficient coverage in 6 classes.

Further discussion of KSAs determined that S5 (skill to process variable monitoring and corrective actions) was not a high priority for this entry-level position. Instead, having K 27, knowledge of Corrective and Preventive Actions (CAPA) and the impact of deviations was given priority. Likewise, S16 (skill in operating bioreactors and recovering products) was not a high priority for an entry-level position and was considered a Knowledge K-22 priority.

S19: Labeling, packaging, and distributing the final product was considered a high priority. Plans for the new training facility will have a fill suite and other equipment to allow students to address this skill. Future processes could include expansion that would permit the production of a protein product, like GFP, and adding a component to label, package, and distribute final products for educational purposes.

S29: Skill performing complex QC lab techniques required in the Cell and Gene Therapy industry was determined to be significant to an entry-level QC technician. Suggestions for implementation include High-performance liquid chromatography (HPLC), droplet digital PCR (ddPCR), and other techniques to be considered with future equipment setup and configurations.

Table 4. Major Courses for Bioprocess Technology Program [10]

Course Number	Course Title	BioWork Certificate	Bioprocess Certificate	Bioprocess AAS
BioWork/ BPM 110	Bioprocess Practices	X	X	X
BioWork/ PTC 110	Industrial Environment	X	X	X
BIO 110	Principles of Biology		X	X
BPM 111	Bioprocess Measurements		X	X
BPM 112	Upstream Bioprocessing			X
BPM 113	Downstream Bioprocessing			X
CHM 131	Introduction to Chemistry			X
CHM 131/A	Introduction to Chemistry Lab			
BIO 175	General Microbiology			X
ISC 121	Environmental Health & Safety			X
ISC 175	Quality Assurance Fundamentals			X
ISC 278	cGMP Quality Systems			X
ISC 280	Validation Fundamentals			X
PTE 116	Pathway to Employ-Bio/Chem			X
PTC 228	Pharmaceutical Issues			X
Gen Ed	Math/English/Econ/Hum			15 hrs

The Bioprocess Technology program encompasses stackable credentials starting with the BioWork Certificate, building to the Bioprocess Technology Certificate, and culminating with the Bioprocess Technology Associate in Applied Science Degree. The course numbers have three-letter prefixes from the following programs: BPM-Bioprocess Manufacturing Technology, PTC-Pharmaceutical Technology, BIO-Biology, CHM-Chemistry, ISC-Industrial Science, PTE-Pathway to Employment with a focus on Biology and Chemistry careers, Gen Ed-General Education. Current Good Manufacturing Practices abbreviated cGMP.

Industry Experience for Community College Faculty

The Biomedical Emerging Technology Applications (BETA) Fellows NSF project [16] sponsored an 8-week experience in the Biopharmaceutical Manufacturing industry at Pfizer, a major employer of the program's students. The BETA skills fellowship aims to get community college instructors into the industry, allowing them to gain experience and increase their leadership traits by experiencing the industry's environment first-hand. Many community college faculty do not have industry experience.

BETA Fellow Dr. Brenda Judge Grubb joined the Technical Operations Team at Pfizer in Sanford, NC, for an 8-week experience. This was a valuable opportunity to interact with process technicians, tour all parts of the facility, meet with managers, sit in on meetings, and have conversations with the engineers and members of the BILT, who arranged for guided tours of all major areas of the facility.

There were many key takeaways from the experience—first, the importance of good documentation and regular communication from the process technicians to the top managers. There was a constant intentional pursuit to make improvements. Secondly, a better understanding of the Industrial environment was gained by being immersed in the environment and learning about the facility and equipment for laboratory procedures for cell culture, fermentation, environmental monitoring, media preparation, lyophilization, qualitative analysis, and other processes. A third important aspect was interacting with industry personnel and getting input for the curriculum and new training facility. The direct exposure of Community College faculty to industry strengthens relationships and increases the participation of industry partners as part of the BILT team members, encouraging the commitment to CCCC. This has been demonstrated by visiting students in class, giving seminars, and participating in networking events. Instructors having industry experience also allow for better instruction to students, enabling them to provide clear examples and scenarios for class instruction that further allow for more thorough coverage of materials across the curriculum.

Value for Employers and Community Colleges

Using the BILT model to define critical KSA requirements for entry-level bioprocess manufacturing technician positions can be an excellent way to bridge the gap and align training with industry demands. This model will allow workforce partnerships to reach their full potential by using a model with industry as co-leaders in curriculum development to ensure a "right-skilled" workforce. Human Relations (HR) and hiring managers writing job descriptions and setting up the requirements for positions need to be aware that many entry-level positions in biomanufacturing can be done by individuals trained in focused technology programs such as this, that provide hands-on training and confer certificates in that area. Furthermore, instruction that leads to an associate degree produces a workforce pool that is highly capable of completing process technician tasks from day one. This is a win-win for the company and the employees. Recruiting, hiring, and training new employees is both time-consuming and expensive. Hiring employees with certificates and associate degrees designed using industry-identified KSAs creates a greater return on this investment. These individuals will be dedicated to the work and more likely to stay with the company for an extended period. Research has shown that employees hired for entry-level jobs who join the workforce with bachelor's degrees may require additional hands-on training and tend to move on to other positions or seek higher degrees [17]. Therefore, more is invested; however, there is not the same return on investment. Future use of the BILT model for aligning workforce development across the college and other industrial systems with the local workforce demands in emerging sectors like electric vehicles, semiconductors, and other industries coming to the area.

Some employers have not invested in collaborations with community colleges because they do not realize the potential value [18-19]. To influence the curriculum and potentially harness customized training for the company's specific workforce, it must be invested in by industry employers and readily accepted by community college faculty and administrators [14].

To make degrees more transparent to industry outside of the immediate area and more portable for the students, two efforts that are emerging and gaining national attention are the Bioscience Core Skills Institute (BCSI) and the Biotechnician Assistant Credentialing Exam (BACE) [20-21]. CCCC, is working towards adding micro-credentials and providing exams for workforce skills assessment that are valid, reliable, and trusted by the bioscience industry. Working with educational and industry partners through the BCSI will provide assessment opportunities and documentation of skills.

The CCCC Biotechnology program has experienced significant expansion since it was relaunched in 2020. The success and growth of the program can be attributed to outreach efforts throughout the high schools, Veteran groups, minority and ESL-focused groups, participation in Career fairs, open houses for friends and family to come to learn about the programs, and the creation of networking events both at CCCC and at the NC Biotechnology Center are all strategies that achieved this result. Another useful tool has been online videos and statewide recruiting tools with forms that direct those interested in the program to information to sign up for BioWork at the Community College in their region. Word of mouth is very common, so not only do we have ambassadors in alumni of the programs, but we often have relatives and coworkers of alumni come to take BioWork as a continuing education course. Continuing education students are encouraged to seek more credentials by enrolling in the curriculum program.

The addition of more full-time faculty included the first position of its kind, a Career navigator, who was tasked with expanding resume writing, interview preparation, and outreach to the local audience, giving visibility to the program to all potential sectors of the communities in our service area that could benefit from the program. The other full-time faculty members and Adjunct faculty actively working in the industry have made it possible to serve more students as the program continues to grow and expand to three counties offering classes in the morning, afternoon, and night. The support of our college administration has drawn statewide and national attention, and grant funding to support new hires and provided funding for the creation of the future home of the program in the Eugene Moore Manufacturing and Biotech Solutions Center. The Biotechnology Solutions Center (BSC) will be a hub of technician training in central North Carolina, housing the BioWork continuing education training, customized industry training, and the Associate in Applied Science degree program, as well as training and certification for future credentialing and certifications for skilled technicians in North Carolina.

The next iteration of this process will focus on the KSAs needed for quality control (QC) technicians and seek the necessary credentials to fill laboratory positions to support cell and gene therapy, environmental monitoring, and other biotechnology technician roles in industry and academia. In addition, more focus on soft skills and career development will be included to help prepare students and match them with employers.

Conclusion

This report can guide other community colleges in developing curricula for technicians in various roles, as programs are tailored to match the needs of potential employers in the regions they serve. Focusing on the skills needed to do entry-level jobs opens the pool of potential employees to a population that has not been tapped. Prioritizing diversity and inclusion in the Biomanufacturing program can attract a more diverse pool of students, including individuals from underrepresented groups. This can help bridge the skilled labor gap by ensuring that a wider range of individuals have access to training and employment opportunities in the biopharma manufacturing industry. Diversity and inclusion efforts can also help identify and address systemic barriers that may prevent certain groups from entering or advancing in the biomanufacturing field. By actively promoting equity, the program can work towards eliminating these barriers and creating a more inclusive and accessible environment for all individuals. A diverse workforce brings together individuals with different backgrounds, perspectives, and experiences. This diversity can lead to enhanced innovation and problem-solving within the biomanufacturing industry. By fostering an inclusive environment that values diverse perspectives, the program can tap into the full potential of its workforce and drive advancements in the field. The biopharma manufacturing industry is evolving rapidly, and companies are increasingly recognizing the importance of diversity and inclusion in their workforce. By incorporating diversity, equity, and inclusion elements in the program, graduates will be better prepared to meet the industry's demands and contribute to a more inclusive and diverse workforce.

Students educated in programs enhanced by the BILT model have the advantage of training better aligned to industry needs. Exposure to professionals in desired positions gives students the benefit of networking, access to work-based learning, internships, and apprenticeship opportunities that lead to employment for a higher percentage of students by participating in the program. Identifying critical KSAs with the BILT model will help bridge the gap between the education provided by institutions and the industry's needs. When students and educators are aware of the upcoming trends and have access to a curriculum tailored to match technician positions of the future, it will result in a better-prepared, more diverse, and inclusive workforce. The important implications include increased representation, addressing systemic barriers, enhanced innovation and problem-solving, and meeting industry demands.

Acknowledgments

The time and dedication of the CCCC BILT team made this work possible. Special thanks to Brad Mickey, who is an industry co-lead; and to the CCCC Biotechnology Faculty, Gregg Parr (Career Navigator), Jarett McLamb (Biotechnology Instructor), Kyrone Nebolisa, Evan Riley, and Seneca Toms (Adjunct Faculty), for their contributions to curriculum alignment and implementation of improvements. This work is supported by equipment funding through the BioMade SBI Digitally Simplified Bioprocessing Fellowship Grant for the Shake Flask CGQ system. The US Economic Development Administration (EDA) Build Back Better Regional Challenge (BBBRC) Grant supports the new training Facility at the Biomanufacturing Solutions Center (BSC) in Sanford, North Carolina. The BETA Fellows project at Pfizer, Sanford, NC, was sponsored by the National Science Foundation (NSF) Award #1800909 through the National Center for the Biotechnology Workforce.

Disclosures. The authors declare no conflicts of interest.

References

[1] "2006 Biopharmaceutical Manufacturing Industry Skill Standards," Northeast Biomanufacturing Center, 2006. Accessed: Apr. 17, 2024. [Online]. Available: https://biomanufacturing.org/curriculum-resources/resources/skill-standards

[2] "Bioscience Skill Standards," InnovATEBIO. Accessed: Apr. 17, 2024. [Online]. Available: https://innovatebio.org/

[3] "Trade Adjustment Assistance Community College and Career Training," U.S. Department of Labor. Accessed: Apr. 17, 2024. [Online]. Available: http://www.dol.gov/agencies/eta/skills-training-grants/community-colleges

[4] "Biotechnology Industry in North Carolina," Economic Development Partnership of North Carolina. Accessed: Apr. 17, 2024. [Online]. Available: https://edpnc.com/industries/biotech-pharmaceuticals/

[5] "Window on the Workplace 2023," North Carolina Biotechnology Center, Dec. 2023. Accessed: Apr. 17, 2024. [Online]. Available: https://www.ncbiotech.org/news/new-report-assesses-workforce-needs-nc-biopharmaceutical-manufacturers

[6] N. J. Lowe, "Job Creation and the Knowledge Economy: Lessons From North Carolina's Life Science Manufacturing Initiative," *Economic Development Quarterly*, vol. 21, no. 4, pp. 339–353, 2007, doi: 10.1177/0891242407306359.

[7] B. Teater, "NC Books $2.1B in New Life Sciences Facilities, 2,700 Jobs in 2022, Wins Accolades for Overall Investments |," North Carolina Biotechnology Center. Accessed: Apr. 17, 2024. [Online]. Available: https://www.ncbiotech.org/news/nc-books-21b-new-life-sciences-facilities-2700-jobs-2022-wins-accolades-overall-investments

[8] J. Ruiz, G. L. Gilleskie, P. Brown, B. Burnett, and R. G. Carbonell, "Comprehensive hands-on training for influenza vaccine manufacturing: A WHO–BARDA–BTEC partnership for global workforce development," *Biochem Molecular Bio Educ*, vol. 42, no. 5, pp. 414–419, 2014, doi: 10.1002/bmb.20817.

[9] "BioWork: Home," BioNetwork: The Life Science Training Initiative of the North Carolina Community College System. Accessed: Apr. 17, 2024. [Online]. Available: https://www.ncbionetwork.org/biowork

[10] "Bioprocess Technology," Central Carolina Community College. Accessed: Jan. 14, 2024. [Online]. Available: https://www.cccc.edu/curriculum/majors/bioprocess/.

[11] A. Beheler , “BILT Model Overview – Pathways To Innovation,” Accessed: Jan. 14, 2024. [Online]. Available: https://www.pathwaystoinnovation.org/bilt-model-overview/

[12] “Implementing The Bilt Model Of Business Engagement,” National Convergence Technology Center. Accessed: 26-Jan-2024. [Online]. Available: https://connectedtech.org/business-industry-leadership-team/

[13] A. Beheler and H. Cotner, “Developing a Culture of Strategic Employer Engagement and Grant Know-How to Support Innovative Technical Programs,” presented at the 2022 ASEE Annual Conference & Exposition, Aug. 2022. Accessed: Apr. 18, 2024. [Online]. Available: https://peer.asee.org/developing-a-culture-of-strategic-employer-engagement-and-grant-know-how-to-support-innovative-technical-programs

[14] A.-C. Anderson, M. Whitney, and D. Hecht, “Building a Well-Equipped Skilled Technical Workforce by Adopting the Framework for a Cross-Disciplinary STEM Core,” *Journal of Advanced Technological Education (J ATE)*, vol. 2, no. 1, Mar. 2023, doi: 10.5281/zenodo.7776366.

[15] “Cell Growth Quantifier (CGQ) for Biomass - Overview,” Scientific Bioprocessing. Accessed: Apr. 18, 2024. [Online]. Available: https://www.scientificbio.com/cgq/#overview

[16] “Biomedical Emerging Technology Applications (BETA) Fellows project National Science Foundation (NSF) Award #1800909 through the National Center for the Biotechnology Workforce. Forsyth Technical Community College,” 2023.

[17] G. M. Green, R. H. Read, S. Lee, T. Tubon, J. G. Hunsberger, and A. Atala, “Recommendations for workforce development in regenerative medicine biomanufacturing.,” *Stem Cells Translational Medicine*, vol. 10, pp. 1365–1371, 2021.

[18] M. Dembicki, “Workforce partnerships missing their full potential,” Community College Daily. Accessed: Apr. 18, 2024. [Online]. Available: https://www.ccdaily.com/2022/12/workforce-partnerships-missing-their-full-potential/

[19] J. Fuller and M. Raman, “The Partnership Imperative: Community Colleges, Employers, and America’s Chronic Skills Gap,” AACC and Harvard Business School. Accessed: 14-Jan-2024. [Online]. Available: https://www.hbs.edu/managing-the-future-of-work/Documents/research/The%20Partnership%20Imperative%2012.12.2022.pdf.

[20] “Bioscience Core Skills Institute,”. Accessed: April 1, 2024. Available: https://bcsi.bio/

[21] “Biotechnician Assistant Credentialing Exam (BACE),”. Accessed: April 1, 2024. Available: https://biotility.research.ufl.edu/bace/

The Impact of Combining Coaching and Mentoring Skills for Successful ATE Grant Proposal Development

BARBARA HUFFMAN DE BELÓN[1]*, ELIZABETH K. HAWTHORNE[2]

[1]*Belón Research and Practice, New Bern, NC 28562, USA*

[2]*Rider University, Lawrenceville, NJ 08648, USA*

**bjbelon@gmail.com*

Abstract: This article describes how combining coaching techniques with mentoring skills can positively impact the quality of grant proposals submitted to the National Science Foundation Advanced Technological Education (NSF ATE). The research findings are based on (1) a foundational pilot study conducted through the National CyberWatch Center that ended in October 2020 and (2) an independent follow-on mentoring project named Fortifying Cybersecurity and Computing Education through ATE Grants (FORCCE-ATE) mentoring project. The FORCCE-ATE model is differentiated from other ATE mentoring initiatives in the method that college faculty mentors are trained with fundamental coaching skills reinforced through multiple practicum sessions (triads). An iterative approach was used to improve the mentor-coach training each year of the project continuously. The mentor-coaches applied their blended mentoring-coaching skills to develop competitive NSF ATE proposals when working with their community college teams. Qualitative data was collected and analyzed by an experienced, independent project evaluator. The evaluator's results show that training mentors with the coaching skills of careful listening and probing questions improves communication and rapport among mentor-coach and mentee team members.

Keywords: coach, mentor, coaching, mentoring, coaching and mentoring, International Coaching Federation, grant development, faculty, college, National Science Foundation

Introduction

Across careers and workspaces, there is a need for the enhancement of communication skills [1,2]. This need is critical at any level, not exclusively for those in managerial positions. One source for developing crucial listening and questioning communication skills is through coaching courses sanctioned by the International Coaching Federation (ICF) [3] and taught by credentialed instructors. This article focuses on only one of the FORCCE-ATE project objectives − mentor training. FORCCE-ATE is based on prior research findings from several peer-reviewed articles. The collection of these articles all concluded that acquiring a specific subset of coaching skills would enhance educators' and mentors' questioning and listening skills [1,2,4-7]. These studies were used in the development of the mentor training that is described throughout this article. In the FORCCE-ATE project, the mentor-coaches applied their new coaching skills when working with their mentee teams to submit competitive NSF ATE proposals. An iterative approach was used to improve the mentor-coach training across project years and, subsequently, the success of ATE grant proposal development among project participants.

This NSF research project sought out established mentors with grant writing knowledge and then enhanced their skill sets by adding coaching skills. As clarified by researcher Larisa Pfeiffer, "Mentoring is learning how someone more successful succeeds; coaching is learning how you will succeed" [7]. Because the coaching skills training would be delivered to adult learners, the research project is aligned with researcher Malcolm Knowles' work on his adult learner-centered Andragony model [8]. This NSF research project began with a foundational pilot year where the methodology utilized only mentoring skills. The progression from mentoring alone to the combined use of mentoring and coaching skills is documented in this paper.

Methods

Participants and Qualitative Data Collection

This research focused on collecting qualitative data to assess the effects of providing coaching skills training to mentors. Participants were all college faculty who had experience as principal investigators on NSF ATE projects. These individuals were tasked with working with other community college teams whose goal was to create and submit an NSF ATE proposal. To gather data for drawing comparisons and conclusions, the following measures were used:

- Pre and post-surveys targeting mentor-coaches
- Pre and post-surveys targeting mentee team participants
- Professional ICF-certified coach focus groups

While the qualitative data collection methods stayed the same year over year, the content of the mentor training was enhanced based on the formative assessment conducted annually by the project's external evaluator. The specific training enhancements for each year are described below.

Pilot Year Methodology and Implementation (2020)

Mentor Selections

In January 2020, the leadership team of a pilot NSF project invited six individuals to serve as mentors to one or two college teams participating in a National Science Foundation (NSF) Advanced Technological Education-funded program to strengthen grant proposals. The requirement for selecting this cadre of mentors was previous leadership experience with NSF grants and familiarity with the NSF grant submission process. Additionally, all mentors had competencies in information technology (IT) or cybersecurity, as defined by the Association for Computing Machinery (ACM):

> "A computing-based discipline involving technology, people, information, and processes to enable assured operations in the context of adversaries. It involves the creation, operation, analysis, and testing of secure computer systems. It is an interdisciplinary course of study, including aspects of law, policy, human factors, ethics, and risk management" [9].

These skill sets qualified the selected faculty to mentor other faculty in specific STEM disciplines who needed to learn the grant development process. As a result of the global pandemic of March 2020, the leadership team swiftly pivoted from planning an in-person grant development workshop to a virtual one using Canvas Free-for-Teachers' version and Zoom technologies.

Mentee Colleges

To be considered for the grant development training, college teams comprised of cybersecurity or IT faculty were required to submit an application that included an institutional support letter. Twelve (12) college teams were selected from the applicant pool.

Following the selection, the mentors received assignments that paired them with one or two college teams consisting of at least two faculty members and a grant writer. These mentors were tasked with advising and guiding the mentee teams through the entire grant development cycle, culminating in the grant submission. Over the next five months (May - September), mentors spent up to 35 hours with their respective teams on the initial idea development for the grant, a three-day virtual workshop, and the final review of the grant application before the October 2020 submission deadline.

Year 1 Methodology and Implementation (2021 - 2022)

The decision to add coaching skills to the mentor development resulted in the development of six (6) one-hour coaching modules, supplementary audio and video materials, and a component consisting of 4.5 hours of practicum (also called triads). The mentor-coach training was executed via online platforms (e.g., Zoom). This combination of coaching skills training plus practicum sessions remains a differentiator between this project and other similar Advanced Technological Education (ATE) mentoring initiatives. In mid-October 2021, the FORCCE-ATE project team received their funding notice, and delivery of the progression of the mentoring-to-mentor-coaching project began.

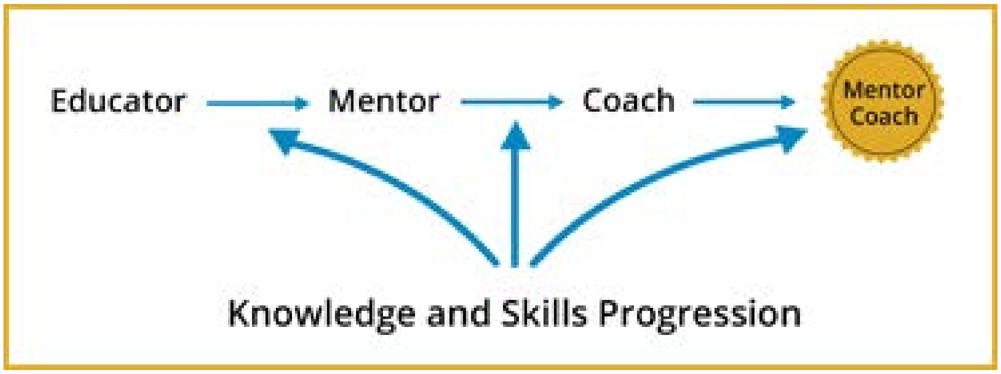


Fig 1. Progression from Educator to Mentor-Coach

This knowledge and skills progression from Educator to Mentor-Coach involved the introduction of instructional components strategically woven into the training:

- In-depth exploration of the NSF grant submission process plus access to related resources
- Coaching knowledge and skills instruction coupled with application through practicum sessions
- Monthly mentor-coach check-in sessions while working with mentee teams
- Additional support resources in between meetings

The FORCCE-ATE coaching model is similar to the model used in two student-centered coaching research studies at the University of North Carolina, Chapel Hill (UNC). Volunteer academic personnel at the UNC at Chapel Hill were also being trained in a similar coaching methodology and set of skills for their role as academic coaches [10,11]. Results from that study showed that the recipients of the academic coaching "who participated in both the in-person and online academic coaching conditions had significant increases in their metacognitive skills." While the UNC study targeted students as the recipients of the coaching, in both the FORCCE-ATE and UNC studies, the (coaching) service was delivered by college faculty that had been given basic training in coaching. The main difference within the FORCCE-ATE project is that faculty were the recipients of the coaching while students were the recipients of coaching in the UNC studies. In both cases, faculty served as coaches.

As with the pilot, potential mentors applied for the FORCCE-ATE program in the late fall of 2021. Of the six (6) selected, only one had participated in the pilot year. Additionally, three faculty from the NSF Mentor-Connect project [12] were invited to participate in the coaching training and practicum sessions, increasing the number attending training sessions to nine.

Mentor-Coach Course Rollout

Prior to the launch of the coach training, the course content, which focused mainly on deep listening skills and powerful question creation, was reviewed by three ICF-certified coaches.

The syllabus included the following content and materials:

- Discussion of ethics in coaching
- Coverage of different coaching methods used internationally
- Differentiation among the roles of counseling, mentoring, consulting, and coaching
- Development of powerful questions and deep listening skills
- Discussion on the importance of action steps taken by clients (those being coached)
- Audio sound bites from coaching sessions
- Video clips by internationally recognized coaches
- Exercises focused on session content
- Live application of coaching knowledge in the form of practicum sessions (i.e., triads)

The workbook, audio files, presentation slide decks, and all supporting materials were ported to the CANVAS LMS online platform so that mentor-coach trainees would have 24/7 access.

Mentor-Coach Triads (Practicum Sessions)

Before the course launch, the next step was to recruit ICF-certified coaches to oversee the practicum sessions (triads). Like other skill practice environments, triads are intentional sessions where the roles of coach, client, and observer are assigned to the participants. Each participant practices newly acquired coaching knowledge across the three rotations, as shown in Figure 2 below. In this case, triads were limited to 20-minute practicing coaching sessions, with an additional 5-10 minutes of recap and evaluation by the participants. After evaluation, the participants rotate into the next assigned role.

Fig. 2. Participant Rotation of Roles in Coaching Triads

Between December 2021 and February 2022, the new mentor cohort, plus three "observers" from the NSF-funded Mentor-Connect project, took part in the inaugural delivery of the course and triads. By obtaining this subset of coaching skills, these mentors received the title of "mentor-coaches."

While the coaching modules provided supporting educational theory and methods, the customized triads became the highlight of the training for the participants. For each of the three 90-minute practicum sessions, participants attempted to utilize their new coaching skills, observe others, and receive input from the ICF-certified coach who was present. So that the participants could reap the benefits from interacting with each of the ICF coaches, the coaches rotated weekly among the three triad groups of mentor-coaches. While other reviewed studies provided similar classroom work on coaching, the FORCCE-ATE project is currently the only one that combines knowledge acquisition with multiple ICF-monitored practicum sessions, coupled with ongoing meetings with mentee teams where the mentor-coach can continue to hone their coaching skills.

Skills Application with Mentees

In mid-April of 2022, ten (10) mentee college teams were selected for participation in a new cohort of the FORCCE-ATE grant development initiative and were subsequently matched with a mentor-coach. Once the mentor-coaches received their college team assignment(s), they began their mentor-coaching journey, ending when an NSF ATE proposal was submitted or at the October 2022 grant submission deadline.

Summer Workshop with Mentee Colleges

As the COVID-19 pandemic subsided, the project reverted to offering an in-person workshop, as originally planned. While interaction with mentee teams utilized online communication platforms (e.g., Zoom, Microsoft Teams), both mentor-coaches and the mentee teams attended the in-person Grant Development Workshop hosted at Prince George's Community College in Largo, MD (PGCC) in June 2022. Along with the workshop's content, this face-to-face meeting helped build trust relationships among mentee teams and mentor-coaches.

Year Two Methodology and Implementation (2022 - 2023)

The process for selecting the mentor-coach cohort and the mentee teams for year two changed little from the previous year. Four (4) of the 2022 mentor-coaches were invited back for year 2 of the grant. Four (4) additional mentors were added through the application process, bringing the total to eight mentor-coaches. With assistance from the Community College Presidents' Initiative in STEM (CCPI-STEM) ATE project [13] plus several other academic organizations, the number of applicants for the mentee teams exceeded that of the previous year, and the team profiles also appeared stronger. In March 2022, 15 new college teams and one (1) returning team (not funded in year 1) were selected for the year-2 mentee cohort. As in the previous year, these teams were paired with a mentor-coach for their April-to-October journey of crafting a competitive proposal for submission to NSF ATE.

Mentor-Coach Training

Since half the mentor-coaches had already received the coaching skills training the previous year, they were only required to attend newly added training modules on team coaching and how to begin with your mentee team. Returning mentor-coaches were also required to participate in the virtual orientation meeting and all three triads.

The *Fundamentals of Coaching* workbook developed for year one received substantial upgrades, including resequencing of materials, additional content for modules 2 and 4, additions to the appendices, and two new modules, as called for in the year one evaluation ("Team Coaching" and "How to Begin"). The final course module, "How to Begin," introduced suggestions on content for the first four meetings with their mentee teams. This module addressed the discomfort mentioned by several mentor-coaches who felt unsure how to structure their initial meeting with their mentee teams. The module's content melded mentoring activities and coaching questions that could be used to build team cohesion and focus. The workbook's title changed in year two to *Coaching Fundamentals for Mentors*.

In addition to the workbook changes, the training materials were enhanced by adding videos. The major points from the content of each of the modules were identified and repurposed in a 4- to 5-minute video, which included audio commentary. The video served as a prerequisite to the actual class. These brief videos were integrated into the Canvas LMS, flagged as mandatory, and linked to homework questions to be answered after viewing the video content.

Mentor-Coach Triads (Practicum Sessions)

The triads were again staffed by three ICF coaches: two returnees and one new coach. The only change in the triad delivery format was to honor the request by the ICF coaches to stay with one assigned triad group throughout the three sessions. They felt they could better evaluate participant growth and skill development if they observed the same mentor-coaches over the three triad sessions. What was added to the triads was a small block of time at the end of the session where the mentor-coach trainer and ICF coaches could privately discuss what they observed.

The goal of providing coaching competencies to the mentor-coaches was to increase their effectiveness during their interactions with their mentee teams. This training began at the end of January and ran through the beginning of March 2023. The three triad/practicum sessions were again required for the entire cohort. In mid-April, the college teams applying for the mentee cohort were selected. Mentor-coaches received their mentee team assignments and were expected to establish a schedule of ongoing meeting dates with their teams.

Summer Workshop with Mentee Colleges

As in year one, all mentor-coaches and at least two representatives from their mentee team attended the in-person Grants Development Workshop in June at PGCC in Largo, MD, facilitated by the FORCCE-ATE leadership team. Different in year two was the requirement to have each mentee team's Academic Dean or other college administrator attend the workshop. Their presence increased the college's overall understanding of the NSF grant process. Additionally, they identified what was at stake for their institution and how an administrator could play a significant role in supporting the mentee team. Additional post-workshop mentor-coaching was provided until the October 6, 2023 ATE submission deadline.

Results and Discussion

In the 2020 pilot year (global pandemic), the training focused on the grant development process and mentoring techniques. Coaching skills were added to the mentor training during the first year of the FORCCE-ATE project. Additional elements were added to the mentor-coach training in subsequent years. The additional training elements are listed in Table 1.

Table 1. Elements Added to the Mentor-Coach Training Each Year

Year	Mentor-Coach Training Element
Pilot Year (2020)	Mentoring Techniques
FORCCE Year 1 (2021-22)	Active Listening and Powerful Questioning
FORCCE Year 2 (2022-23)	Team Coaching and Starting with Your Team
FORCCE Year 3 (2023-24)	Assistive Technology

Pilot Year

Over the next five months (May - September), mentors spent up to 35 hours with their respective mentee teams developing the initial idea for the grant, attending a three-day virtual workshop, and reviewing the final grant application. All work had to be completed before the October 2020 submission deadline. In this pilot year of the grant-writing project, 11 of the 12 college teams submitted a project proposal to NSF. Subsequently, nine of the eleven colleges received funding for an 82% success rate compared to the average ATE successful funding rate of 23%.

Not only did this cohort's funding percentage exceed expectations, but the comments from the mentee teams reflected their satisfaction with their new knowledge set. The mentoring was shown to affect the production of competitive grant proposals positively. The research question then became the following: what other ways could the entire grant development process and learning experience be improved? Click the interactive map link for additional background information on the participating colleges. See Figure 3 below.

Fig. 3. Pilot Year - Nine Colleges Received ATE Funding

Link to active map: https://www.google.com/maps/d/u/0edit?mid=19kfcCXv2igz6AlgcUW8EKrO82nqXfTo&usp=sharing

Lessons Learned from Pilot Study

In the 2020 Pilot delivery analysis, the leadership team identified the following areas needing improvement. Filling the role of mentor coordinator earlier in the process was required to give sufficient time for creating the educational plan and training materials. The management resolution was to add a Co-PI to oversee the mentor training in the follow-on ATE grant proposal. The leadership team identified a missed opportunity to assist college teams to better prepare for the in-person grant development workshop. Also, a requirement for mentee teams to complete a pre-workshop questionnaire was added to the mentoring process. The observation that most mentee teams struggled with preparing NSF budgets and associated justification resulted in the addition of budget reviews by a leadership team member.

Related Research Studies

In 2020, two separate studies were conducted at the University of North Carolina (UNC), Chapel Hill, NC, which provided a two-day training course in coaching skills to UNC faculty and permanent staff [10, 11]. UNC's research showed positive behavioral effects accruing to attendees from in-person and virtual classes in coaching skills that utilized the coaching skills in interactions with students and peers. A second study by M. Erikson at Providence College, RI, trained graduate and undergraduate students in basic coaching skills, which they applied in peer-coaching situations throughout one semester. Their research found that "peer coaching positively affected students' personal and leadership development." However, having a well-trained coach to deliver the coaching educational aspects was crucial. Subsequent literature searches identified research on using coaching with teams [14] with implementing a "brain-based" approach to coaching [15], and a new frontier linking neuroscience and coaching [16, 17]. While research into coaching effectiveness is increasing, the number of studies utilizing a combination of mentoring and coaching with faculty subjects remains few.

NSF Project after the Pilot Year (2020): FORCCE-ATE

A new ATE project was proposed for the next grant submission cycle based on the lessons learned during the pilot year and related research findings previously described. Several added elements differentiated the proposed project from the pilot project. ICF-certified coach training research [18] showed that the mentors benefited from coaching skills, especially during the idea development phase of the grant creation process. In mentor preparation, a unique educational component added basic coaching skills to the existing mentor skills. Consequently, a co-principal investigator with formal training in coaching was selected to handle the mentor-cohort training. The working hypothesis was that mentoring, augmented by coaching skills, would enhance creativity, team focus, and buy-in and increase the overall impact of the mentor-coach role. With more engaged and focused grant writing teams, the effect should also be seen in an increase in the number of successfully funded grant proposals to the NSF ATE program solicitation. NSF funded the submission for the 2021-2024 cycle, and the *FORtifying Cybersecurity and Computing Education through ATE grants* (FORCCE-ATE) project (DUE #2055250) became a reality.

Year One (2021-2022)

Results

As with the previous year, the mentoring-coaching with the mentee cohort ended in October 2022 at the ATE submission deadline. Of the 10 college teams participating in the first cohort of FORCCE-ATE, four (4) submitted an NSF ATE grant proposal. Out of those submissions, two (2) proposals were subsequently funded. According to NSF, the number of awards trended downward soon after the long-term and societal effects of the 2020 global pandemic. Even with this downward trend, the FORCCE-ATE funding rate was 50%, as compared with the overall NSF funding rate of approximately 20% in the years immediately following the pandemic [19].

Discussion

The evaluation plan for determining the effects of providing coach skills training gathered data from the ICF coaches and the mentor-coach cohort. The ICF coaches were interviewed by the project evaluator in one-on-one settings. The coaches all agreed that the elements within the training had given the students the knowledge to listen deeply and ask probing, open-ended questions. Over the three practicum sessions, they reported seeing growth in applying skills. One recommendation was to augment the training with an ongoing practice plan to help cement the skills presented in the class training. Also recommended was adding the viewing of one complete coaching session before the first triads to give the students a better understanding of the dynamics of a real-life coaching session. Assessment of their coaching skills training and practice sessions by the mentor-coaches was done via both surveys and interviews by the project evaluator. The first survey was released after the completion of the training and triads. This survey was designed as a self-assessment focusing on perceived gains in knowledge and skills, relevance of training to the mentor-coaching assignment, and generally applicable, observed benefits to the mentor-coaches.

The evaluator's report noted that "participants overwhelmingly enjoyed the training and found the triads to be a particularly valuable learning experience." The survey also showed that participants felt the need to listen more intently. On a more granular level, 75% of the respondents felt that their ability to evaluate an individual's statements and behaviors had been increased.

One consistent theme was that while the mentor-coaches strongly endorsed the coaching skills training, they found it challenging to know when to coach versus mentor. They also identified a need for specific training on how to coach teams.

In terms of the biggest "take-aways," statements included the following:

> "Coaching is well-suited for use during ideation (i.e., idea creation)."
>
> "The value of using coaching skills became clear."
>
> "Most useful in the learning was how to optimize the client's experience with powerful questions."

When asked about how they envision applying their newly acquired coaching skills, answers revolved around the power of listening and asking open-ended questions. Examples:

> "I loved the idea of not 'fixing' the client's issues but rather questioning to help them find solutions."
>
> "I hope to have improved interactions with peers and students."

To evaluate the mentor-coach process, participants were asked to respond to questions about their perception of the training sessions' content and delivery, their learning gains, and their preparedness to serve as a mentor-coach. In Figure 4, while the original scale ranged from "strongly agree" to "strongly disagree," there were zero responses to the strongly disagree column. This figure condenses the categories in line with participants' responses.

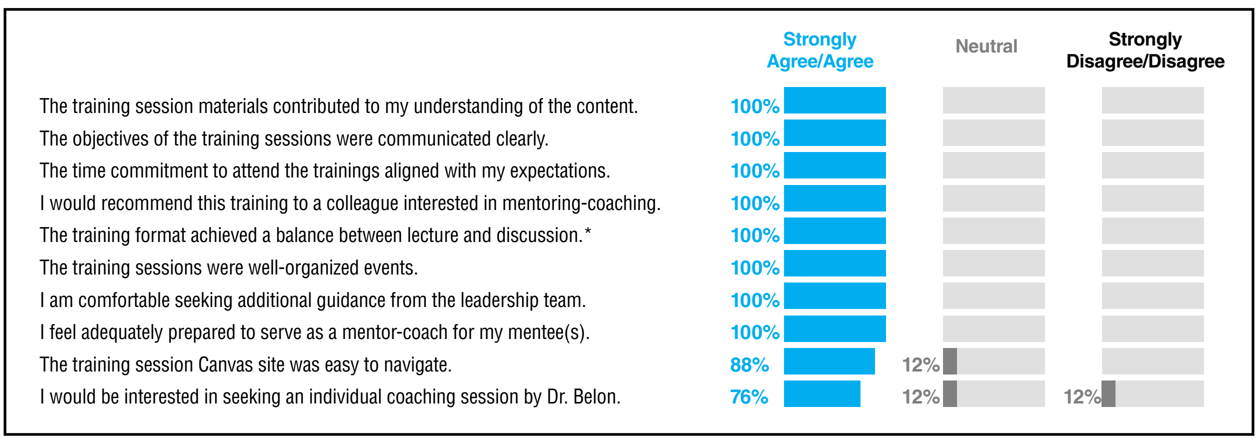


Fig.4. Year 1 Mentor-Coach Training Sessions Evaluation Findings (2022); n = 7 and n=8*

Figure 5 expands upon the evaluation report findings from Year 1 to include mentor-coach perceptions.

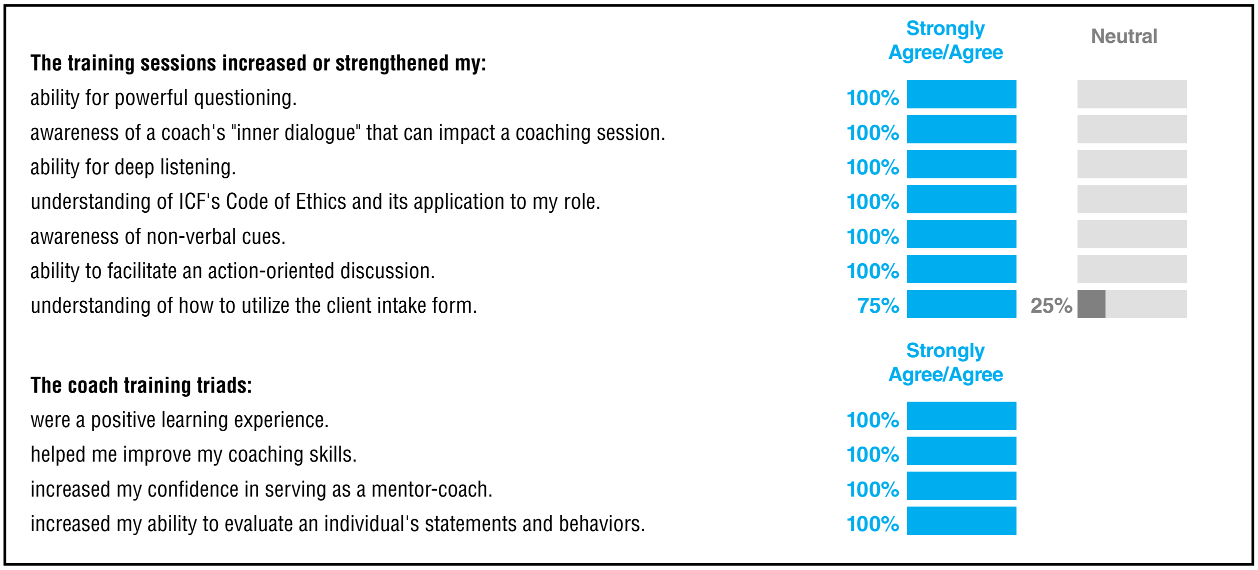


Fig. 5. Year 1 Mentor-Coach Training Sessions Evaluation Findings (2022); n=8

While it would be helpful to compare the results from the 2020 proposal submissions with those from 2022, the noticeably different characteristics of the applicant teams precluded that comparison. Some teams were directed to participate by their upper management, whether they were interested or not. Others had no institutional capacity or support, lacking grants offices or anyone with local NSF grant development experience. While all the mentee teams received grant training at the June workshop and all were assigned competent mentor-coaches there were other factors in play, including two years of the societal effects of the global pandemic that could not be mitigated by the expertise and efforts of the FORCCE-ATE leadership or mentor-coach staff.

Year Two (2022-2023)

Results

At the close of the October 2023 NSF grant filing period, 12 of the participating 16 teams reported submitting their grant proposals. At the time of publication, seven mentee colleges received an ATE award. The four (4) remaining mentee teams chose to wait until the 2024-25 grant cycle to submit. See Figure 6 for additional background information on the participating colleges. Click the link to access the interactive map.

Fig. 6. Year 2 Participants - 16 Mentee Teams and 12 Proposal Submissions

Link to active map: https://www.google.com/maps/d/u/0edit?mid=19kfcCXv2igz6AlgcUW8EKrO82nqXfTo&usp=sharing

Discussion

The assessments of coach training, triads, and instructional materials were again evaluated via two survey instruments and a series of stakeholder interviews. In the post-training survey, mentor-coaches again reported that they valued the training in deep listening and asking powerful questions and were looking forward to putting these skills into practice with their mentee teams. They felt they now understood the difference between mentoring, which is more prescriptive, and coaching, which supports solution-based, higher-level thinking among those being coached.

In the survey administered in late August 2023, after four months of working with their mentee teams, the respondents felt they had more of a practical understanding of utilizing mentoring and coaching skills during the grant development process. Their self-assessment also revealed that all but one thought they had made gains in their coaching skills, including how to facilitate actions that would advance the grant development process. The following are individual comments from the mentor-coaches.

- **On training:** "I learned new ways to get to the root of the question that the client wants to discuss."
- **Biggest takeaway:** "The importance of careful listening as a coach."
- **On future application:** "I see that coaching works in teaching, especially when students ask questions about lessons they've learned in a course."

As part of the year two project evaluation, participants were asked to respond to a series of questions about their individual learning gains from the training sessions and triads. It should be noted that for Figures 7 and 8, the same respondent chose "strongly disagree" for every survey item even though s/he provided positive comments for the open-ended questions. This respondent likely misread the direction of the Likert-style scale.

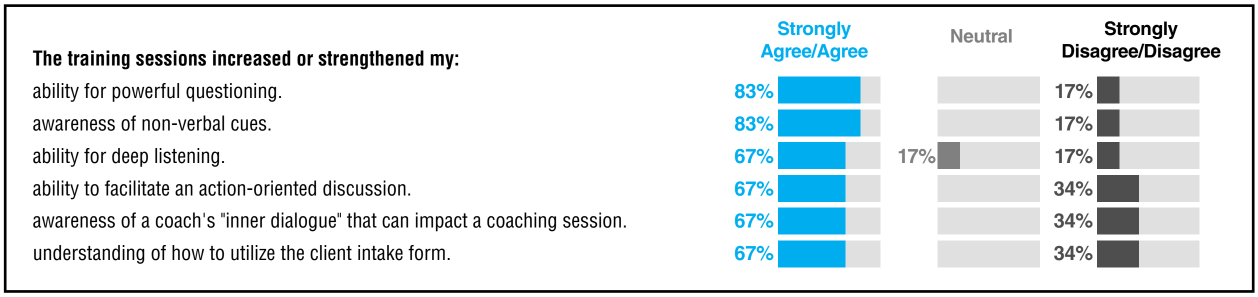


Fig. 7. Year 2 Mentor-Coach Training Sessions Evaluation Findings (2023); n=6

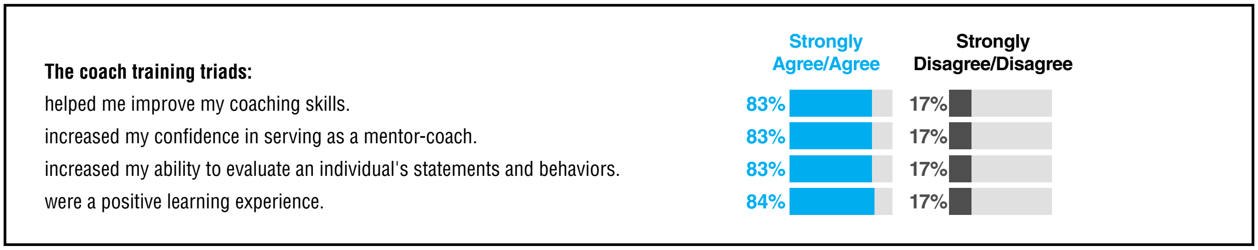


Fig. 8. Year 2 Mentor-Coach Triad Evaluation Findings (2023); n=6

Although the study is not complete and the collection of additional quantitative evidence on the effectiveness of providing educator-mentors with coaching skills continues, this observation stands out:

> Teaching basic coaching skills of listening and asking thought-provoking questions empowers the recipient (mentors) of the coaching skills to confidently use these skills at the appropriate times in their career and work environment. Their coaching drives their clients (mentee teams) to examine, synthesize, hypothesize, and validate their current understandings while moving toward their expressed goals.

While the collection of quantitative data, such as submission and funded grants, tells one story, the effect that coaching had on the mentee teams is more difficult to assess. When queried, the mentor-coaches concurred that their mentee teams appreciated and responded positively to coaching questions.

> *"I used coaching to encourage my teams when working on their goals and when they needed to find information that had already been shared in training."*

Self-reflections by the mentor-coaches consistently stated that adding coaching competencies strengthened their mentoring effectiveness and enhanced their communication skills in their professional and private lives. The PI of the Mentor-Connect project, who attended the coaching skills training, reported:

> *"What an eye-opener and enriching experience! It was extremely helpful to us to understand the difference between mentoring and coaching and to learn what is and isn't good coaching – not to mention how hard it is to get it right!"*

Conclusion and Future Directions

In summary, augmenting the skill set of faculty mentors with fundamental coaching skills for working with individuals and teams resulted in improved communication among the mentors and mentee teams. The coaching skills of deep listening and asking powerful questions served to motivate the college teams to develop a competitive ATE grant proposal. The combination of mentoring and coaching skills also empowered the mentor-coaches to use these newly acquired skills professionally and personally. The FORCCE-ATE research conclusions were consistent with the results of other studies cited in this paper. These results confirmed that the combination of coaching and mentoring skills is superior to relying solely on mentoring. Combining coaching with mentoring can be considered a viable, promising practice. In particular, the use of probing questions by the mentor-coaches was the impetus for high-level and creative thinking on the part of the mentee teams. An unanticipated but significant impact on the ATE community will be the expansion of the national pool of mentors equipped with coaching competencies.

Funded for three years, the FORCCE-ATE project will conclude in Fall 2024 with the October ATE submission deadline. Because of the long lead time needed for the NSF review and selection process can take up to nine months post-submission for notification letters to be sent to the awardee colleges. In the meantime, the submission rate of the mentee colleges provides valuable and impressive comparison data for three years. The final FORCCE-ATE funding rate can only be calculated once the last mentee team is officially notified in 2025. The future summative findings of the NSF FORCCE-ATE project will encompass four years of quantitative and qualitative data, including the pilot year. At the conclusion of the FORCCE-ATE initiative, overall project findings, including submission and funding rates, will be made available for the benefit of the broader ATE community.

Acknowledgements. This article reflects the planning and execution of the NSF FORCCE-ATE project, award #205525. We want to acknowledge the following individuals and groups who were instrumental in developing this research paper. First, we recognize our J ATE coach, Dr. Thomas Stoebe, who shared his experience crafting publication-worthy research papers. Next, we owe a debt of gratitude to our project evaluator, Dr. Blake Urbach, who designed the data collection instruments and produced the tailored dashboards that appear in Figures 4, 5, 7, and 8. Next, we are grateful to our Co-PI, Dr. Vera Zdravkovich, and all the FORCCE-ATE mentor-coaches for coming along this incredible journey of discovery with us over the years. We acknowledge the design skills of the Nelly Group that translated textual descriptions into visually appealing graphics for figures 1 and 2. Last but not least, we thank Elaine Craft of Mentor-Connect for participating in and supporting our mentor-coach training and for sharing her significant experience in mentor training for the ATE grant development process.

Disclosures. The authors declare no conflicts of interest.

References

[1] M. Erickson, S. Collins, B. Finocchio, and J. Oakley, “Developing Students’ Coaching Ability Through Peer Coaching,” *Journal of Management Education*, vol. 44, no. 1, pp. 9–38, Feb. 2020, doi: 10.1177/1052562919858645.

[2] R. H. Stowers and R. T. Barker, “The Coaching and Mentoring Process: The Obvious Knowledge and Skill Set for Organizational Communication Professors,” *Journal of Technical Writing and Communication*, vol. 40, no. 3, pp. 363–371, Jul. 2010, doi: 10.2190/TW.40.3.g.

[3] “International Coaching Federation- Professional Coaching Association,” International Coaching Federation. [Online]. Available: https://coachingfederation.org

[4] B. Garvey, P. Stokes, D. Megginson, and E. Kullar, “Coaching and Mentoring: Theory and Practice (3rd edition),” *The Coaching Psychologist*, vol. 14, no. 2, pp. 124–125, Dec. 2018, doi: 10.53841/bpstcp.2018.14.2.124.

[5] I. Nadeem, B. Garvey, and M. Down, “The Adequacy of Competency Frameworks for Coaching Academic Deans: A Critical Review.” *International Journal of Evidence Based Coaching and Mentoring*, vol. 19, no. 2, pp. 3–23, 2021, doi: 10.24384/ntr0-xf66.

[6] H. Fehring, S. Rodrigues, Eds. *Teaching, Coaching, and Mentoring Adult Learners* London New York: Routledge, 2017.

[7] L. Pfeiffer, “Mentorship vs. Executive Coaching to Address the Leadership Crisis in Community Colleges,” vol. 35, no. 1. [Online]. Available: https://www.league.org/leadership-abstracts/mentorship-vs-executive-coaching-address-leadership-crisis-community-colleges . Jan-2022

[8] M. Knowles, “The modern practice of adult education: Andragogy versus pedagogy,” The Association Press. New York. 1970

[9] “Curricula Recommendations,” Association of Computing Machinery. [Online]. Available: https://www.acm.org/education/curricula-recommendations

[10] "Coach Approach Training," Learning Center. Accessed: Aug. 21, 2023. [Online]. Available: https://learningcenter.unc.edu/coach-approach-training/

[11] M. A. Howlett et al., "An Academic Coaching Training Program for University Professionals: A Mixed Methods Examination," *Journal of Student Affairs Research and Practice*, vol. 58, no. 3, pp. 335–349, 2021, doi: 10.1080/19496591.2020.1784750.

[12] "Mentor-Connect: A Leadership Development & Outreach Initiative for ATE," [Online]. Available: https://mentor-connect.org/ [13] "CCPI-STEM," [Online]. Available: https://www.ccpi-stem.org/

[13] "CCPI-STEM," [Online]. Available: https://www.ccpi-stem.org/

[14] M. A. Howlett et al., "Investigating the Effects of Academic Coaching on College Students' Metacognition," *Innovative Higher Education*, vol. 46, no. 2, 2021, doi: 10.1007/s10755-020-09533-7.

[15] L. L. Hauser, "Shape-Shifting: A Behavioral Team Coaching Model for Coach Education, Research, and Practice," *Journal of Psychological Issues in Organizational Culture*, vol. 5, no. 2, pp. 48–71, 2014, doi: 10.1002/jpoc.21144.

[16] D. Rock and J. Schwartz,, "A Brain-Based Approach to Coaching" *International Journal of Coaching in Organizations*, vol. 4, no. 2, pp. 32–44, 2006.

[17] A. M. Grant, "Coaching the brain: Neuro-science or neuro-nonsense?" *The Coaching Psychologist*, vol. 11, no. 1, pp. 21–27, Jun. 2015, doi: 10.53841/bpstcp.2015.11.1.21.

[18] "Fluxify," [Online]. Available: https://fluxify.net/

[19] "Merit Review FY 2021," National Science Foundation, 2021. [Online]. Available: https://www.nsf.gov/nsb/publications/2022/merit_review/FY_2021_Merit_Review_Digest.pdf

Nanotechnology Outreach at Mall of America: Fostering STEAM Interest

ROBERT GIASOLLI[1]*, DAVID TAO[2], SUE NEUEN[3]

[1]*Cagent Vascular Incorporated, Wayne, PA 19087, USA*

[2]*Natural Sciences Division, Pasadena City College, Pasadena, CA 91106, USA*

[3]*Educate for Tomorrow, Honolulu, HI 96824, USA*

**rgiasolli@cagentvascular.com*

Abstract: This paper describes a simple outreach approach to engage and educate learners about the scale of familiar items, all smaller than the width of human hair. In less than 10 minutes, participants were guided through a game-like hands-on 'nanotechnology' activity. The term 'nanotechnology' and its association with scaled objects was utilized to spark participant curiosity and enthusiasm in STEAM (science, technology, engineering, arts, and math). To assess effectiveness, a pre and post-Likert scale self-assessment was given to 91 participants. Although the data is limited in size, control, and environmental factors, the results showed a positive trend in participant enjoyment and self-confidence in STEAM subjects after engagement in this simple outreach approach.

Keywords: STEAM, STEM, nanotechnology, education

Introduction

In the STEAM fields, there is a need for workforce growth, inclusive of a broad demographic, without limitations on women and minority populations [1-3]. In line with the need to increase the workforce is a need for creative and effective approaches to engage students of all demographics in STEAM subjects. Incorporating nanotechnology into hands-on engagement approaches offers opportunities to add a "spark" to learning something new in the fascinating world of the small. Students can begin to see the interconnectedness of the STEAM subjects due to nanotechnology's far-reaching applications, spanning medicine, electronics, energy, and materials science [4, 5]. By introducing students to nanotechnology, they gain a window into the limitless possibilities of STEAM and its practical applications in their lives.

Several educational institutions and teachers have embraced nanotechnology to enrich STEAM education [6-13]. Participants were engaged in a simple nanotechnology hands-on activity during this exploratory case study. The authors observed and collected data showing a positive average increase in STEAM interest of 10% in the general public (ages 9-18) wanting to learn more about the world of the small.

Methods

To celebrate its 30th Birthday, The Mall of America partnered with the Advanced Technological Education Community and the National Science Foundation for the purpose of making STEAM subjects accessible and exciting for young people outside the traditional classroom setting. The Micro Nano Technology Education Center (MNT-EC), funded by the National Science Foundation under DUE ATE #2000281, collaborated with Educate for Tomorrow (E for T) at the STEAM event to offer engaging activities aimed at building awareness of nanotechnology, its impact and career pathway possibilities. In this exploratory case study, the authors considered how a shopping center, transformed into an educational hub, could be a venue for engaging young minds by sharing the fascinating world of nanotechnology.

The activity from which the authors gathered data was taken from "Exploring the World of the Small," an E for T teaching module appropriate for students above 6th grade and applicable to most learning environments [14].

To first guide their understanding of scale and how small a nanometer actually is, the instructors presented the students with a single dark, human hair taped onto white cardstock. The students were asked to imagine slicing the width of that hair 100,000 times to represent a nanometer. Next, students were asked to find one millimeter on a metric ruler. Using these simple, tangible objects, the instructors explained that one millimeter is equivalent to one thousand micrometers; one micrometer is equivalent to one thousand nanometers.

In the "Exploring the World of the Small" activity, students were challenged to arrange scrambled images displayed on ten 8 x 8-inch cards from largest to smallest in size. All objects were based on the nanoscale ranging from 0.15 to 100,000 nanometers, the largest being a human hair, which they had just observed. The objects on the cards included images of human hair, UV and IR wavelengths, blood cells, bacteria, dust particles, DNA helix, computer wire chips, a carbon atom, and even the distance between two carbon atoms.

Figure 1: Arranging images from "The World of the Small" from largest to smallest.

Many of the groups that engaged in the activity struggled with understanding the scale of the images. To reduce the difficulty for some of the groups, the instructors would ask questions about image pairs that were out of order. The most common image that was misplaced was the width of the computer chip wire, where the common placement was second or third in the ten-card order of scale. The instructors encouraged the groups to openly discuss their thinking with each other and asked them to consider alternate pieces of information to guide them. For instance, when sizing the computer chip wire, the instructors might say, "Did you know that visible light is too large to see computer chip wires?" For larger objects, the instructors might say, "Which of these objects have you seen through a classroom microscope?" By the end of the exercise, the instructor would have asked enough questions to guide the group in arranging the images in the correct order.

To assess the outcomes of the materials and methods, the authors gathered ninety-one pre and post-assessments from middle school and high school students. The assessments gauged the effectiveness of the materials and the student's comfort level in learning new ideas in the nano-science world. The students were asked to evaluate their comfort level and interest in STEAM areas on a scale of 1-5 before and after engaging in the activity. On the scale given, one would represent being "not interested," while a five would represent being "highly interested." The participants were also asked which fields in STEAM interested them the most.

The survey included the following questions:

- How much do you enjoy discovering new things about your world?
- How much do you enjoy doing a math problem?
- How interested are you in learning about the world of small things?
- How much do you enjoy exploring new areas in STEAM?
- Pre assessment (PRE-) only- Does a career in a STEAM field interest you?
- Pre assessment only- Which field of STEAM interests you the most?
- Post assessment (POST-) only- Did you learn something new from the activities?
- Post assessment only- After today, do you plan to explore more about nanotechnology?

Results

From student responses, the pre-assessment number and percentage of the ninety-one participants who were interested in the various STEAM fields are as follows in decreasing order: Art 24.6% (29/91), Technology 22.9% (27/91), Engineering 22.0% (26/91), Science 21.2% (25/91), and Mathematics 9.3% (11/91).

Table 1. Tabulated data of 91 participants, the field of interest, the mean of responses (on a scale of 1-5), and percent change post engagement.

STEAM field that interests you the most	SCIENCE		TECHNOLOGY		ENGINEERING		ART		MATH		ALL PARTICIPANTS	
	MEAN	% CHANGE	MEAN	% CHANGE	MEAN	% CHANGE	MEAN	% CHANGE	MEAN	% CHANGE	MEAN	% CHANGE
PRE-How much do you enjoy discovering new things about your world?	4.5	4%	4.22	5%	4.35	-4%	4.28	3%	3.91	9%	4.22	3% p=0.124
POST-How much do you enjoy discovering new things about your world?	4.7		4.44		4.19		4.41		4.27		4.34	
PRE-How much do you enjoy doing a math problem?	3.0	7%	3.15	7%	3.23	6%	3.00	6%	4.45	-2%	3.19	5% p=0.022
POST-How much do you enjoy doing a math problem?	3.2		3.37		3.42		3.17		4.36		3.34	
PRE-How interested are you in learning about the world of small things?	4.2	0%	3.70	14%	3.81	8%	3.76	13%	3.82	10%	3.76	10% p=9.6E-07
POST-How interested are you in learning about the world of small things?	4.2		4.22		4.12		4.24		4.18		4.13	
PRE-How much do you enjoy exploring new areas in STEAM?	4.2	3%	4.15	7%	4.35	-2%	4.00	5%	3.55	15%	4.01	5% p=0.019
POST-How much do you enjoy exploring new areas in STEAM?	4.4		4.44		4.27		4.21		4.09		4.22	
Did you learn something new from the activity?	4.8		4.74		4.69		4.79		4.82		4.67	

The data in Table 1 indicates both a positive trend from the pre-activity to post-activity assessments and that the data is unlikely due to random chance. The most significant increase pertained to the question, "How interested are you in learning about the world of small things?" Here, there was a mean increase for all participants of 10% with a p-value of 9.6E-07 when applying a t-test function to the data. For the second and third questions related to solving math problems or exploring new areas in STEAM, all participants had a mean 5% increase with corresponding p-values of 0.022 and 0.019. All three of these data sets show low p-values, indicating that it is unlikely the change in the data set occurred due to random chance. Only the first question showed no statistical difference with a p-value of 0.124, although the mean score increased by 3% from the pre- to post-assessment. The positive mean improvements and the statistical differences shown from pre to post align with what the authors observed during the activity. One repeated comment was the group's surprise that light wavelengths were in the middle of the image set and that the width of the computer chip wire was below the width of light wavelengths. These types of statements were often followed by "How do they make things that small?" Of course, the instructors were more than happy to explain.

A set of small negative changes in the mean were collected for two of the questions in groups identified as most interested in Engineering and for one of the questions in the Math group. The two negative data sets in the Engineering group are from similar questions (i.e., "How much do you enjoy discovering new things about the world?" and "How interested are you in learning about the world of the small?"). Since the questions are similar, the authors could also anticipate the responses to be similar. What is unclear is what drove the respondents to reduce their interest in discovery. Separately, the negative data set from the Math group was related to their enjoyment of doing math problems. There is no sure explanation for why the Engineering and Math-minded students decreased some responses post-activity; the authors considered the possibility that the activity itself or the group they were paired with may have led some to lose interest or self-confidence when introduced to something totally new.

At the completion of the exercise, in addition to the post questions listed above, the students were asked two new questions. One, "Did you learn something new from the activity?" about three-fourths or 76% of the participants selected a "5," representing "Yes, I did!" Another 16% selected a rating of "4" also indicating a positive learning experience. And two, "After today do you plan to explore more about Nanotechnology?" Here, 32% of the students claimed that they most likely would explore more about nanotechnology, and 52% indicated that they might.

Conclusion

The authors recognize that the size of the study, lack of a control group, not collecting demographic information, and the challenges associated with the environment where the data was collected all limit the ability to draw meaningful conclusions from the results outlined in Table 1. Subjectively, since it was not collected rigorously, the authors observed no distinct demographic group, recalling a broad range of ethnicities and a nearly equal pairing of genders. Our method included open dialogue and group discussion, positive encouragement of the authors to aid understanding, and hints using familiar items, all with no limit on time or discussion. How any of these guided learning approaches might have influenced the increase or decrease in mean values is not clear, nor was it controlled for. Independent of these limitations, the authors were encouraged by the positive trends shown in most of the segmented groups and thought such activities entwined with advanced technologies should be considered to enhance interest in STEAM. In future research, the authors recommend exploring a broader set of activities with more structure to enable repeatability and greater confidence in the outcomes.

Despite the difficulty of unfamiliar nanoscale content, many participants said, “I enjoyed the Nanotechnology Scale Card game,” and asked where they could get a copy. When asked how they would describe their learning experience, they simply said, “It was awesome” or “I didn’t know there were things that small!”

Acknowledgements. This work was supported by the National Science Foundation (NSF) under the NSF ATE Award #2000281, Micro Nano Technology Education Center.

Disclosures. The authors declare no conflicts of interest.

References

[1] *Successful K-12 STEM Education: Identifying Effective Approaches in Science, Technology, Engineering, and Mathematics*. Washington, D.C.: National Academies Press, 2011. doi: 10.17226/13158.

[2] “Women, Minorities, and Persons with Disabilities in Science and Engineering: 2019,” National Science Foundation. [Online]. Available: https://ncses.nsf.gov/pubs/nsf19304/

[3] “Charting a Course for Success: America’s Strategy for STEM Education,” Committee on STEM Education National Science and Technology Council, Dec. 2018.

[4] A. Singh, S. Dubey, and H. Dubey, “Nanotechnology: The future engineering.,” *IJAIR*, vol. 6, no. 2, pp. 230–233, 2019.

[5] B. Bhushan, “Introduction to Nanotechnology,” in *Springer Handbook of Nanotechnology*, B. Bhushan, Ed., Berlin, Heidelberg: Springer, 2017, pp. 1–12. doi: 10.1007/978-3-540-29857-1_1.

[6] S. Sakhnini and R. Blonder, “Nanotechnology applications as a context for teaching the essential concepts of NST,” *International Journal of Science Education*, vol. 38, no. 3, pp. 521–538, Feb. 2016, doi: 10.1080/09500693.2016.1152518.

[7] A. Mandrikas, E. Michailidi, and D. Stavrou, “Teaching nanotechnology in primary education,” *Research in Science & Technological Education*, vol. 38, no. 4, pp. 377–395, Oct. 2020, doi: 10.1080/02635143.2019.1631783.

[8] N. I. Ghattas and J. S. Carver, “Integrating nanotechnology into school education: a review of the literature,” *Research in Science & Technological Education*, vol. 30, no. 3, pp. 271–284, Nov. 2012, doi: 10.1080/02635143.2012.732058.

[9] A. Lisotti, V. D. Renzi, and G. Goldoni, “The NANOLAB Project: Educational Nanoscience at High School,” *MRS Online Proceedings Library* (OPL), vol. 1657, p. mrsf13, Jan. 2014, doi: 10.1557/opl.2014.374.

[10] J. L. Feather and M. F. Aznar, *Nanoscience Education, Workforce Training, and K-12 Resources*. Boca Raton: CRC Press, 2017. doi: 10.1201/9781315219417.

[11] M. Mallmann, “Nanotechnology in school,” *Science in School*, no. 10, Dec. 2008, [Online]. Available: https://www.scienceinschool.org/article/2008/nanotechnology/

[12] B. Bhushan, “Introduction to Nanotechnology: History, Status, and Importance of Nanoscience and Nanotechnology Education,” in *Global Perspectives of Nanoscience and Engineering Education*, K. Winkelmann and B. Bhushan, Eds., Cham: Springer International Publishing, 2016, pp. 1–31. doi: 10.1007/978-3-319-31833-2_1.

[13] S. Arabacıoğlu, “Can Nanotechnology Keep Us Dry in the Rain: An Inquiry-Based Activity to Help Students Improve Their Investigation Skills,” *IJTES*, vol. 6, no. 3, pp. 410–426, Aug. 2022, doi: 10.46328/ijtes.395.

[14] R. Giasolli and S. Neuen, “Exploring the World of the Small,”. Available: https://drive.google.com/drive/folders/1QAddzahCpIeSztrsL-g0Dp8roqgmOtGB.

Data, Insights, and Solutions to Aid NSF ATE and 2-Year Colleges in Creating and Sustaining "Grant Active" Cultures

BEN REID[1]*, SHALEE HODGSON[1], KEVIN COOPER[2], RASSOUL DASTMOZD[3], DAVID BROWN[4]

[1]*Research and Evaluation, Impact Allies, Vero Beach, FL 32960 USA*

[2]*Applied Science and Technology, Indian River State College, Fort Pierce, FL 34981 USA*

[3]*PIVOT4Change Consulting, St. Paul, MN 55102 USA*

[4]*Nine Twenty-Four Strategies, Chula Vista, CA 91913 USA*

**breid@impactallies.com*

Abstract: The National Science Foundation (NSF) Advanced Technological Education (ATE) program is effective in assisting two-year college (2YC) institutions of higher education to improve the education of technicians in science and engineering, yet grant proposals from 2YCs to ATE (and NSF as a whole) have declined in number over the past decade. The problem of NSF proposals declining in numbers is multifaceted, though data demonstrates that both 2YCs and NSF can reverse or mitigate the decline in ATE proposals through identified measures; 2YCs can change their grants culture through specific institutional changes, and NSF can aid 2YCs to build their capacity to develop competitive proposals through mentoring and professional development sustainably. This article discusses data, insights, and solutions through the lens of two NSF ATE projects: Project Vision (a mentoring project) and Grant Insights (an applied research project).

Keywords: NSF ATE, grant mentorship, capacity building, broadening participation, survey findings, root cause analysis, institutional investments, decision-support systems, artificial intelligence, big data, mixed methods, applied research, cluster algorithm, computational analytics

Introduction

Advanced Technological Education (ATE) is a program managed by the Division of Undergraduate Education (DUE) within the Directorate for STEM Education (EDU) of the National Science Foundation (NSF). "With a focus on two-year Institutions of Higher Education (IHEs), the ATE program supports the education of technicians for the high-technology fields that drive our nation's economy. The program involves partnerships between academic institutions (grades 7-12, IHEs), industry, and economic development agencies to promote improvement in the education of science and engineering technicians at the undergraduate and secondary institution school levels [1]." ATE celebrated 30 years as a program in 2023. It is highly esteemed by its community of Principal Investigators (PIs) and is recognized by its broad community of practice as a huge success and important to the nation.

"We like to think ATE is the gold standard for funding opportunities in the federal government," said James L. Moore III, assistant director for the STEM Education Directorate at NSF. "Since its inception, ATE has been a model of how impactful partnerships can be in America, particularly when it comes to preparing a skilled technical workforce not only for today but for tomorrow," he said. "The program has transformed institutions and communities and helped students see themselves in well-paying STEM careers. It continues to play a significant role in developing the workforce," Moore said, adding that he is looking forward to "even bigger investments in community colleges."' Echoing these statements, American Association of Community Colleges (AACC) President and CEO Walter Bumphus stated, "It seems like we have hundreds of partnerships at AACC, but we don't have a partnership any more significant than with ATE and NSF," he said [2].

"Since 1994, NSF has invested $1.5 billion—$1,455,091,553, to be exact—in ATE grants. Five hundred and five community and technical colleges have received most of those funds. However, four-year colleges and other organizations that partner with two-year colleges are also eligible for ATE grants." This equates to funding roughly half of the approximately 1,100 community and technical colleges [2].

Yet despite ATE's successes, the number of proposals to the ATE program, and in fact, the EDU directorate and the entire NSF agency, have declined over the past several years [3, 4, 5]. NSF's official workbook, "NSF By the Numbers: Providing Statistical and Funding Information," shows that total proposals evaluated by NSF dropped from 48,197 in the fiscal year 2014 to 38,341 in 2023, a decrease of 20.44%. For proposals evaluated by NSF, specifically from two-year institutions to the Directorate of STEM Education (EDU), the number dropped from 279 to 188, a decrease of 32.62%. For proposals evaluated by NSF specifically from 2-year and Baccalaureate granting institutions (which categorically best represent community and technical colleges while excluding universities awarding Masters and Ph.D. degrees) to EDU, the number dropped from 505 to 322, a decrease of 35.6% [6].

The reasons for this decline vary but include factors such as a complex application process, lack of faculty and staff capacity and expertise due to other priorities, and burnout [7]. Additional barriers to proposal development include the lack of an institutional culture and commitment that values or supports grant work, lack of experience or knowledge about the proposal development process, and limited technical expertise to support proposal development [7]. Finally, while faculty in 2YCs benefit from developing grant proposals, the role of these faculty is typically different from that of four-year institution faculty, focused more on teaching than research [4, 8]. Having noted these and other obstacles to 2YCs that could be overcome by providing external support to 2YC faculty and administrators, ATE began supporting mentoring and capacity-building projects to help colleges pursue and sustain grant development efforts and ultimately achieve the NSF ATE mission of assisting 2-year IHEs to improve the education of technicians in science and engineering.

However, while effective, institutional investments from NSF and individual 2YCs still suffer from inefficiencies; for example, not all mentoring efforts result in grant submissions or sustainability. Part of the inefficiencies is that the variances explaining grant funding and outcomes across the profile of 2YCs are not yet understood, nor are AI tools combining big data and localized data being widely used. Thus, individual 2YCs and Principal Investigators (PIs) having the greatest likelihood of success with grants are not being intentionally identified through data-driven processes at the onset of NSF mentoring projects; the effecting result is that NSF and 2YCs are not making the most well-informed and judicious decisions regarding where and how to invest the time, effort, and resources towards professional development and institutional capacity building.

This article focuses on data, insights, and solutions for improving 2-year colleges' and mentorship programs' efforts to build grant capacity and sustainability. It is based on the authors' involvement in two ATE-supported projects:

1. Project Vision, an ATE mentoring project, was established in May 2020 under DUE # 2018198, "Broadening Institutional Participation in the NSF Advanced Technological Education Program." Ben Reid and Shalee Hodgson are the independent evaluation team; Kevin Cooper is the PI; Rassoul Dastmozd and David Brown are the co-PIs. Project Vision helps colleges discover and match innovative ideas with NSF funding opportunities and is led by a seasoned team of NSF ATE experts, former faculty and senior college administrators, and former NSF program officers. Project Vision's goal is to provide 2YCs with expertise to generate ideas and subsequently support capacity building at each college so that these colleges can regularly submit proposals when appropriate to DUE.
2. Grant Insights, an ATE-applied research project, was established in October 2022 under DUE # 2202169, "Grant Insights for Research and Development (GIRD): Using Big Data Centered Mixed Methods to Explain Variances in Grant Funding and Outcomes at Two-Year Colleges." Reid is the PI, Dastmozd is a co-PI, and Hodgson and Cooper are on the Advisory Board. The research objective is to explain variances in grant funding and outcomes amongst similar 2YCs. Mixed methods research design is being conducted combining four types of data: (1) algorithm-derived meta-data on 2YC characteristics and performance, (2) public and campus institutional data, (3) surveys of college and program faculty and administrators, and (4) in-depth interviews with college and program faculty and administrators. Grant Insights employs this innovative research design approach to classify colleges based on campus characteristics and draw comparisons between their grant infrastructures, allowing the researchers to identify best practices employed by colleges that are proficient in securing external funding that can be adopted by colleges that are not yet as proficient. The goal is for NSF ATE and 2YCs to use these project results to determine impactful practices that can guide institutional investments.

This article communicates:

- Project Vision's survey results: Understanding Proposal Submissions from Two-Year Colleges (2YCs). The purpose of the nationally distributed survey was to understand proposal submission trends, motivators, and inhibitors at 2YCs from the perspective of faculty, administrators, and presidents. It received 238 responses from 134 unique 2YCs and highlighted the variances in grant funding and the effects of incentives, support, and changes to senior administrations upon 2YC grantsmanship and proposal submissions.
- Project Vision's root-causes analysis: Addressing the Key Factors to Being Grant Active.
- Grant Insights' innovative quantitative research methods, which use big data algorithms, cluster analyses, and decision-support systems commonly used in the financial and healthcare sectors, are applied in this project to 2YCs.
- Project Vision's use of Grant Insights' computational analytic tools to identify appropriate prospective mentee 2YCs more efficiently.
- Grant Insights and Project Vision studies are underway to identify, respectively, the characteristics and factors that differentiate colleges with varying levels of external funding and the characteristics of colleges where mentorship efforts have led to relatively low and high success rates. The intended purpose of these studies is to inform NSF and IHE institutional investments with a high return on investment and broaden participation.

Methods

This section addresses three methods for their corresponding results in the following section:

1. Project Vision's survey results: Understanding Proposal Submissions from Two-Year Colleges.
2. Project Vision's root-causes analysis: Addressing the Key Factors to Being Grant Active.
3. Grant Insights' quantitative research methods using big data algorithms, cluster analyses, and decision-support systems.

Project Vision's Survey Results: Understanding Proposal Submissions from Two-Year Colleges

The first project activity of Project Vision's PI and evaluator teams was to collaboratively develop (using multiple rounds of iterations) and distribute a survey to assess the landscape at the nation's two-year colleges regarding issues connected to pursuing NSF grant support. These survey results (See Results section) helped inform Project Vision's mentorship efforts [9].

- Survey Title: Understanding Proposal Submissions from Two-Year Colleges.
- Purpose of the Survey: To understand proposal submission trends, motivators, and inhibitors at 2YCs from the perspective of faculty, administrators, and presidents.
- The survey was disseminated through multiple channels, including the Project Vision PI and evaluator teams, ATE lead program officer, ATE Central, AACC, Rural Community College Alliance (RCCA), CREATE National Energy Center, Regional Center for Nuclear Education and Training (RCNET), Center for Laser and Fiber Optic Technical Education (LASER-TEC), and National Center for Systems Securing and Information Assurance (CSSIA). Two hundred thirty-eight responses were received from 134 unique 2YCs, and highlighted the variances in grant funding and the effects of incentives, support, and changes to senior administrations upon 2YC grantsmanship and proposal submissions.

Root-Cause Analysis by Project Vision: Addressing the Key Factors to Being Grant Active

Following Project Vision's pilot year and the first months working with Cohort 2, the Project Vision leadership team and external evaluator took a step back to assess the learnings to date. Three broad evaluation questions measured outcomes and addressed opportunities: performance versus plan, consequences of Project Vision mentee institutions, and consequences of Project Vision on NSF DUE. The data sources included three mentorship surveys, pre, mid, and post; notes from open office hours, which were held monthly for mentee colleges and subject matter experts (SME); notes from topic-specific calls that were based on common cohort foci areas; a professional development webinar series; project documentation from PIs, Co-PIs, SMEs and the project manager; mentee colleges' verbal and forwarded Proposal Panel Reviews; and interviews of Project Vision PIs and SMEs. After analyzing all these data, two insights to improve operations and underlying factors to sustained grant activity were realized: 1) there were differences internally (PIs, SMEs, evaluator) and within the community of practice (other mentor organizations and 2YC stakeholders) on the ways different people speak of and measure the factors that lead to grant success and sustainability (e.g., characteristics, strengths, limitations, impediments) and, 2) only a few factors are significant in determining whether a college will be a repeat submitter of grant proposals.

So, the team sought to identify the key factors and create a common language set and quantifiable reporting system, which could be used as a regression analysis model to measure how the factors helped or hindered the achievement of a college's grant activity results. This model formed the basis for the next two pieces phases to identify the root causes behind grant proposal activity at 2YCs:

- The evaluator conducted in-depth interviews with the three PI/Co-PIs and eight SMEs (range: 8 to 47 minutes; mean: 32 minutes). Collectively, these individuals have more than 200 years of experience in higher education and NSF award roles. The interviews were coded for common themes and presented back to the group of participants for discussion, clarifying modifications, and consensus. Derived from the responses common themes were three key factors and seven primary sub-variables most determinant of whether a 2YC is likely to become and sustain being "grant active."
- This framework formed the post-mentorship report out survey, which is now integrated from multiple perspectives: mentee faculty, mentee administrators, Project Vision PI/Co-PIs, and Project Vision SMEs.

Grant Insights' Quantitative Research Methods Using Big Data Algorithms, Cluster Analyses, and Decision-Support Systems

Large industries use cluster algorithms to identify and categorize organizations that are similar in style. For example, mutual funds create diverse portfolios by using algorithms to place companies into different clusters and invest in companies in each of those clusters. Co-PI Dr. Baechle developed the Portfolio Mapper as a research tool to illustrate non-intuitive relationships among stock trades; a case in point, his analyses of Fortune 500 companies reveal that Tesla trades more like a software company than a car company due to Tesla's strengths in automation, sensory, and battery technologies. Another car company, like Ford Motor Company, could refer to this analysis and assess whether strategically adjusting its organizational culture and operations may cause it to function and be valued more like Tesla.

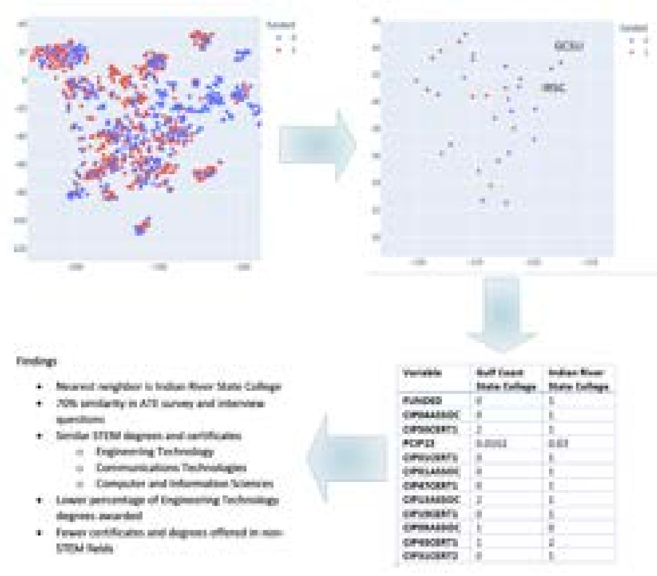


Fig. 1. Visual Representation of Grant Insights Process

As a preliminary exercise, we created a beta algorithm starting with 2,330 variables of real data points from the US Department of Education (USDOE) College Scorecard and NSF. Figure 1 clusters colleges with ATE funding (red) and colleges without ATE funding (blue) based on hundreds of factors. We can compare colleges to peer institutions on hundreds of factors and common factors between grant-proficient colleges and how less proficient colleges differ. The major strength of this project is the application of big data analyses common in high-tech industries with limited application in higher education.

Results and Discussion

This section addresses the corresponding results from the previous section, along with discussing why, how, and the results of Project Vision's use of Grant Insights' analytic tools:

1. Project Vision's survey results: Understanding Proposal Submissions from Two-Year Colleges (Figure 2 and Table 1).
2. Project Vision's root-causes analysis: Addressing the Key Factors to Being Grant Active.
3. Project Vision's use of Grant Insights' computational analytic tools to identify appropriate prospective mentee 2YCs more efficiently.

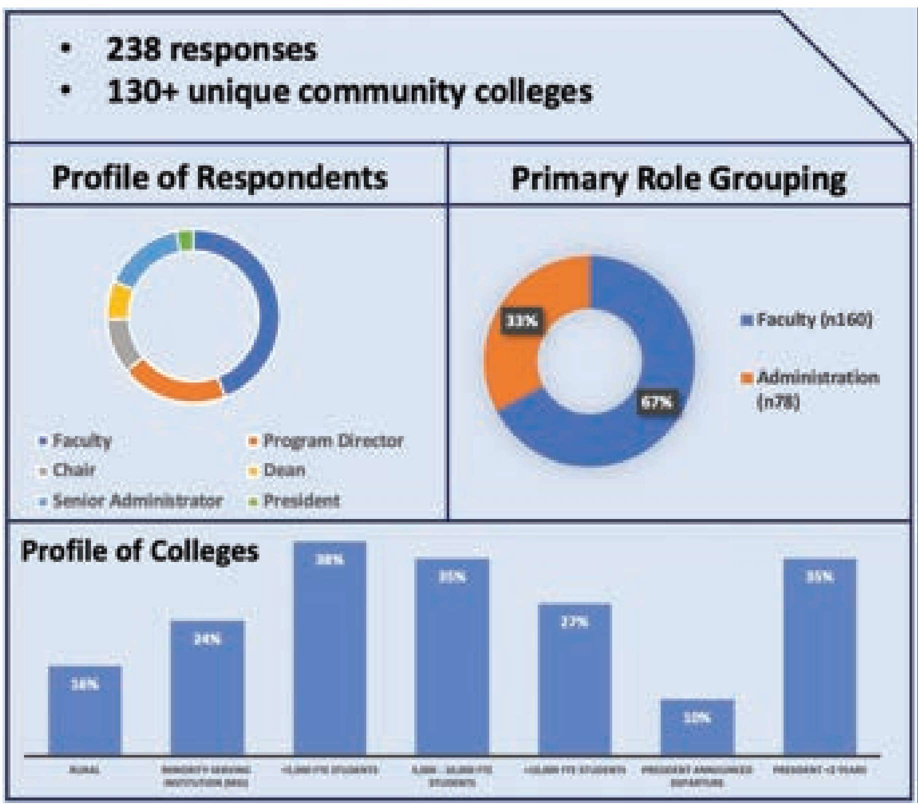


Fig. 2. Project Vision's survey results: Understanding Proposal Submissions from Two-Year Colleges.

Figure 2 provides a breakdown of Project Vision's 238 survey responses from 130+ unique community colleges. This includes the types of respondents by job title and primary role, as well as a profile of responding colleges that included the identifying categories of rural location, minority-serving institution, less than 5,000 FTE students, 5,000-10,000 FTE students, a president that had announced their departure, and a president that had been at the college less than two years [9].

Table 1. Project Vision survey results: Four key insights

Key Insights	Details
1) Lack of INCENTIVES is the greatest limiting factor for faculty to develop grant proposals.	• 69% (n=163) disagree that their college is structured to incentivize faculty to pursue grant funding. • 82% (n=194) need more incentives for developing proposals and implementing an award. • 83% would be motivated [41% definitely, 27% probably, 15% would consider] to submit a grant proposal for a stipend or release time for their development effort(s). • 88% would be motivated [41% definitely, 29% probably, 18% would consider] to submit a grant proposal for a stipend or release time for the grant management responsibilities.
Suggestion: As a requirement in the NSF-ATE solicitation, state that proposals must describe how faculty are to be motivated to complete faculty adoption of the work.	
2) Faculty need more SUPPORT in developing proposals and managing awards.	• 71% (n=168) need more support writing grant proposals. • 74% need more institutional support in managing the grant award. • 69% need more assistance formulating an innovative idea to match grant funding opportunities. • 72% need more assistance identifying and bringing together partners in a grant proposal.
Suggestion: Continue scaling independent mentoring organizations and encourage peer-to-peer mentoring among already funded ATE grant recipients. Additionally, promote peer mentoring at ATE PI and HI-TEC Conference sessions.	
3) Effect of changes to senior administration on proposal submissions.	• Highly dependent on prior experience with grants of the incoming president (qualitative interviews) • Disconnect between faculty and administration perspectives on the effect (administration thought the number of proposals increased while faculty thought the opposite)
Suggestion: Explicitly emphasize professional development, encouragement, and dissemination of the value of ATE grant funding to the College Board of Trustees, so it is a key criterion in selecting a new president.	
4) Key themes from qualitative interviews of presidents that promote grant-seeking efforts.	• Major themes emerged: (a) support for grant-seeking efforts from presidents, (b) alignment with the institution's strategic priorities, (c) having an infrastructure in place (human, talent, capacity), and (d) sustainability efforts after the grant project is completed at the recipient institutions.

Table 1 illustrates the three key takeaways from the Project Vision Survey, along with a fourth takeaway from qualitative interviews conducted by the project team coinciding with the survey conducted by the independent evaluation team, and suggested actions to support colleges becoming and sustaining "grant active" status. Details summarizing survey responses are also provided, giving insight into how and why the key takeaways were developed [9]. This analysis highlights that while existing mentoring projects support grant work in 2YCs, gaps still exist to contend with in strengthening the success of 2YCs in proposal development.

Project Vision's Root-Causes Analysis: Addressing the Key Factors to Being Grant Active

The data analysis and interview coded themes produced three key factors and seven primary sub-variables most determinant of whether a 2YC is likely to become and sustain being "grant active." Below are the key factors and variables using plain language from the interviews:

1. Value Proposition <u>Buy-in</u> of Grants, NSF, ATE, and Industry-partnerships
    1.1. Administrators - understand the benefits and the costs and agree to make it happen.
    1.2. Faculty - understand the benefits and the costs and agree to at least "jump in the pool"; thereupon, their overall experience will largely determine if they will "stay in the pool" and integrate grants and research in their academic careers complementing teaching.
2. Faculty / Principal Investigator User Experience <u>Design</u>
    2.1. Compensation models - equitable course release time or additional contract for grant work.
    2.2. Support structures - specifically, human resources; "Academic Support Staff" or time from executives to operationally and fiscally manage and report on the grant.
    2.3. Encouraging environment - Administrator/Leadership attitude and actions that communicate to faculty that grants are seen as positive and valuable.

3. Depth of Team in Capacity and Expertise
    3.1. Sufficient number of faculty members and disciplines.
    3.2. Driven grants department or equivalent and administrators providing grant expertise.

*Additionally, recognized as a key factor but ultimately outside the sphere of direct influence of 2YCs was the size and type of local and regional industry employers.

Project Vision Cohort 1: Post-mentorship Survey Results

After the interviews of the three PI/Co-PIs and eight SMEs were coded and produced the above framework of Key Factors to Being Grant Active, they were converted into survey questions and administered to Project Vision's first cohort in a Post-Mentorship Survey with the following results (Tables 2-4) [10].

Table 2. Do your college and colleagues buy into the value proposition of "grants," NSF, ATE, and industry partnerships?[a]

Primary sub-variables	Somewhat/ mostly disagree	Slightly disagree	Neither agree nor disagree	Slightly agree	Somewhat/ mostly agree	Completely agree
Administrators are active in and advocate for grant funding and industry partnerships.		7%			20%	33%
Faculty are active in and advocate for grant funding and industry partnerships.	13%	27%	13%	20%	20%	7%

[a]Overall rating, no=1, yes=14

Table 3. In your lived experience and observations, is the faculty with grant development and PI roles a positive experience?[b]

Primary sub-variables	Completely Disagree	Somewhat/ mostly disagree	Slightly disagree	Neither agree nor disagree	Slightly agree	Somewhat/ mostly agree	Completely agree
There are equitable compensation models at my college.		13%	7%	27%	20%	7%	27%
There are adequate support structures in place at my college.	7%	13%	13%	13%	13%	13%	27%
There is a grant-encouraging environment at my college.		7%		13%	40%	13%	27%

[b]Overall rating, no=2, yes=13

Table 4. Does the college have "depth of team" in capacity and expertise?[c]

Primary sub-variables	Completely Disagree	Somewhat/ mostly disagree	Slightly disagree	Neither agree nor disagree	Slightly agree	Somewhat/ mostly agree	Completely agree
The college has sufficient numbers and expertise of faculty members and program disciplines.		13%	7%	7%	27%	33%	13%
The college has sufficient numbers and expertise in grants department and administrators.	13%		7%	20%	27%	33%	

[c]Overall rating, no=7, yes=8

The Project Vision Cohort 1 Post-mentorship Survey was administered to gain feedback directly from the faculty and administrators most engaged in the Project Vision mentoring regarding their professional gains and experiences, the usefulness of Project Vision's offerings, and their broad observations and opinions on where their college stands in terms of capacity and how to engage and sustain grant activity. Twenty-five participants received the survey, and 15 responded (60% response rate), including eight faculty and seven administrators from eight two-year colleges [10].

Tables 2-4 provide detailed survey results, illustrating the three key factors and seven primary sub-variables determining whether a 2YC is likely to become and sustain being "grant active." The responses were used as a forecasting and regression model for each mentee college but were reported in aggregate for confidentiality purposes. The range of responses correlates to the differences between colleges and disconnects between faculty and administration [10].

The significance of the Project Vision mentored colleges was further compared and correlated with the previous national survey results on these topics. For example, when asked about their overall "grant experience" (a key indicator of whether faculty and administrators will continually seek to incorporate PI roles into their primary job responsibilities), the respondents to the national survey (n=226) answered 53% Positive, 43% Mixed, and 4% Negative [9]; whereas Project Vision's first cohort respondents (n=15) replied 93% Positive, 7% Mixed [10].

Project Vision's Use of Grant Insights' Computational Analytic Tools to Identify Appropriate Prospective Mentee 2YCs More Efficiently

Project Vision began using the Grant Insights analytic tools in its third year to recruit for its fourth cohort to identify appropriate prospective mentee 2YCs and PIs more efficiently. To recruit Project Vision's first three cohorts, it took personalized outreach messages to an average of 74 2YCs to recruit 13 2YCs for a single mentee cohort. For its fourth cohort, Project Vision targeted 26 2YCs using the Grant Insights tools and recruited 18. By finding and assessing 2YCs that are statistically most similar to one another (not just geographically or by a subjective set of benchmarks), Project Vision was able to identify colleges "statistically nearby" 2YCs that have high-performing track records with ATE funding yet do not have ATE themselves. This particular method and tool helped with more accurate and efficient identification of appropriately ready 2YCs, explaining the value proposition and contextualizing the pitch of why that new 2YC should strongly consider pursuing NSF ATE funding. Using traditional methods, the 3-year average was one recruit for every 5.7 outreaches to a prospective 2YC; using the Grant Insights tool, that number was reduced to 1 recruit for every 1.4 outreach, an accuracy, and human resource efficiency savings of 400%.

Because four cohorts is not a statistically significant sample size, we are continuing to track inputs and outcomes to assess whether and how these analytic tools and processes evolve over time from a promising practice to a best practice, along with understanding how others use them in their particular use cases.

These methods, processes, and results have been shared and discussed with the NSF ATE community through two different conferences to date:

1. High Impact Technology Exchange Conference (HI-TEC), July 26, 2023 in Atlanta, GA [11]
   - Session title: Using AI and Machine Learning to Broaden Participation in the ATE Community
   - Abstract: Employ big data sets and tools and AI (Artificial Intelligence) and ML (Machine Learning) techniques to be better equipped to harness the data revolution. Learn how to add big data sets and use tools of dimensional reduction, cluster algorithms, and spectral analysis in your specific ATE work for the aim of increasing participation (e.g., STEM enrollment, completion, diversity metrics, funding, and usage of a technology) in your respective projects.
   - Presenters: Ben Reid, Director and Principal Investigator, Grant Insights for Research and Development (GIRD), Impact Allies, Vero Beach, FL; Kevin Cooper, Director and Principal Investigator, Project Vision, Indian River State College, Fort Pierce, FL
2. ATE Principal Investigators Conference, October 25, 2023, in Washington, D.C. [12]
   - Workshop title: Using AI to Broaden Participation in ATE + How to Conduct Applied Research
   - Abstract: Two distinct foci applicable across STEM disciplines are addressed in this hands-on workshop: (1) how to employ big data sets and Artificial Intelligence, and (2) how to design and conduct applied research. Through the lens of an applied research project that uses big data with localized data to understand grant ecosystems, participants will learn how to use these skill sets in their specific ATE work for the purpose of increasing participation (e.g., STEM enrollment, completion, diversity metrics, funding, usage of a technology) in their respective fields.
   - Presenters: Christopher Baechle, Co-PI, Impact Allies, FL; Rassoul Dastmozd, Co-PI, Project Vision and GIRD, MN; Ben Reid, Director and PI, Impact Allies, FL; Will Tyson, Co-PI, University of South Florida, FL

Conclusion

For 2YCs in the United States, a culture that supports institutions in being “grant active” can be very valuable in supporting faculty professional development, innovation, and new program development. Both Project Vision and Grant Insights, through their respective foci, have made significant contributions to the knowledge base of how to contribute to the NSF ATE mission of assisting 2-year IHEs to improve the education of technicians in science and engineering. Yet, much remains to be accomplished through mixed methods research, evaluation of practice, development of tools, replication of promising practices by independent researchers, and refinement by testing the resulting methods, tools, and best practices. Project Vision will continue to measure and evaluate its work with mentee colleges, and Grant Insights will be producing findings reports this year from its separate mixed methods applied research and computational analytics. Grant Insights and Project Vision studies underway identify, respectively, what characteristics and factors differentiate colleges with varying levels of external funding and the characteristics of colleges where mentorship efforts have led to relatively low and high success rates. The intended purpose of these studies is to inform NSF and IHEs which institutional investments have high and low returns on investment and broaden participation in the NSF ATE mission.

Acknowledgments This work was supported by the National Science Foundation (NSF) under awards 2018198 and 2202169.

Disclosures. The authors declare no conflicts of interest.

References

[1] "Advanced Technological Education (ATE)," National Science Foundation. [Online]. Available: https://new.nsf.gov/funding/opportunities/advanced-technological-education-ate

[2] M. Patton, "Reflecting on 30 Years of ATE," Community College Daily. [Online]. Available: https://www.ccdaily.com/2023/10/reflecting-on-30-years-of-ate/

[3] R. Dastmozd, D. Brown, K. Cooper, "Project Vision Handbook," National Science Foundation, NSF GRANT No. 2018198, Jun. 2020. Available: https://projectvis.org/wp-content/uploads/2020/08/PV-Handbook-ADA.pdf

[4] M. Mastronardi, D. R. Brown, M. Borrego, and J. Krupczak, "Capacity Building Workshop for Two-Year Colleges Seeking U.S. National Science Foundation Funding," *Community College Journal of Research and Practice*, vol. 0, no. 0, pp. 1–13, 2023, doi: 10.1080/10668926.2023.2236039.

[5] E. L. Craft, K. Wosczyna-Birch, and C. B. Forrest, "Gaining the Competitive Edge in Proposal Submission to the National Science Foundation Advanced Technological Education Program (NSF-ATE): Mentor-Connect," presented at the 2017 ASEE Annual Conference & Exposition, Jun. 2017. Accessed: Apr. 18, 2024. [Online]. Available: https://peer.asee.org/gaining-the-competitive-edge-in-proposal-submission-to-the-national-science-foundation-advanced-technological-education-program-nsf-ate-mentor-connect

[6] "Workbook: NSF by Numbers," National Science Foundation. Available: https://tableau.external.nsf.gov/views/NSFbyNumbers Trends?%3AisGuestRedirectFromVizportal=y&%3Aembed=y&%3Alinktarget=_blank&%3Atoolbar=top

[7] R. A. Goff-Albritton, P. A. Cola, J. Pierre, S. D. Yerra, and I. Garcia, "Faculty Views on the Barriers and Facilitators to Grant Activities in the USA: A Systematic Literature Review," *Journal of Research Administration*, vol. 53, no. 2, pp. 14–39, 2022,

[8] P. Renninger, A. Meilof, T. Pitts, and J. K. Smalley, "Why Should Community College Faculty Write Grant Proposals?," *Community College Journal of Research and Practice*, vol. 31, no. 9, pp. 725–729, Sep. 2007, doi: 10.1080/10668920701564032.

[9] *"Project Vision's Survey Results: Understanding Proposal Submissions from Two-Year Colleges," Project Vision,* National Science Foundation.

[10] "*Project Vision: Cohort 1 Post-Mentorship Survey Results," Project Vision*, National Science Foundation.

[11] "Sessions 2023 (Concurrent)," High Impact Technology Exchange Conference. [Online]. Available: https://www.highimpact-tec.org/sessions-2023/

[12] "2023 ATE Conference," AACC American Association of Community Colleges. [Online]. Available: https://www.aacc.nche.edu/programs/advanced-technological-education/2022-ate-conference/

ATE Assessment Practices: Reconceptualizing the Role of Participants in Professional Development Evaluation

ARLEN GULLICKSON[1], ROBIN DATTA[2]*, AMY GULLICKSON[3], MIA CHEN[4]

[1]*The Evaluation Center, Western Michigan University, Kalamazoo, MI, 49008, USA*

[2]*Department of Political Science, Edmonds College, Lynnwood, WA, 98036, USA*

[3]*Assessment and Evaluation Research Center, University of Melbourne, Melbourne, Vic, 3010, Australia*

[4]*Faculty of Education, University of Melbourne, Melbourne, Vic, 3010, Australia*

**rdatta@edmonds.edu*

Abstract: Research shows formative assessments substantially strengthen learning and support summative assessment/evaluation practices. These practices are not widely applied in ATE's professional development (PD) efforts. This study focuses on participant teachers' assessment involvement to increase student learning and enhance outcome evaluations. We surveyed all principal investigators of ATE projects in 2022 who applied assessments in their 2021 PD efforts (N=70). Findings show that a minority of PD efforts apply formative assessment practices to strengthen PD outcomes or meet ATE's evaluation specifications. Assessment practices were most prevalent for summative purposes at the close of PD activity; a large majority assessed teachers' interest and learning in the PD and their intentions to use and teach what was learned on return to their classrooms. A third or less followed up to assess outcomes in teachers' schools. Similarly, thirty percent or less addressed matters of context at any stage of the PD efforts, and a few, 11 percent, followed up to assess the context in the schools. Concomitantly, the findings show where and how attention to formative assessment in the PD learning process can increase teacher involvement in assessment practices, making PD instruction more effective and strengthening outcome evaluations in participant teachers' home classrooms.

Keywords: formative assessment, summative assessment, evaluation, formative evaluation, summative evaluation, professional development

Introduction

This study focuses on the nature and use of formative and summative assessment in professional development (PD) projects in the Advanced Technological Education (ATE) program. Through a special section of the annual ATE PI survey, we surveyed P.I.s whose grants included providing PD to learn when and how assessments are conducted, and the purposes served. The survey items were based on a framework we developed using logic modeling and the literature on evaluation and assessment. Our goal was to understand current purposes and practices, particularly related to the role of teacher participants in developing the PD, learning about assessment, and reporting data on their student-level outcomes. This research was a COVID adaptation of our project Formative Assessment for ATE 2: a workshop to develop assessment and evaluation practices. Our long-term project team aims to effectively engage with PD providers to strengthen PD outcomes through strong assessment and evaluation practices. Based on the literature and our findings, the integration of formative assessment and evaluation has the potential to sharply increase learning gains for participant teachers and their students.

Background

The United States faces stiff international competition in emerging twenty-first-century STEM markets and fields [1]. To be successful in this competitive environment requires the U.S. to develop a resilient and agile workforce [2]. Increasing the resilience and agility of workers requires attention to building learning structures, scaffolding, and continuing educational opportunities to help workers learn and take agency for their learning.

The ATE program aims to help meet those needs by developing workforce technicians, most often taught in community college and technician education settings. PD, also called professional learning, delivers instruction to teachers in those workforce settings. As such, it is integral to workforce development efforts, occurs in all workforce development education settings, and involves a significant proportion of education budgets. In ATE in 2015 (the last P.I. survey where this was asked), PD was 22 percent ($14M) of the $64M annual budget. In 2021, when the ATE budget was $75M, 39 percent of grantees reported doing PD (see Table S14).

These PD efforts are intended to increase student knowledge, skill, and interest in technology and improve the technology workforce. Figure 1 represents the strategy employed by NSF through ATE to engage PD as a tool for workforce development in a basic theory of change model—that is, an articulated process that makes visible the embedded ideas about how actions create impacts [3]. As Figure 1 shows, NSF funds the ATE program, which distributes those funds to grantees to attract students to STEM areas and engage them in quality education so they can improve the workforce. The number of grantees that engage in PD varies by year, but typically half deliver PD, and these efforts reach many community colleges and secondary education institutions [4].

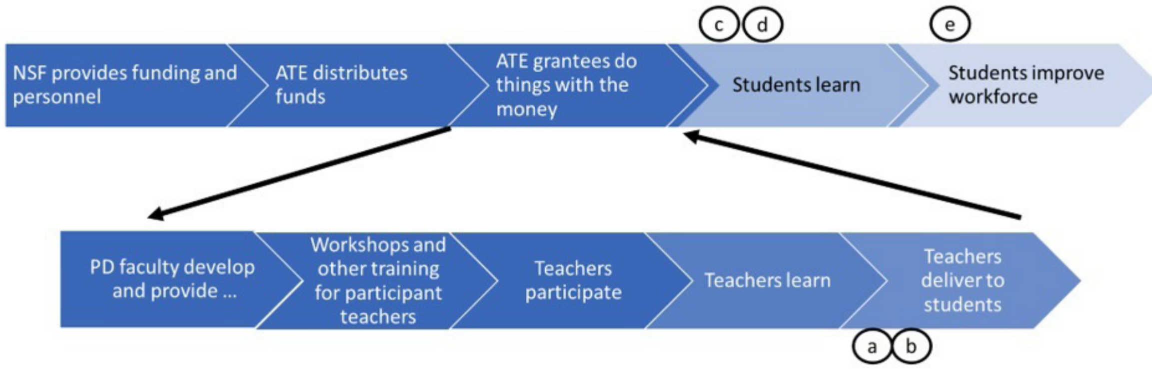


Figure 1. ATE PD theory of change, including timing of evaluation and assessment expectations.

The value added from PD comes first from the number of faculty/teachers directly reached in PD workshops. Second, and more significant, its value derives from its multiplier effects whenever those teachers pass that new knowledge or skill on to their students. Thus, a single PD instructor who provides learning to teacher participants could conceivably increase learning among hundreds if not thousands of students taught by those teachers.

To understand the impact of this important aspect of the ATE program, the solicitation focuses on summative evaluation. Those expectations are specified in the ATE guidelines for proposals [5]:

a) Demonstrate use in the classrooms.

b) Demonstrate sustainable changes in practice of participating faculty and teachers.

c) Measure changes in students' perceptions of technical careers.

d) Measure changes in student learning outcomes.

e) Demonstrate an increase in qualified technicians for the industry.

Points a-e have been mapped onto Figure 1 to demonstrate where they occur in the theory of change related to the PD and ATE process and goals. All occur after the PD workshop experience, focusing on actions and behaviors in participants' classrooms and in industries that will employ their students. Collecting data on points a-e requires some preparation and action before, during, at the end, and after the PD providing robust data on learning (b and d) requires some assessment.

Data from previous studies of PD offered by ATE projects [6-9] indicates variation in preparation for, compliance with, and quality of data related to those guidelines. Summary findings from those four studies report:

- Before the PD, most participant teachers agreed, when recruited, to provide follow-up feedback on the impact of the PD on their instruction. Fewer, about 40%, agreed to give feedback on their students' learning [9].
- During the PD, about a third of participants received instruction on student assessment and tools and protocols for gathering and reporting on student impacts [9].
- At the end of the PD program (i.e., at the end of the PD instruction activity), about three-fourths of projects collected data consistently. Most collected participants' reactions, their opinions about the training, and information about PD content [6-9]. Records from 2009 and 2010 show that half to three-fourths of the projects gathered self-assessment information from participants about their learning [7-8]. In those same years, less than a quarter used exams (instructor or externally prepared) to assess participant achievements.
- After the PD, in three of the four years, a majority reported following up with participant teachers to assess implementation following the completion of instruction [6, 7, 9]. About 40 percent assessed student impacts; in no year did that reach a majority [6-9].

These reports also indicate that most PD assessment efforts engage teachers as respondents rather than as collaborators who conduct assessments in their school situations. The result is that most post-PD assessments are conducted by an external evaluator, who typically gathers only cursory data from participant teachers about their instruction or student impacts coupled with the PD The post-PD context helps to explain why. First, dependence solely on an external evaluator imposes substantial costs, legal questions, and logistical difficulties when data are collected from classrooms. For example, an external evaluator cannot personally gather data from students without meeting substantial state and local school rules that protect students. Even if the school-based rules can be met, the time required and associated costs for collecting these data pose significant hurdles for most evaluations. Second, participant teachers are likely to teach the PD content at different times, to various extents, and in other types of classes, making it difficult to time data gathering or ask a common set of questions.

Methods

Assessment and evaluation can serve both formative and summative purposes; they come with associated resource and opportunity costs. For PD efforts to gain the most value from them, they need to work hand in hand with data from formative and summative assessments, providing information for formative and summative evaluation and supporting learning for the PD team, participating teachers, and their students. Thus, we combined assessment and evaluation literature and practice to develop our survey questions.

We used a logic model to map backward the data required to meet the ATE guidelines, the timing and process of consent, and data collection for formative and summative use. This process highlighted that participant teachers would have significant advantages if they were considered part of the team for data collection. They can gather classroom data cost-effectively (e.g., eliminate travel costs) and readily meet legal challenges. Most importantly, based on the literature, proper assessment can serve both PD evaluations, their own teaching needs, and increase student achievement.

The literature on classroom assessment supported our thinking about assessment in PD, as evaluation of PD for educators has characteristics common to evaluation practices in regular classroom instruction. Assessment is the systematic gathering and use of information for summative evaluation decisions (grades) and as feedback between teachers and students (formative). Grades are most commonly associated with assessment practices. "Summative assessment is a form of appraisal that occurs at the end of an instructional unit or at a specific point in time, such as the end of the school year. It evaluates mastery of learning and offers information on what students know and do not know" [10]. Summative assessments compare poorly with formative assessments regarding their effects on student learning [11]. With an overall effect size of 0.05, summative assessment does little to support student learning [12] directly; it is sufficient to move a class average from the 50th percentile to the 52nd percentile.

Formative assessment can be used throughout the learning process to frame the direction instruction takes, serve course corrections, increase student engagement and interest, and empower students' personal and corporate evaluative thinking that serves their learning. Formative assessment can be as simple as structured question interactions with students. Black and Wiliam's synthesis of assessment practices [13], demonstrated the powerful effects of formative assessment practices as instruction tools and precursors for summative evaluation. Their work prompted the terminology "assessment for learning" that is widely used today to describe ". . . any assessment for which the first priority is to serve the purpose of promoting students' learning" [14]. Additional research showed assessments to be extraordinarily powerful when used for learning purposes, both in increasing learning and establishing the effects of instruction through summative evaluation efforts [15]. Hattie's work [15] showed that feedback, a key component of assessment for learning, strongly influenced learning effects. His findings across 1,287 studies showed an average effect size of 0.73. That effect is sufficient to move a class average from the 50th to the 76th percentile—in standard U.S. grading scales, that moves the average from fail to a C+.

Clearly, if ATE PD is to deliver the strongest possible learning impacts, formative assessments need to be incorporated in the PD; teachers need to learn how to incorporate those same formative assessment principles in their home classrooms. Data collected from those efforts can, in turn, serve the program evaluation of the PD effort. The habit of exchanging data about learning throughout the PD process, from workshop activities to home classrooms, will strengthen both outcomes and evidence.

As demonstrated by the previous ATE survey data, most PD data collection focuses directly on PD instruction and what is learned and used from that instruction. We designed our survey questions to (a) re-investigate those questions and (b) explore formative assessment practices, including how teachers were prepared for instruction and assessment in their home classrooms.

To address our first purpose, confirmation of previous findings about PD evaluations, this study included questions regarding when assessments occur in PD programs, the purposes served by the evaluations, and the proportion of projects engaged in the assessment activities. To address the second purpose, we sought information about teachers' involvement throughout the PD process: planning for assessment and evaluation, what information was gathered, and the purposes for collecting data in the PD workshop and post-workshop classroom situations. We did not focus on P.I., PD instructor, or evaluator perceived roles in the assessment processes.

Our team partnered with EvaluATE to include items in a special topics section of the 2022 ATE PI survey administered by EvaluATE [16]. This section presented seven questions, each with a set of checkbox response options:

1. Why did your project conduct an assessment of your professional development activities in 2021?
2. For professional development (PD) work your project completed in 2021, which of the following types of information did you collect prior to the PD activity?
3. At the time participants were recruited, did they agree to provide follow-up feedback on the impact of the professional development on any of the following topics?
4. For professional development (PD) work your project completed in 2021, which of the following types of information did you collect during the PD activity?
5. Indicate whether the following participant-based actions were part of your project's professional development activities.
6. For professional development (PD) work your project completed in 2021, which of the following types of information did you collect at the conclusion of the PD activity?
7. For professional development (PD) work your project completed in 2021, which of the following types of information did you collect after the PD activity and after participants applied the workshop materials in their home classrooms?

As the above seven questions show, the first item asked respondents to identify the purposes served by their assessment practices during the PD work. The remaining six items sought to determine the nature of data gathered across the lifetime of their PD program:

1. Before the PD instruction, PD participants were invited to attend when the PD program was being prepared. (Questions 2 and 3)
2. During the implementation of the PD instruction. (Questions 4 and 5)
3. At the close of the PD instruction program. (Question 6)
4. After completion of PD instruction when, PD participants returned to their institutions to teach PD-related materials and skills. (Question 7)

The questions focused on the data and practices at each point that would provide evidence for claims about whether changes/increases that had occurred could be determined based on the nature of assessments conducted in the respective PD components.

The survey was administered by EvaluATE under the direction of Lyssa Wilson Becho at Western Michigan University in 2022. The survey was open for completion from February 22, 2022, through April 15, 2022, with a total response of 364 out of 396 active grants, a 92 percent response rate. When the survey closed, a member of the EvaluATE staff cleaned the data to remove potential duplicate responses and investigate outliers and missing responses. Data from the special topics section and project characteristics were then shared with FAS4ATE2 for analysis.

The main survey identified 145 projects that conducted PD as part of their work in 2021. Of those respondents, 70 stated that they conducted assessments as part of their PD efforts. Those 70 projects served as the sample for this study. Because the survey was conducted as a census, data for the seven items were treated as population measures and analyzed via SPSS using descriptive statistics (i.e., frequencies and crosstabs) with no inferential tests.

Results and Discussion

We present the results here as they would unfold in a typical PD, examining activities conducted and information collected before, during, at the end of, and after the PD We also include an analysis of data related to the key factors related to high-quality PD across those four points in time. A discussion of these results and their implications is included in the following section. The relevant tables and figures are included in the supplemental file available through the J ATE website.

For PD to be successful, it must point toward intended outcomes in the classrooms of participant teachers. The expectations are that these teachers' students' knowledge, interest, and achievements in the PD-affected courses are improved. Furthermore, these students enter and strengthen the technician workforce. That success requires direct learning by teachers in the PD activity. Importantly, teachers must prepare during the PD activity for their following teaching efforts. This preparation includes development and assurances that these teachers can and will teach what they have learned, effectively use assessments to guide their instruction and show its effects on the students. The P.I. and PD instructor[s] are responsible for working with participant teachers to achieve these outcomes. Yet, our findings show that most PD evaluation and assessment efforts focus on participants' direct learning.

In addition, the findings below discuss only the 70 projects who reported doing the assessments. Seventy-five projects delivering PD did not report they conducted any assessment. Thus, *the percentages reported here can be roughly halved for an overall sense of assessment practices in ATE PD projects.*

Stage 1: Prior to the PD activity

A majority (55%) of special section respondents indicated that a purpose for using assessment before the PD was to confirm the alignment of participant learning needs with planned activities. That purpose is confirmed by the majority response (66%), that prior to the PD activity, they collected information about participants' *knowledge or skills* in the professional development focus area. A minority (26%) assessed participant's *valuation* of ideas, materials, and techniques for use in their home institutions. Slightly more, 36 percent, responded that they collected information about participants' *intent* to implement these things. The smallest percent (20%) indicated that they collected information about *contextual* factors that could influence participants' use of the PD

Most P.I.s also reported that when recruited, the participants agreed to provide feedback on the impact of the PD on their learning (54%) and on their incorporation and implementation of what they learned (59%). As noted below, fewer P.I.s followed up to gather such data after the PD instruction.

Stage 2: During the PD activity

None of the response options was checked by a majority. Few reported they assessed to learn participant characteristics or address their assessment practices. Those findings are consistent with responses regarding the purposes for which assessments were used. When asked why they used assessments, a minority indicated they assessed: (a) to guide participant learning (29%) or (b) to improve teaching and learning (36%). A comparable number (36%) indicated they gathered information about participants' learning/achievement related to the PD Half reported gathering participants' *opinions* about the PD (50%). Fewer reported assessing participants' *valuation* of the PD's ideas, materials, or techniques for use in their home institutions (44%), or their *intent to implement* the PD in their home classrooms (43%). Correctly implementing the ideas, materials, or techniques is a critical step in guiding learning; only 12 percent reported gathering such information.

A near majority (47%) stated that their purpose for using assessments in the PD was to understand how participants incorporated and implemented what they learned in their home classrooms. A much smaller proportion indicated they followed through to prepare participants for such data collection. Thirty percent indicated their participants received instruction on student assessment. Similarly, 31 percent reported that participants were taught how to use assessment tools. Fewer P.I.s (26%) indicated that they provided assessment tools to their participants to use locally with their students. About the same proportion, 23 percent, reported that participants were given time to try these tools. Fewer yet provided information to help these participants report information back to the project from their classroom situations. Approximately one-sixth provided participants with reporting tools (17%), taught them how to use the tools (16%), or gave them practice with such tools (16%).

Stage 3: At the conclusion of the PD activity

Respondents reported most assessments happening near or at the close of PD instruction. A large majority of P.I.s (84%) who conducted these assessments reported they did so to assess outcomes and impact of professional development activities. In most cases, more than two-thirds of P.I.s using assessment reported collecting relevant information after PD instruction:

- Participants' opinions about the PD (87%)
- Information about participants' intent to implement new ideas, materials, or techniques from the PD in their home classrooms (70%)
- Information about participants' learning/achievement related to the PD (69%)
- Information about participants' valuation of new ideas, materials, or techniques for use in their home institutions (64%)

Only one response option in this category garnered less than a majority. That option, "Information about any contextual factors that could influence participants' use of PD information," was reported by 26 percent of those using assessments.

Stage 4: After the PD activity and after participants applied the workshop materials in their home classrooms.

None of this category's responses reached 50 percent. About a third of respondents (34%) indicated they collected data about participants' intentions to implement new ideas, materials, or techniques from the PD in their home classrooms. Half that number, one-sixth (17%), stated they gathered information about whether participants correctly implemented the ideas, materials, or techniques from the PD Similar proportions of respondents asked about the PD's impact on student interest (20%) or student achievement (19%). In sum, data collection was not a substantial characteristic at this final stage of PD work.

Cross-stage factors

Across the lifetime of a PD effort, the team established four factors as key to implementing PD learning and materials in local settings:

1. Participants' learning/achievement related to the PD,
2. participants' valuation of new ideas, materials, or techniques for use in their home institutions,
3. participants' intent to implement new ideas, materials, or techniques in their home classrooms,
4. contextual factors that could influence participants' use of professional development [17].

Data collection practices varied greatly across the four factors and the PD components in which data were gathered. The greatest attention to data gathering occurred at the close of the PD activity when the majority of those conducting assessments gathered information on the first three factors. Just more than a quarter of projects reported collecting data on the fourth factor at that time. In fact, the contextual matters are addressed by substantially fewer projects at all points in the PD process.

Similarly, a third or less of those conducting assessments address any of the four factors after the conclusion of the PD activity. Those small percentages are telegraphed by the small percentage of projects that assess these matters during the PD activity. In sum, those using assessment attend to data gathering primarily at the close of the PD activity, with far fewer attending to it at other points in the PD program. Clearly, data collection lags most in matters of context and post-PD assessment.

The previous ATE survey findings were generally based on evaluation questions, with no specific mention of assessment. Our study treated assessment as a subset of evaluation activities and asked P.I.s to respond only if they included assessment in their PD We defined assessment in the survey as "i) defining learning goals, ii) selecting and designing assessment tasks, iii) collecting, analyzing, interpreting, and using information to increase learning, development, and achievement." Only half of the P.I.s whose projects delivered PD responded that they did any assessment at all. The amount of assessment reported was typically half as much as the evaluation reported in the previous surveys. Our data supports the historical findings, which show only a minority of PD efforts meet one or more of ATE's five evaluation expectations. The pattern of the data also matched that of the reported evaluation practices: a little before the PD, almost none during, a lot at the end of PD delivery, and a little after. Most of the assessment effort happens at the end of the PD learning activity, and it is summative. Participant teachers are respondents in evaluative activities; the attempt to get classroom-level learning data is likely not feasible. Very few P.I.s reported any attention to the cross-stage factors, particularly contextual factors, that would influence participant teachers' implementation of their learning. Clearly, most PD providers treat the end of the PD workshop instruction as the conclusion of their PD work.

As Figure 1 above demonstrates, NSF and ATE's aim with this kind of PD effort is to pass along as much benefit as possible from from the PD providers through to the classroom students of the PD participants, who will then carry it on into the workforce. Therefore, PD efforts need to do whatever they can to help participant teachers learn and be prepared to help their students learn. The current situation means that ATE is missing out on two influential contributions that build on each other: formative assessment and the multiplier effect. While the majority of P.I.s reported their PD efforts address some formative assessment prior to workshop instruction, only a minority applied it during the period of instruction and after the close of the PD workshop. The focus on summative aspects of assessment means participant teachers do not get the benefit of formative assessment for their own learning and thus are not prepared for that aspect of their role in conveying the PD instruction in ways that serve their own students' needs. The follow-on effect is that teachers may be less able to deliver the PD learning to their students, reducing their teaching impact. The ATE evaluation expectations focus on participant teachers' use in the classrooms and the effects on their students because this is where the multiplier effects occur. When the major effort in PD delivery ends with the PD instruction, and evaluation and assessment do the same, that multiplier effect is not realized and cannot be reported.

To maximise the multiplier effect in this situation requires four shifts.

The first is a mindset shift from teacher as deliverer of expert content to an understanding that only learners can learn [18]. To support learners in this endeavor, the teachers' role shifts to facilitator of learning. To take up this role, teachers need to understand what students know and the impact of their teaching on their students – this applies to teachers and learners in PD and in participant teachers' classrooms [19, 20]. Developing an exchange of information about how learners are learning is the heart of formative assessment.

The second shift is to integrate formative assessment into PD and preparation for participant teachers' return to their classrooms. Like all learners, teachers need to understand how their learning is progressing throughout the PD They also need to practice engaging their students in assessment for learning practices. Orienting assessments at the end of PD instruction as formative rather than a final "grading" step can remove the pejorative aspects of such tests. This reorientation can strengthen teachers' self-efficacy for teaching the material and facilitate collaborative interactions among teacher participants. Such interactions can carry forward in virtual conversations and support as the teachers return to their respective schools. Learning how to use formative assessment with their students can increase the intended multiplier effects of training the trainer PD. Their students become agents in their own learning, and by learning how to learn, they become the resilient, agile members of the workforce that ATE aims to create.

This signals the third shift: moving teachers from participants to collaborators in the PD and its evaluation. Participant teachers are uniquely able to provide feedback on their learning and their students' learning to the PD team to help them improve. Their location in classrooms positions them to contribute to post-PD evaluations because they are charged with summative assessments of their students' learning. If prepared and supported to be collaborators, they could provide summary information from their formative and summative assessments of students for the summative evaluation of the PD.

Finally, the planning horizon of PD activity, including assessment and evaluation, needs to be broadened to begin before participants arrive at the training and continue after participants have implemented the training in their classrooms. The longer time period will allow PD deliverers and participants to prepare for learning at the PD, engage in formative assessment during the PD, share that learning after the PD, and document the results throughout.

Our theoretical model for PD, viewed in concert with findings from each of the four PD components, the literature and the ATE evaluation expectations, suggests several practical steps teams can take to implement these shifts in each stage of PD planning and delivery:

1. Pre-workshop: P.I.s and evaluators work together to plan general strategies for including participant teachers.
2. Pre- and during the workshop: P.I. works with PD instructors to bring them onboard for collaboration with participant teachers.
3. Pre- and during the workshop: P.I.s engage with participants to reach agreements to include post-PD participant involvement as part of the PD process.
4. During the workshop, P.I. and PD instructors work with participants at the beginning of PD to plan for participant-teacher involvement, including assessing contextual factors that might impede implementation.
5. During the workshop: As part of PD instruction, the PD instructor engages participant teachers in the assessment process for instruction and outcome assessment purposes to prepare them to conduct these assessments in their classrooms.
6. During and after the workshop: Evaluator and participant teachers collaborate on how to engage in post-PD assessment processes to meet ATE evaluation expectations.

These four shifts and six steps combine to provide a pathway to reorient PD toward greater use of formative assessment practices in ways that increase learning among participants and participants' students and ultimately serve ATE's interest in summative evaluations in post-PD classrooms.

Future research

The literature and our study findings identified four cross-stage factors that influence the impact of PD at the classroom level: participant teachers' learning, valuation of the learning, intent to implement, and implementation context. as key to implementing sound PD Our work is descriptive only; therefore, further research would be needed to provide causality evidence regarding the deficiencies noted among ATE PD evaluations. Considering that more than half of the projects stated they did not employ assessments, we think this is a deficiency that warrants follow up. We strongly encourage ATE to fund studies that look closely at the effects of these four factors, emphasizing comparison between those engaging in various assessment practices and those not applying the practices. Among the four, the limited attention to contextual factors stands out as an especially important area to study to determine its effects on learning among participants and their students and enhance evaluation use. Our survey findings also highlighted some PD efforts that were engaged with formative assessment throughout the PD and gathered data about student impacts. There are some successful cases out there which would bear further investigation to document their processes and capture examples of good practice. Comparison with less successful efforts could provide additional lessons and help improve PD efforts in ATE and beyond.

Conclusion

Concerns about an evaluative follow-up to check outcomes in schools after PD instruction have been raised and discussed at least since the early 1970s. A compelling argument then and now has been that such evaluation efforts are too onerous and should not be imposed on the PD program, the P.I.s, or the teacher participants. That argument overlooks or ignores the wealth of evidence that applying formative assessment practices before, during, and after PD instruction substantially strengthens the PD education process. When formative assessment to serve learning is applied, PD is stronger, and learning is increased throughout the process from instruction of PD participants to teachers' use in their classrooms and their own students' learning. Summative evaluations are also strengthened because formative assessments point to and prepare for summative assessments of intended outcomes. Formative and summative assessments then provide robust data for evaluation.

PD is a highly funded activity encompassing substantial outcome expectations that too often are not substantiated with sound evaluation. As we suggest above, the significant challenges of delivering and evaluating PD effectively can be addressed with structurally sound planning and actions that integrate evaluation and formative assessment throughout the life of a PD intervention. Changing any process that has been operating for many years is fraught with problems and will take substantial time, effort, and patience. Our work provides a pathway to produce that change; we believe the outcomes will be sufficiently rewarding to pay the price for change. The key will be shifting mindsets about learners, assessment, the role of teachers as collaborators, and the timeline of PD Then, many hands can make the work lighter.

Acknowledgements. The authors are grateful to Laureate Professor John Hattie, who worked with Arlen and Amy on earlier versions of this project and related articles. This work was supported by the National Science Foundation under Grant No. 1853472. 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.

Supplement. For supporting content see https://micronanoeducation.org/wp-content/uploads/2024/02/ATE-Assessment-Practices-suppplemental-1.pdf

References

[1] D. DeChiaro, "China's STEM workforce a challenge for U.S. policymakers.," *Roll Call. Accessed: Aug. 10, 2021. [Online]. Available: https://rollcall.com/2021/08/10/tech-tuesday/*

[2] J. L. Graves, Jr, M. Kearney, G. Barabino, and S. Malcom, "Inequality in Science and the Case for a New Agenda," Proc Natl Acad Sci U S A, vol. 119, no. 10, p. e2117831119, Mar. 2022, doi: 10.1073/pnas.2117831119.[3] S.C. Funnell and P.J. Rogers, *Purposeful Program Theory: Effective Use of Theories of Change and Logic Models*. 1st edition. San Francisco, CA: Jossey-Bass, 2011.

[4] V.A. Marshall, E. Sturgis, L.W. Becho, L.A. Wingate, and A. Gullickson, "ATE Annual Survey 2021 Report," The Evaluation Center, Western Michigan University, 2021.

[5] "Advanced Technological Education (ATE) Program Solicitation NSF 21-598," NSF - National Science Foundation, 2021. [Online]. Available: https://new.nsf.gov/funding/opportunities/advanced-technological-education-ate/nsf21-598/solicitation

[6] A.R. Gullickson, C.L.S. Coryn, and C.E. Hanssen, "ATE Indicators of Productivity: Six-Year Trends 2000-2005," The Evaluation Center, Western Michigan University, 2005.

[7] L.A. Wingate and A.R. Gullickson, "2009 Survey Snapshot: ATE Project & Center Professional Development Evaluation Practices," EvaluATE, Western Michigan University, 2009.

[8] L.A. Wingate and A.R. Gullickson, "2010 Survey Snapshot: ATE Project & Center Professional Development Evaluation Practices,"EvaluATE, Western Michigan University, 2010.

[9] C.D. Smith, L.A. Wingate, E. Perk, L.N. Wilson, and A.R. Gullickson, "ATE Annual Survey 2015 Report," The Evaluation Center, Western Michigan University, 2015.

[10] J. States, R. Detrich, and R. Keyworth, "Overview of Summative Assessment," The Wing Institute, Morningside Academy, 2018.

[11] "Summative Assessment," Wing Institute at Morningside Academy. [Online]. Available: https://www.winginstitute.org/assessment-summative

[12] S.S. Yeh, "The cost-effectiveness of five policies for improving student achievement," *American Journal of Evaluation, vol. 28, no. 4, pp. 416–436, Dec. 2007, doi: 10.1177/1098214007307928*.

[13] P. Black and D. Wiliam, "Assessment and Classroom Learning," *Assessment in Education: Principles, Policy & Practice*, vol. 5, no. 1, pp. 7–74, Mar. 1998, doi: 10.1080/0969595980050102.

[14] P. Black, C. Harrison, C. Lee, B. Marshall, and D. Wiliam, *Assessment for Learning: Putting It into Practice*. Maidenhead, U.K.: Open university Press, 2003.

[15] J. Hattie, *Visible Learning: A Synthesis of over 800 Meta-Analyses Relating to Achievement*. 1st edition. London ; New York: Routledge, 2008.

[16] "ATE 2022 Survey Questions," [Online]. Available: https://atesurvey.evalu-ate.org/survey-resources/.

[17] T.R. Guskey, "Gauge impact with 5 levels of data," *Journal of Staff Development*, vol. 37, no. 1, pp. 32–37, Feb. 2016.

[18] G. Nuthall, *The Hidden Lives of Learners*. Wellington: Nzcer Press, 2007.

[19] J. Hattie, *Visible Learning for Teachers: Maximizing Impact on Learning*, 1st edition. London; New York: Routledge, 2012.

[20] J. Hattie, "The applicability of Visible Learning to higher education," *Scholarship of Teaching and Learning in Psychology*, vol. 1, no. 1, pp. 79–91, 2015, doi: 10.1037/stl0000021.

[i] We've created some tools to help. Register and download them here: "https://tinyurl.com/PDFASuserRego"https://tinyurl.com/PDFASuserRego.

Student Career Goals and Science Attitudes at an Urban Community College

KRISTYN VANDERWAAL MILLS[1]*, TRAVIS MILLS[1]

[1]*STEM Department, Saint Paul College, St. Paul MN 55102, USA*

**kristyn.vanderwaalmills@saintpaul.edu*

Abstract: An equity gap exists in the STEM workforce, and there is a lack of published data on student motivation and career goals at the two-year college level. We collected data on student motivations for choosing a career in STEM and found a similar equity gap in student career goals at our college. In addition, we provided faculty mentoring and career development to increase student knowledge and awareness of STEM careers. Our data show participation in these activities correlated with increased interest in STEM careers. Others can use this information to help build programs and recruit students into STEM fields and STEM careers.

Keywords: community colleges, self-efficacy, science identity, intrinsic motivation, STEM, health career goals

Introduction

A challenge for the STEM field is that the STEM workforce does not reflect the demographics of the country's workforce [1]. This is an equity gap, and it implies significant barriers to the participation of underrepresented groups in a STEM career. The STEM workforce includes those fields that require significant experience in the science, technology, engineering, and mathematics fields and represents 23% of the total workforce in the U.S. [1]. It should be noted that the STEM workforce is different than the healthcare workforce, which includes nurses, physicians, and others who regularly care for patients and accounts for 9.3% of the total workforce in the United States [2].

For example, women comprise 52% of the U.S. workforce but only 34% of the STEM workforce [1]. However, almost 80% of workers in the healthcare professions are female, compared with roughly half of the overall workforce [2]. Women are underrepresented in STEM careers but overrepresented in healthcare careers. We also see an equity gap in black and Hispanic participation in STEM careers [1]. There are likely multiple reasons for such gaps to exist. For example, there is a possibility that undergraduate students do not differentiate between the STEM and healthcare fields, even though the fields are different and require different skill sets and training. We acknowledge that there are also systemic barriers to entry into STEM career fields.

Saint Paul College (SPC) is well-situated to study this equity gap. SPC is an urban community and technical college with a high percentage of students of color (66%), first-generation college students (62%), and low-income students as determined by Pell Grant eligibility (65%). SPC also has programs that can help increase participation in STEM. In 2016, SPC established a Science and Engineering Technology program aimed at placing STEM students directly into the workforce or transfer programs. Most educational research data comes from 4-year institutions [3], yet 50% of STEM undergraduates begin their scientific studies at community and technical schools [1]. Therefore, understanding career motivations at the community college level is important.

Disparities seen in the workforce could be addressed by increasing students' awareness of STEM careers and career readiness through high-impact practices (HIPs) [4]. Star and Minchella's work noted that "to attain 'great jobs and great lives', [students] require high impact experiences inside and outside the classroom" [5]. A 2017 study of engineering students at a university found that students who participated in co-curricular activities gained more career and interpersonal skills than non-participants [6]. HIPs such as scholarships and support services also increased direct measures of student success, including retention, persistence, and graduation rates [7, 8, 9]. Mentoring experiences increased the persistence and retention of students of color, and participation in research was correlated with increased graduation rates [10]. HIPs have a greater impact on underrepresented students' success, and promote underrepresented students' access to STEM [4].

The studies highlighted above took place at four-year universities. Community and technical colleges serve a different population of students, but we would expect that HIPs would have similar impacts. A minority of studies looked specifically at the success of HIPs at community colleges. Berchiolli et al. note that projects at community and technical colleges provide opportunities that are "especially meaningful for students who have expressed an interest in STEM but are not engaged by the traditional large lecture and laboratory environment central to large research universities" [11]. A 2018 study found that participation in undergraduate research at a community college increased the proportion of students who transferred into a four-year STEM program [12]. To better engage students on career goals and promote their success, we employed three HIPs: (1) faculty mentoring, (2) science-related campus events and career-building workshops, and (3) undergraduate research projects.

Several studies suggest that students who participate in research experiences have increased science identity, self-efficacy, and science abilities [13, 14]. Hanauer et al. [15] and Pinelli et al. [16] found that career awareness activities and faculty connections increase awareness of science careers and increase the proportion of students who transfer or are employed in science. In addition, Stets et al. found that increased science identity correlated with science as a career choice [17].

We hypothesize several reasons for the equity gap in the STEM workforce. First, science attitudes and identity may correlate with career choice, and the demographics underrepresented in STEM would then show lower science attitudes and identity. Second, there may be a lack of awareness of careers in the STEM fields and heightened awareness of careers available in the healthcare sector. We believe that employing HIPs will improve awareness of STEM careers for our students.

Methods

Survey Tool

We created a "Science Attitudes and Career Goals" survey using validated survey instruments introduced in two principal articles: Chemers et al., 2011 and Glynn et al., 2013 [18, 19]. We only included sections of each instrument relevant to our research and community college students. Because we used questions from these validated survey tools, some Likert scales were 4-point, and some were 5-point. We used the questions related to the following factors: commitment to a science career, science identity, intrinsic motivation in science, and science self-efficacy. The career and academic goals list was taken from the PRiSE survey, which assessed Persistence in Science and Engineering [20]. After the consent section, we asked questions about the student's ID, participation in co-curricular activities, and scholarship status. See Supplemental Material 1 for details of survey design and survey questions.

During analysis, we renamed the health career choices as follows: "Medical professional (e.g. doctor, dentist, veterinarian)" became "Med/Vet/Dent" and "Health professional (e.g. nurse, pharmacist)" became "Nursing/Health/Pharm." We grouped the following career choices in a category called "Scientist": "Biologist," "Earth/Environmental scientist," "Astronomer," "Chemist," "Physicist," "Computer scientist," "Social scientist (e.g. psychologist, sociologist)," "Other scientist," "Mathematician," "Science teacher," or "Math teacher." The "engineer" choice on the survey retained its name throughout the analysis. The following career choices were combined into "All others": "Business person," "Lawyer," "English/Language Arts specialist," or "Other non-science-related career." A "Not sure" career choice selection was not included in the analysis.

Recruitment of Students and Data Collection

The student survey was open for several weeks in the middle of each semester. Faculty announced through the online course management system: "You are expected to take a reflection survey as part of normal course assessment. The survey is a self-assessment of your own skills and attitudes with no correct or incorrect answers. You will have the option of having your survey answers used in a research study on student attitudes and abilities. More details are provided in this survey link."

The survey was administered in General Chemistry 1, Organic Chemistry, and Genetics. General Chemistry 1 is a gateway science course required for students pursuing science, engineering, and health careers. Organic Chemistry and Genetics are second-year science courses at our college. They have science course prerequisites and are also required for students pursuing both science and health careers.

We had 514 responses from General Chemistry 1 from 2019-2023, which was a response rate of 31%. The survey was also given in second-year science courses from 2021-2023 (Organic Chemistry and Genetics) (n=203), with a response rate of 36%. The responses had similar demographics to the course demographics. 61% of responses were female (29% male), and these courses were composed of 66% female (34% male). The racial demographics of the courses were 20% Asian, 41% Black, 7% Hispanic, and 31% White. The respondents demographics were 20% Asian, 37% Black, 10% Hispanic, and 34% White. A subset of these students also received scholarships and faculty mentoring as part of the Science Scholars Program (started in Spring 2022) or participated in SciCAP (started in spring 2021), a career exploration and faculty mentoring program (n=52). We paired survey data with demographic and academic data and removed data from non-consenting students and students under 18 years of age.

Analysis

Data were aggregated into a single dataset for statistical analysis. Factor scores were calculated for commitment to a science career (CarSci, 4-point Likert-scale), science identity (SciID, 4-point Likert-scale), intrinsic motivation in science (SciMot, 5-point Likert-scale), and science self-efficacy (SciSE, 5-point Likert-scale). Binomial outcomes (Yes/No) were created for certain categorical dependent variables (Science Career Choice, Participation in scholarship program, faculty mentoring, or career guidance). As in our previous work, categorical and binomial outcomes were analyzed using mixed-effect generalized linear models (GLMs) with logistic regression. Continuous variables, including factor scores, were analyzed with GLMs with a logit link function and a beta distribution for the response to account for the fact that the dependent variable was bound between 0 and 1. Logistic and beta GLMs were performed using the *lme4* and *glmmTMB* packages [21, 22, 23], respectively, in R Statistical Software (v3.2.4).

Variables were first screened in univariable analyses with either logistic or beta GLMs. All variables were included in a full model for multivariable regression, which was then backward-selected until a minimal univariable model was reached. Model comparisons of multi- and univariable models were performed to select the best-fit model using the Akaike information criterion corrected for small sample size (AICc). Models with AICc values within 2.0 of the model with the lowest AICc were considered equally good fits for the data [24]. The purpose of model selection was to find the model that best explains the data, and variables that are dropped from the best-fit model can be considered to have a statistically insignificant influence on the outcome of interest.

Independent variables that were examined for their effects on science career choice included course level, race, Pell eligibility, gender, first-generation status, credit load, science identity, intrinsic motivation, science self-efficacy, and commitment to a career in science. We also analyzed if course level (general chemistry 1 vs. second-year science courses (organic chemistry or genetics), race, Pell eligibility, gender, first-generation status, or credit load correlates with scores for science identity, intrinsic motivation, science self-efficacy, and commitment to a career in science. We also examined if receiving mentoring correlated with scores for science identity, intrinsic motivation, science self-efficacy, commitment to a career in science, following semester credits, or career in science.

Results and Discussion

Student career goals correlate with demographics

To explore the hypotheses presented above, we began analysis of the data by exploring a correlation between student career goals and demographics. Our multivariable model concurrently considers race and gender, as well as whether a student was a first-generation college student, whether the student was taking a full-time or part-time credit load, and whether a student was Pell eligible. This means it looks at the effect of gender after controlling the other variables, or the effect of race while accounting for the effects of other variables. In addition, the model is additive, so if a student’s identity intersects (ex., Asian and female), then the predicted outcome is the effect of being female added to the effect of being Asian. A graphical summary of the racial and gender data is presented in Figure 1, and the modeling statistics are presented in Table 1.

Students who identify as Black or African American, Hispanic, or female are underrepresented in the STEM workforce [1]. Our multivariable model shows that those same students are significantly less likely than students identifying as white or male to select a science or engineering career goal (Figure 1, Table 1). Instead, these groups are more likely to pursue a career in health. The correlation between racial and gender demographics is consistent with the equity gap observed in the STEM workforce. Asian students are not underrepresented in the STEM workforce [1]. However, we find Asian students are significantly less likely to select a science or engineer career goal (Table 1). This inconsistency with national data is likely because the Asian population in Saint Paul is not the same as in much of the country. Minneapolis and Saint Paul have one of the highest populations of Hmong in the country and are the most populous Asian subgroup in Minnesota [25]. These Southeast Asian recent immigrants may have different career goals and motivations than the Asian demographic over the entire country.

The exact reason for the correlation between racial demographics and career choice is unknown, but we hypothesize that science and engineering careers are unknown to students, especially student groups that are already underrepresented in STEM. Students might also find the path toward a science career less clear. Again, with fewer role models in STEM in their racial groups and genders, students are less likely to hear about how to become a scientist. Third, students may perceive that STEM careers do not align with their desired career values. For example, some students may see STEM as an individual focus instead of being community-minded. There is some literature support for this idea. One study from Australia found that students from collectivist cultures highly value a sense of belonging and peer/parental influence in career choice. In contrast, students from individualist cultures highly value aptitude for a particular career [26]. A second study by Eccles and Wang investigated why males and females pursue math and science careers. They found that females who valued altruism and people orientation were more likely to pursue biology or medical careers [27].

No significant correlation was found between career choice and course load (part-time versus full-time) or first-generation status. Additionally, a student's grade in their science course was not correlated with career choice, nor was the level of the course (first-year course, second-year course, etc.).

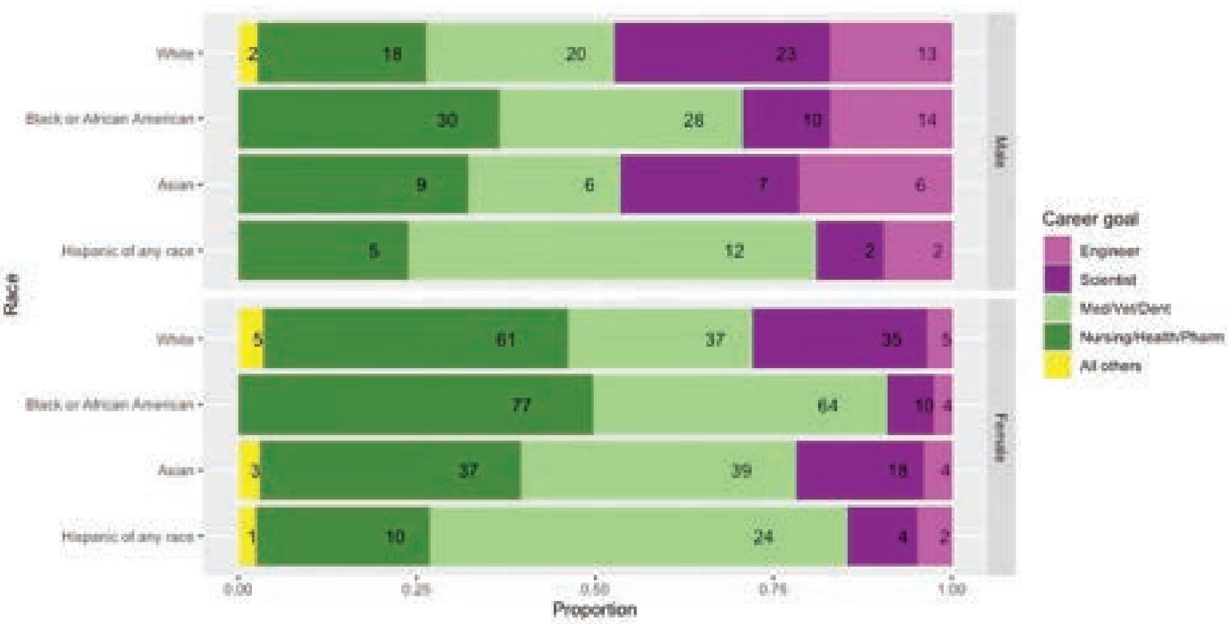


Fig. 1. Career Goals by race and gender. Numbers listed above indicate the number of survey respondents in each category. Black, Hispanic, Asian, and female students are significantly less likely to select a career in STEM than white or male students. Statistical data supporting Figure 1 are presented in Table 1.

Table 1. Multivariable Model of Demographic and Science Attitudes' Effects on Career Goals

Variable (glm)	Estimate	Standard Error
(Intercept)	-0.93	1.07
Gender Female (ref: male)***	-0.97	0.27
1st Generation (ref: not 1st gen)	-0.55	0.29
Part-time Load (ref: full-time)	-0.23	0.26
Pell Eligible**	0.92	0.31
Race (ref: white)		
Black***	-1.90	0.38
Asian*	-0.85	0.37
Hispanic**	-1.27	0.51
Science Identity	0.46	0.24
Intrinsic Motivation	0.00	0.32
Self-Efficacy	-0.10	0.23
Commitment to a career in science	0.12	0.31

[a]*P-values: * = p<0.05, ** = p<0.005, *** = p<0.0005*

Student attitudes towards science are not associated with career goals.

We also explored correlations between a student's career goal (science/engineer versus other) and their self-assessed science identity, intrinsic motivation, self-efficacy, and commitment to a career in science. Figure 2 shows that science/engineer career goals are not associated with higher scores for commitment to a career in science, science identity, self-efficacy, or intrinsic motivation. Table 1 shows data that support Figure 2. Table 2 shows that although science attitudes are not associated with career goals, science attitudes are correlated with other demographic factors. Students identifying as Black and those in second-year courses report higher science identity than other respondents. Students in second-year courses have higher self-efficacy; Asian students have lower self-efficacy. Asian students or students who earned a C have lower intrinsic motivation. Pell-eligible and female students reported having a higher commitment to a career in science (but still chose a science/engineer career less frequently than others). Finally, students who earned a C or DFW (grade of D, F, or W for withdrawal) have a lower commitment to a career in science.

We hypothesized that a science or engineering career goal would be associated with higher scores for self-efficacy, intrinsic motivation, science identity, or commitment to a career in science. This was not the case. This suggests that pre-health and pre-science students are equally engaged, and engagement is not the key to convincing students to pursue science as a career. Also, preliminary data from our focus groups suggest that many students consider health careers to be a science career and a way to apply strong scientific skills. Our data show that females have a significantly stronger commitment to a career in science but are choosing health careers. This might suggest that female students perceive that healthcare better matches their career values [27].

Science identity also did not align with science or engineer career goals (Figure 2). This was in contrast to the finding of Stets et al. in 2017 [17], but in line with work from Dou et al. in 2021 [28]. Dou et al. compared STEM majors and pre-med majors and found that pre-med majors had higher science identity scores than their STEM major peers and equal self-efficacy scores. Together with our study, this suggests that improving students' science identity or self-efficacy would not encourage students to pursue STEM over health.

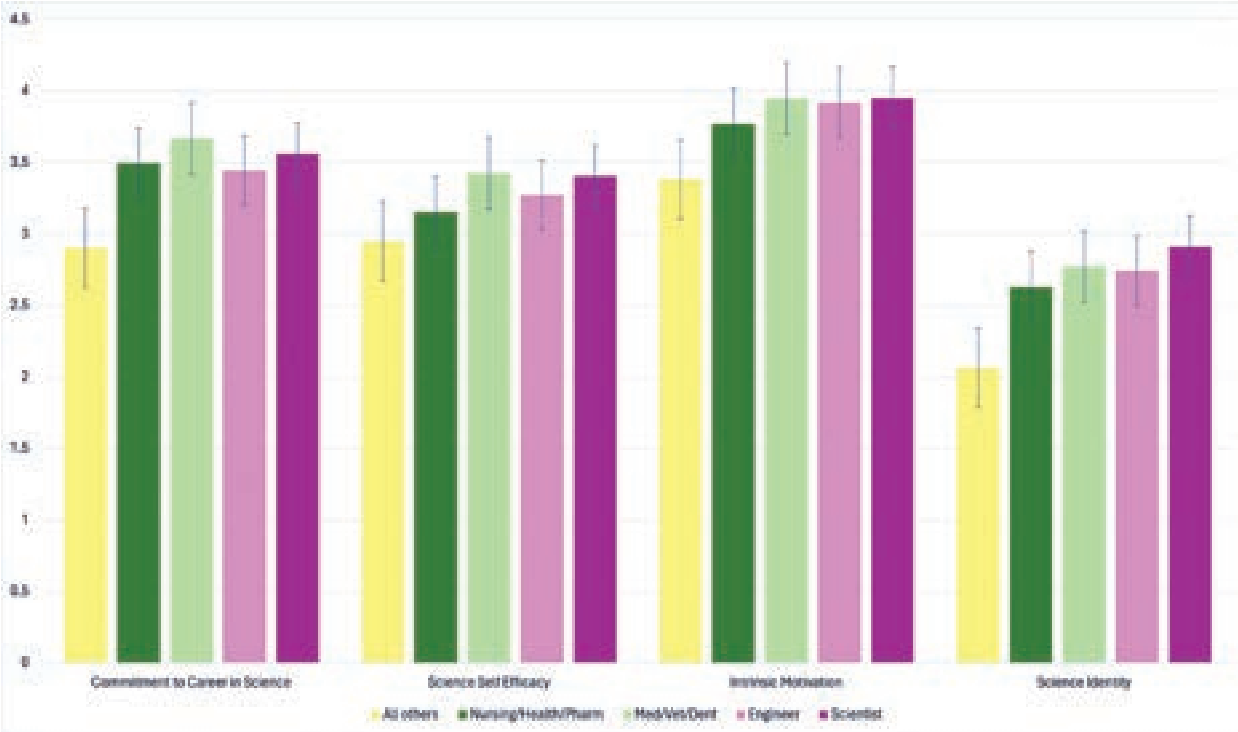


Fig. 2. Science Attitudes by Career Goal. No correlation was found between career choice and scores for commitment to a career in science, science self-efficacy, intrinsic motivation, or science identity. Supporting data are presented in Table 1.

Table 2. Multivariable Model of Demographic Effects on Science Attitudes. Standard error is shown in parentheses, and p-values are marked with asterisks. [a]

Variable (glm)	Commitment to Career in Science Estimate (4 pt scale)	Science Identity Estimate (4 pt scale)	Science Self-Efficacy Estimate (5 pt scale)	Intrinsic Motivation Estimate (5 pt scale)
(Intercept)	3.29 (+/- 0.09)***	2.39 (+/- 0.12)***	3.24 (+/- 0.12)***	3.89 (+/- 0.09)***
Gender Female (ref: male)	0.14 (+/- 0.07)*	-0.05 (+/- 0.09)	-0.07 (+/- 0.42)	-0.01 (+/- 0.07)
1st Generation (ref: not 1st gen)	-0.00 (+/- 0.07)	-0.01 (+/- 0.09)	-0.06 (+/- 0.09)	0.06 (+/- 0.07)
Part-time Load (ref: full-time)	-0.02 (+/- 0.06)	0.05 (+/- 0.08)	0.04 (+/- 0.08)	-0.04 (+/- 0.06)
Pell Eligible	0.16 (+/- 0.07)*	0.17 (+/- 0.10)	-0.00 (+/- 0.10)	0.02 (+/- 0.07)
Race (ref: white)				
Black	0.12 (+/- 0.09)	0.39 (+/- 0.11)***	0.11 (+/- 0.11)	0.10 (+/- 0.09)
Asian	-0.04 (+/- 0.10)	0.05 (+/- 0.13)	-0.36 (+/- 0.13)**	-0.26 (+/- 0.10)**
Hispanic	0.19 (+/- 0.12)	0.23 (+/- 0.15)	-0.05 (+/- 0.15)	0.14 (+/- 0.12)
2nd Year Courses (ref: gen chem)	0.15 (+/- 0.10)	0.27 (+/- 0.13)*	0.27 (+/- 0.13)*	-0.01 (+/- 0.10)
Science Scholar (ref: gen chem)	0.22 (+/- 0.41)	0.62 (+/- 0.53)	0.84 (+/- 0.54)	0.31 (+/- 0.41)
Chem Grade (ref: A Grade)				
Grade B	-0.03 (+/- 0.08)	0.06 (+/- 0.10)	0.06 (+/- 0.10)	-0.07 (+/- 0.08)
Grade C	-0.22 (+/- 0.09)*	-0.05 (+/- 0.12)	-0.08 (+/- 0.12)	-0.27 (+/- 0.09)**
Grade D/F/W	-0.20 (+/- 0.10)*	-0.17 (+/- 0.13)	0.03 (+/- 0.13)	-0.17 (+/- 0.10)

[a] *P-values: * = p<0.05, ** = p<0.005, *** = p<0.0005*

Participation in faculty mentoring and career exploration is associated with STEM career goals

We expected that students who participate in scholarships, faculty mentoring, career planning, and research would choose science/engineering careers more often. We expected this even after discovering that career goals are not associated with science attitudes, as these interventions are focused on coaching and awareness of careers. We found that students who participated in these activities were significantly more likely to choose science and engineering career goals ($p<0.005$; Figure 3). We saw this trend even with the lower number of students who participated in these interventions.

As we did not see associations between science attitudes and career goals, these interventions must be influencing student career goal choice for other reasons. Possibly, faculty mentorship encourages students to talk about their career goals and forces students to examine why they chose the path they did. This idea is consistent with the 2019 work from Dou et al., who found that one big predictor for K12 students to pursue STEM was talking about science with friends and family [29]. Students in our programs are certainly getting exposure to more science career options through guest speakers and career workshops that might open their minds to more career possibilities.

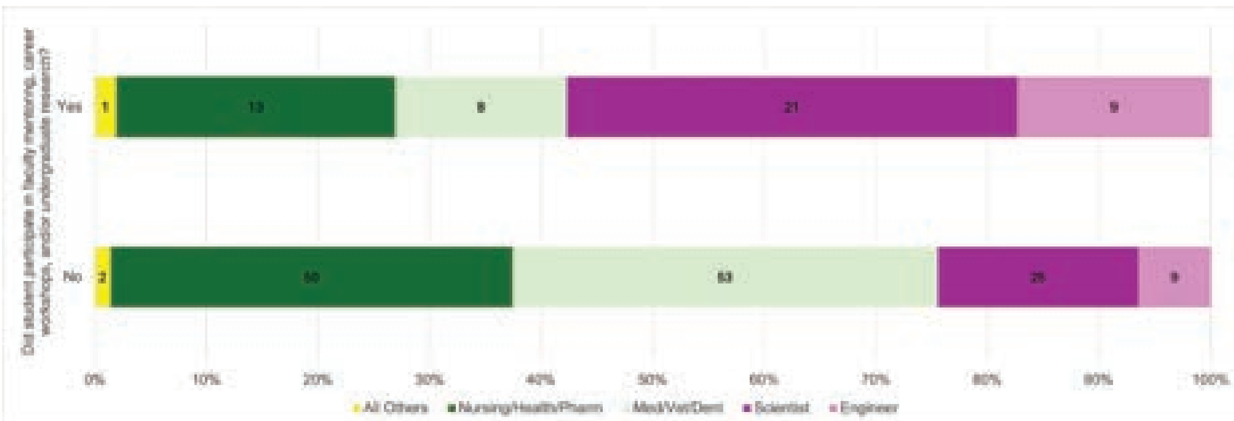


Fig. 3. Career goals by participation in faculty mentoring (with a scholarship), career planning, or undergraduate research. Students who participate in these activities are significantly more likely to choose science and engineering career goals (p<0.005).

Limitations

The authors recognize that there is likely a self-selection bias, as students with science career goals may be more inclined to participate in the Science Scholars, SciCAP, and undergraduate research programs. Additionally, multiplicative interactions (e.g., students who received multiple interventions), could not be accounted for in the analysis. Individual variables (e.g., having a mentor without a scholarship or a scholarship without a mentor), variability in instructors, class, year, COVID, etc. could not be analyzed due to survey limitations.

Conclusion

As a direct result of this project, our college is taking additional measures to give students more guidance on careers. Our Guided Learning Pathways are adding career exploration exercises into courses, so students understand their own reasons for choosing a career and have exposure to many career options. We also expanded our Career and Academic Planning Program (SciCAP) to help students develop a path to their career goals, provide guest speakers in various STEM and health careers, and connect students with a faculty mentor to discuss career and academic plans.

These initiatives give us the opportunity to gather additional data about career choice and understand what interventions motivate students to consider alternative career options. Through surveys and focus groups, we will examine student awareness of careers, career values, and pathways to different careers. This work made us aware that many students have little career guidance, and one method to make a meaningful difference in equity in STEM careers is to give students more opportunities to explore careers during their college tenure.

Acknowledgments. This work was supported by NSF-ATE grant #1902473 and NSF-S-STEM grant #2130501. Thanks to Saint Paul College's chemistry faculty and Institutional Research team for survey administration, and to CC BIO-INSITES for assistance with analysis.

Disclosures. The authors declare no conflicts of interest.

Supplement Materials: Please see https://micronanoeducation.org/wp-content/uploads/2024/05/Supplemental-Material.pdf

References

[1] A. Okrent and A. Burke, "Participation of Demographic Groups in STEM. The STEM Labor Force of Today: Scientists, Engineers, and Skilled Technical Workers," National Science Foundation, Aug. 2021. Accessed: Jan. 11, 2024. [Online]. Available: https://ncses.nsf.gov/pubs/nsb20212/participation-of-demographic-groups-in-stem

[2] S. Smith and A. Blank, "Healthcare Occupations: Characteristics of the Employed : Spotlight on Statistics: U.S. Bureau of Labor Statistics," Bureau of Labor Statistics. Accessed: Jan. 11, 2024. [Online]. Available: https://www.bls.gov/spotlight/2023/healthcare-occupations-in-2022/home.htm

[3] J. N. Schinske et al., "Broadening Participation in Biology Education Research: Engaging Community College Students and Faculty," LSE, vol. 16, no. 2, Jun. 2017, doi: 10.1187/cbe.16-10-0289.

[4] G. D. Kuh, *High-Impact Educational Practices: What They Are, Who Has Access to Them, and Why They Matter*. Association of American Colleges & Universities, 2008. [Online]. Available: https://www.aacu.org/publication/high-impact-educational-practices-what-they-are-who-has-access-to-them-and-why-they-matter

[5] L. Starr and D. Minchella, "Learning beyond the Science Classroom: A Roadmap to Success," *Journal of STEM Education: Innovations and Research*, vol. 17, no. 1, pp. 52–57, 2016.

[6] D. R. Simmons, E. G. Creamer, and R. Yu, "Involvement in Out-of-Class Activities: A Mixed Research Synthesis Examining Outcomes with a Focus on Engineering Students," *Journal of STEM Education: Innovations and Research*, vol. 18, no. 2, pp. 10–16, 2017.

[7] L. Goralnik, L. Thorp, and A. Rickborn, "Food System Field Experience: STEM Identity and Change Agency for Undergraduate Sustainability Learners," *Journal of Experiential Education*, vol. 41, no. 3, pp. 312–328, Sep. 2018, doi: 10.1177/1053825918774810.

[8] L. C. Ononye and S. Bong, "The Study of the Effectiveness of Scholarship Grant Program on Low-Income Engineering Technology Students.," *Journal of STEM Education: Innovations and Research*, vol. 18, no. 5, 2017, Accessed: Apr. 19, 2024. [Online]. Available: https://www.jstem.org/jstem/index.php/JSTEM/article/view/2246

[9] H. Salmun and F. Buonaiuto, "The Catalyst Scholarship Program at Hunter College. A partnership among earth science, physics, computer science and mathematics," *Journal of STEM Education: Innovations and Research*, vol. 17, (2), pp. 42-50, 2016.

[10] M. T. Jones, A. E. L. Barlow, and M. Villarejo, "Importance of Undergraduate Research for Minority Persistence and Achievement in Biology," *The Journal of Higher Education*, vol. 81, no. 1, pp. 82–115, 2010, Accessed: Apr. 19, 2024. [Online]. Available: https://www.jstor.org/stable/27750767

[11] B. Berchiolli, F. Movahedzadeh, and A. Cherif, "Assessing Student Success in a Project-Based Learning Biology Course at a Community College," *The American Biology Teacher*, vol. 80, no. 1, pp. 6–10, Jan. 2018, doi: 10.1525/abt.2018.80.1.6.

[12] H. Thiry, T. J. Weston, S. L. Laursen, and A.-B. Hunter, "The benefits of multi-year research experiences: differences in novice and experienced students' reported gains from undergraduate research," *CBE Life Sci Educ*, vol. 11, no. 3, pp. 260–272, 2012, doi: 10.1187/cbe.11-11-0098.

[13] S. E. Brownell et al., "A High-Enrollment Course-Based Undergraduate Research Experience Improves Student Conceptions of Scientific Thinking and Ability to Interpret Data," *CBE Life Sci Educ*, vol. 14, no. 2, p. ar21, Jun. 2015, doi: 10.1187/cbe.14-05-0092.

[14] P. Chen, A. Hernandez, and J. Dong, "Impact of Collaborative Project-Based Learning on Self-Efficacy of Urban Minority Students in Engineering," *Journal of Urban Learning, Teaching, and Research*, vol. 11, pp. 26–39, 2015, [Online].

[15] D. I. Hanauer, J. Frederick, B. Fotinakes, and S. A. Strobel, "Linguistic Analysis of Project Ownership for Undergraduate Research Experiences," *CBE Life Sci Educ*, vol. 11, no. 4, pp. 378–385, 2012, doi: 10.1187/cbe.12-04-0043.

[16] T. E. Pinelli and C. W. Hall, "Collaborative Educational Experiences through Higher Education-Industry Partnerships," presented at the 2012 ASQ STEM Agenda in Education, the Workplace and Society, Menomonie, WI, Jul. 2012.

[17] J. E. Stets, P. S. Brenner, P. J. Burke, and R. T. Serpe, "The science identity and entering a science occupation," *Soc Sci Res*, vol. 64, pp. 1–14, May 2017, doi: 10.1016/j.ssresearch.2016.10.016.

[18] M. M. Chemers, E. L. Zurbriggen, M. Syed, B. K. Goza, and S. Bearman, "The role of efficacy and identity in science career commitment among underrepresented minority students," *Journal of Social Issues*, vol. 67, no. 3, pp. 469–491, 2011, doi: 10.1111/j.1540-4560.2011.01710.x.

[19] S. M. Glynn, P. Brickman, N. Armstrong, and G. Taasoobshirazi, "Science motivation questionnaire II: Validation with science majors and nonscience majors," *Journal of Research in Science Teaching*, vol. 48, no. 10, pp. 1159–1176, 2011, doi: 10.1002/tea.20442.

[20] "PRiSE Survey," Harvard-Smithsonian Center for Astrophysics. Accessed: Jan. 2024. [Online]. Available: https://lweb.cfa.harvard.edu/sed/projects/PRiSE_survey_proof.pdf.

[21] D. Bates, M. Mächler, B. Bolker, and S. Walker, "Fitting Linear Mixed-Effects Models Using lme4," *Journal of Statistical Software*, vol. 67, pp. 1–48, Oct. 2015, doi: 10.18637/jss.v067.i01.

[22] M. E. Brooks et al., "glmmTMB: Generalized Linear Mixed Models using Template Model Builder. R package v0.2.2.0," October 2023. Accessed: Jan 2024 [Online]. Available: https://cran.r-project.org/web/packages/glmmTMB/glmmTMB.pdf

[23] K. E. Vander Waal Mills, M. Gucinski, and K. Vander Waal, "Implementation of Open Textbooks in Community and Technical College Biology Courses: The Good, the Bad, and the Data," *CBE Life Sci Educ*, vol. 18, no. 3, p. ar44, Sep. 2019, doi: 10.1187/cbe.19-01-0022.

[24] K. P. Burnham and D. R. Anderson, Eds., *Model Selection and Multimodel Inference*, 2nd ed. Springer New York, NY, 2002.

[25] H. Linehan and MNHS Reference Staff, "Hmong-Americans in Minnesota: Overview," Minnesota Historical Society Library. Accessed: March 2024. [Online]. Available: https://libguides.mnhs.org/hmong/ov

[26] P. Auyeung and J. Sands, "Factors influencing accounting students' career choice: a cross-cultural validation study," *Accounting Education*, vol. 6, no. 1, pp. 13–23, Mar. 1997, doi: 10.1080/096392897331596.

[27] J. S. Eccles and M.-T. Wang, "What motivates females and males to pursue careers in mathematics and science?," *International Journal of Behavioral Development*, vol. 40, no. 2, pp. 100–106, Mar. 2016, doi: 10.1177/0165025415616201.

[28] R. Dou, H. Cian, and V. Espinosa-Suarez, "Undergraduate STEM Majors on and off the Pre-Med/Health Track: A STEM Identity Perspective," *LSE*, vol. 20, no. 2, p. ar24, Jun. 2021, doi: 10.1187/cbe.20-12-0281.

[29] R. Dou, Z. Hazari, K. Dabney, G. Sonnert, and P. Sadler, "Early informal STEM experiences and STEM identity: The importance of talking science," *Science Education*, vol. 103, no. 3, pp. 623–637, 2019, doi: 10.1002/sce.21499.

Development of a Smart Manufacturing Technology Earn and Learn Program at a Rural Community College

ELIZABETH AZHIKANNICKAL[1]*, FENG HUA[1], BLAKE URBACH[2], MICHAEL WHITE[3], BOB HAAS[4], KS KU[3]

[1]*Department of Engineering Technologies, Marion Technical College, Marion, OH 43302, USA*

[2]*Preferred Program Evaluations, Orlando, FL 32814, USA*

[3]*Department of Business and Information Technology, Marion Technical College, Marion, OH 43302, USA*

[4]*Office of Academic Affairs and Student Services, Marion Technical College, Marion, OH 43302, USA*

**azhikannickale@mtc.edu*

Abstract: Manufacturing continues to be a vital component of the Ohio economy. Ohio's manufacturing sector employs over 600,000 skilled individuals, the third-largest manufacturing workforce in the U.S. [1]. With additional manufacturing industries moving into Ohio, including Intel and its supply chain partners, there is a growing need for industry-ready, skilled engineering technicians. In addition, with the increasing use of automated systems and network connectivity of these systems in manufacturing operations, technicians need to be equipped with skills in the area of smart manufacturing. This article details the development of a Smart Manufacturing Technology (SMT) associate's degree that is modeled as an earn-and-learn program. The program is equipped with various experiential learning opportunities, and additional industry-recognized certifications are embedded within specific courses. Summer camps were designed and delivered to expose middle and high school students to smart manufacturing and to build a pipeline of students into this program. A professional development summit was delivered each year of the grant. The purpose of the summit was to increase high school instructors' awareness of smart manufacturing so that they can better advise students about this in-demand field and teach courses in the SMT pathway.

Keywords: work-based learning, smart manufacturing, Industry 4.0, industry certification, earn and learn

Introduction

The manufacturing industry continues to grow and requires a workforce of skilled technicians to ensure operations run smoothly and effectively troubleshoot problems so that downtimes are minimized. According to Deloitte and the Manufacturing Institute, estimates indicate that the skills gap may leave 2.4 million positions unfilled between 2018 and 2028 [2]. The skills gap analysis suggests that the top three causes of skills shortage are shifting skill sets due to increased automation, negative perceptions about manufacturing careers, and baby boomer retirements [2].

The National Association of Manufacturers report shows that Ohio manufacturers account for 16.12% of the total output in the state, employ 12.74% of the workforce, and the total output from manufacturing was $112 billion in 2019 [3]. The 2020-21 Ohio Manufacturing Counts report from The Ohio Manufacturers' Association (OMA) shows that "Ohio has ranked second nationally in the total number of new site selections in the past eight years" [4]. The report also shows that locally, in Marion County, Ohio, manufacturing accounts for 19.8% of total county employment [4].

As a result of the pandemic, significant supply chain disruptions have also adversely affected the U.S. manufacturing industry. The pandemic has also confirmed the need for manufacturers to be able to source key devices and components locally to avoid delays in their internal operations. This includes semiconductor chips for use in a variety of engineering components and applications. In September 2022, Intel began constructing two new leading-edge microchip manufacturing facilities in Licking County, Ohio. Licking County is 47 miles from Marion Technical College (MTC), which is located in Marion County. Intel will hire 3,000 individuals in the next three years in semiconductor manufacturing, and they have stated that two-thirds (~2,000) of their employees will be associate degree-prepared engineering technicians. As the U.S. manufacturing industry positions itself to be more self or "locally" reliant and remain competitive in the global market, an adequate, skilled, technical workforce is needed to fill key advanced manufacturing roles, including those related to smart manufacturing or Industry 4.0.

According to the National Institute of Standards and Technology (NIST), the term smart manufacturing describes "fully integrated, collaborative manufacturing systems that respond in real time to meet changing demands and conditions in the factory, in the supply network, and in customer needs" [5]. Smart manufacturing is the application of smart technology such as sensors, controllers, and data storage in the manufacturing industry, as well as the integration and connectivity of these devices throughout operations. This allow for the maximization of plant efficiency and accuracy using real-time data. At the same time, the movement of the manufacturing industry toward the smart manufacturing approach requires a skilled workforce in the maintenance and troubleshooting of these systems.

In order to ensure graduating engineering technicians are prepared to successfully transition into industries implementing smart manufacturing, engineering technology programs integrating work-based learning are highly desirable. Work-based learning, also referred to as experiential learning or on-the-job training, is spread throughout an engineering technology students' academic program, allowing them to practice the knowledge and skills learned in the classroom. It also allows employers to directly impact developing their future workforce.

The Ohio Department of Education defines the following as the guiding principles behind work-based learning [6]:

- Work-based learning experiences must occur at a work site.
- Work-based learning experiences must be co-supervised by an instructor or other educational representative and an employer or business mentor.
- A learning agreement built on professional, academic, and technical competencies aligned to the student's program of study, student success, or graduation plans must be in place.

In 2013, Honda North America's shortage of technically skilled workers, specifically in electro-mechanical support, proved challenging [7]. A partnership between Columbus State Community College (CSCC) and Honda North America resulted in the development of the Modern Manufacturing Work Study (MMWS) program in 2013 [7]. CSCC's earn-and-learn model approach embeds students within a company for up to 18 months. During this time, the student engages in paid work/on-the-job training part-time three days per week while attending classes full-time two days per week [7]. Refer to Figure 1 for the MMWS framework.

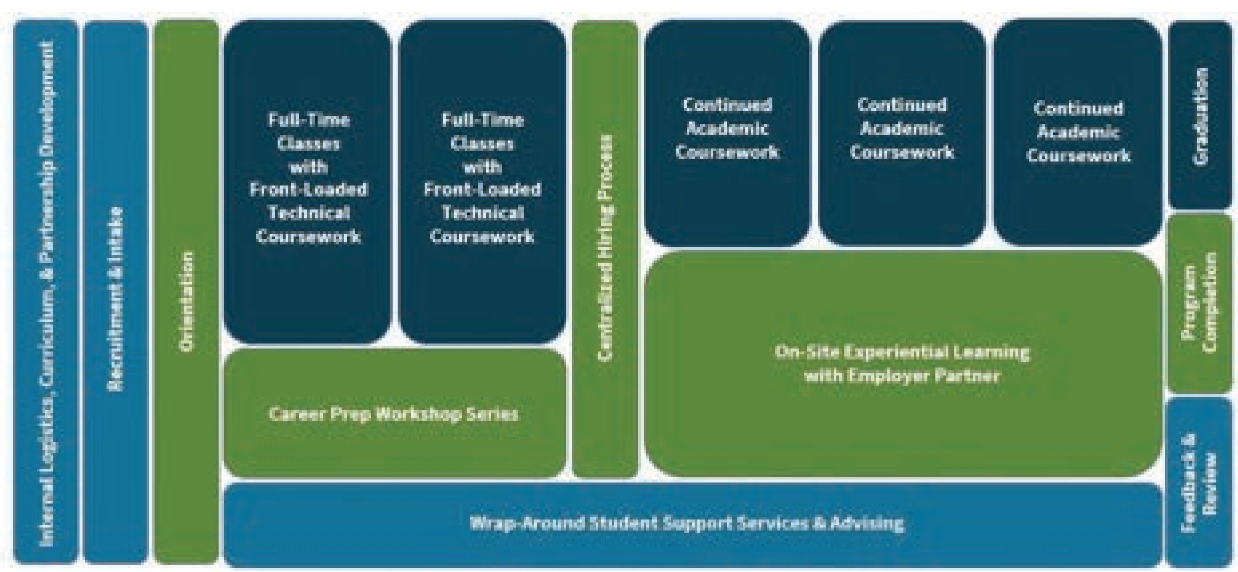


Fig. 1. Framework for Columbus State Community College's Modern Manufacturing Work Study Program [7]

Similarly, in 2015, Lorain County Community College (LCCC) partnered with Team NEO, a regional economic development entity, to assemble employers to partner on developing an earn-and-learn program [7]. The earn-and-learn programs described are embedded within existing engineering technology programs at the College (such as electro-mechanical engineering technology, automation engineering technology, etc.). They are not necessarily embedded within a fully integrated smart manufacturing program combining key aspects of automation (process control, robotics, etc.) and information technology (sensor and controller connectivity, manufacturing networking and cybersecurity, etc.).

This work will outline the development of a Smart Manufacturing Technology Associate of Applied Science degree at MTC. This program is modeled as a paid earn-and-learn program, embedded with experiential learning opportunities, a career readiness course, and industry-recognized credentials. MTC incorporated the year-long work placement model, similar to the colleges mentioned above, to provide students with longer on-the-job training, which could allow them to experience multiple departments within a given company. It would also better prepare students to transition to a full-time technician or maintenance position with the same company or another, with less training to be provided by the employer. Similar to CSCC's MMWS program, progressing students through MTC's earn-and-learn program will also involve more frequent check-ins with the student's supervisor/mentor. This is to ensure that the student is performing/progressing well and to gain feedback on skills the student may be lacking, which can be used to update the current curriculum. Other key program features, including the curriculum, training for instructors to provide industry certifications, smart manufacturing-related professional development events for high school instructors, and wraparound services to prepare students for the work placement, will be discussed along with recommendations. Currently, the work placement is not for credit. Events organized and carried out to recruit middle and high school students into this new program will also be addressed in addition to the external evaluation of the efficacy of this initiative.

Methods

The Smart Manufacturing Technology earn and learn program is the first of its type at MTC. The other Associate of Applied Science or Associate of Technical Studies programs offered in the Engineering Technologies Department at the College (Electrical Engineering Technology, Electrical Engineering Technology – Alternative Energy Option, and Robotics and Automation Engineering Technology) require students to complete a 150-hour industry co-op in their final term of the program. As per the Ohio Department of Higher Education (ODHE), these programs are required to include 30-35 semester credit hours of technical courses and 30 semester credit hours of non-technical courses, including a minimum of 15 semester credit hours of general education courses and the remaining semester credit hours made up of applied general education courses.

The development of the SMT earn and learn program was one of the outcomes of a three-year National Science Foundation (NSF) Advanced Technological Education (ATE) grant awarded to MTC in 2020. The grant title is "Bridging the Skills Gap in Smart Manufacturing through a New Technician Education Program," the award number is 2000177. The program was developed to build a pipeline of students with both technical and on-the-job training to fill existing and upcoming engineering technician and maintenance roles with local manufacturers. More specifically, students completing this program will be well suited to work in such areas as controls, robotics (integration, operation, and troubleshooting), and manufacturing cybersecurity. The program is structured so that students complete technical courses in the first two semesters and general education courses in the third semester of the program. In their fourth and fifth semesters, students complete the remaining technical courses two days per week and complete paid on-the-job training at a manufacturing facility the other three days of the week. Table 1 below shows the term-by-term curriculum for the SMT earn and learn program.

Table 1. MTC Smart Manufacturing Technology Curriculum

Course code	Course title	Credits
FIRST SEMESTER (FALL)		
GET1000	Introduction to Engineering	2
EET1000	Introduction to Electricity	2
EET2010	Introduction to Programmable Controllers	2
TMT1110	Applied Technical Math	3
CIT1100	Introduction to Programming Concepts w/Python	3
OIS1240	Computer Applications	3
FYE1000	Academic and Career Success	1
SECOND SEMESTER (SPRING)		
EET2510	Automated Process Control	3
EET1500	Circuit Analysis I	3
SMT1200	Instrumentation and Control	2
EET2060	Advanced Programmable Controllers	3
ENG1000	English Composition	3
MET1500	Mechanical Drives	3
THIRD SEMESTER (SUMMER)		
COM1400	Oral Communication	3
SOC2020	Ethnic and Cultural Diversity	3
EXP2800	Career Readiness	1
SOC1200	Sociology	3
or		
PSY1100	Introduction to Psychology	3
FOURTH SEMESTER (FALL)		
EET1550	Circuit Analysis II	3
SMT1100	Cybersecurity and Networking in Manufacturing	3
EET1301	Robot Handling Tool Operations and Programming	2
MTH1245	College Algebra	3
FIFTH SEMESTER (SPRING)		
PHY1110	Applied Physics	4
GET2300	Engineering Statistics	2
SMT2000	iRVision Operation and Programming – 2D	2
TEC0000	Technical Elective	3

Three new courses were developed for the SMT curriculum, given in Table 1. The other courses were taken from existing Engineering Technology programs at the College. The new courses include SMT1100 (Cybersecurity and Networking in Manufacturing), SMT1200 (Instrumentation and Control), and SMT2000 (iRVision Operation and Programming – 2D). These courses were developed in consultation with MTC's Engineering Advisory Committee, which indicated the current and future need for technicians with experience installing and troubleshooting instruments and devices. They also expressed the need for technicians to have a working knowledge of programmable logic controllers and robotic vision, both in terms of the hardware and basic troubleshooting. Local employers have indicated the advantages of training/upskilling existing employees, as opposed to subcontracting work externally, in order to keep delays and costs to a minimum—creation of the new courses involved the development of lecture material, assessments, and lab activities. Process control equipment to support the SMT1200 course was purchased with NSF grant funding. This equipment is used to control the fluid in a tank to a specified level, as is typical in a manufacturing or food production facility. The SMT1200 course allows students to install, operate, and troubleshoot sensors (flow, pressure, temperature, etc.), understand how these sensors serve as inputs to a controller, and see how these devices are network-connected for predictive and/or preventative maintenance purposes.

In the third semester of the program, students take a Career Readiness course (EXP 2800) to prepare for work placement in the fourth and fifth semesters. This course aims to help students transition from the classroom to the world of work. Each student will conduct a job search, practice interview techniques, improve upon personal and professional communication skills, and develop a functional resume. In the third semester, students will also work with the Career Services Department at the College to secure a work placement and to complete all of the required documentation (employer and College) related to the work placement. For example, before the student begins the work placement, an employer agreement form is completed in consultation with the placement employer/supervisor. The form requires that the student and the supervisor outline a learning plan (i.e., activities that the student will be involved in during the course of the placement or an on-the-job training checklist) as well as any training required as part of the students' onboarding with the corresponding completion dates. In addition, there is an area on the form for a member of the Career Services team to document student performance and progress at equal intervals based on feedback from the employer and the student (verbal, written, etc.). At the end of the placement, the student will complete a presentation, guided by a formal rubric, summarizing their on-the-job training. After the yearlong work placement, the student and the employer will also complete a written evaluation.

It is expected that the student will be engaged in duties during the work placement that apply or build on the skills gained in the first year of technical coursework. For example, if the student is employed in a robotics capacity, key skills that they will apply from robotics courses taken in the program may include:

- Jogging the robot to a target position and recording a position value (position register) using the teach pendant
- Opening an existing production program and modifying a position value (position register)
- Creating a basic robotic program as well as testing and running the program. This may also involve adjusting speed, force, and to run in step, cycle, and continuous modes.
- Setting up collision avoidance and detection
- Backing up and restoring program files, system parameters, and control software images

The Smart Manufacturing Technology earn and learn program also has shorter-term experiential learning opportunities embedded in the curriculum before the yearlong work placement. For example, in the GET1000 (Introduction to Engineering) course in the program's first term, each student is required to complete a four-hour industry job shadow. With support from the College's Career Services Department, students select a company to complete their job shadow experience. Typically, the students will shadow an operations, maintenance, production, or quality technician to gain insight into their role, daily activities, and involvement with other areas of the company. The students are also required to complete a short personal reflection at the conclusion of the job shadow.

The program is also set up so that students have the opportunity to obtain three additional industry-recognized certifications in addition to the associate's degree. Table 2 lists the three industry-recognized certifications and the requirements for obtaining the certifications.

Table 2. Additional industry-recognized certifications embedded in the SMT program

Course	Industry certification	Requirements to obtain certification
GET1000 (Introduction to Engineering)	OSHA-10	Complete 10-hour online module
EET1301(Robot Handling Tool Operations and Programming)	FANUC Handling Tool Operations and Programming	Complete course
SMT2000 (iRVision Operation and Programming – 2D)	FANUC iRVision Operation and Programming – 2D	Complete course

In order to be able to grant students the FANUC certification, the faculty member must achieve a "Train-the-Trainer" status. The first step towards the faculty member obtaining this designation includes completing training on the software and equipment provided by the manufacturer (FANUC). The second step entails the faculty member submitting a teaching video (to FANUC) covering at least one topic related to the operation of the equipment covered in the certification. This video would need approval from FANUC.

As part of the NSF ATE grant, funding was also provided to organize and deliver outreach events to expose middle and high school students to smart manufacturing and to build a pipeline of students into the new SMT program. A four-day SMT summer camp was delivered each year of the grant (2021-2023) during the summer. The camp was open to participants ages 12-18 years and was free of charge. Due to the high interest in the camp, a morning session and an afternoon session were made available. The maximum number of students per session was set at 12. The first two days of the camp had an information technology (IT) focus where students learned about using sensors, programming using a Raspberry Pi, and the hardware and software aspects of controlling a drone. Raspberry Pi Sense HAT units and CoDrone Pros were purchased, using grant funds, for camp participants to work together in teams of two. The third day of the camp focused on advanced manufacturing and industrial robotics. The participants learned about the operation and programming of industry-scale robots (FANUC and Yaskawa) and troubleshooting a mini factory line equipped with sensors, relays, and controllers. The participants spent time in the College's Esports Arena on the fourth and final day, participating in gaming activities. T-shirts, water bottles, and drawstring bags with the College's SMT logo were purchased with grant funds and given out to participants at the conclusion of the camp.

A participant survey, designed by the program evaluator on the project team (Ms. Blake Urbach, Principal Consultant of Preferred Program Evaluations), was administered to gain feedback on the effectiveness of the 2022 camp in engaging participants and increasing their understanding of and interest in smart manufacturing. On the last day of the camp, the online survey was administered to the participants, the results were compiled, and the program evaluator provided a dashboard summary. Twenty participants completed the electronic survey. All of the respondents identified as male. Seventy percent of respondents were middle school students (grades 6-8), and the other 30% were high school students (grades 9-12). Overall, the participants were satisfied with the camp activities and their interactions with the instructors, student volunteers, and peers. Eighty-five percent of participants agreed that the camp strengthened their interest in continuing to study smart manufacturing, and nearly all of the respondents would recommend this camp to their contemporaries. Figure 2 below provides a few sample questions from the survey. Participants were asked to rate their experience at the summer camp using a Likert scale of "strongly disagree" to "strongly agree," which has been consolidated in this table.

	Criteria	Agree (%)	Disagree (%)
Strengths	Camp activities offered plenty of time for hands-on engagement	95	5
	More knowledgeable about robotics and control prior to participating	85	15
	Strengthened my interest in studying smart manufacturing technology	85	15
Weaknesses	The length of this camp was the right amount of time to complete the activities	65	35

Fig. 2. 2022 SMT Summer Camp Participant Survey results

A professional development summit intended to increase local high school instructors' awareness and competencies related to smart manufacturing was delivered in the summers of 2021-2023. These events were organized to be a combination of two to three of the following: industry keynote speakers, a presentation covering progress on SMT grant-related activities, an SMT student panel, and breakout sessions providing participants with demos and hands-on activities using the industry scale equipment supporting the SMT curriculum. The summit also allowed participants to network with one another, the Engineering and IT faculty, and the grant project team members. As with the summer camp, the program evaluator designed a comprehensive participant survey. The purpose of the survey was twofold. The first was to provide an understanding of how to best serve high school instructors, particularly those teaching in the career technical education (CTE) area, with professional development engagements in the discipline. The second was to encourage introducing smart manufacturing concepts into existing courses taught by high school instructors and to gage their interest in delivering (at the high school) college credit plus (CCP) or articulated courses which feed into the SMT pathway.

Results and Discussion

Currently, ten students (as of Fall 2023) have declared this program as their primary major or as one of their majors if they complete multiple majors. When asked if the earn-and-learn component influenced their decision to enroll in this degree program, one student shared, "The fact that I'm already employed makes the earn-and-learn degree more feasible." Another added, "Earn-and-learn works well with my work schedule, plus I can beef up my resume." The students shared that the technical skills they gained and/or improved due to completing SMT courses included troubleshooting, mechanical skills, writing instructions for machines, and programming a logic controller. Reported gains and improvement in soft skills included problem-solving, critical thinking, and communication.

In consultation with employer partners, internal college departments (Career Services, Academic Advising, etc.), and utilizing feedback from stakeholder interviews carried out by the program evaluator, the project team will continue to look at ways to improve the earn and learn program. The project team has already identified one area where an improvement would need to be made. For example, currently, there are no credit hours associated with the two-semester work placement. Theoretically, students could complete the degree without completing the work placement, although this is a requirement of the degree and relayed to the student in initial advising meetings. One option would be to replace the three-credit hour Technical Elective course (TEC0000) with two work placement courses (i.e., Earn and Learn 1 and Earn and Learn 2). Earn and Learn 1 (one credit hour) would be taken in the fourth semester, and Earn and Learn 2 (two credit hours) would be taken in the fifth semester. Each credit hour equates to 150 hours of on-the-job training, so students must complete a minimum of 450 hours of paid work to get credit for the two courses.

The sustainability of the SMT earn and learn program and a plan for continuing to deliver yearly outreach events such as the SMT summer camp are under discussion. Since the camp is open to students at the middle school level, the intent is that these students will continue to attend the camp each year until they matriculate to MTC into the SMT (or other engineering technology) program. Discussions on whether to hold separate camps for middle and high school students are also underway. Incorporating an additional question at the end of the camp survey to gauge high school students' interest in enrolling in the Smart Manufacturing program directly after graduation would also be helpful. This would allow Advisors, Admissions, and the Engineering team to perform further outreach and stay connected to these students. Supplies for activities to engage these students each year, without repetition or duplication of activities, will be an important point to consider. As a start, grant funds have been used to purchase various kits and outreach material/giveaways for future camps and to engage students at various skill levels.

Conclusion

With the increased need for engineering technicians to fill Industry 4.0 roles, engineering technology programs with embedded work-based learning opportunities will ensure graduates are work-ready. The Smart Manufacturing Technology earn and learn program, outlined here, incorporates two terms of on-the-job training, ample hands-on labs centered around automation systems, and the opportunity to obtain additional industry-recognized certifications. Summer camps are being delivered to expose local middle and high school students to the IT and engineering aspects of smart manufacturing and to build a pipeline of students into the new program. Further data (both qualitative and quantitative) will need to be collected to assess student performance at work placement sites as well as overall employer satisfaction. It is expected that this program can be replicated at other community colleges looking to prepare technicians for Industry 4.0 roles.

Acknowledgements. This work was supported by the National Science Foundation (NSF) under award 2000177.

Disclosures. The authors declare no conflicts of interest.

References

[1] "Advanced & Additive Manufacturing Innovation in Ohio," JobsOhio. Accessed: Mar. 05, 2024. [Online]. Available: https://www.jobsohio.com

[2] "2018 Manufacturing Skills Gap Study," Nov. 2018. Accessed: Mar. 05, 2024. [Online]. Available: https://www2.deloitte.com/us/en/pages/manufacturing/articles/future-of-manufacturing-skills-gap-study.html

[3] "2021 Ohio Manufacturing Facts," National Association of Manufacturers. Accessed: Mar. 05, 2024. [Online]. Available: https://nam.org/state-manufacturing-data/2021-ohio-manufacturing-facts/

[4] "2020-21 Ohio Manufacturing Counts: Facts About the Economic Impact of Ohio Manufacturing," Ohio Manufacturers' Association, May 2020. Accessed: Mar. 05, 2024. [Online]. Available: https://www.ohiomfg.com/wp-content/uploads/OMA_ManufacturingCounts2020.pdf

[5] "Product Definitions for Smart Manufacturing," NIST. Accessed: Mar. 05, 2024. [Online]. Available: https://www.nist.gov/programs-projects/product-definitions-smart-manufacturing

[6] "Ohio Employer Guide to Work-Based Learning," Ohio Department of Education, Jun. 2022. Accessed: Mar. 05, 2024. [Online]. Available: https://education.ohio.gov/getattachment/Topics/Career-Tech/Work-Based-Learning/Work-Based-Learning-for-Businesses-and-Communities/Employer-Guide-to-Work-Based-Learning.pdf.aspx?lang=en-US

[7] "Advanced Manufacturing: A Look At Two Of Ohio's Most Innovative Earn-And-Learn Models. Replication Guide 2020," Columbus State Community College and Lorain County Community College., 2020. Accessed: Mar. 05, 2024. [Online]. Available: https://ohiotechnet.org/content/uploads/2020/07/EARN_Project_Replication_Guide.pdf

Professional Learning Externship as a Strategy to Increase Educator Understanding of Emerging Technological Fields

JOSH LABRIE[1]*, NATASHA SCHUH-NUHFER[1], CHRISTOPHER RUSSELL[1], JENNIFER A. GRUBER[2]

[1]*Information and Engineering Technologies Division, Northern Virginia Community College, Annandale, VA 22003, USA*

[2]*Research and Evaluation, Magnolia Consulting, LLC, Charlottesville, VA 22902, USA*

**jlabrie@nvcc.edu*

Abstract: Markets with emerging technologies face a challenge in finding employees with the knowledge base and skills necessary to fulfill their workforce needs. Generating awareness of these career fields is essential to meet workforce needs now and into the future. This paper discusses the extent to which educator awareness of the engineering technology (ET) and data center operations (DCO) programs and careers change as a result of participation in a professional learning (PL) externship program. Secondary educators in the PL program learned specifics of Northern Virginia Community College's (NOVA) ET programs, toured an ET facility and data center, and developed a plan to disseminate the ET credentialing and career information to their colleagues, students, and parents. In post-participation surveys, educators indicated increased awareness of and interest in ET education programs and career pathways. Additionally, educators indicated an understanding of the industry's need for ET talent and the skills and technical knowledge students need for ET careers. The data supports an educator externship as a PL mechanism for post-secondary institutions to increase awareness of the educational pathways and careers in emerging technologies.

Keywords: outreach, professional learning, educator externship, engineering technology, semiconductor, data center operations, emerging technologies, industry site visits

Introduction

In 2022, the American Semiconductor Academy and SEMI identified the semiconductor industry's key challenge: invisibility to most students and the public. Similarly, the National Institute of Standards and Technology reported a need to "enhance the image and visibility of the semiconductor industry" [1], and the National Semiconductor Economic Roadmap developed an initiative for "driving parent and youth awareness of semiconductor work as a career choice by developing fun and accessible programming" [2]. Delivering on the Promise of CHIPS and Science: Community Colleges and the Semiconductor Workforce calls for officials to "Invest in nationwide programs or in community colleges that are promoting visibility of the semiconductor industry to students and the public" [3]. The abundant growth of the data center industry across the US is also increasing the demand for technicians who require similar knowledge, skills, and abilities as technicians for the semiconductor industry, thus stressing the ET workforce pipeline further. Data Center labor income grew nationally from $43B to $75B from 2017 to 2021 [4], a 74% increase and almost three times the growth across all US industries for the same period. These reports, taken together, suggest meeting the technical engineering needs of employers requires an investment in the community to broaden and diversify the STEM pipeline while educating parents and educators about high-tech manufacturing and technician careers.

High school students gather knowledge about careers through many sources, including parents, teachers, counselors, and peers. Counselors, in particular, have an outsized role in providing students with targeted recommendations for post-secondary education, often advising students directly towards considering (or rejecting) certain disciplines or institutions. Despite their role in directing students towards STEM disciplines, calls for improving career pathways typically focus on professional learning (PL) for in-service teachers [5]. Extant PL programs for counselors tend to address social-emotional and crisis counseling rather than targeted career development; moreover, these programs are uncommon and limited in scope and duration [6]. Given the role of counselors in the student-career information ecosystem, counselor-focused interventions to help solve information awareness gaps for in-demand fields are warranted.

This paper discusses the structure and design of an educator externship and the extent to which it improved educator awareness of ET and DCO educational programs and careers. The PL was structured for CTE personnel and high school counselors to raise awareness for these relatively invisible ET educational and career pathways in the region. Participants received a programmatic overview of ET and DCO credentials and facilities, toured a local ET manufacturer and a data center, and submitted a plan of how they wanted to apply their newfound knowledge to their practice. The data support the effectiveness of the PL program in increasing educator awareness of emerging technologies and highlight the importance of such programs in supporting post-secondary institutional efforts to meet industry workforce demands.

Program Context & Structure

In Northern Virginia, the semiconductor and data center industries are growing and generating high demand for a skilled ET workforce. Micron started a $3 billion upgrade of their Northern Virginia facility in 2018, which estimated 1,100 new jobs by 2030 [7], and now employee retention is a concern as new facilities open across the US. Northern Virginia is also the largest data center market in the world, and Virginia data center employment increased from 65,500 jobs in 2017 to 86,290 in 2021, a 32% increase [4]. CBRE's 2023 H1 report [8] indicates the data center market increased by 12% during the first half of 2023 and 19.2% year-over-year. Not surprisingly, the DC Metropolitan Area is home to the third highest concentration of technology workers in the country [9], but that talent largely works within Information Technology (IT), not ET.

NOVA's Expanding Regional Capacity for Training in ET and Data Center Operations project, herein referred to as *DCO Tech*, attempts to ameliorate the ET workforce talent shortage by improving the visibility and awareness of ET career pathways in the region through a two-pronged outreach approach: a Summer Bridge Program for high school students and an Educator Externship for career and technical education (CTE) educators and counselors. At the onset of DCO Tech, the project's external evaluator conducted interviews to better understand stakeholder awareness of ET career pathways, roles in fostering and supporting the ET pathways, and ideas for improving ET pathways. The interview findings indicated there was a lack of awareness of these career pathways due to misconceptions of modern manufacturing and competing demands for students' attention [10]. Recommendations from these findings included providing career exploration opportunities and communicating information about skillsets, pathways to employment, and benefits of the careers to students, parents, and educators as strategies to improve K-12 student awareness. Project evaluation surveys of K-12 educators echo these sentiments, suggesting little student or educator knowledge of data center career pathways [11].

The IET marketing team updated the NOVA website and developed an IET marketing folder with academic program flyers for six pathways, a poster, and flyers for the bridge and educator externship programs. NOVA's STEM program coordinators delivered two folders and posters directly to all 70 high school counseling offices in the service area during the winters of 2022 and 2023. When possible, NOVA staff met with school administrators, educators, school and career counselors, and advisors to discuss the NOVA IET programs and recruit participants for the externship program. This was an essential programmatic step that produced high interest in the educator externship. The marketing plan produced 27 applicants from targeted recruitment of CTE educators and counselors to the externship program in Year 1, with (75%) completing the program. In Year 2, 25 educators applied to the program and were accepted, 16 (64%) completed the program.

Educator Externship Program Design

Best practices for educator PL programs require preparation, reflection during and after the program, and completion of a product [12]. The educator externship was designed to provide a short PL opportunity for educators and counselors to learn more about ET and DCO programs and careers. The secondary educator externship consisted of four required components: two industry site tours, a tour of NOVA's ET labs and program overview, and a submitted plan of action. Those completing all components of the program received a $500 stipend. In Year 2, a Program Introduction meeting was added to the schedule to provide a formal introduction to NOVA's programs ahead of the industry site tours. Table 1 provides an overview of the externship.

Table 1: Secondary Educator Externship Program Components

Component	Description
Programs Introduction Meeting Virtual (added in 2023)	Virtual meeting providing an overview of the NOVA ET and DCO pathways, where to find program course information, career insight information, and externship requirements
Engineering Technology Industry Tour In-person	• Tour of advanced chip manufacturer Micron Technology or Lockheed Martin's Manassas Site • Q&A with current employees, industry recruiters, and community outreach coordinators
Data Center Tour In-person	• Tour one of five data center partner facilities (CoreSite, Equinix, STACK Infrastructure, Iron Mountain, QTS Data Centers) • Q&A with current employees, industry recruiters, and community outreach coordinators
NOVA Fab Lab Tour In-person	• Tour of the NOVA Fab Lab, makerspace, and engineering technology classrooms • Review of the ET and DCO programs; discussion of how to improve student recruitment
Plan of Action Asynchronous	Participants create a plan explaining what they learned from the externship, how they will disseminate their knowledge at their school/organization, and how NOVA can assist them with their plans.

Tours were conducted from April through May, and the final session in July was held at the NOVA Fab Lab, a 10,000 square foot digital fabrication lab on the Manassas campus built in partnership with industry partners like Micron Technology to support the engineering technology programs. Plans of action were due by mid-August, ahead of the new school year. The 2023 program included a kick-off meeting in March.

Methods

Participants

In total, 34 educators completed the 2022 and 2023 externship programs. Participants came from five of the eight school districts within NOVA's service region, including predominantly high school college/career counselors and advisors. Educators were given the option to opt in or out of the program's external evaluation study during the application process. Overall, 25 educators (74%) opted to participate in the evaluation study.

Data Collection

Following the completion of the professional development day at the NOVA Fab Lab and the conclusion of the program, participants submitted Plans of Action to articulate how they would implement what they learned during the externship. The externship participants who opted into the program's evaluation study were then sent a survey upon completion of the program.

Educator Externship Plans of Action

Educators' plans of action included three prompts worded as questions: a) what they learned through participating in the externship; b) what actions they will take to share the information they learned, and c) how NOVA and industry partners can connect with them to improve student/teacher/counselor understanding of the ET and DCO pathways and careers.

Educator Externship Survey

The externship survey was designed as part of the external evaluation of the DCO Tech project. The purpose of the survey was to understand participants' perceptions of the program and examine its intended outcomes. The survey included a combination of Likert-scale questions and open-ended questions. The measures addressed in this paper include participants' perceived a) awareness of engineering technology and data center education programs and career opportunities, b) understanding the importance of different skillsets for these careers, and c) confidence in advising students about these careers. The survey was designed as a retrospective pre-posttest, in which respondents provide their "pre" and "post" ratings at the same time (in this case, after participating in the program). Previous research has validated retrospective pre-posttest designs and highlights them as an opportunity to address response shift bias for educational programs [13, 14]. Of the 2022 cohort, 16 of the 18 (89%) opted into the study and provided complete responses to the survey. Of the 2023 cohort, nine of the 16 (56%) opted into the study and provided complete responses to the survey.

Data Analysis

Educator Externship Plans of Action

The program team analyzed qualitative data from all of the submitted plans of action using a thematic analysis approach incorporating both deductive and inductive coding processes [15]. An initial round of deductive coding was performed using structural codes aligned to the plan of action open questions. The program team then conducted a second round of inductive coding to complement and extend the initial round of coding.

Educator Externship Survey

First, the 2022 and 2023 externship survey responses were combined. Then, means and standard deviations were calculated for the retrospective pre-post survey items and the raw mean differences between the pre and post ratings were calculated.

Results and Discussion

Plan of Action: Four themes were identified from the Plans of Action: Industry and Institutional Knowledge Learned, Dissemination and Implementation Plans, Challenges to Generating Student Interest, and Desire for Collaboration with NOVA. See Table 2 for the four themes and the top three corresponding codes and quotes for each.

Table 2: Externship Participant Plan of Action Form Themes and Quotes (Combined 2022 and 2023, n=34)

Industry and Institutional Knowledge Learned	
Industry need for talent (n = 27, 79%)	"Careers in technology and data operations are exploding in this area, and there's a great need to ensure students are aware of said opportunities."
Technical/operational details (n = 17, 50%)	"I like that it doesn't just have to be people in the engineering field, but also can be those interested in the business side of things."
NOVA programs & credentials (n = 17, 50%)	"The hands-on training opportunities that are incorporated into the different degree programs offered at NOVA allows students interested in this field with the opportunity to complete requirements in a short amount of time."
Dissemination and Implementation Plans	
Sharing with colleagues (n = 26, 76%)	"Work with all CTE teachers to help identify students who are interested and skilled in moving forward in the tech field but may not be interested or able to attend 4 year college."
Direct student discussion (n = 22, 65%)	"I will embed information about these programs into post-secondary planning lessons."
Parental engagement (n = 16, 47%)	"The first action is to inform parents of the opportunities and how the electives and general education classes help facilitate the educational pathways to be successful and acquire these types of jobs."

Challenges to Generating Student Interest	
Academic/Administrative (n = 9, 26%)	"I'm extremely excited to share your opportunities with our students and staff, but educators have so much thrown at them it's easy for things to fall off their radar."
External (n = 8, 24%)	"There are many students and families that believe a 4 year degree is the only way to pursue their career, and that certainly is not the case."
Industry working conditions (n = 5, 15%)	"…work hours and schedules that do not mirror the average 9 to 5 may be a deterrent for many young adults who have never had experiences with 10 hour shifts and working on holidays."
Desire for Collaboration with NOVA	
Dedicated NOVA staff member (n = 28, 82%)	"Seek staffing support from NOVA for one NOVA employee to support questions, presentations, information, outreach, etc. within the division."
Presentations from NOVA staff (n = 21, 62%)	"Would like to coordinate a NOVA visit specifically for our SPED/CTE students and host a Lunch and Learns."
Field trips (n=19, 56%)	"Continue providing student tours since it would give them a hands-on opportunity to visualize themselves in the program."

Note: Quotes used are from separate individuals

Educator Externship Survey Results

Responses to the Externship survey are summarized in Table 3. Participant responses indicated they had a higher awareness of engineering technology and data center education programs and career opportunities after the externship program relative to before, particularly regarding their awareness of NOVA DCO programs. Participant responses also indicated they had increased understanding of the importance of different skillsets for DCO and ET careers after the externship program relative to before, particularly regarding the importance of mechanical skills. Finally, participant responses indicated they had increased confidence in advising students about ET and DCO careers after the externship program relative to before, particularly regarding providing secondary students with resources on ET or DCO career pathways.

Table 3: Combined 2022 and 2023 Externship Program Survey Results (n=25)

	Before		After		
Awareness of the following opportunities:	**Mean**	**SD**	**Mean**	**SD**	**Mean Difference**
NOVA ET Educational Programs	2.36	1.15	4.44	1.16	2.08
ET Careers in Northern VA	2.52	1.30	4.32	1.25	1.80
NOVA DCO Educational Programs	2.08	1.15	4.44	1.19	2.36
DCO Careers in Northern VA	2.40	1.29	4.44	1.19	2.04
Importance of the following skills for ET careers:	**Mean**	**SD**	**Mean**	**SD**	**Mean Difference**
Technical Aptitude	3.79	0.88	4.46	0.93	0.67
Communication, Collaboration, and Teamwork Skills	4.04	1.08	4.91	0.28	0.87
Dependability and Reliability	4.08	0.97	4.96	0.20	0.88
Mathematics	3.86	1.03	4.04	1.23	0.18
Technology Skills (e.g., programming, data analytics, cloud computing)	3.71	1.08	4.13	1.19	0.42
Mechanical Skills (e.g., engineering, hands-on troubleshooting)	3.83	0.92	4.75	0.53	0.92
Confidence in the following:	**Mean**	**SD**	**Mean**	**SD**	**Mean Difference**
Advising secondary students on the types of classes they should take in high school to prepare for an Engineering Technology degree.	3.13	1.3	4.42	0.78	1.29
Advising secondary students on how to obtain an Engineering Technology or Data Center Operations degree or certification.	2.71	1.46	4.54	0.59	1.83
Providing secondary students with resources on Engineering Technology or Data Center Operations career pathways.	2.79	1.25	4.67	0.57	1.88
Educating my colleagues on guiding secondary students towards Engineering Technology or Data Center Operations careers.	2.83	1.30	4.61	0.58	1.78

Note: SD=Standard Deviation. Scale: 1=Not at all; 2=Slightly; 3=Somewhat; 4=Moderately; 5=Very

Discussion

The results presented above suggest that participation in the externship improved educator awareness of ET and DCO educational programs and careers. The educator externship survey and plan of action analysis both suggest that the externship improved educator awareness for these career pathways and for NOVA's academic programs. Educators in the externship program showed the largest improvement in their self-reported awareness of NOVA's DCO and ET educational programs and careers. While the marketing effort for these programs and pathways was successful in recruiting educators, the surveys revealed that word of mouth marketing is likely since 81% of educators plan to share their new knowledge with a colleague. Externship participants also indicated a need for more collaboration between NOVA, industry, and secondary schools.

Educators' plans of action frequently demonstrated a burgeoning knowledge about the industries and technologies that were discussed during the externship. Plans emphasized some of the key skills and competencies mentioned during tours, such as manual dexterity, high reliability, and a mission-critical mindset. Participants also highlighted some industrial systems common to data centers and semiconductor fabrication, such as power delivery, cooling systems, and programmable logic controllers. Educators contrasted the requirements for these technician careers with 4-year engineering degrees – for example, one participant noted that with "…only two semesters of college education and certification, entry level jobs [at Micron] are high paying" (Participant #17). Another suggested that many students would find these pathways appealing, given that "less math [is] required for those students who don't excel in math, or simply don't want to take the level required for a BS in Engineering" (Participant #20). Throughout plans, the high salaries for these technician roles were consistently brought up as a key selling point for students and parents; as one participant argued, "the starting salaries in these fields stood out to me…for students who may otherwise be hesitant to participate in a 2-year or a certificate program" (Participant #13). These statements offer a view of how counselors are likely to present technician career options to students and demonstrate their expectations of a bias towards 4-year bachelor's degrees.

Educators showed an increase in their self-reported confidence in advising students of ET resources and educational preparation for ET careers. Externship participants planned multiple avenues of disseminating what they learned during the industry site tours and NOVA's ET and DCO program presentations. Broadly, participants' plans for disseminating what they learned were sharing information directly with colleagues, individual student counseling sessions, and direct parent engagement. Most common was the plan to share with colleagues – participants suggested bringing their new knowledge to classroom teachers in relevant disciplines (e.g., CTE, Engineering), presenting it in internal meetings, and adding content to school newsletters. Participant plans for direct student engagement highlighted the need for early intervention. As one participant put it, "it would be beneficial to introduce these early on in high school, when many students have not yet chosen a career path" (Participant #13). Other participants discussed plans to introduce 2-year pathways to students as an alternative pathway, implying that discussions about post-secondary education plans typically center around 4-year degrees.

Nearly all educators felt it would be important to collaborate with NOVA and industry representatives. This collaboration could be working with a staff member for classroom presentations, career nights and speaking with parents, or coordinating field trips to NOVA or an industry partner. Participants emphasized that these techniques could "get students excited about careers in these fields" (Participant #13), allow "students to learn first-hand from professionals" (Participant #33), and "get buy-in from students and parents" (Participant #9). Field trips – either to NOVA's campuses or to industrial sites – were brought up as the most engaging option to spark interest in students. Participant 18 argued that "students will gain a wealth of knowledge by coming and touring the NOVA Fab Lab and learning more about the campus, degrees, programs, and jobs available upon graduation." Most commonly, however, was the suggestion to hire or identify a NOVA staff member to act as a liaison to schools. While many of the strategies recommended by participants are common to outreach programs, participants did not believe their own institutions would be able to offer students technical or experiential learning in emerging technological fields. In other words, while established technical disciplines such as computer science are well integrated into the high school setting, participants in this externship believed that further student engagement in ET or DCO would require outside assistance.

Despite the positive experience of participating in the program, educators raised concerns about the lack of time to fully devote to sharing the information learned. Educators also described the 24x7 career and work-life balance as possible barriers to student interest. There was general agreement that a hands-on approach and in-person experiences would have the greatest impact on drawing students into these career paths. Also of note was the level of participation of college and career counselors compared to CTE educators, whom the project coordinators thought would be the largest participant group when the project was proposed. While college and career counselors can reach a wider student audience, CTE educators working directly with students in the classroom can connect CTE concepts to real-world applications and can more easily identify those students whose aptitude make them ideal candidates for ET careers.

While NOVA chose an educator externship to provide PL to CTE educators and counselors to improve awareness for ET and DCO industries, there are many educational solutions that could be chosen to improve awareness for an industry, such as traditional summer bridge programs for students, extended work-based learning programs, camps, social media campaigns, and face-to-face interactions found at STEM expos, fairs, and conferences [16]. NOVA chose both a student-focused experience for an immediate impact on student recruitment and the educator PL as a long-term strategy to improve awareness and, ultimately, student enrollment.

One challenge to this outreach approach that was not considered during the design process and should be considered by any post-secondary institutions wishing to design similar outreach programs, is the involvement of parents in facilitating the discussion of the types of high wage, in-demand careers available to their children through low-cost educational training options found at community colleges like NOVA. Tackling parent expectations and the myths of 2-year colleges are challenges that community colleges commonly face and could limit the effectiveness of outreach programs to increase student enrollment. As stated by one of the participating high school career counselors: "I would like to set up a parent informational night about NOVA's Engineering Technology Program. I think the parents would benefit from learning about other options than the four-year pathway for their children" (Participant #19).

Conclusion

Markets with emerging technologies need a workforce educated in those technologies. Meeting high-tech manufacturing and technician workforce demands requires investment by post-secondary institutions and industry to broaden and diversify the STEM pipeline through educator, parent, and student outreach programs. The data presented here suggest that NOVA increased educator awareness of ET and DCO careers and NOVA's credentialling pathways to these in-demand, high wage careers through an educator externship. Key to awareness development for participants was access to industry partners and their facilities and the ability to reach all stakeholders who influence students' career decision-making. Dissemination of ET career pathway information through externship participants and continued collaboration with NOVA for classroom visits and speaking engagements with parents and students are cost-effective and likely critical mechanisms to increase the pipeline of students into the ET workforce in Northern Virginia.

Acknowledgements. This work was supported in part by the National Science Foundation (NSF) under award 2055717. Additional support comes from the Growth and Opportunity Virginia grant program, the NOVA Foundation, and private grant programs to cover participant transportation costs.

Disclosures. The authors declare no conflicts of interest.

References

[1] "Incentives, Infrastructure, and Research and Development Needs to Support a Strong Domestic Semiconductor Industry: Summary of Responses to Request for Information," National Institute of Standards and Technology, Special Publication NIST SP 1282, Aug. 2022. [Online]. Available: https://nvlpubs.nist.gov/nistpubs/SpecialPublications/NIST.SP.1282.pdf

[2] "The National Semiconductor Economic Roadmap," Arizona Commerce Authority, Dec. 2022 [Online]. Available: https://www.azcommerce.com/media/1uubpnti/national-semiconductor-economic-roadmap-final.pdf

[3] J. Gluck, K. Sodhi, A. Higuchi, and A. Jayanti, "Delivering on the Promise of CHIPS and Science: Community Colleges and the Semiconductor Workforce," Belfer Center for Science and International Affairs, Cambridge, MA, USA. 2023 [Online]. Available: https://www.belfercenter.org/publication/community-colleges-and-semiconductor-workforce

[4] "Economic, Environmental, and Social Impacts of Data Centers in the United States," Data Center Coalition, VA, USA. 2023 [Online]. Available: https://www.centerofyourdigitalworld.org/impact-study/#07

[5] C. D. Schmidt, G. B. Hardinge, and L. J. Rokutani, "Expanding the School Counselor Repertoire Through STEM-Focused Career Development." *The Career Dev. Quart.*, vol. 60, no. 1, pp. 25-35, Mar. 2012, doi: 10.1002/j.2161-0045.2012.00003.x

[6] T. Anctil, C. Smith, P. Schenk, and C. Dahir. "Professional School Counselors' Career Development Practices and Continuing Education Needs." *The Career Dev. Quart.*, vol. 60, no. 2, pp. 109-121, Jun. 2012, doi: 10.1002/j.2161-0045.2012.00009.x

[7] "Governor Northam Announces Major Investment in Micron's Semiconductor Manufacturing Facility in Manassas," Virginia Economic Development Partnership, Richmond, VA, USA. August 29, 2018 [Online]. Available: https://www.vedp.org/press-release/2018-08/micron-technology-inc

[8] "North America Data Center Trends H1 2023," CBRE, Dallas, TX, USA. 2023 [Online]. Available: https://www.cbre.com/insights/reports/north-america-data-center-trends-h1-2023

[9] "State of the Tech Workforce," Computing Technology Industry Association, Downers Grove, IL, USA. 2023 [Online]. Available: https://www.cyberstates.org/pdf/CompTIA_State_of_the_tech_workforce_2023.pdf

[10] E. Peery, "DCO Tech Evaluation: Baseline Interview Summary," Magnolia Consulting, LLC, Charlottesville, VA, USA. 2022

[11] J.A. Gruber, "Northern Virginia Community College DCO Tech Project: Year 2 Evaluation Interim Report," Magnolia Consulting, LLC, Charlottesville, VA, USA. 2022

[12] L. Johnson, R. White, I. Charner, J. Cole, and G. Promboin, "Work-Based Learning Manual: How-to Guide for Work-based Learning," FHI 360, Durham, NC, USA. 2018 [Online]. Available: https://wbl.fhi360.org/teacher-externships

[13] F. Bhanji, et al. "The Retrospective Pre–Post: A Practical Method to Evaluate Learning From an Educational Program." *Acad. Emergency Med.*, vol. 19, pp. 189-194, 2012, doi: 10.1111/j.1553-2712.2011.01270.x.

[14] T. Little, et al. "The Retrospective Pretest–Posttest Design Redux: On its Validity as an Alternative to Traditional Pretest-Posttest Measurement." *Int. J. Behav. Develop.*, vol. 44, no. 2, pp. 75-183, Mar. 2020, doi: 10.1177/0165025419877973

[15] V. Clark, V. Braun, and N. Hayfield, "Thematic analysis" in *Qualitative psychology: A practical guide to research methods*, J. Smith, Ed., London, UK: SAGE, 2015, pp.222-248.

[16] J. Ashcroft, K. Sweimeh, J. Beck, and L. Fletcher, "Strategies to Increase Awareness, Recruitment, and Success in Community College Advanced Technical Education Programs," *J ATE*, vol 1, no 1, pp. 28-35, 2022, doi: 10.5281/zenodo.6506510

Every Last Drop: Reflections on a Small Enrollment Program

KEITH M. STURGES[1]*, CRISTINA M. CARBAJO[2]

[1]*Indikus Evaluation and Planning, Ashland City, Tennessee, 37015, USA*

[2]*Department of Natural and Behavioral Sciences, Pellissippi State Community College, Knoxville, Tennessee, 37932, USA*

**ksturges@indikus.com*

Abstract: Is it worth the effort for community colleges to pursue NSF ATE grant funds for small enrollment programs? This manuscript describes our experiences with a program that served 11 students and four local employers in a high-need field. This collaborative writing effort is presented as a grant program postmortem review to share our experiences and review pertinent literature so that others, particularly prospective community college grant recipients and evaluators of those grants, may learn from our experiences. We discussed ways we were able to leverage a small program to our advantage and the size-specific issues that we were unable to resolve.

Keywords: small enrollment programs; program funding; qualitative evaluation; confidentiality; small grants

Introduction

The topic of this manuscript is small grant pilot-funded programs. We (the project coordinator/faculty, member of a water treatment program and the project's evaluator) describe our reflections from a four-year National Science Foundation (NSF) funded Advanced Technological Education (ATE) grant. While earlier literature defines small programs as those that involve fewer than 100 students and are taught by five or fewer instructors [1], ours was considerably smaller than this, serving a total of 11 students (5 in Cohort 1 and 6 in Cohort 2). It was operated entirely by one faculty member who was also the project's coordinator. Despite its remarkably small enrollment and, thus, small budget, by the end of the grant's three-year performance period, the Water Quality Technology (WQT) program boasted job placement for 10 of its enrollees.

Furthermore, those students exceeded the state average certification examination pass rate. The grant-funded program enhanced the college's capacity to offer a degree in WQT, resulted in a complete curriculum, and established relationships with regional employers. Its external evaluation provided formative feedback and summative results that met NSF expectations and were consistent with evaluation standards while staying within budget. The program met its goals and was, by that definition, successful. But the experience was not free from challenges.

Fig. 1. Students Brad Bales (left) and Lisa Sforza (right) are shown at their treatment facilities. Both passed the highest levels of state certification in their field.

WQT Context

In 2018, in response to local water industry concerns about the lack of skilled, certified operators in the region, Pellissippi State Community College (PSCC) applied for and was awarded an ATE grant to launch its new drinking water and wastewater degree program. While many small programs are established as pilots that are intended to be scaled up if successful, WQT was designed to be small to meet local demand for qualified technicians. There is demand for highly skilled workers throughout the US, with many plants competing for certified workers [2]. However, the pass rate for state certification is often low. In Tennessee, for example, pass rates for the state-level certification exam are around 25% [3]. In addition to current available positions, the water industry will likely incur considerable demand over the next decade, with up to 40% of current workers projected to retire [2]. Approximately 25 new positions may open in PSCC's area in the next five years, using statewide projections [4]. Thus, although there is an urgent demand for certified wastewater operators, projections suggest there will never be a need for large numbers of graduates in a given region, including ours.

The WQT program awards students an Associate of Applied Science Degree upon completing 60 credit hours. The two-year degree educates students with a combination of STEM courses, professional development, general education courses, and nine WQT-specific courses paced over four semesters. To actualize WQT, one full-time faculty member developed, launched, and coordinated the program. She developed and continually refined course curricula, mentored and advised students, established and maintained relationships with local employers, taught program-specific courses, and coordinated student internships and site visits at treatment facilities and, because of this, will be referred to as faculty/coordinator throughout this paper. She also implemented and refined WQT with ongoing input from the evaluator, which was conducted concurrently with WQT delivery. In line with the size of the program, the evaluation was also small. Over the performance period, the evaluator collected data from the 11 students and four employers who also served as internship supervisors. Reports were delivered throughout the four years to serve both formative and outcomes purposes.

Method

In what began as an informal review, it occurred to us that the small program offered unique advantages and also came with what seemed to be several insurmountable challenges. We used a program retrospective review, a collaborative postmortem [5] process intended to identify strengths and weaknesses in the program's design, implementation, and outcomes. Our intention was to explore the macro implications of the small enrollment program. To do this, we reviewed program notes and evaluation reports and then met to develop a series of themes that seemed to step from the program's size. We then organized the themes into five domains (see Matrix 1). Two questions for reflection guided our retrospective review:

1. In what ways were we able to use the program's small size to our advantage?
2. What were the unresolved issues related to the program's size?

The set of themes we present in this paper is not exhaustive but reflects our experiences. Nonetheless, while advantages and seemingly insurmountable challenges are tied to each institution of higher education's (IHE) unique context, we believe many or most will be relevant to other small enrollment grant-funded programs regardless of context, region, or field of study.

Literature on Small Enrollment Programs

While the literature on small enrollment programs is scant [6], we identified some potentially noteworthy trends. Designers and directors of small IHE academic programs will likely agree that there are at least two inherent difficulties associated with academic programs designed for small enrollment. First, it is challenging to compare assessment results since data generated from small enrollment programs are not generalizable [6]. Many IHEs create alternative assessments for small enrollment programs, including using portfolios, evidence-based frameworks, and qualitative indicators [6]. Second, it is difficult to attract and retain staff who are willing to commit to the myriad responsibilities, excessive workloads, and unspoken obligations associated with running a "one-person" program [7], [8], [9].

From an evaluation standpoint, little published guidance may be applied to small enrollment programs. Bamberger et al. describe the Shoestring Evaluation approach as one that attempts to be as "methodologically sound as possible when operating with budget and time constraints" [10]. According to the authors, the approach mitigates problems associated with small-budget evaluations, including random sampling, quality control, and control for evaluator bias. This article and subsequent published works (e.g., Ravillion) make clear that mixed methods approaches are paramount for small-budget evaluations [11]. Moreover, because small evaluations, which tend to involve fewer decision-makers, are less political in nature and support closer working relationships between the evaluator and program staff, they also tend to favor continuous improvement over summative results [12], [13].

Results

WQT's small size offered advantages or leverage points that we might not have as easily enjoyed on a larger program. While some of these benefits would likely have been achieved in a larger program, we believe—based on previous experiences—that the quality of these issues was enhanced by WQT's size. At the same time, WQT's size also presented us with challenges that we were unable to mitigate.

Advantage 1: WQT Made Extensive Use of Individualized Student Supports

WQT used small cohorts to take advantage of the learning community structure, which tends to encourage greater engagement and course pass rates [14], [15]. It also emphasized individualized student attention and support, which have been shown to increase student retention and academic success [16], [17], [18].

WQT's size made integrating the flipped classroom and other active learning strategies easy. The faculty/coordinator commonly had students view lectures remotely and was, thus, able to focus on hands-on activities in the classroom and through site visits. This included demonstrating to students how to test water samples and then coaching them as they performed the tests. In addition, the faculty/coordinator created and used targeted strategies outside of regular class requirements to help students understand the relationship between theory and water treatment. For example, students utilized a computer-based modeling program with unique problem-solving scenarios, such as flooding, to help them understand the relationship between classroom theory and real-life situations.

We leveraged WQT's small size to support an informal learning environment. The faculty/coordinator facilitated and encouraged students to participate in small group study, project-based assignments, and supported test preparation. Students enrolled in WQT benefitted from the small cohort structure because they could develop peer relationships and form study groups with peers taking several of the same courses across disciplines simultaneously. These peer relationships and study groups are likely to have also helped reduce student attrition. For example, one student, an adult who returned to college after another career, was unsure about his abilities to complete WQT. However, he later reported that because of the informal and peer-supported small learning environment, he became more confident and excelled in courses.

WQT's size allowed for formal and informal individualized attention for each student. The program coordinator met regularly with each student throughout each semester to discuss updates about course progress and areas in which students were struggling. She was familiar with each student's academic progress, study habits, strengths, support needs, time management and soft skills, and personal issues. Some students encountered difficult personal circumstances while studying WQT and others, at the time of their enrollment, had not established professional or life skills. The faculty/coordinator assumed the responsibility of working with each student to mitigate the effect of these difficulties on students' academic progress.

WQT's small size increased students' opportunities for hands-on site visits to treatment facilities. We believe the small size of WQT ensured that every student was able to visit multiple plants and, thus, increase their exposure to treatment techniques and hands-on procedures (e.g., testing water samples). The faculty/coordinator served as a liaison between facilities and students, scheduling all site visits and internship placements each year. This exposure to various plants allowed students to better understand variations in how plants operate.

Because of the small program size, the faculty/coordinator was able to engage all students in professional trade event opportunities. Beginning in the first year of WQT's implementation, the faculty/coordinator brought all students to conferences and technical presentations. In addition to attending lectures and networking events, the students were recognized in a Young Professionals Luncheon. As a result, several students secured jobs from connections made during that conference.

Advantage 2: WQT's Evaluation Emphasized Use for Continuous Improvement

The evaluation was fully integrated into WQT to provide ongoing feedback. A core assumption of the evaluation approach we selected is that in addition to generating compelling evidence that reported on the extent to which WQT met its goals, it provided ongoing access to results that were designed to assist in decision-making [19]. We avoided a checkbox evaluation or one that perfunctorily utilized instrumentation designed for larger, more complicated studies. We used the small size to our advantage by combining a rapid and responsive feedback approach with a thematic framework [20] that would follow each individual's progress through the program and into employment. The evaluation used mixed methods including, for example, questionnaires, individual interviews, and student assessment data (comparative with the state average, number of attempts to pass, and the pass rate for WQT students).

The small program design permitted the evaluator to maintain connections across data sources. We knew that a qualitative design would be ideal given ongoing communication with each student, the faculty, and the employers, but that the limited budget would not allow for an intensive design such as ethnography [20] or multiple case study analysis design [21]. We simplified this to be able to report by cohort the experiences of each individual using student and internship host questionnaires, regular conversational interviews with the faculty/coordinator, biannual interviews with students and employers, and extant data (e.g., certification test results). Unlike more traditional evaluations that may showcase one type of data or analytic method as the primary indicator of program effectiveness, the WQT evaluation relied on various methods and data sources used systematically, consistently, and collectively to emphasize triangulated findings.

Although qualitative inquiry tends to be labor intensive, its use in this small evaluation supported a rapid data collection and reporting cycle. In response to program needs and limitations articulated during the planning year, the evaluator used a reporting approach that was influenced by rapid evaluation and assessment methods or REAM [22]. The idea was to maintain a balance between speed, usefulness, and credibility of the evaluation results. Through the use of Rapid Response Reports, we were able to summarize the inquiry's purpose, present responses, and major themes, and offer recommendations and next steps for the evaluation within one week of each data collection event. This ensured that the WQT evaluation users received actionable feedback in a timely manner. It also created a dialogic process between the evaluator and faculty/coordinator, leading to new or alternative interpretations of results and questions for follow-up inquiry.

The small program size supported full integration of the evaluation and supported evaluation use. Because programs that involve fewer stakeholders and that have a local orientation are inherently less political, they tend to be easier to make full use of evaluation results [12]. Our discussions—between the evaluator and faculty/coordinator—concentrated on the results' implications for program enhancement and program delivery. For example, in situations where there was variation in student responses about the usefulness of hands-on laboratory experience, we conducted follow-up inquiries to better understand how that element of WQT benefitted some students and not others. As another example, qualitative results provided compelling evidence that incoming plant job applicants were underprepared for leadership roles. We used feedback from recently hired employees and plant leaders to secure the creation of a leadership course for WQT students. In fact, because the evaluation study included few outcome indicators throughout WQT's performance period, we gave priority to formative feedback over outcome findings.

Challenge 1: Key Players Were Overburdened and Stretched

As noted previously, WQT's budget covered a small program evaluation and personnel costs for one faculty member who was also the coordinator. Particularly for the faculty/coordinator, WQT's support for one person was taxing. We describe two themes that were associated with stretched resources.

Limited resources and support stretched the single faculty member who also served as WQT's program coordinator. While more extensive programs would distribute teaching and lesson development across several faculty/coordinators, WQT required the program coordinator to design, create, and teach all nine WQT courses. This amounted to four to five unique courses every semester, each with its own preparation, and, because of the niche nature of the WQT subject matter, identifying resources since traditional textbooks and other formal teaching resources do not exist. Moreover, the faculty/coordinator scheduled all courses, all of which were face-to-face. Finally, although most academic appointments do not include extensive course advising, professional and academic career support, or job placement, as WQT's single point of contact, she was overwhelmed by student requests. These roles and responsibilities collectively amounted to regular schedules of 12- to 14-hour days.

Requests for student visits overburdened local treatment plants. While not directly resulting from the grant-funded program's size, the limited number of local plants largely dictated WQT's size. During the course of WQT delivery, some plant directors noted that they were overburdened by requests for student site visits or to serve as hosts for student field experiences and requested that the number of visits be reduced.

Challenge 2: The Evaluation Confronted Reporting Challenges

Although measures were taken to balance credibility and privacy, public reports of the evaluation's findings were not robust partly because of threats to confidentiality. As described above, WQT's evaluation combined rapid evaluation and mixed methods to gauge each student's progression through the program, engagement in field experiences, certification examination scores, and employment in the field. However, because of the small enrollment, participants were identifiable. Confidentiality is an ethical principle in evaluation, especially when reporting sensitive data, which may include employment and assessment activities. Ideally, through deidentification, aggregation of larger data sets, individuals' opinions about the program, its usefulness and value, and ways it may be improved may be offered to evaluation audiences with little prospect of reprisal or discomfort. With only a few students matriculated in some WQT sections and only four participating employers and all of them having familiarity with each other, individual participants could, potentially, have been identified by each other and by the WQT faculty/coordinator through evaluation reports of findings.

The team decided that because of confidentiality concerns, outcomes results would not be shared publicly. Because of the small context and just a few students and employers participating in the evaluation, we quickly realized that participants were identifiable through evaluation reports. Descriptions of water treatment facilities, facility personnel, and internship focus could easily link any of the facilities and, thus, employers to specific students. While the evaluator ensured that participants understood that they could be identified by WQT grant leadership, they were also assured that their confidentiality would be maintained beyond reports to the college. Thus, we were limited in our presentation of outcomes (i.e., those that presented a complete case from program entry to employment) to the public and the sponsoring agency. Moreover, our decision to frame this manuscript around WQT as an example of a small program instead of providing rich examples from the evaluation stems from this decision.

Limited options were available for sharing formative feedback without revealing participants' identities. The small number of participants—as few as three students in a cohort—also meant that evaluation reports designed to share formative feedback exposed participants' identities. For example, during an early implementation feedback session, after the evaluator had completed interviews with four students, results suggested that three students felt completely on track and were fully supported. However, the fourth student's comments indicated they did not feel they were receiving sufficient attention. The faculty/coordinator immediately identified the student based on previous conversations and the relationship with the student. As mentioned above, in a larger study, an evaluator would use deidentification and aggregation techniques to protect identities.

Challenge 3: The Small Size Contributed to Institutional Risk and Threats to Sustainability

In reflecting on the institutional inputs and investments, we believe the organizations involved undertook risks. We describe two themes that were associated with the likelihood of WQT sustainability. First, WQT's continuation depended on the commitment of just one person.

WQT's continued implementation and sustainability depended on one faculty/coordinator's commitment. As illustrated throughout this manuscript, one key staff person assumed all roles and responsibilities for WQT. We believe that had she resigned or become unable to work for an extended period, finding a suitable replacement would have been improbable. With graduating students earning greater salaries and working more comfortable shifts in fields like WQT, it would be unlikely to attract a pool of qualified and committed candidates from industry or academia.

Likewise, WQT's continuation depended on the ongoing participation of just a few local treatment plants, which was sometimes tenuous. The requests of the WQT program continually taxed the few local utilities. Even with careful planning and coordination with host facilities, because they were overstretched from site visit requests, some facilities declared that they would only provide student tours once a year or less. Had one treatment plant withdrawn from participation in the grant, other plants would have been further taxed which may have threatened WQT's continuation.

Matrix 1. Summary of Main Themes

Advantages Associated with the Small Program Size		Enduring Challenges Associated with the Small Program Size		
Student Learning	Evaluation Use	Stakeholder Relations	Evaluation Confidentiality	Institutional Risks
• Easy to use active learning strategies and informal student supports • Lots of individual student support • Students had many opportunities for hands-on learning • All students were able to participate in trade and professional events	• Easy to triangulate across data sources and follow "cases" • Supported rapid reporting cycle • Full use of evaluation findings	• Faculty member / coordinator was overburdened • Industry hosts were overburdened	• Because of the small n, the evaluation results were not made public • Participant identities were not always protected	• Program continuations were dependent on one faculty member, one evaluator, and a few industry contacts

Conclusion

While the grant funding ended, the WQT program continues to serve regional water treatment facilities. Moreover, the program continues to experience the challenges and opportunities we describe in this manuscript. Through our journey of co-authoring this manuscript, we reflected on the inputs and actions that led to WQT's small-scale successes. Our premise is that the WQT grant-funded program enabled students from various life experiences to obtain employment, employers had access to credentialed prospective employees and had their needs heard by the college, and curricula and frameworks were developed to support the program. It was also a rewarding experience for the faculty/coordinator and the evaluator. To realize these successes, we understand that it required a tremendous amount of commitment and support from the college, the dean, and employers, and it took more than a small amount of our commitment and flexibility from the program's implementers. For example, the faculty/coordinator was willing to engage fully in discussions about evaluation results and use them to improve the program. Moreover, she often posed follow-up questions that the evaluator used to collect and describe additional information. We believe the working relationships and supports were absolutely paramount for achieving WQT's successes.

Nevertheless, as we illustrated, small enrollment programs are vulnerable in a strategic sense because their continuation and sustainability are dependent on the commitment of just a handful of key players. If even one of WQT's key players had become sidelined, WQT's trajectory would have been very different. One person's prolonged absence or resignation should not have the potential to effectively kill a program. Moreover, running a small enrollment program may be complicated by college restrictions about the minimum number of matriculants for a course to be offered, requiring the one-person to stretch beyond what is otherwise reasonable to meet students' needs and keep them on track to graduate on time. And, as we noted in the unresolved challenges, the evaluation of particularly small programs has the potential to reveal participant identities, which, in turn, may make them vulnerable to retaliation. While we do not believe that was the case in WQT, unfortunately, it is not an unfathomable issue. Finally, because of the small sample, the evaluator was unable to utilize standard techniques such as disaggregation or inferential statistics. In the corpus of traditional evaluation designs, this inability has the strong potential to reduce the study's ability to make strong assertions about equity and outcomes.

We believe that all aspects of small enrollment programs benefit from emphasizing interpersonal relationships. This includes selecting an evaluation design that prioritizes depth over breadth. We recommend that small enrollment ATE grant recipients and evaluators consider suitable small study designs and models such as case studies, ethnographic evaluations, and participatory evaluations. The successful implementation of a small enrollment program and its subsequent integration into the IHE requires balancing ideals—organizational, human capital, pedagogical, and methodological—with the practical realities of budget, workforce demand (and need), and time limitations. We offer those considering a small enrollment grant-funded program or who are already launching one to consider the following questions for reflection.

1. How likely is it that your IHE will be able to sustain the small enrollment program beyond the funding period while minimizing institutional risks associated with one-person program staffing, threats of competition, and overburdening local partnerships?
2. How likely is it that your program's external evaluation will be able to satisfactorily ensure the protection of program participants' confidentiality while also generating and communicating formative feedback for evaluation users and outcomes results for broader circulation?
3. Is your program's external evaluation design able to credibly and compellingly report on program outputs, outcomes, and program equity?
4. What assets and opportunities does your IHE have that will likely boost the chances of a small enrollment grant-funded program's success?

Finally, we are sure that there must be a greater appreciation of the importance of small enrollment programs, especially for high-needs technical fields that are perennially difficult to staff. The foundational themes we present in this manuscript may be used as a starting point for further inquiry. More specifically, the ATE community would benefit from a systematic research study of small enrollment program challenges, assets, and needs. Such a study could include a survey of purposefully selected small enrollment programs combined with follow-up qualitative data to learn about the breadth and depth of small enrollment programs.

Acknowledgments. This work was supported by the National Science Foundation (NSF) under award 1800789.

Disclosures. The authors declare no conflicts of interest.

References

[1] J. W. Way, "A Manual for Small Program Evaluation," unpublished.

[2] American Water Works Association, "State of the Water Industry 2023," 2023. [Online]. Available: https://www.awwa.org/Portals/0/Awwa/Professional%20Development/2020SOTWIreport.pdf

[3] Tennessee Department of Environment and Conservation, "Dataset on State Certification Pass Rates, 2019-2023," 2023.

[4] Fleming Training Center, "Data on Demographics of Certified Water Treatment Plant Operators, 2023," 2023.

[5] K. Sturges and C. Howley, "Building capacity in state education agencies: Using organizational theory to guide technical assistance," *Journal of Organizational Theory in Education*, September, no. 3, 1-19, 2018.

[6] E. Huber, "Investigating the praxis of evaluating small-scale learning and teaching projects in higher education," thesis, Macquarie University, Oct. 03 –2018. [Online]. Available: https://figshare.mq.edu.au/articles/thesis/Investigating_the_praxis_of_evaluating_small-scale_learning_and_teaching_projects_in_higher_education/19435472/1

[7] M. Walia, N. Sharma, and G. Lata, "Challenges in Retaining Faculty in New and Upcoming Medical Colleges: A Faculty Member's Perspective," *Journal of Datta Meghe Institute of Medical Sciences*, vol. 18, no. 1, p. 79, Mar. 2023, doi: 10.4103/jdmimsu.jdmimsu_235_22.

[8] G. L. Peirce, S. P. Desselle, J. R. Draugalis, A. R. Spies, T. S. Davis, and M. Bolino, "Identifying Psychological Contract Breaches to Guide Improvements in Faculty Recruitment, Retention, and Development," *Am J Pharm Educ*, vol. 76, no. 6, p. 108, Aug. 2012, doi: 10.5688/ajpe766108.

[9] F. Nausheen, M. M. Agarwal, and J. J. Estrada, et al, "A Survey of Retaining Faculty at a New Medical School: Opportunities, Challenges and Solutions," *BMC Med Educ*, vol. 18, no. 223, Sep 2018, doi: 10.1186/s12909-018-1330-z.

[10] M. Bamberger, J. Rugh, M. Church, and L. Fort, "Shoestring Evaluation: Designing Impact Evaluations under Budget, Time and Data Constraints," *American Journal of Evaluation*, vol. 25, no 1, 5-37, 2004, doi: https://doi.org/10.1177/109821400402500102.

[11] M. Ravallion, "Can We Trust Shoestring Evaluations?," *The World Bank Economic Review*, vol. 28, no. 3, 2014, 413–431, doi: https://doi.org/10.1093/wber/lht016.

[12] M. Q. Patton, *Essentials of Utilization Focused Evaluation*, Thousand Oaks, CA: Sage Publications, 2021.

[13] M. E. Baron, "Designing Internal Evaluation for a Small Organization with Limited Resources," *New Directions for Evaluation*, vol 2011, no. 132, Dec. 2011, doi: https://doi.org/10.1002/ev.398.

[14] E. P. Bettinger, A. Boatman, and B. T. Long, "Student Supports: Developmental Education and Other Academic Programs," *The Future of Children*, vol. 23, no. 11, 2013, doi: https://doi.org/10.1353/foc.2013.0003

[15] C. M. Zhao and G. D. Kuh, "Adding Value: Learning Communities and Student Engagement," *Research in Higher Education*, vol. 45, no. 2, 2004.

[16] E. N. Waiwaiole, E. M. Bohlig, and K. J. Massey, "Student Success: Identifying High-Impact Practices," *New Directions for Community Colleges*, vol. 2016, no. 175, 45–55.

[17] S. R. Johnson and F. K. Stage, "Academic Engagement and Student Success: Do High-Impact Practices Mean Higher Graduation Rates?," *The Journal of Higher Education*, vol. 89, no. 5, 753–781, 2018, doi: https://doi.org/10.1080/00221546.2018.1441107.

[18] Q. Shi, R. Cresiski, S. Thanki, and L. Navarrete, L. "Unlocking Undergraduate Student Success: A Study of High-Impact Practices in a Comprehensive and Diverse College," *Journal of Postsecondary Student Success*, vol. 2, no. 4, 83–107, 2023.

[19] D. L. Stufflebeam and G. Zhang, *The CIPP Evaluation Model: How to Evaluate for Improvement and Accountability*, New York, USA: The Guilford Press, 2017.

[20] B. Harry, K. Sturges, and J. K. Klingner, "Mapping the Process: An Exemplar of Process and Challenge in Grounded Theory Analysis," *Educational Researcher*, vol. 2005, no. 34, 3-13, 2005.

[21] R. E. Stake, *Multiple Case Study Analysis*, New York, USA: The Guilford Press, 2006.

[22] M. McNall and P. G. Foster-Fishman, "Methods of Rapid Evaluation, Assessment, and Appraisal," *American Journal of Evaluation*, vol. 28, no. 2, 151-168, 2007.

Not "Just a Hobby": The Influence of Early Interest and Hobbies on Community College IT Student Decision-Making

ELIZA K. PETERSON[1]*, MICHELLE VAN NOY[1], SAM SCOVILL[1], AND RENEE EDWARDS[2]

[1]Education and Employment Research Center, School of Management and Labor Relations, Rutgers, the State University of New Jersey, Piscataway, NJ 08854

[2]Heldrich Center for Workforce Development, Edward J. Bloustein School of Planning and Public Policy, Rutgers, the State University of New Jersey, 30 Livingston Avenue, New Brunswick, NJ 08901

**eliza.peterson@rutgers.edu*

Abstract: This study aimed to find how IT-related hobbies and interests impacted students' educational and career decision-making. Methods: As part of a six-year-long, ATE-funded study of IT students at Ivy Tech Community College, our team conducted semi-structured, phenomenological interviews. These interviews were analyzed using keyword searches and a combined inductive-deductive approach to coding to explore how IT-related hobbies and interests interacted with other personal characteristics to inform student decision-making. Findings: Our team identified a potential link between early IT interest, IT-related hobbies, and persistence in IT education and careers. Many participants in the study had a moment of clarity where they realized that their IT hobby could become their career, the "hobby-to-career reckoning." Contributions: This piece explores the potential connection between IT interests/hobbies and student outcomes within the field of IT while exploring the different social factors that may impact student decision-making and the role of the hobby-to-career reckoning in the decision-making process. This piece will give practitioners and researchers insight into how early interest in IT and IT-related hobbies may impact student decision-making about IT educational programs and careers.

Keywords: information technology, student decision-making, community college, hobbies

Introduction

Amateur computer hobbyists helped spark the technological revolution that moved the computer away from the institution and into the home [1]. Since then, Information Technology (IT) has exploded in popularity and variety for professionals and hobbyists alike. Today, IT hobbies can take the form of video gaming, PC building, programming, server managing, and even hacking. While there is work on the connection between IT hobbies and careers, much of it centers on undergraduates at four-year schools, gender disparities, and current IT professionals who have already entered the field. There seems to be a lack of understanding of how IT hobbies influence decision-making about education and careers, particularly for community college students.

Theoretical Framework

Social cognitive career theory (SCCT), happenstance learning theory, and career construction theory, serve to undergird this paper's discussion of the role of early interest and IT hobbies on student decision making. In happenstance learning theory, hobbies are a venue or learning event through which individuals can develop their vocational identity [2]. SCCT, meanwhile, posits that individuals develop a greater sense of self-efficacy within certain activities, which helps to form their vocational interests [3]. This meshes well with career construction theory, which presents hobbies as a testing ground or rehearsal space for finding out if an individual might have an aptitude for the career areas in which they are interested [4]. This theory asserts that children develop an understanding of themselves, their skills, and the foundations of their vocational self-concepts through engagement in hobbies and other activities. Career construction theory also emphasizes the importance of parents in developing a career identity because parents often serve as vocational role models for their children. These theories resonate in the literature about IT students and professionals.

IT Student Decision-Making

Some studies suggest that an early interest in computers and technology may lead students to pursue IT programs and careers. Studies have shown that early computer interest guides undergraduate students toward an IT major [5], [6]. This connection expands beyond schooling, with IT professionals in one study pointing to factors like early exposure to IT and the development of IT interests or computing hobbies as contributors to their decision to pursue an IT career [7]. Research also indicates that students with a personal interest in IT/ computing often had an epiphanic moment – what our team calls a "hobby-to-career reckoning" - when they realized that their strong interest could be a career [8].

The connection between student decision-making and hobbies may be field-dependent, with the best-established connections being found in STEM fields. To illustrate, studies have identified field-related hobbies as influential to student decision-making in agriculture, horticulture, and engineering, as well as to career decision-making for engineering professors [9], [10], [11], [12]. Jones, et. al. (2019) found salient connections between STEM hobbies and STEM careers. They found that, compared to non-STEM career hobbyists, the STEM-career hobbyists were more interested in STEM courses in school and more likely to identify their hobbies as an influence on their choice to pursue a career in STEM [13].

Some scholarship on IT undergraduates indicates that there is a link between field-related hobbies and pursuit of a STEM educational program or career, though this may be complicated by personal characteristics like family background and type of hobby. One study found that, in a group of undergraduate Computer Science students, long-time computer-related hobbies were the second most popular reason they chose to enter a computer science program, following the most popular reason, strong employment prospects [6]. Some scholars have called into question the influence of video gaming on interest in Computer Science [14]. Still, others have established support for the link between video gaming and choosing a STEM major [15], [16]. The nature of this link may be dependent on parental involvement and the type of gaming platforms available in the home [16]. It may also depend on the nature of the hobby; for example, those involved in video game modification have been found to use their hobby as career inspiration and even use their projects as part of their portfolio when applying for jobs [17]. Similarly, researchers have found that self-taught programming hobbyists have more positive attitudes toward IT, lower chances of dropping out, and higher grades than their peers who had only programmed in school or had no prior programming experience [18]. Additionally, in a study of engineering students, researchers found that students with hobbies like programming, video game development, and robotics had higher self-efficacy scores than their peers that did not participate in these hobbies [19].

Personal background, particularly a student's identity and family, play a role in developing interest and hobbies in IT and, later, pursuing a career in the field. Racial and socioeconomic gaps in childhood computer access in the home [16,17] may prevent individuals from developing an interest in the IT field. The digital divide – race and class based differences in access to computers, technology usage patterns, and computer literacy - tends to be most potent for African American and Latina women, and those living in high-poverty areas, where low-SES students may have fewer chances to develop IT skills and lower levels of IT self-efficacy than their peers [20], [21], [22], [23], [24], [25], [26], [27], [28], [29], [30]. Parental influence is particularly salient in discussions of decision-making, IT, and class. Low-SES parents may be less comfortable with computers and more restrictive with their children's use of technology [31], [32]. Parental IT influence, like providing access to computers or exposure to computing activities, has been identified as important to decision-making about IT education and careers, particularly for women [30], [31], [32], [33]. More generally, parents with STEM careers and field-specific cultural capital may be connected to a student's choice to pursue and succeed in a STEM major and career [18], [33], [34].

There are many influences in individuals' respective backgrounds that may lead to the development of an IT interest or an IT-related hobby, and there are many indicators that these factors may facilitate student success in the field. However, scholarship on the connection between hobbies and IT education and student decision-making is somewhat limited, particularly for those enrolled in community colleges. This paper seeks to add to the growing body of literature highlighting the role of early established interest and IT-related hobbies in IT education and employment outcomes by focusing on findings from a study of Ivy Tech Community College IT students. This paper focuses on one of the most compelling aspects of a larger study with a broader scope: the prevalence of early IT interest and the influence of IT hobbyists on decision-making within the samples. The research team found that individuals with an early-established interest in IT who pursue extracurricular IT-related hobbies in adolescence and adulthood ("IT hobbyists") may be particularly strong candidates for completing community college IT programs and pursuing jobs in the field. This study indicates that they may have a better chance for a positive IT outcome than their non-hobbyist peers, such as completing an IT degree or certificate program, pursuing higher education in IT, or landing an IT career. These IT hobbyists in the sample often had a moment of epiphany where they realized that their hobby could be a viable career, a moment our team calls "hobby-to-career reckoning." This article explores these findings in further detail and is organized around the following two research questions:

1. How does early interest in IT and IT-related hobbies impact student decision-making about IT educational programs and careers?
2. Do IT hobbyists and those with an early interest in computing engage with IT educational programs and careers differently than their peers without an early interest in IT-related hobbies?

Methods

This paper was developed as part of an extensive, multi-year research partnership between Ivy Tech Community College and Rutgers Education and Employment Research Center (EERC), centered on student decision-making in Ivy Tech Community College's School of IT, funded by a grant from the National Science Foundation Advanced Technological Education (NSF-ATE) program. This paper is closely related to findings from a forthcoming longitudinal study, one of the significant products of this research partnership [35]. This study includes various samples of Ivy Tech IT students, but this article focuses on just two groups: the Longitudinal and Completer samples. Selection criteria for inclusion in the longitudinal sample included students who 1) could participate in a student survey conducted by the research team, 2) volunteered to participate in the longitudinal study, and 3) completed at least two of the three rounds of interviews. Participants received a $25 Amazon gift card for each 45-60-minute interview they completed with the research team. Completer students were identified by Ivy Tech staff, recruited via email, and offered a $25 Amazon gift card for their participation.

The participants were interviewed in a semi-structured, semi-phenomenological fashion using a literature-based protocol [36]. In the interviews, participants were asked about their background, educational and career decisions, and factors or experiences that influenced their decision-making process. For more about the interview protocol and longitudinal study methods, see Edwards et al., 2023 [35]. Twenty-six students completed two or more rounds of interviews and were included in the longitudinal study. This paper also draws from another sample, the Completer sample, a group of 17 interviewees who completed an Ivy Tech IT degree or certificate in 2020. The initial round of complete interviews occurred in the summer of 2020, with a limited round of follow-up interviews occurring the next summer. The completer interviews followed a similar protocol to those used in the longitudinal interviews, with some changes to account for their changed status (i.e., graduates as opposed to current students) and the timing of the interviews.

As part of the more extensive ATE-targeted research study, both sets of interviews were coded in a combined deductive and inductive fashion using NVivo qualitative data analysis software. Some of these codes were relevant to the themes discussed in this piece, such as: "access to IT," "hobby-to-career reckoning," and "personal and family resources and opportunities." These codes were used as a jumping-off point to identify quotes illustrative of larger trends within the datasets, in this case, those quotes regarding early interest and hobby development. We synthesized these results into a working model aiming, seen below in Figure 1, to illustrate how these different factors and experiences interact, based on the participants in this sample, to guide the thinking of readers.

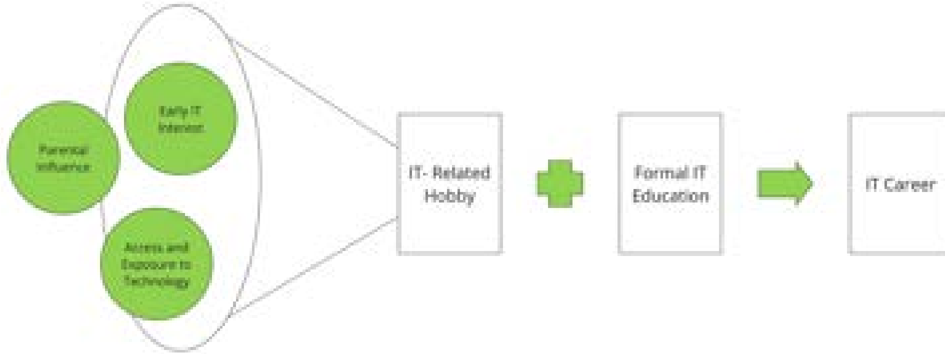


Fig. 1. Working model of an IT hobby-to-career pathway.

Findings

Participants often expressed an early interest in IT and mentioned their IT-related hobbies. The following sub-sections describe how early interest and IT-related hobbies impacted participants' decision-making about IT education and careers. In the following sub-section, I will discuss the hobby-to-career reckoning experienced by many participants. Finally, I will explain how these characteristics – early interest, IT-related hobbies, and hobby-to-career reckonings - interacted with participants' education and career outcomes, particularly their ability to continue their formal involvement in IT.

Early Interest in Information Technology

In one or more interviews, students who mentioned a fascination with or interest in technology, computers, and computing that formed before they reached adulthood were considered early interest students by our team. The longitudinal sample comprised 26 participants, 21 of whom showed an early interest in IT. Early interest was similarly strong but slightly less prominent in the Completer sample; 13 of the 17 participants had an early IT interest. These early interest participants often commented, "I've always been interested in computing," or "I'd always wanted to go into tech all my life." Though many participants said that they have "always" been interested in technology and computers, many also could point to a specific moment that their interest was sparked. This moment usually occurs at a very young age and almost always happens before they graduate high school. This interest-sparking moment was typically precipitated by access to computers or video game consoles, which was particularly notable when such technology was less common.

The interest-sparking moment was often connected to the influence of an adult, usually a parent, who had an IT-related interest, hobby, or job. One participant exemplified this trend, sharing: "One of my earliest memories was sitting on my father's lap playing an Alf game." Another participant described how his mother sparked his interest in IT: "My mother previously worked a lot with computers for her job. She is a nurse and had to do a lot of input, and she had one. She played a lot of video games, and so I did too; she played World of Warcraft, and so I did too." Though many participants had adults in their lives who sparked their interest via video games, other participants were exposed to computing via educational activities or their parents' workplace. Participants mentioned academic exposure to computing in their education or via observing their parent's education. For instance, one participant said, "When I was in junior high, my dad also studied to fix computers. I helped him study for that as well...Ever since, I have always been drawn to people who work with computers and pick their brain about it." Another participant was influenced both by his educational activities as well as his father's hobbies, stating that:

> "My parents did a lot of those games that are learning-oriented. That's how I started using computers in the very beginning. But, from that I just started messing with the computers, learning to fix them. My dad knows how to fix computers a little bit. I learned some of that from him, some developing skills, and soon I was fixing his computers."

Many participants were passed the baton by their parents and encouraged to move forward with their IT interests. Sometimes, parents even helped cultivate the IT skills of participants; one participant said, "My dad knows how to fix computers a little bit. I learned some of that from him, some developing skills and soon I was fixing his computers. Any time my computer goes down I fix it myself." On the other hand, some participants mentioned how their parents' lack of access to technology impacted their interest in development. One participant said that,

> "My family was slow on computers, so I had dialup until 2006 or something, but I would always…just open up the computer and see what was in it…just trying to figure out what each thing did, and my parents couldn't help me because they weren't very computer oriented."

These key interest-sparking experiences, whether facilitated by parents or independently initiated, helped participants develop their interest in IT at a very young age, which often followed them throughout life. There seemed to be a connection between early IT interest and having an IT-related hobby later. Of the 21 longitudinal participants who did express an early interest in IT, the majority (16 out of 21) were considered IT hobbyists by our research team.

IT Hobbyists

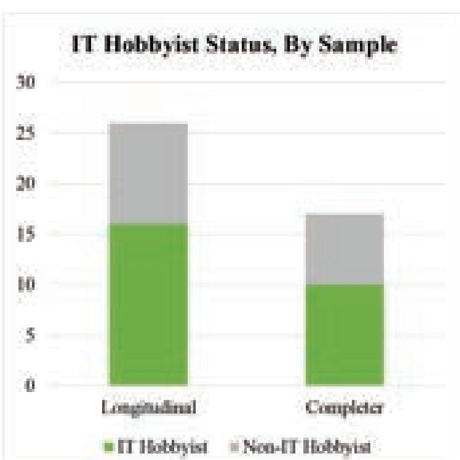
IT Hobbyists were participants who mentioned actively participating in at least one IT-related hobby at the time of one or more of their interviews. Most participants in the longitudinal and completer samples were IT Hobbyists: 16 out of 26 and 10 out of 17, respectively. We were able to collect more specific information about the hobbies of our longitudinal sample. The IT-related hobbies held by our participants fit into 7 main categories: video gaming, independent study of IT, PC/console building, coding/programming, video game modification/server management, and other IT-related hobby. Half of the 16 IT hobbyists in the longitudinal sample participated in more than one of these hobby categories. Video gaming was by far the most popular hobby category, followed by video game modification/server management and independent study of IT. The two IT hobby types with the most significant overlap were video gaming and video game modification/server management, with 5 participants participating in both hobby types. For more details on the exact counts of hobby participation, see Figure 2 below.

Video gaming was often a type of hobby that was adopted at a very young age and was frequently facilitated by a participant's parents. Video games mentioned by participants included Neopets, Minecraft, World of Warcraft, and Webkinz. They also mentioned consoles such as Super Nintendos, Ataris, Play Stations, Game Cubes, and the Sega Genesis. However, many participants also participated in video games played on a desktop or laptop computer. This hobby was often very social – it allowed participants to deepen existing bonds with family and friends and create new ones virtually. For example, one participant said

> "[I] especially like the multiplayer [video] games because it was an outlet for me to communicate with other people. And sadly, I've been generally shunned by other people in my peer groups, so it's…a good outlet for me."

Video gaming often sparked a lifelong love of computers and technology that participants would later take advantage of when they realized that their hobby could potentially lead to a career pathway.

.



IT-Related Hobbies in the Longitudinal Sample, by count	
IT Hobby Category	**Number of Participants***
Video gaming	11
Independent Study of IT	5
Video game modification/server management	5
PC/console building	4
Coding/programming	3
Other IT-related hobby	1
*These counts are not mutually exclusive. Participants may have had hobbies in multiple categories. For the purposes of this study, video gaming was separate from video game modification/server management due to the much higher technical skill required for participation in the latter hobby.	

Fig. 2. IT Hobbyist status, by sample, and IT-Related Hobbies in the Longitudinal Sample, by count.

Hobby-to-Career Reckoning

One of the most prominent themes among the hobbyists in this sample was the notion of the "hobby-to-career reckoning" – the epiphanic moment where a participant realized that their long-time IT-related hobby could be a viable career path. Many participants expressed that, though they had been involved in an IT hobby for a long time, they didn't realize the pragmatic implications of their hobby. Many participants downplayed their hobby, making statements like, "For me I think it was always a hobby and I didn't necessarily consider it as a career until later," or "Even though I am currently administrating a gaming community and their servers, it's really just a hobby. It's not something I can put on a resume," or "I took apart computers on my own. It was basically just a hobby." Even when participants were engaging in complex and skilled activities for their hobby, such as administrating video game servers or deconstructing hardware, they initially saw these activities as "just" a hobby. Later on, they realized that this hobby could be helpful for their career and could guide their choice to enroll in an IT program, their choice of major, and even their choice of job.

One participant summed up the hobby-to-career reckoning well, describing his decision to transfer from a Business program to an IT program at Ivy Tech:

> "I feel like when I started getting into coding, I was coding mods for video games. And it was just a hobby. And I realized I have a lot of fun doing this…And I made the switch because I realized that I felt like everyone was pushing me to business. But what I really enjoyed was learning programming."

Another participant described when he realized that his hobby of coding flash games could be a marketable skill: "I guess I never realized that the same skill set I used to make my goofy games was the same skillset that they like teach in school and market to employers." Some participants expressed worries that mentioning their video game-related hobbies might be unattractive to potential employers and that there was something of a negative connotation to their hobby. For example, one participant said

> "And even though I am currently administrating a gaming community and their servers, it's just a hobby. It's not something I can put on a resume. At least now I have a start. I have the first certification. And when I get my degree, I can finally go back and apply for some other options besides Geek Squad."

He later added, "I think it's just the word gaming community. That's kind of a negative," alluding to the negative stereotypes that sometimes surround video gamers. More common, though, was participants simply did not connect their hobby to a career, not that their hobby necessarily had negative implications.

What sparked the hobby-to-career reckoning moment varied among the participants. Sometimes, it came from self-reflection and other times from discussions with others or institutional experiences. For example, one participant said,

> "I guess once I decided it was time to go after school and once I got my foot in the door with programming classes to see how similar what they were teaching in class was to my hobbies… that could be the moment I guess."

One participant described a long-time interest in IT and a hobby of independent coding and learning about IT but had initially been dissuaded from entering the field by his family who "didn't get it." Being a low-income, first-generation student, his family may have been hesitant to embrace a technology career initially, which aligns with the literature on the participant [31]. His hobby-to-career reckoning was sparked during a business course that he was taking at Ivy Tech, which led him to enroll in and complete an associate degree in software development. Institutional or individual influences may spark the hobby-to-career reckoning, though participants were not always able to identify these influences specifically. The hobby-to-career reckoning moment is important to student decision-making about what program or job to pursue. It may influence their ability to complete an educational program and, later, get hired.

The Impact of Hobbies and Interests on Student Outcomes

In both samples, particularly the longitudinal sample, there was an interesting interplay between the characteristics of early IT interest, having an IT hobby, and the student's tendency to stay in or complete an IT educational program or enter the field of IT professionally. We noticed that having an IT-related hobby may be connected to having an early interest in IT. Of the five longitudinal participants who did not express an early interest in IT, none were considered IT hobbyists by our team, and, perhaps even more notably, none of them were still formally involved in IT at the time of their final interview. In the completer sample, 10 of the 13 participants who were still formally involved in IT at the time of their interviews had either an early IT interest, an IT related hobby, or, most commonly, both. Interestingly, three of the completers still formally involved in IT had reported neither an early interest nor an IT-related hobby. This difference between samples may be caused by the fact that the completers had earned an IT certificate or degree and, thus, were more likely to secure a job in IT than the longitudinal participants, who may or may not have finished their program at the time of the interviews. In both samples, having an early interest in IT and having an IT-related hobby seemed connected to a participant's choice to stay formally involved in IT. All of the longitudinal participants who remained formally involved in IT had an early interest in IT and had an IT-related hobby. In fact, most of the participants who remained formally involved in IT had both characteristics; only three had an early interest in IT but no IT-related hobby. This may indicate that having an early interest in IT can lead to having an IT-related hobby later and that both characteristics may facilitate persistence in IT education and careers.

Participants with IT-related hobbies had practical skills that helped them to get ahead in the classroom and in the workforce. For example, one participant described how his game design hobby helped him in these environments: "When I started taking classes after the job, initially I was surprised. I kind of already knew, not everything, but most of what we were covering in class." Another participant said his coding bootcamp program filled in some of the gaps in his knowledge, but "it helps that I've been a hobbyist programmer all my life." As a software engineer at J.P. Morgan, he was one of the strongest success stories in the Longitudinal sample, achieving his goal of an IT job at a large, stable institution. He shared how his hobbyist background was an asset, particularly when finishing projects up quickly to meet tight deadlines because "That's kind of where I shine, because the sort of sloppy hobbyist coder in me has been doing that all my life." His early interest in IT and his long-time hobby helped him secure the type of role he wanted and excel in that role. Individuals with an early interest in IT may have the passion to push them through more difficult moments in their educational/career pathway because they have "always loved technology." Participants who were still formally involved in IT educationally, professionally, or some combination of the two at the time of their final interview with the team often had an IT hobby or had an early-established interest in the field. These traits may provide participants with skills and passion that drive them to complete academic and certificate programs and to successfully pursue careers in the field.

Table 1. Longitudinal and Completer samples, IT continuation status, by early interest and IT hobbyist classification.

	Longitudinal Sample			**Completer Sample**		
Formally Involved in IT?	**Yes**	**No**	**Total**	**Yes**	**No**	**Total**
Early Interest / IT Hobbyist	10	6	16	6	3	9
Early Interest / Non-IT Hobbyist	3	2	5	3	1	4
No Early Interest /IT Hobbyist	0	0	0	1	0	1
No Early Interest / Non-IT Hobbyist	0	5	5	3	0	3
Total	**13**	**13**	**26**	**13**	**4**	**17**

Discussion

Our findings about parental influence on IT interest incubation are consistent with literature emphasizing the importance of parental support and influence on interest in IT education and careers [32], [33], [34], [37], [38]. Our study, though, deepens the emphasis on the role of parents in fostering interest in IT as a hobby, as well as the role of video games in the relationship. Among the participants in this study, early interest in

IT seemed connected to having an IT-related hobby later, and both traits indicated that a participant may be more persistent in the field of IT, educationally and professionally. These results are consistent with an earlier study of Australian IT professionals, which found that IT professionals may tend to have their interest in IT sparked at an early age, an interest characterized as "hobby-like," and maintain an intrinsic motivation to pursue IT later on [7]. Some researchers have also highlighted the moment of discovery in the IT-student pathway, which we noticed strongly in the sample and dubbed the "hobby-to-career" reckoning [8]. One study found that, among a sample of video game players, online gaming preferences and behavior vary depending on gender and job category, and that different types of games may foster the development of different soft skills, that, in turn may influence career choice [5]. This study also found gender and career choice differences when considering the importance of IT-related hobbies. However, our sample included various categories of IT-related hobbies, not just online gaming.

Limitations

This study provides some interesting insights into the way that IT students at community colleges make decisions about their education and career, with the caveat that our sample was limited in size and not fully representative. Since participants no longer associated with Ivy Tech may be less likely to complete the later interviews, there may have been a larger number of non-IT continuers than this sample was able to capture. Another group that may not have been well-captured in this sample is women. Our team may not have been able to comprehensively analyze the decision-making process of women in IT, due to the small number of female participants. Also, important to consider is the lack of racial/ethnic diversity within the sample, which is reflective of population trends at Ivy Tech, Indiana in general, and within the field of IT, but means that our exploration of the decision-making process among non-white IT students is limited. This study, however, can serve to guide further research on the role of early IT-interest and IT-related hobbies in the decision-making process for aspiring IT students and professionals.

Conclusion

This work provides the foreground for future research on the influence of early IT interest and IT hobby-having on the decision-making of IT students and IT professionals. It prompts further questions such as: Does having an IT-related hobby lead to persistence and success in the field of IT educationally and professionally? Would the promotion of IT-related hobbies among historically underrepresented groups lead to a more diverse pool of IT students and professionals? Are some IT-related hobbies more useful educationally and professionally than others? How strong is this connection between hobbies, early interest, and career? What is the role of parents and relatives in fostering these interests? Future research should work toward developing methodologies that include, perhaps, linking workforce data to get a better handle on student outcomes, as opposed to relying on student self-reporting. Another major avenue for future research is recruiting a more racial and ethnically diverse population, given the lack in this sample. Similarly, recruiting women and gender nonconforming participants would expand understanding of how community college students in these groups make decisions about IT education and careers. Literature in this subject area tends to revolve around STEM major choice without an IT focus, groups underrepresented in the IT field (women, African Americans, Latinos) and undergraduates at four-year schools, without much space dedicated to community college students specifically.

This study, however, adds to the body of work that explores student voice, and particularly the community college student voice, in discussions about who chooses an IT educational program or career and why they make such a choice. In this sample, one of the most notable trends was that parents often facilitated participants' early interest in IT by sharing their own interests and hobbies. We also noticed a potential connection between having an IT-related hobby and having childhood interest in IT among the participants. IT hobby-having was somewhat correlated with gender in our sample; IT-related hobbies were more common among male participants than female ones. We also found that frequently, individuals with IT hobbies may have a moment where they realize that their informal experience might be valuable in the workplace, which we call the hobby-to-career reckoning. In this sample, having an early interest in IT and having an IT-related hobby seemed like potential indicators that an individual would persist in the field by completing their IT educational program and even entering a related career. Parents and practitioners alike may wish to keep these findings in mind, by encouraging and fostering IT-related hobbies and interests, and by helping individuals see that skills gained through their hobbies could be useful in community college courses, and even in the workforce.

Acknowledgements. This work was supported by the National Science Foundation (NSF) under award #1801043, Pathways into Careers in Information Technology: Community College Student Decision-Making about Academic Programs and Jobs.

Disclosures. The authors declare no conflicts of interest.

References

[1] J. Abbate, "Getting small: a short history of the personal computer," *Proc. IEEE*, vol. 87, no. 9, pp. 1695–1698, Sep. 1999, doi: 10.1109/5.784256.

[2] J. D. Krumboltz, "The Happenstance Learning Theory," *J. Career Assess*., vol. 17, no. 2, pp. 135–154, 2009, doi: 10.1177/1069072708328861.

[3] R. W. Lent, S. D. Brown, and G. Hackett, "Social Cognitive Career Theory," in *Career Choice and Development*, 4th ed., Jossey-Bass, 2002. [Online]. Available: http://www.borbelytiborbors.extra.hu/ZSKF/CareerDevelopment.pdf#page=276

[4] M. Savikas, "Career construction: A developmental theory of vocational behavior," in *Career Choice and Development*, D. Brown and Associates, Eds., San Francisco, CA: Jossey-Bass, 2002.

[5] A.-S. Wallinheimo, A. Hosein, D. Barrie, A. Chernyavskiy, I. Agafonova, and P. Williams, "How Online Gaming Could Enhance Your Career Prospects," *Simul. Gaming*, vol. 54, no. 1, pp. 28–44, Feb. 2023, doi: 10.1177/10468781221137361.

[6] M. Papastergiou, "Are Computer Science and Information Technology still masculine fields? High school students' perceptions and career choices," *Comput. Educ*., vol. 51, no. 2, pp. 594–608, Sep. 2008, doi: 10.1016/j.compedu.2007.06.009.

[7] L. E. C. Potter, L. A. von Hellens, and S. H. Nielsen, "Childhood interest in IT and the choice of IT as a career: the experiences of a group of IT professionals," in *Proceedings of the special interest group on management information system's 47th annual conference on Computer personnel research*, in SIGMIS CPR '09. New York, NY, USA: Association for Computing Machinery, May 2009, pp. 33–40. doi: 10.1145/1542130.1542138.

[8] M. Hewner and M. Guzdial, "Attitudes about Computing in Postsecondary Graduates," in *Proceedings of the Fourth International Workshop on Computing Education Research*, in ICER '08. New York, NY, USA: Association for Computing Machinery, 2008, pp. 71–78. doi: 10.1145/1404520.1404528.

[9] C. M. Jagacinski, W. K. Lebold, K. W. Linden, and K. D. Shell, "Factors Influencing the Choice of an Engineering Career," *IEEE Trans. Educ.*, vol. 28, no. 1, pp. 36–42, Feb. 1985, doi: 10.1109/TE.1985.4321729.

[10] J. Rayfield, T. P. Murphrey, C. Skaggs, and J. Shafer, "Factors that Influence Student Decisions to Enroll in a College of Agriculture and Life Sciences," *NACTA J.*, vol. 57, no. 1, pp. 88–93, Mar. 2013.

[11] G. Naizer, "Science and engineering professors: Why did they choose sci," *Sch. Sci. Math.*, vol. 93, no. 6, p. 321, Oct. 1993.

[12] J. C. Bradley, T. Kohlleppel, T. M. Waliczek, and J. M. Zajicek, "Factors Affecting Recruitment of Horticulture Students at Major Universities," *HortTechnology Horttech, vol. 10*, no. 3, pp. 631–636, Jan. 2000, doi: 10.21273/HORTTECH.10.3.631.

[13] M. G. Jones, G. Childers, E. Corin, K. Chesnutt, and T. Andre, "Free choice science learning and STEM career choice," *Int. J. Sci. Educ.* Part B, vol. 9, no. 1, pp. 29–39, 2019.

[14] B. J. DiSalvo and A. Bruckman, "Questioning Video Games' Influence on CS Interest," in *Proceedings of the 4th International Conference on Foundations of Digital Games*, in FDG '09. New York, NY, USA: Association for Computing Machinery, 2009, pp. 272–278. doi: 10.1145/1536513.1536561.

[15] S. V. Turner, P. W. Bernt, and N. Pecora, "Why Women Choose Information Technology Careers: Educational, Social, and Familial Influences," in *Annual Meeting of the American Educational Research Association*, New Orleans, LA, Apr. 2002. Accessed: Aug. 08, 2023. [Online]. Available: https://eric.ed.gov/?id=ED465878

[16] J. Baxter-Webb, "The role of gaming platforms in young males' trajectories of technical expertise," *Trans. Digit. Games Res. Assoc*., vol. 2, no. 3, 2016.

[17] O. Sotamaa, "When the Game Is Not Enough: Motivations and Practices Among Computer Game Modding Culture," *Games Cult*., vol. 5, no. 3, pp. 239–255, Jul. 2010, doi: 10.1177/1555412009359765.

[18] C. Chen, S. Jeckel, G. Sonnert, and P. M. Sadler, "' Cowboy' and" Cowgirl" Programming and Success in College Computer Science.," *Int. J. Comput. Sci. Educ*. Sch., vol. 2, no. 4, p. n4, 2019.

[19] T. D. Fantz, T. J. Siller, and M. A. Demiranda, "Pre-Collegiate Factors Influencing the Self-Efficacy of Engineering Students," *J. Eng. Educ.*, vol. 100, no. 3, pp. 604–623, Jul. 2011, doi: 10.1002/j.2168-9830.2011.tb00028.x.

[20] H. Ono and H.-J. Tsai, "Race, Parental Socioeconomic Status, and Computer Use Time Outside of School Among Young American Children, 1997 to 2003," *J. Fam. Issues, vol. 29*, no. 12, pp. 1650–1672, Dec. 2008, doi: 10.1177/0192513X08321150.

[21] S. M. González-Betancor, A. J. López-Puig, and M. E. Cardenal, "Digital inequality at home. The school as compensatory agent," *Comput. Educ., vol. 168*, p. 104195, Jul. 2021, doi: 10.1016/j.compedu.2021.104195.

[22] R. Hawkins and A. E. Paris, "Computer Literacy and Computer Use Among College Students: Differences in Black and White," *J. Negro Educ., vol. 66, no. 2, pp*. 147–158, 1997, doi: 10.2307/2967224.

[23] H. Jackson, L. Hansen, L.-S. Tang, J. Willemain, and H. J. C. Ellis, "Changes to an IT program in response to the IT 2008 curriculum guidelines," in *Proceedings of the 10th ACM conference on SIG-information technology education*, in SIGITE '09. New York, NY, USA: Association for Computing Machinery, Oct. 2009, pp. 192–198. doi: 10.1145/1631728.1631780.

[24] K. Mossberger, C. J. Tolbert, and M. Gilbert, "Race, Place, and Information Technology," *Urban Aff. Rev., vol. 41*, no. 5, pp. 583–620, May 2006, doi: 10.1177/1078087405283511.

[25] A. D. Ritzhaupt, L. Cheng, W. Luo, and T. N. Hohlfeld, "The Digital Divide in Formal Educational Settings: The Past, Present, and Future Relevance," in *Handbook of Research in Educational Communications and Technology: Learning Design*, Cham: Springer International Publishing, 2020, pp. 483–504. doi: 10.1007/978-3-030-36119-8_23.

[26] S. M. Smith, "The Digital Divide: Gender and Racial Differences in Information Technology Education," *Inf. Technol. Learn. Perform. J., vol. 23*, no. 1, pp. 13–23, Spring 2005.

[27] M. K. Eamon, “Digital Divide in Computer Access and Use Between Poor and Non-Poor Youth,” *J. Sociol. Soc. Welf., vol. 31, no. 2, Jun. 2004*, doi: 10.15453/0191-5096.2985.

[28] I. Vekiri, “Socioeconomic differences in elementary students’ ICT beliefs and out-of-school experiences,” *Comput. Educ., vol. 54, no. 4*, pp. 941–950, May 2010, doi: 10.1016/j.compedu.2009.09.029.

[29] A. Jepson and T. Perl, “Priming the Pipeline,” *SIGCSE Bull*, vol. 34, no. 2, pp. 36–39, Jun. 2002, doi: 10.1145/543812.543826.

[30] Jane Margolis, *Stuck in the Shallow End : Education, Race, and Computing*. Cambridge, Mass: The MIT Press, 2008. [Online]. Available: https://login.proxy.libraries.rutgers.edu/login?url=https://search.ebscohost.com/login.aspx?direct=true&db=e000xna&AN=237766&site=ehost-live

[31] D. L. Linebarger and A. R. Chernin, “Young children, parents, computers,” *IT&SOCIETY, vol. 1*, no. 4, pp. 87–106, 2003.

[32] S. Livingstone, G. Mascheroni, M. Dreier, S. Chaudron, and K. Lagae, “How parents of young children manage digital devices at home: The role of income, education and parental style,” *EU Kids Online LSE*, 2015.

[33] N. Tilbrook and D. Shifrer, “Field-specific cultural capital and persistence in college majors,” *Soc. Sci. Res., vol. 103*, p. 102654, Mar. 2022, doi: 10.1016/j.ssresearch.2021.102654.

[34] A. Cheng, K. Kopotic, and G. Zamarro, “Parental Occupational Choice and Children’s Entry into a Stem Field.” Rochester, NY, Sep. 01, 2019. doi: 10.2139/ssrn.3457307.

[35] E. K. Peterson, R. Edwards, M. Van Noy, S. Scovill, and M. L. Espino, “Exploring Student Decision Making: a Longitudinal Study of Community College Information Technology Students,” Rutgers University, School of Management and Labor Relations, Education and Employment Research Center, Dec. 2023. [Online]. Available: https://smlr.rutgers.edu/sites/default/files/Documents/Centers/EERC/Longitudinal%20IT%20Decision%20Making%2012.8.pdf

[36] E. Farrell, “Researching Lived Experience in Education: Misunderstood or Missed Opportunity?,” *Int. J. Qual. Methods, vol. 19*, p. 1609406920942066, Jan. 2020, doi: 10.1177/1609406920942066.

[37] S. M. Coyne, L. M. Padilla-Walker, L. Stockdale, and R. D. Day, “Game On… Girls: Associations Between Co-playing Video Games and Adolescent Behavioral and Family Outcomes,” *J. Adolesc. Health, vol. 49*, no. 2, pp. 160–165, Aug. 2011, doi: 10.1016/j.jadohealth.2010.11.249.

[38] G. Sonnert, “Parents who influence their children to become scientists: Effects of gender and parental education,” *Soc. Stud. Sci., vol. 39*, no. 6, pp. 927–941, 2009, doi: 10.1177/0306312709335843.

K-12 Educational Cybersecurity Scaling Program Designed to Meet Industry Needs

THOMAS W. BROWN III[1]*, VICTORIA FERRELL[2]

[1] *Davis iTEC Cybersecurity Center, Forsyth Technical Community College, Winston-Salem, NC 27103, USA*

[2] *IT-Cybersecurity and IT-System Security, Forsyth Technical Community College, Winston-Salem, NC 27103, USA*

**tbrown@forsythtech.edu*

Abstract: The demand for trained cybersecurity professionals is paramount in securing digital assets at various levels, from individuals to organizations and even nations. The scarcity of cybersecurity talent is a critical concern across the United States, with over 663,000 unfilled cybersecurity positions reported in diverse sectors. The repercussions of this talent gap are evident, as cybercrime affects millions globally, costing an average of $3.86 million per global data breach incident. With the various initiatives around North Carolina, there was a gap in the cyber education of K-12 teachers, which has a direct pipeline to the students' obtaining degrees and scholarships and participating in workforce development projects. To address this challenge, the Cyber Fellows program at Forsyth Tech was created to increase the number of cybersecurity professionals, enhance the expertise of cybersecurity faculty, and diversify the cybersecurity workforce in the Piedmont Triad region in North Carolina. The program also focuses on enhancing the cybersecurity skills of middle and high school teachers, aiming to increase the number of qualified adjunct faculty. This article highlights the program's significant contributions to bridging the cybersecurity talent gap, fostering diversity, and equipping educators to cultivate a future generation of cybersecurity professionals.

Keywords: cybersecurity, high school, middle school, student, teachers, diversity

Introduction

Trained cybersecurity professionals are crucial for safeguarding organizations, individuals, and nations from threats in the digital landscape. Unfortunately, cybersecurity talent remains in critically short supply across the United States. According to cyberseek.org roughly 663,434 vacant cybersecurity positions must be filled across various industries, such as banking, energy markets, and military operations [1]. The consequences of not meeting the demand are far-reaching. In 2020, it was reported that roughly 906 million people worldwide were affected by cybercrime [2], and each time there is a global data breach, the average costs are $3.86 million globally [3]. The majority of the cyber attacks were from hackers around the globe, ranging from 17-year-old hackers to Chinese state-sponsored attacks [4].

In 2020, at least 38 states introduced legislation or resolutions to deal with cybersecurity. For example, California enacted the California Cybersecurity Integration Center, which monitored cybersecurity incidents and recorded whether the center's investigations resulted in prosecution. Georgia used leftover Coronavirus funds to enhance cybersecurity technology. Indiana adopted laws that require counties to use cybersecurity companies for various tasks and qualified personnel who have access to the statewide voter registration system. Louisiana provided mandatory Cybersecurity training for all state and local employees [5].

Several states have adopted proactive measures to enhance cybersecurity training and allocate funding for a wide array of programs and staff. In contrast, Forsyth Tech has made a deliberate choice to facilitate the introduction of K-12 Career and Technology Education instructors to the field of cybersecurity. This initiative aims to equip educators with the necessary tools and knowledge to elevate cyber hygiene within their classrooms while empowering them to expand their expertise in the realm of cybersecurity.

In 2020, the North Carolina Department of Information Technology launched the NC CyberStart program, which teaches high school students cybersecurity skills through online challenges and games. This helped create a cybersecurity talent pipeline in the community college system [6]. The North Carolina General Assembly allocated $15 million in funding for the Cybersecurity Talent Initiative Fund to provide scholarships and grants for cybersecurity degrees [7]. The North Carolina Department of Commerce has awarded grants totaling almost $288,000 to support three innovative youth workforce development projects [8].

Despite these efforts, Winston-Salem/Forsyth County Schools (WS/FCS) and Stokes County Schools (about 5,800 students) raised concerns that there was a need for better teacher preparation in cybersecurity education. With the various initiatives around the state, there was a gap in the cyber education of K-12 teachers, which had a direct pipeline to the students obtaining degrees and scholarships and participating in workforce development projects.

To fill this gap, the Cyber Fellows program was built for K-12 Career Technical Education (CTE) teachers to integrate cyber hygiene directly into their instructional lessons throughout the year. We accomplished this by providing CTE teachers in the Winston-Salem Forsyth County School and Stokes County schools with the opportunity to complete a one-year Cybersecurity certificate program at Forsyth Technical Community College. In addition to earning their certificates, teachers had the opportunity to prepare for and complete the CompTIA Security+ exam. Armed with this expertise, they could return to their classrooms equipped with enhanced cybersecurity instructional resources to instill better cyber hygiene practices among their students. Furthermore, teachers who successfully completed the certificate program became eligible and were hired as adjunct instructors at Forsyth Tech.

Methods

The Cyber Fellows program aims to achieve objectives that will measure the success of the project: increase the number of cybersecurity professionals, improve the expertise of cybersecurity faculty at both secondary and post-secondary levels, and diversify the cybersecurity workforce in the Piedmont Triad region as seen in Figure 1.

Figure 1: Three project goals and the end result.

Recruitment and Enrollment

To increase rates of persistence and retention in our cybersecurity programs and increase the number of students who are dual enrolled in our cybersecurity courses, were recruited from 18 high schools and career fairs, hosting summer camps:

- Crosby Scholars
- African American Males Pursuing Educational Dreams (AAMPED)
- Hispanic Latino Male Success (HLMS)
- Show, Help, Empower (SHE)
- Summer GenCyber camps
- Winston-Salem Girl Scouts
- FOCUS events
- Forsyth Tech Science Technology Engineering and Math (STEM) events
- GEAR Up events with Winston-Salem State University

With these events, we introduced potential students to cybersecurity concepts through interactive and informative activities such as the RING Project activities, Trycyber.us, Raspberry Pi activities, drone activities, and Kahoot quizzes. To increase retention rates, we introduced new curriculum resources into our program, such as the EC-Council Essential Series with CyberQ, Jones and Bartlett Learning, Cellebrite UFED Touch and Physical Analyzer, and VMWare. We offered free cybersecurity certification vouchers funded by various grants, access to cyber ranges, tabletop exercises, and competitions. We also offered one-on-one mentoring for students in the program.

Recruitment and Process with Cyber Fellows Teacher

Nineteen high school and middle school teachers were recruited to participate in the first two cohorts. Goal two's objectives were to increase the cybersecurity skills, knowledge, and abilities of 24 middle and high school teachers. We also wanted to increase the number of qualified adjunct cybersecurity faculty at Forsyth Tech. We advertised the Cyber Fellows program through the North Carolina Department of Instruction (NCDPI), the WS/FCS CTE Department, and the Stokes County Schools administration. We were able to work with NCDPI through previous relationships in collaboration with the Carolina Cyber Network, the WSFCS, and Stokes County School systems.

Using the online signup form sent via NCDPI, we recruited eight qualified teachers for Year 1 and eight qualified teachers for Year 2. Throughout the program, we had monthly meetings with the cohorts and introduced a K-12 Cybersecurity curriculum that they could use in their classrooms. We also had speakers during Cybersecurity Awareness Month who introduced faculty to the 2D and 3D Cybersecurity Career Exploration Program and the Ring Project. Cyber Fellows completed the Forsyth Tech IT-Cybersecurity Certificate program. These courses allow the students to gain foundational cybersecurity skills. This certificate is also part of the K-12 Career and College Promise pathway. This certificate includes four classes:

- CCT-110 – Introduction to Cyber Crime. Students worked with the EC Council Ethical Hacking Essentials Curriculum [9].
- SEC 110 – Security Concepts. Students work with the CompTIA Security+ Certification Curriculum [10].
- CCT 112 – Cybersecurity Ethics. Students learn about ethical issues that cybersecurity professionals encounter.
- SEC 160 - Security Administration I. Students work on the Cisco Cyber Ops Curriculum.

Once the Cyber Fellows complete the IT Cybersecurity certificate, they participate in a two-day, six-hour boot camp on the CompTIA Security+ Certification, which is an industry-recognized credential. Participants are provided a voucher to take the CompTIA Security+ Exam. Once the certificate courses are completed, the

Cyber Fellows receive a $250 stipend. When they complete the Security+ exam, they receive another $250 stipend. Lastly, fellows have the opportunity to attend cybersecurity conferences nationally (3CS, HI-TEC, NICE/K-12).

Results and Discussion

Over the initial two phases of our Cyber Fellows project, progress can be summarized as follows: significantly boosted diversity in the cybersecurity sector, going from three underrepresented individuals/minorities on staff in 2021 to a 10-member team by 2023, as seen in Figure 2.

Gender equity has led to substantial growth, with the number of female adjuncts and full-time faculty increasing from just one in 2021 to a team of eight by 2023. Our Cybersecurity and Systems Security programs have flourished, expanding its adjunct faculty from six members in 2021 to a dynamic group of thirteen in 2023.

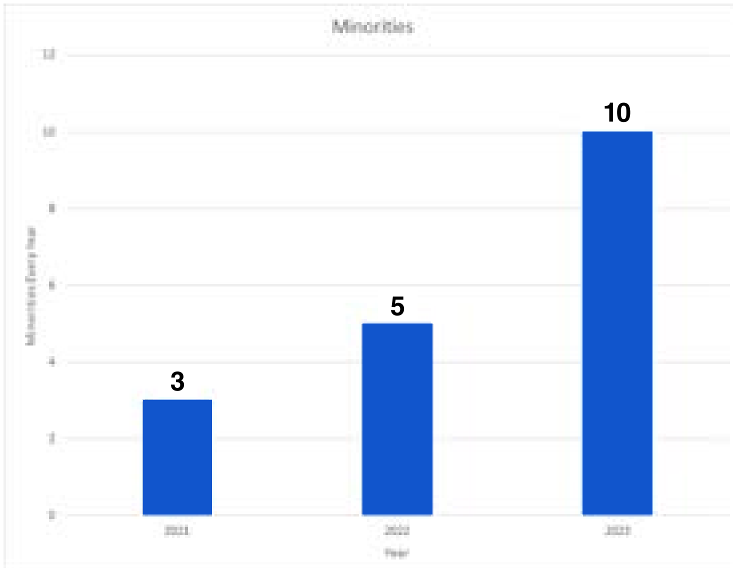


Figure 2: Minority Employment Increase in a 3 Year Period

In the project's inaugural year, we hosted five Cyber Fellows. In the second year, we elevated our participation to six individuals, and by the third year, we had successfully expanded our capacity statewide to accommodate a cohort of 23 Cyber Fellows, as seen in Figure 3. Notably, the cumulative Grade Point Average for our Cyber Fellows in the years 2022 and Spring 2023 stood at 3.8.

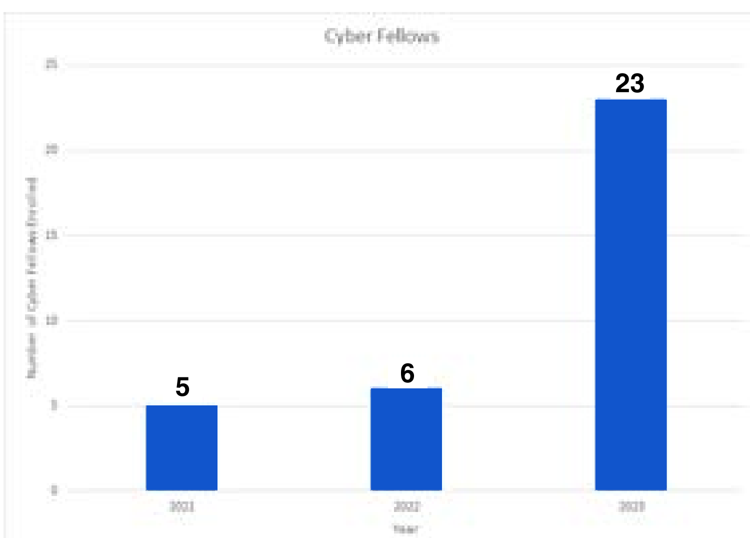


Figure 3: Cyber Fellows in a 3 Year Period

Through our recruitment techniques and processes beyond the college campus, we achieved remarkable results in the Center of Academic Excellence Outreach Competition. In 2021, we proudly secured the 2nd position nationally, and in 2022, we maintained our excellence, clinching the 6th spot. It's worth noting that among the top 10 contenders, we stood as the sole community college, competing against over 400+ schools nationwide.

Our enrollment in our Cybersecurity and Systems Security programs in 2021 was 163 Career and College Promise students (High School CCP) and adult learners in our Associate's Degree and certificate programs. In 2022, enrollment increased to 193 students. As of August 2023, our current enrollment numbers are 275 combined adult learners and CCP students, as seen in Figure 4.

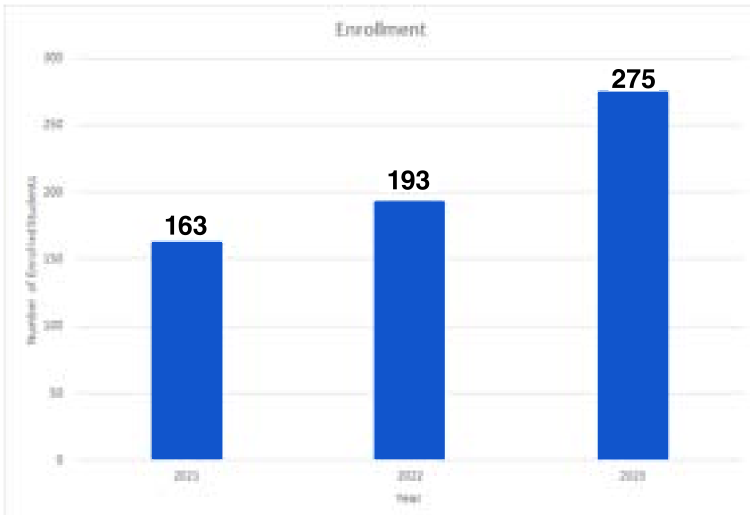


Figure 4: Curriculum and CCP Enrollment in a 3 Year Period

Even though we've had successes, there have been challenges along the way. Staffing challenges and the need for key personnel have highlighted the importance of proper preparation and resource allocation. Collaborations with state agencies and curriculum governing bodies have been instrumental in streamlining the educational journey for students, ensuring they receive the necessary course credit, and promoting a seamless transition from high school to higher education.

Conclusion

The Cyber Fellows program's success is evident in the significant improvements in diversity and gender equity within the Forsyth Tech cybersecurity faculty pool, with eight new adjunct instructors and enrollment in the cybersecurity programs, which has risen from 163 students to 275 students in two years. Additionally, the program's participation and achievements in national competitions showcase its effectiveness in cybersecurity education. The CTE instructor's willingness to participate and the approval and support from the North Carolina Department of Instruction have made this program flourish and allowed the project to expand throughout the state of North Carolina in its third year.

The Cyber Fellows program represents a significant step in addressing the shortage of cybersecurity professionals by empowering K-12 teachers, diversifying the cybersecurity workforce, and helping K-12 students establish a pathway from high school to community college via Cybersecurity. It serves as a model for similar initiatives, demonstrating the potential for improving cybersecurity education and the pipeline of qualified professionals.

Acknowledgements. This work was supported by the National Science Foundation (NSF) Advanced Technological Education DUE #2055253.

Disclosures. The authors declare no conflicts of interest.

References

[1] “Cybersecurity Supply And Demand Heat Map,” CyberSeek. [Online]. Available: https://www.cyberseek.org/heatmap.html

[2] “Sonicwall Cyber Threat Report,” SonicWall, 2021.

[3] J. Firch, “10 Cyber Security Trends You Can’t Ignore In 2021,” PurpleSec. [Online]. Available: https://purplesec.us/cyber-security-trends-2021/.

[4] E.-C. University, “Top Ten Cyberattacks of 2020-2021,” Accredited Online Cyber Security Degree Programs | EC-Council University. [Online]. https://www.eccu.edu/blog/cybersecurity/top-ten-cyberattacks-of-2020-2021/.

[5] “Cybersecurity Legislation 2020,” [Online]. Available: https://www.ncsl.org/technology-and-communication/cybersecurity-legislation-2020

[6] “CyberStart America,” North Carolina Department of Information Technology. [Online]. Available: https://it.nc.gov/cyberstart.

[7] “Senate Bill 105 / SL 2021-180 (2021-2022 Session) - North Carolina General Assembly,” [Online]. Available: https://www.ncleg.gov/BillLookUp/2021/S105-CCS.

[8] P. Bethea, “N.C. Commerce awards grants to three local workforce boards for Youth Initiatives | NC Commerce,” North Carolina Department of Commerce. [Online]. Available: https://www.commerce.nc.gov/news/press-releases/nc-commerce-awards-grants-three-local-workforce-boards-youth-initiatives.

[9] “Ethical Hacking Essentials (EHE),” EC-Council Learning. [Online]. Available: https://codered.eccouncil.org/course/ethical-hacking-essentials?logged=false

[10] CompTIA, “Security+ (Plus) Certification | CompTIA IT Certifications,” CompTIA. [Online]. Available: https://www.comptia.org/certifications/security.

METAR SMS Text Message Service to Support Part 107 Compliance: A Classroom Lab Exercise

JOSEPH M. BURGETT[1]

[1]Nieri Department of Construction Development and Planning, Clemson University, 2-134 Lee Hall, Clemson SC, 29631 United States of America

**jmburg@clemson.edu*

Abstract: Unmanned aircraft systems (UAS) have been used to support a wide range of industries. Code of Federal Regulations Title 14 Part 107 provides the rules that govern most commercial UAS missions. Section 107.51 of the regulations limits the maximum UAS altitude to 400 feet above the ground or structure and a minimum clearance of 500 feet below clouds. The required cloud clearance is often easy to comply with as most cloud coverage is thousands of feet above the ground and well above the 400-foot ceiling. However, many missions require the UAS to fly nearly low-altitude clouds or early morning fog. In these situations, the pilot must know the altitude of the clouds to maintain the necessary clearance. Accurately estimating cloud height visually is very difficult to do. However, the Federal Aviation Administration (FAA) has partnered with Leidos Flight Services to develop an SMS text service through the 1800wxbrief.com service to receive real-time Meteorological Aerodrome Report (METARs) weather reports in plain text. This paper shows how this new tool can be used to determine cloud height and incorporate it into a classroom activity to support Part 107 compliance.

Keywords: Part 107, Unmanned Aircraft System, drones, METAR, cloud

Introduction

Unmanned aircraft systems (UAS), colloquially referred to as "drones," are a tool that has seen significant growth over the past decade. Drones currently support various industries, including construction, law enforcement, agriculture, and cinematography [1]. The rapid growth of drone use started with the release of the Code of Federal Regulations Title 14 Part 107 (Part 107) in 2016 [2] and is the "default regulation for drones weighing under 55 pounds" [3]. Part 107 provides specific requirements governing lawful UAS operations, including a maximum of 400ft above ground level altitude, limitations of flights over people, and additional lighting requirements for night operations. This rapid communication manuscript will focus on section 107.51.d.1. The regulation requires remote command pilots (RPICs) to maintain a minimum 500-foot buffer below clouds. The purpose is to give RPICs sufficient space to avoid crewed aircraft operating in a cloud where visibility is reduced.

- *Section 107.51: A remote pilot in command and the person manipulating the flight controls of the small unmanned aircraft system must comply with all of the following operating limitations when operating a small unmanned aircraft system…(d) The minimum distance of the small unmanned aircraft from clouds must be no less than: (1) 500 feet below the cloud; and (2) 2,000 feet horizontally from the cloud.*

The requirement to maintain a minimum of 500 feet from the underside of a cloud is a non-issue for many missions as the cloud altitude is significantly above the allowable 400ft ceiling. However, it is not unusual for a mission to occur when low-altitude clouds or early morning fog are present. RPICs must know the cloud height to know their maximum mission altitude. A challenge for many RPICs is that most commercial weather services do not provide low-level cloud altitudes. The goal of this rapid communication is to demonstrate how a text messaging service from 1800wxbrief.com by Leidos Flight Services can help meet the requirements of Section 107.51 and be integrated into a field exercise for a collegial UAS training program.

Background

Part 107 requires pilots to pass a knowledge test before earning their remote pilot certificate. A skill assessed with the knowledge test is reading a meteorological terminal air report (METAR). The FAA defines a METAR as "observation of current surface weather reported in a standard international format" [4]. Unlike many commercial weather reports, the METAR provides cloud height information.

METAR

The METAR below is the example used in the FAA's Pilot's Handbook of Aeronautical Knowledge (FAA-H-8083-25B, chapter 13) [5].

- *METAR KGGG 161753Z AUTO 14021G26KT 3/4SM +TSRA BR BKN008 OVC012CB 8/17 A2970 RMK PRESFR*

METARs are issued every hour and always report the amount, height above ground level (AGL), and the presence of towering cumulus (TCU) or cumulonimbus (CB) clouds [5]. As such, the METAR can be useful for RPICs to maintain the 500-foot buffer from low-altitude clouds. In the example above, "BKN008" means broken clouds at 800ft. "OVC012CB" means the skies are overcast at 1,200ft with cumulonimbus clouds.

There are two challenges for UAS pilots using the METAR. First, while knowing how to read the METAR is required for the Part 107 exam, most UAS pilots don't commonly use it, and the skill is quickly lost. The second challenge is that accessing current METAR either by radio frequencies of nearby airports or through an internet connection may require additional equipment (radio, computer, internet access, etc.) and be inconvenient during hot and dusty conditions associated with fieldwork.

Laboratory Activity

Leidos Flight Services is an FAA partner and service provider of 1800wxbrief.com. Recently, the 1800wxbrief.com service began offering real-time METAR forecasts as a text message service, which addresses both challenges. Users can text 358-782 in the following sequence: "M, space, and the four-letter airport code" for the METAR. You can also text "M, space, the four-letter airport code, PT" to get the METAR in plain text. See Figure 1 for an example under two separate weather conditions. Full instructions can be provided by texting "FLTSVC" to 358-782.

Laboratory Assignment

The text below describes a laboratory assignment instructor can use to incorporate this tool into their curriculum.

- *You are a Remote Pilot in Command assigned to inspect a communication tower that is 1,150ft AGL. The communication tower is located in class G airspace near the Columbia Metro (KCAE) airport in Columbia, SC. How high can you inspect the tower with a UAS, given the cloud condition reported at the airport's METAR right now? Provide evidence that supports your answer.*

There are several ways that this question can be answered; however, a straightforward solution is to text "M KCAE PT" to 358-782 to get the METAR in plain text. The question is dynamic, and the answer will vary based on the weather near the airport. The correct answer will be the lowest altitude of the cloud cover minus the 500-foot buffer. The example below is the plain text METAR from the text service. It shows the entire height of the tower can be expected as the cloud cover ceiling is at 18,000ft AGL. The maximum height that pilots can fly is 1,550ft (tower height + 400ft), which is well below the cloud deck. Additional laboratory assignments using this service are provided in the Supplemental Material.

- *Current conditions at KCAE issued Aug 15 at 1156Z. Wind from 2500 at 3 knots, 10 statute miles visibility, Few Clouds at 18,000, Temperature 270C, Dewpoint 250C, Altimeter is 29.92.*

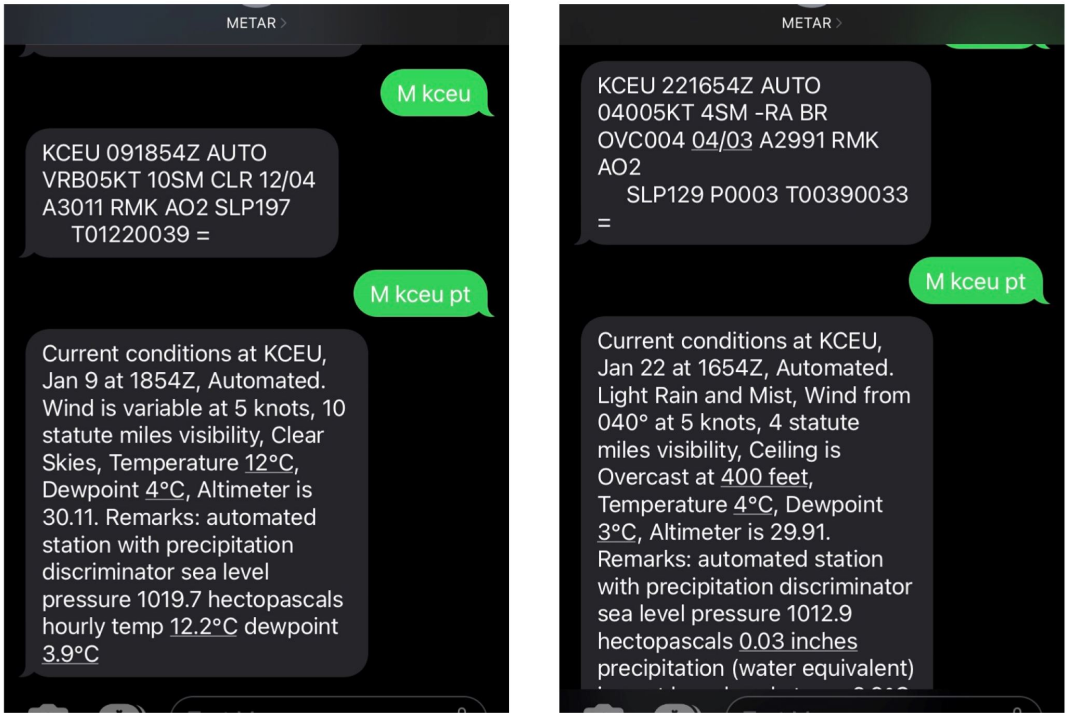


Fig. 1. Examples of the METAR text service (a) under ideal and (b) poor conditions.

The question can be varied by substituting the airport ID with one the students are familiar with. Instructors can also make checking the METAR with the text service part of their flight operations. While not the focus of this paper, this tool can also be used to help students learn how to read the METAR during the Part 107 knowledge exam prep by texting for various airports METAR, attempting to decode it by themselves, and checking their interpretation by texting for the METAR in plain text.

Learning Objective and Outcome

A "learning objective" is defined as what an instructor, activity, or class intends to do [6]. In this case, the overarching objective is for students to learn how to determine the altitude of low-level clouds to comply with Part 107 Section 107.51. The learning objective below can be a template for instructors' syllabi or assignment descriptions.

- *Learning Objective: Learn how to determine the altitude of low-level clouds to comply with the 500-foot buffer requirement of Part 107, section 107.51.*

A learning objective differs from a "learning outcome." A learning outcome describes in measurable terms what a student can do after completing an activity [6]. A vital component of a learning outcome is that it is "measurable" to be compared against a cognitive framework. Bloom's taxonomy is a common cognitive framework that divides knowledge levels into six categories: remember, understand, apply, analyze, evaluate, and create [7]. The learning outcome below provides a template instructors can use in their courses using the "evaluate" level of knowledge. Descriptions of "evaluate" include appraise, argue, defend, judge, selection, value, and critique [7].

- *Learning Outcome: Defend if current weather conditions allow for a UAS mission to be completed within the requirements provided in CRF Title 14 Part 107 section 107.51.*

Acknowledgements. This work was supported by the Nieri Department of Construction, Development and Planning at Clemson University. The author would like to thank the faculty and staff for continuing to support his research in the field of applied UAS.

Disclosures. The authors declare no conflicts of interest.

Supplement Materials: Please see https://micronanoeducation.org/wp-content/uploads/2023/10/Supplemental-Material_DOI.docx

References

[1] J. M. Burgett, "UAS Law Enforcement Technicians in South Carolina: An Exploration of Supply and Demand," *Micro Nano Technology Education Center*, vol. 2, no. 1, Mar. 2023, Accessed: Mar. 07, 2024. [Online]. Available: https://micronanoeducation.org/journal/volume-2-issue-1/uas-law-enforcement-technicians-in-south-carolina-an-exploration-of-supply-and-demand/

[2] Federal Aviation Administration, Department of Transportation, *Title 14 - Part 107 -- Small Unmanned Aircraft Systems*, vol. 14 CFR Part 107. 2016. Accessed: Mar. 07, 2024. [Online]. Available: https://www.ecfr.gov/current/title-14/part-107

[3] "Recreational Flyers & Community-Based Organizations | Federal Aviation Administration," Federal Aviation Administration. Accessed: Mar. 07, 2024. [Online]. Available: https://www.faa.gov/uas/recreational_flyers

[4] "Remote Pilot – Small Unmanned Aircraft Systems Study Guide," Federal Aviation Administration, FAA-G-8082-22, Aug. 2016. [Online]. Available: https://www.faa.gov/sites/faa.gov/files/regulations_policies/handbooks_manuals/aviation/remote_pilot_study_guide.pdf

[5] "Pilot's Handbook of Aeronautical Knowledge," Federal Aviation Administration, FAA-H-8083-25B, Aug. 2016. Accessed: Mar. 08, 2024. [Online]. Available: https://www.faa.gov/aviation/phak/pilots-handbook-aeronautical-knowledge-faa-h-8083-25b

[6] "Course Objectives & Learning Outcomes," DePaul University. Accessed: Aug. 15, 2023. [Online]. Available: https://resources.depaul.edu/teaching-commons/teaching-guides/course-design/Pages/course-objectives-learning-outcomes.aspx

[7] P. Artmstrong, "Bloom's Taxonomy," Vanderbilt University - Center For Teachings. Accessed: Mar. 08, 2024. [Online]. Available: https://cft.vanderbilt.edu/guides-sub-pages/blooms-taxonomy/

Building a Micro/Nanotechnology Cleanroom Training

JENS-UWE KUHN[1]*, DEMIS JOHN[2]

[1]*Educational Programs, Santa Barbara City College, Santa Barbara, CA 93109, USA*

[2]*Department of Electrical and Computer Engineering, University of California Santa Barbara, Santa Barbara, CA 93106, USA*

**jkuhn@sbcc.edu*

Abstract: The Central Coast Partnership for Regional Industry-Focused Micro/Nanotechnology Education (CC-PRIME) is a regional collaboration between Santa Barbara City College (SBCC), the University of California Santa Barbara (UCSB), and local industry partners, with the goal of addressing a demonstrated local workforce need in the field. Existing training available through the Support Center for Microsystems Education (SCME) was adapted with input from local industry to develop an initial cleanroom training in Micro/Nanotechnology for community college students and faculty. Two summer training sessions have been implemented, with student focus groups and industry feedback guiding modifications and additional training development. Ongoing input from local industry partners and an opportunity to leverage the existing SCME curriculum that project staff and faculty were trained on have proven critical in the development of the training. Access to local cleanroom facilities and staff and initial training for community college faculty were essential to successfully implementing the project. Additional modules and trainings are being developed to build out further and broaden this initial cleanroom training.

Keywords: micro/nano technology, regional collaboration, cleanroom training, curriculum, local workforce

Introduction

The California Central Coast hosts a surprisingly large number of high-tech semiconductor and micro- and nanotechnology companies. The cities of Santa Barbara, Goleta, and Carpinteria in Santa Barbara County host more than 45 companies that utilize semiconductor cleanroom facilities in their manufacturing [1]. The facilities span the Micro/Nanotechnology and semiconductor application space, including integrated photonics, microelectronics, microfluidics, medical imaging, biotechnology, infrared, defense, and space-based applications [1].

Many local high-tech companies regularly utilize the Nanofabrication (NanoFab) Facility at the University of California Santa Barbara (UCSB) [2]. This 12,000 square foot, class 100 and 1,000 state–of–the–art cleanroom facility is available to researchers, faculty, and industry [3]. Additional cleanroom facilities at UCSB that are primarily utilized by faculty and researchers include the Quantum Structures Facility (QSF) at UCSB's California NanoSystems Institute. The QSF houses a mix of traditional semiconductor processing equipment, specialty deposition tools, a photoluminescent/Raman spectroscopy suite, and a Crystal Growth Facility [4]. It is one of the locations for the new National Science Foundation (NSF) funded Quantum Foundry [5].

Santa Barbara City College (SBCC), a public community college and Hispanic Serving Institution, has a long history of collaborating with UCSB, often through its Center for Science and Engineering Partnerships (CSEP), particularly in Physical and Life Sciences and Engineering. Through these existing collaborations, UCSB NanoFab staff, researchers, and SBCC faculty and administrators initially connected with local Micro/Nanotechnology industry partners.

Table 1. Project Partners, Roles, and Facilities

Project Partner	Acronym	Role/Facility
Santa Barbara City College [6]	SBCC	Community College; Project Lead
University of California, Santa Barbara [7]	UCSB	R1 Research Institution; Project Subawardee; Cleanroom Facilities
NanoFabrication Facility [2]	NanoFab	UCSB Research and Industry Cleanroom Facility; Technical Project Staff
California NanoSystems Institute [8]	CNSI	Project Lecture/UCSB Lab Facilities; Project Support Staff
Quantum Structures Facility [4]	QSF	CNSI Cleanroom Facility/ Project Cleanroom; Technical Project Staff
Center for Science and Engineering Partnerships [9]	CSEP	External Evaluator
Math, Engineering, Science Achievement Program [10]	MESA	SBCC Student Recruitment and Support

This collaboration between SBCC, local high-tech industry partners, and UCSB's NanoFab and QSF cleanroom facilities grew into the Central Coast Partnership for Regional Industry-Focused Micro/Nanotechnology Education (CC-PRIME), currently funded through the National Science Foundation (NSF), in an effort to solve this critical regional workforce development challenge.

CC-PRIME is a collaborative project between SBCC and UCSB to utilize local industry input and leverage the advanced cleanroom facilities at UCSB to fill a demonstrated local industry need for job-ready cleanroom technicians. The project goals are (1) to build industry visibility and relations within the community, (2) to provide SBCC students and faculty with training and experiences in manufacturing at the university cleanroom facility, and (3) to create a student educational pathway to acquire semiconductor manufacturing jobs, incorporating industry input.

Informal inquiries revealed that California Central Coast high-tech companies experience great difficulty and financial risk in hiring technicians and operators in Micro/Nanotechnology and semiconductors [11]. While positions at the bachelor's and graduate degree levels often can be filled with local talent graduating from UCSB or graduates from other institutions moving to the region, filling positions at the technician/operator and associate's degree levels has proven extremely difficult for many companies in the area [11], [12], [13]. No Micro/Nanotechnology-specific training existed at SBCC or other regional community colleges. Many companies have resorted to hiring non-local applicants from other institutions with cleanroom experience and training/degrees/certificates. Still, without local roots, they tend to leave due to the region's extraordinarily high cost of housing. This particular challenge is most acutely felt by small companies where person power is at a premium [11], [12], [14].

Methods

Initial Training Development

Identifying and connecting to existing resources in the Micro/Nanotechnology education sector proved critical for generating the initial framework of the CC-PRIME project. This included the three NSF-funded Advanced Technological Education (ATE) Centers: the Micro Nano Technology Education Center (MNT-EC) at Pasadena City College [15], the Support Center for Microsystems Education (SCME) at the University of New Mexico [16], and the Nanotechnology Applications and Career Knowledge Network (NACK) at Pennsylvania State University [17]. The established 40-hour-long microchip fabrication "bootcamp" developed by Dr. Matthias Pleil at the University of New Mexico proved particularly suitable as a model for adaptation to our local industry needs [16].

In addition to Dr. Pleil providing documentation, curriculum resources, and advising regarding his overall cleanroom training and micro-pressure sensor fabrication lab, several CC-PRIME project leads, including two UCSB cleanroom staff and one SBCC faculty member, were able to participate in SCME's week-long training at its cleanroom facility at the University of New Mexico. Attending Dr. Pleil's training as participants provided valuable insights for project leads at both institutions beyond the covered curriculum. This was particularly true for the set-up and streamlining of the overall training methodology, including splitting each session into classroom and cleanroom sections, effective utilization of graduate student TA assistance, and establishing the requirement to offer online safety training before starting the class. Having an instructor with specific semiconductor industry experience was also noted as a particularly important and helpful training component.

While some of these training components could have been pulled from training outlines and shared course curricula, it is doubtful that their relative importance and associated values would have become apparent. These integral components of SCME's cleanroom training have been developed, implemented, evaluated, and reformulated over many years. These nuances and the relative importance of different training components would not have been as apparent to our project staff and faculty without completing the existing training ourselves. Having this knowledge readily available facilitated and informed the formation of our training, particularly with respect to which program components are critical to keep for this project and which might be less critical and could reasonably be adapted to our local needs.

CC-PRIME's initial industry needs assessment among the project's Industry Advisory Board (IAB) members identified exposure to working in a cleanroom environment as a critical component of an initial technician/operator training and overall showed significant alignment with SCME's microchip fabrication bootcamp curriculum [18]. Some IAB members expressed a desire for additional company-specific training, e.g., on specific instrumentation/processes heavily utilized at their facility. Accommodating very company-specific training needs proved not to be feasible for a variety of reasons. This approach would have focused the student training on a small subset of companies rather than being broadly applicable to the entire industry. Student recruitment is highly dependent on the broad applicability of the training in that it should make the student a viable candidate for as many jobs/companies as possible. We found that the students' needs for broadly applicable training conflicted with the industry request for training specific to one company's needs. It was critical to explain this disparity to our industry partners, who often did not intuit the student perspective but very much appreciated the insight. Therefore, the overall focus of adapting the existing curriculum was on training components that would broadly apply to many industry partners, e.g., those focused on production tracking methods and communication protocols that we have observed at many local semiconductor companies [18], [19].

Table 2. Initial Industry Advisory Board (IAB) Members

Company	Location	Employees
BEGA North America	Carpinteria, CA	500 +
Freedom Photonics LLC (a Luminar company)	Goleta, CA	< 500
Kyocera SLD Laser	Goleta, CA	500 +
Nexus Photonics	Goleta, CA	< 500
Praevium Research Inc.	Goleta, CA	< 500
Thorlabs Crystalline Mirrors	Santa Barbara, CA	500 +
Transphorm Inc.	Goleta, CA	< 500

Implementation

To facilitate the initial training, SCME-trained CC-PRIME project staff identified and trained two UCSB graduate students to primarily support sessions in the cleanroom. A retired semiconductor professional from one of the local industry partners was recruited as additional instructional support and to provide the participants with relevant industry input.

In the summer of 2022, the initial training was carried out at the QSF facility at UCSB, overseen by an industry professional supported by two graduate students and the project staff originally trained at the University of New Mexico's SCME. One of the objectives of the CC-PRIME project was to train faculty in the first training before bringing in students. The initial training was performed during ten roughly half-day sessions over two weeks to enable better use of periodic downtime for individual trainees during several cleanroom processes and to give trainees more flexibility with their schedules. The initial faculty cohort consisted of four community college faculty from SBCC and Allan Hancock College, a neighboring community college, and six up-skilling participants [20]. The project's first-year focus was on faculty professional development, testing, and streamlining the developed training and corresponding processes. Focusing on faculty professional development prior to opening the training to students allowed for increasing awareness about the local Micro/Nanotechnology industry and its employee needs among faculty. It also provided faculty with an opportunity to bring back training experiences and modules into their existing courses at the community college and equipped them with the background knowledge to serve as ambassadors for the program going forward [21].

In the summer of 2023, the subsequent training was again carried out at the QSF facility, with six community college student participants and four industry/non-academic participants. Based on previous staff and participant feedback, the training was adjusted to be held in five full-day sessions over one week. Community college student recruitment relied heavily on existing student support structures and associated programs at SBCC, such as the Math, Engineering, and Science Achievement (MESA) Program[10] and the STEM Transfer Program (STP) [22]. Faculty who participated in the previous training served as ambassadors for student outreach and recruitment. Interested students were asked to complete a brief application, including a transcript and a personal statement discussing their educational goals and reasons for participating. Student participants were selected based on merit criteria, previously completed courses, and training alignment with their academic goals. All student participants were SBCC Engineering and Computer Science majors on initial transfer pathways. Industry participants were selected with help from IAB members based on the alignment of the training with IAB member-specific employee upskilling needs [23].

Results and Discussion

The initial cleanroom training during the summer of 2022 focused on faculty professional development and was completed by four community college faculty. Several industry partners, including IAB member Kyocera SLD Laser, sent six new or existing employees to the same training as an upskilling opportunity, providing additional industry exposure to faculty and networking opportunities between faculty and industry. As a result of the training, and in addition to collaborating with industry to develop additional course curricula and training modules, the role of faculty to serve as ambassadors to students for the program and the local industry was strengthened. Through this direct industry exposure, participating faculty have gained a much deeper understanding of the existing local Micro/Nanotechnology industry sector, its workforce needs, and the corresponding job opportunities that exist in the local area for community college students [1], [12], [13], [21], [24].

The subsequent cleanroom training during summer 2023 was slightly modified based on previous participant feedback, primarily with respect to logistical and operational day-to-day aspects of the training. It was completed by six community college students and four industry/non-academic participants. Similarly to the networking aspect between faculty and industry participants, providing students with an opportunity to learn side-by-side with industry members resulted in additional exposure to the local industry and networking opportunities for students [23].

After completion of the training, the project's external evaluator held focus groups with training participants to gather their feedback and level of satisfaction with it. Participants were asked for their reasons for participating, what they hoped to get out of the training, and whether it accomplished what they had hoped for. Participants were also interviewed about the curriculum, whether the training covered the concepts and techniques they had envisioned being covered, and whether they felt adequately prepared for it with respect to their previously completed courses. Additional questions centered around logistical aspects of the training, support during the training, and participants' future educational and career goals [21], [23].

The external evaluator reported that all participants felt that the training experience met their expectations. Faculty who participated gained greater familiarity with and exposure to the local Micro/Nanotechnology industry, specifically its cleanroom utilization. They also have begun to explore ways of potentially using the training at their respective institutions and assisting with student outreach and recruitment [21], [23]. For industry, one main goal has been for the training to help mitigate the existing local talent shortage in Micro/Nanotechnology [11], [13]. In addition, trainees not currently working in cleanroom environments noted the benefit of improving their understanding of the overall cleanroom processes and familiarizing themselves with the various requisites to pursue a cleanroom job [21], [23]. Students noted that, besides the technical training and skills learned in the cleanroom and during corresponding lectures, they expanded their understanding of possible local career paths in Micro/Nanotechnology that they did not know existed prior to taking the training. They also formed valuable connections with local industry partners and staff and faculty at the four-year institution [21], [23].

All participants from all three groups, community college students, faculty, and industry, reported that the training met and exceeded their expectations and needs. Several expressed an interest in additional and more in-depth training. At the same time, some thought that additional prior preparatory knowledge could be helpful, such as around chemical concepts or commonly used acronyms. Some students noted that having more explicit connections to potential internships or job opportunities with local companies could be beneficial [21], [23]. This is now integrated into the program more directly through additional follow-up with industry partners about job openings or internship opportunities and also by directly connecting students who completed the training to industry collaborators.

Industry partners noted a desire for additional training, not all of which would need to be in a cleanroom, and some of which vary from company to company in terms of what learning objectives should be covered. This includes areas related to semiconductor manufacturing, equipment maintenance, facilities maintenance, and assembly and testing [21], [23]. Dialogues with IAB members and other industry partners are currently ongoing to identify the next steps in building additional training opportunities and modules [18], [19], [25].

Faculty have expressed interest in ongoing collaborations and networking opportunities with industry partners for them and their students [21], [23]. Current efforts include guest lectures, industry tours, community outreach events, and other professional networking opportunities to grow awareness about this field and associated local employment needs and opportunities.

Conclusion

In developing this Micro/Nanotechnology cleanroom training, several key points have emerged as having been critical throughout the development and initial implementation phases:

Addressing local need

The project was initially developed in an attempt to address a local and somewhat specific workforce development need [11], [13]. Keeping efforts centered around that idea when developing and implementing the program and growing and expanding it has proven to be critical. It has ensured local industry buy-in, assisted with local community college student recruitment and outreach, and generated buy-in from additional local and regional community and workforce development partners [26]. This is particularly important as this training is not specifically designed to serve large-scale semiconductor fabrication facilities, which do not exist in our region [14].

Working collaboratively with local industry partners

The project's IAB members have been instrumental in designing the training curriculum in collaboration with faculty. Getting industry partners to collaborate and come to a consensus on specific training needs in addressing the common workforce challenge has opened up networking and outreach opportunities that were not available to students and faculty before [21], [23]. Local industry input into the specific workforce training needs continues to guide the development of additional training modules to ultimately become part of an entirely new student pathway into the semiconductor industry [18], [19].

Gaining access to cleanroom facility

Access to a cleanroom facility is critical for this particular training. We have been fortunate to be able to build on long-standing collaborations between the two partnering institutions, SBCC and UCSB, to gain access to one of UCSB's cleanroom facilities for this training. It is likely that some of the additional training currently in development will also require cleanroom access; however, we are also exploring options of designing additional training modules in regular laboratory settings with the appropriate equipment. Maximizing cleanroom utilization for those training components that truly need to be carried out in a cleanroom environment will reduce constraints around cleanroom access times.

Utilizing existing and established training curriculum

Adapting the existing SCME microchip fabrication bootcamp curriculum to our specific local needs has been critical to our successful launch [16]. Dr. Matthias Pleil's willingness to share SCME's established curriculum with us and allow us to adapt it with input from our local industry partners enabled us to develop and initially implement this training in a much shorter time than we would have otherwise been able to. Particularly important in this regard was the fact that several of our project staff members and faculty were able to complete SCME's training themselves first. This proved to be critical, as it provided direct insight into the training itself. The relative importance of certain aspects of the training, its previous iterations, improvements, reasoning behind them, and first-hand experience regarding some of the specific logistical or pedagogical considerations became apparent. This would not have been effectively relayed through simple sharing of curriculum resources without going through the training first.

Training faculty first

Our initial program design called for training community college faculty prior to rolling out the training to students, with the idea of testing certain aspects with faculty before bringing in students. In addition to that effect, this also provided for increased networking opportunities between industry and faculty, and it continues to aid in faculty being able to bring the experience to their classrooms. This has helped with creating overall awareness of this local industry in the community and with recruitment and outreach efforts.

Being able to leverage an existing training curriculum that project staff and faculty have experienced themselves and collaboratively adapting it to local industry needs has been critically important in enabling the successful launch of this Micro/Nanotechnology cleanroom training. Additional curriculum and associated training are currently in development, along with efforts to broaden the community and partner outreach and local awareness. Additional semiconductor-focused workforce development grant proposals were developed as a result of this initiative and in collaboration with multiple local workforce development organizations to broaden access to local Micro/Nanotechnology training opportunities [11], [26].

Acknowledgements. This work was supported by the National Science Foundation under ATE award 2100405, Central Coast Partnership for Regional Industry-Focused Micro/Nanotechnology Education (CC-PRIME).

Disclosures. The authors declare no conflicts of interest.

References

[1] D. Pricco, "Santa Barbara Startups and Tech Companies: Hardware." Accessed: Jan. 25, 2024. [Online]. Available: https://www.sbtechlist.com/?wpbdp_category=hardware

[2] "UCSB Nanofabrication Facility." University of California Santa Barbara. Accessed: Jan. 26, 2024. [Online]. Available: https://nanofab.ucsb.edu/

[3] B. Thibeault, "NanoFab User Access Data," University of California Santa Barbara, Sep. 2023.

[4] "Quantum Structures Facility." University of California Santa Barbara. Accessed: Jan. 26, 2024. [Online]. Available: https://www.cnsi.ucsb.edu/facilities/quantum-structures

[5] "UCSB NSF Quantum Foundry." University of California Santa Barbara. Accessed: Jan. 29, 2024. [Online]. Available: https://quantumfoundry.ucsb.edu/

[6] "SBCC College Facts." Santa Barbara City College. Accessed: Dec. 15, 2023. [Online]. Available: https://www.sbcc.edu/about/collegefacts.php

[7] "UCSB Facts and Figures." University of California Santa Barbara. Accessed: Dec. 13, 2023. [Online]. Available: https://www.ucsb.edu/about/facts-and-figures

[8] "California NanoSystems Institute." University of California Santa Barbara. Accessed: Jan. 26, 2024. [Online]. Available: https://www.cnsi.ucsb.edu/

[9] "Center for Science and Engineering Partnerships - Evaluation Services." University of California Santa Barbara. Accessed: Jan. 26, 2024. [Online]. Available: https://csep.ucsb.edu/evaluation

[10] "Math, Engineering, Science Achievement Program." Santa Barbara City College. Accessed: Jan. 29, 2024. [Online]. Available: https://www.sbcc.edu/mesa/

[11] K. Miller, "Industry Survey: Impediments to Growth," presented at the Santa Barbara South Coast Chamber of Commerce, Manufacturing & Technology Committee Roundtable, Santa Barbara, CA, Jan. 31, 2020.

[12] E. Johnston, "2023 Central Coast Workforce Analysis." TIP Strategies, Apr. 12, 2023. Accessed: Jan. 25, 2024. [Online]. Available: https://public.tableau.com/app/profile/tipstrategies/viz/2023REACHWorkforceAnalysis/Title

[13] B. Werner, "Industry Jobs Listings September 2023 - Public." Sep. 30, 2023. Accessed: Jan. 12, 2024. [Online]. Available: https://docs.google.com/spreadsheets/d/14WC_eB5x9qi7SYPm1pZgFbfB4bIBTmCFe10RKQtFQPc/edit#gid=0

[14] E. Johnston, "2022 Central Coast Economic Explorer." TIP Strategies, Jul. 05, 2023. Accessed: Jan. 12, 2024. [Online]. Available: https://public.tableau.com/app/profile/tipstrategies/viz/2022REACHEconomicExplorer/Title

[15] "Micro Nano Technology Education Center." Accessed: Jan. 22, 2024. [Online]. Available: https://micronanoeducation.org

[16] "Support Center for Microsystems Education." Accessed: Jan. 25, 2024. [Online]. Available: https://scme-support.org

[17] "Nanotechnology Applications and Career Knowledge Center." Accessed: Jan. 25, 2024. [Online]. Available: https://www.cneu.psu.edu/nano4me/

[18] E. Sciaky, "CC-PRIME Needs Assessment Interviews with Industry Advisory Board Members," Center for Science and Engineering Partnerships, Spring 2022.

[19] T. J. McCue, "Microsystems Process Technician: Knowledge, Skills & Abilities," Micro Nano Technology Education Center, Jun. 2023. Accessed: Jan. 25, 2024. [Online]. Available: https://micronanoeducation.org/semiconductor-jobs-knowledge-skills-and-abilities/

[20] "All About Allan Hancock College." Allan Hancock College. Accessed: Jan. 29, 2024. [Online]. Available: https://www.hancockcollege.edu/about/index.php

[21] E. Sciaky, A. Leak, and L. Lenaburg, "CC-PRIME Post-Training Focus Group Report 2022," Center for Science and Engineering Partnerships, Apr. 2023.

[22] "STEM Transfer Program." Santa Barbara City College. Accessed: Jan. 29, 2024. [Online]. Available: https://www.sbcc.edu/stem/stemtransferprogram.php

[23] E. Sciaky and L. Lenaburg, “CC-PRIME Post-Training Focus Group Report 2023,” Center for Science and Engineering Partnerships, Oct. 2023.

[24] E. Shein, “Global Chip Shortage: Everything You Need to Know.” TechRepublic, Oct. 19, 2023. Accessed: Jan. 25, 2024. [Online]. Available: https://www.techrepublic.com/article/global-chip-shortage-cheat-sheet/

[25] “National Talent Hub: Connecting Industry, Talent, and Training Like Never Before.” National Institute for Innovation and Technology. Accessed: Jan. 10, 2024. [Online]. Available: https://nationaltalenthub.com/

[26] “About the Workforce Development Board.” County of Santa Barbara: Workforce Development Board. Accessed: Jan. 12, 2024. [Online]. Available: https://www.countyofsb.org/1947/About-the-Workforce-Development-Board

Materials Technology Education Processes and Outcomes: The MatEdU Program

THOMAS STOEBE[1], IMELDA COSSETTE[2], KIM GRADY[3]

[1]*Department of Materials Science and Engineering, University of Washington, Seattle, WA 98195*

[2]*Materials Technology Education Project, Edmonds College, Lynnwood, WA 98036*

[3]*BehaveHeuristics, Apache Junction, AZ 85116*

**tstoebe@icloud.com*

Abstract: The National Resource Center for Materials Technology Education (MatEdU) and its continuation program, the MatEdU Online Digital Library, has made major progress in areas related to education, technology training, inter-communication, and networking in materials technology. A significant impact of this National Science Foundation-funded Advanced Technological Education resource center has been implementing materials technology into multiple areas, from technology and electronics education to advanced manufacturing, energy materials, and critical materials utilization. Using its website as its centerpiece, workshops, and educational modules along with opportunities for undergraduate research and faculty mentoring at community colleges are available. Practical examples abound, including guitar building, additive manufacturing, and numerous types of advanced materials and applications. This paper provides the information future programs will need to build follow-up programs to enhance technology education further.

Keywords: materials, education, technology, workshops, curricula, mentoring, networking

Introduction

Materials technology is the basis for developing new and advanced systems in areas from aerospace and automotive to household appliances, all of which are made of materials whose properties are enhanced by their structure, properties, and processing techniques used for their production. The use of micro- and nano-scale materials in combination with enhanced processing yield new and specific enhancements in mechanical, electrical, optical, and magnetic behavior. New processing techniques utilizing natural materials can also improve the environment and create a greener future. New horizons are becoming achievable today with scientific and engineering advances in materials.

These advances create a need for enhanced materials technology education, which may include re-training in new systems and new tools for education from elementary school to technology education institutions. Advanced educational programs can demonstrate the critical relationship between materials structure and properties and the importance of processing in determining the final properties of a manufactured structural or electronic part. Additionally, hands-on materials-related activities have been proven to help learners of any age experience the excitement of science applied to technology, leading to potential interest and future pursuit of materials technology study or careers.

The many new materials configurations and combinations that will be employed in structures and electronics in the coming years include: composite, nano, micro, and two-dimensional materials. These are the metamaterials that will enhance the products of the future. Developing technology-related professional and educational activities leads to a greater understanding of materials processing knowledge that is critical for taking full advantage of new technological advances. This paper presents the approach and impact of the MatEdU program on these needs.

Materials Technology Education (MatEdU) Project

In the mid-1990s, The Boeing Company had already begun researching the possibility of replacing traditional metal parts in their airplanes with parts made using composite technology. If integrated correctly, the results would increase fuel efficiency while reducing the plane's overall weight. However, a challenge emerged. The state did not have training programs or a trained workforce in composites that could step into this new era.

Washington's Governor Gary Locke (1997-2005) made a promise to Boeing that, if they kept the composites work in Puget Sound, he would work with the community and technical colleges in Washington State to create and offer training programs focused on composites that would, in turn, provide Boeing the trained workforce it needed.

Edmonds College (formerly Edmonds Community College) accepted that challenge and, in the fall of 2003, set up the state's first Associates Degree and Certificate program in Materials Science. Although composites were the initial focus, Edmonds included basic information on other materials such as ceramics, metals, etc. The creation of the initial program provided Edmonds the opportunity to submit a National Science Foundation (NSF) Advanced Technological Education (ATE) proposal in 2004 to expand the program. The proposal was awarded in 2005 and established the National Resource Center for Materials Technology Education (MatEd), which was eventually rebranded as MatEdU.

A team of engineers, technologists, scientists, and educators developed or collected curricula, resources, and ideas whereby instructors could integrate materials and technology into existing or new curricula at all levels and in many STEM subjects. The team benefitted from collaborations with various professional groups, foundations, and numerous community and technical colleges and universities.

The team also developed a set of partnerships that enhanced communication and provided networking opportunities for many other projects and centers—revealing the materials focus needed for these partner programs to function. Workshops and curricula emphasizing technologies dealing with engineering materials were being requested from K -12 teachers and college technology instructors. The project that emerged was called the National Resource Center for Materials Technology Education, and later, Online Instructional Resources for Materials Technology Education, and it continued for 18 years, with completion in 2023. The project is comprehensively called "MatEdU".

The well-known work of Dr. Rustum Roy [1] and colleagues, which focused on convincing scientists in general and funding agencies in particular that an everyday technology and science focus could enhance interest and enthusiasm for technology and science study, motivated the many undertakings in this project. Pursuits were planned and orchestrated to convince instructors that the science and technology of everyday materials could be a useful tool.

Early work in this area included focused classes for instructors at several universities; one such class formed the groundwork for a current K-12 teacher program sponsored annually in many locations by the ASM Materials Education Foundation [2]. Individual contributions to the literature [3-6] and later follow-up focus work for technology instructors in manufacturing [7] added to the need for a program such as MatEdU.

MatEdU continued to evolve and has infused the need for materials knowledge into programs from manufacturing technology to health-related fields, utilizing unique experiences such as guitar building, hands-on curricula, and student-based projects and providing mentoring and a model for both networking and communication in the advanced technological education area.

This paper presents first the website, where all information relevant to the project is stored, including a wide variety of resources for educators and students. This is followed by a discussion of the programs and projects that have grown out of needs identified for educational materials and from collaborations with outside groups. This includes curriculum development, conferences, workshops, research opportunities, and help in the development of future projects.

The Website: www.materialseducation.org

The MatEdU website provides a guide to the programs and resources available in the broad area of materials technology education. It is not comprehensive, but focuses on resources and curricula in areas of practical application as related to engineering and science. Activities need to engage the student, especially at the younger ages. The lessons, referred to as "modules" in this program, proceed from introductory levels to more difficult concepts and applications, where instructors can adapt the materials to their class and situation.

As can be seen on the accompanying web page image, site visitors are provided with information for both educators and students, along with a variety of other educational material in areas including:

- Educator's areas of interest, such as core competencies in technology; curriculum collections; and related programs,
- Resources, including curricula in materials, engineering, and technology; useful websites and videos; NSF programs; textbooks; and related papers and publications,
- Career resources and career pathways, and
- News in materials technology and related areas.

The contents of these website sections are discussed below as relevant to the development and use of materials technology curricula, available resources and references, and specific programs of interest to instructors and students.

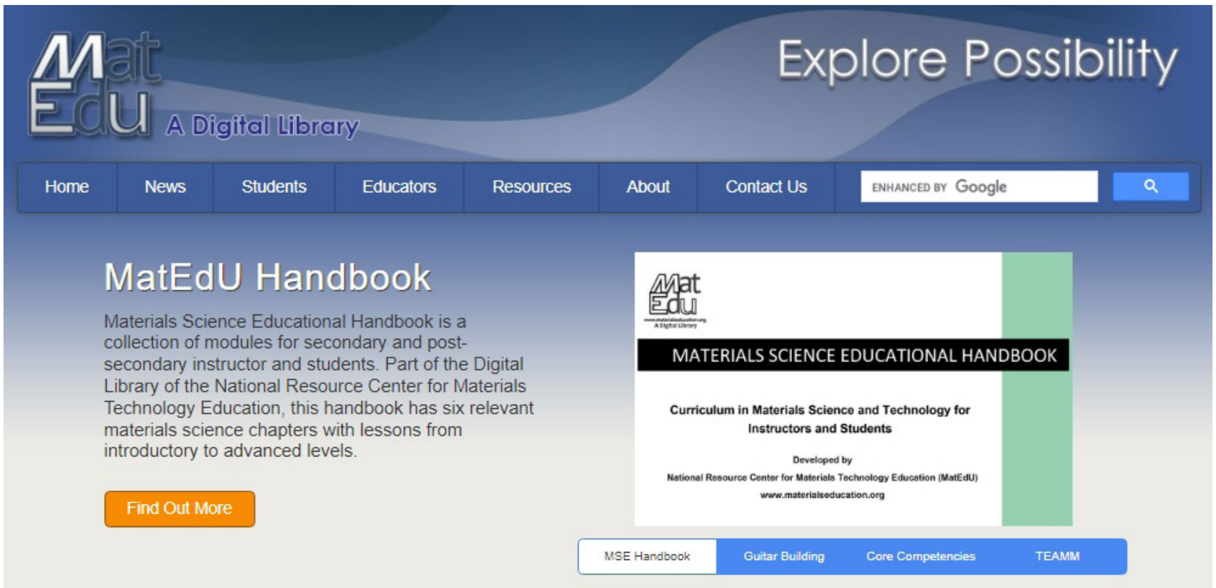


Fig. 1 The MatEdU Website. Available at https://materialseducation.org/.

In 2013, a system for assessing the impact and effectiveness of the website was devised. The intention was to gather information on three key metrics used in website analysis: time on the site, pages most viewed, and downloads. The data collected helped identify the content and information that benefited the audience most. Downloads provided an indicator of the site's "sales and revenue." Even though no sales took place, this was a good way to put a value on the most downloaded modules. Later, it was also possible to view where and how site visitors entered the site. Data showed that visitors entered most often using search engines and often using the keyword search term "types of materials." These data were used to upgrade the site so that the most used search terms were present in the site's metadata. It was also possible to see the external locations from which visitors entered the site. This was valuable information both in knowing where the links originated and in approaching valued partners to form backlink campaigns to elevate the site's overall ranking on the web, driving more traffic to the site.

The website has expanded in scope since its inception and will continue to be an important go-to site for materials information into the future. To accomplish this, while MatEdU is closing, the website is being migrated to become a part of the NSF ATE-funded Micro Nano Technology Education Center (MNT-EC) at www.micronanoeducation.org. MNT-EC includes programs for educators, students, and industry partners in all aspects of micro and nanotechnology, utilizing today's technological advances in materials and microsystems as it uses the information on www.materialseducation.org.

Educators tab

The website's Educators tab includes everything an educator might need to understand and develop programs related to materials technology. This includes a highly successful workshop program, a clear definition of core competencies for technicians, and curriculum modules for use in the classroom.

Materials in STEM (M-STEM)

M-STEM is the newer name for a long-running series of programs of practical materials lessons, labs, and case studies that have been presented in workshops for and by educators. These workshops relate to all aspects of STEM (Science, Technology, Engineering, and Mathematics) and involve educators talking with educators—basically saying, "If I can do it, you can too!" A key ingredient of these workshops is that they were staged in various parts of the U.S., engaging different school and college districts, so that nearly anyone interested could attend on a rotating basis.

M-STEM is built on the basis of the long-standing "National Educator's Workshop" program developed by Dr. Jim Jacobs at Norfolk State University. Teachers at K-12 schools, and instructors at community and 4-year colleges interested in materials technology gathered annually beginning in 1986 to exchange lessons, labs and case studies that would excite student interest. Here, each participant shared their latest labs, demonstrations, and ideas with others, which led to further innovations in curricula, to be presented at future workshops. MatEdU managed the NEW Call for Papers and peer review process; however, upon Dr. Jacobs' retirement in 2010, MatEdU took over the overall management and production of NEW. The annual workshop was broadened and renamed "Materials in STEM" (M-STEM) in 2015, sponsored by MatEdU, which ran successfully until 2019 when cancelled by the pandemic. The complete archives for these programs, including the curriculum presentations, are provided under the Educators tab on the MatEdU website [8].

Core Competencies

Core Competencies for technicians working in technology fields are a critical piece in knowing what is important for inclusion in the development of curriculum and technician education. MatEdU undertook a broad survey of practitioners in the fields of materials [9], plus competencies needed for work in marine technology, nanotechnology [10], corrosion, additive manufacturing and medical devices technology, all of which are available collectively in one reference [11]. These core competency needs are presented under the Educators tab on the MatEdU website for use in developing curricula. The core competencies have also been made available to industry for their use in training and in some cases, technician hiring.

MatEdU Modules

These maintain a focus on materials, technology, and science appropriate for students from middle school to technical/community college levels. These curricula have been collected using specific criteria, and each module is peer-reviewed to ensure that it works in the classroom at its designed level and is copyrighted to protect the author's intellectual property. A uniform format is used to ensure that instructors can navigate the module. Modules often include a lab experiment, a PowerPoint presentation, references, and instructor notes. Modules are designed to align with core competencies and with **Standards for Technological Literacy** [12]. K-12 modules are designed to align with the concepts found in the **Next Generation Science Standards** [13] and applicable connections to **A Framework for K-12 Science Education** [14]. Alignment helps college, school, or district personnel identify the concepts in each module that satisfy their own system's curricular requirements.

A search engine on the MatEdU website is available to help find curricula by level, subject, and author. Subjects range from Additive Manufacturing to Wood, with many other topics in-between.

Modules developed early in the program included simple introductory demonstrations and labs, such as:

- Materials Science of Household Appliances
- Micro-to-Macro: Linking Microstructure to Material Properties
- Composite Materials—Sticks and Glue
- Classification of Materials
- Odd Behavior of Rubber Bands

These modules may be found by title on the MatEdU website using the search engine.

Subject matter for more recent modules has evolved from conventional subjects, including materials design and processing methods, to subjects more relevant to today's needs. For example, subjects of recently developed modules include the following, which may also be searched by title on the website:

- Introduction to Magnetic Composites
- Additive Manufacturing of Magnetic Materials
- Lithium The Third Element (basics of Li-ion batteries)
- 3D Printing Filament Recycling
- Sustainable Composite Materials from Renewable Resources
- Global Impact with Activity (Impact of Design and Innovation)
- Evaluating the Next Generation of Solar Cells

Over 150 separate modules are available. Copyright ensures that other publishers can copy none of these modules, but copyright permissions in all modules state that the material may be reproduced and used for educational purposes. Peer review ensures that the module will work in a classroom and that the technology and science are presented correctly and, in a manner, where both the instructor and students can understand and carry out the module's objectives.

Materials Science Educational Handbook

It was clear from some instructors that choosing a specific module for their class was difficult without guidance. To provide this guidance, a set of modules, taken from the overall list of MatEdU modules, was collected specifically for instructors who wanted a materials technology and science "curriculum" that was classroom-ready. This handbook consists of six chapters, beginning at an introductory level, then continuing through metals and alloys, composite materials, polymers and plastics, ceramic materials, and engineering materials and design [15]. These are independent chapters and have been shown to assist instructors in developing their own materials technology programs.

Resources tab

This section of the website provides a wide variety of carefully chosen educational resources related to materials. Other specific instructional resources are also listed in this section. This includes a series of references, including:

- Engineering teaching libraries
- Materials professional organizations with educational programs
- Relevant websites and textbooks
- Career resources
- Papers and publications of interest

Using numerous collaborations, including important published works from a wide variety of sources, assures that this listing will be useful to educators in general and specific technological programs in particular.

News and Student tabs

Materials and related science/technology advances have been coming fast and furiously in recent years. The Innovative News tab provides an overview of some advances in materials and technology and related advances in micro- and nanotechnology, materials availability, sustainability, associated micro-electronics, environmental issues, manufacturing innovations, and digital informatics and biotechnology. These innovative news articles, taken from many sources, combine material concepts with many applications in fields as diverse as maritime, aerospace, and automotive. Students are continually learning more about the all-encompassing issues that material interactions can have on the lifetime of products and seem to be developing new means for problem-solving that can "save the planet."

The Student tab provides information for students interested in technology careers, from internships to college programs. Some of these areas offer incentives for students to learn more. The popularity of the MatEdU website has encouraged numerous outside programs and projects to request to be listed on the website, either as resources or as student opportunities. Generally, only non-profit organizations are considered and listed only if they would substantially enhance our audience. Recent requests not yet listed include opportunities in energy and climate resources in addition to more traditional areas. Internships and apprenticeships are included as they interest students but are not necessarily considered in college-related resources.

Programs and Projects

Integrating all of the resources above, eighteen years of MatEdU has resulted in a wide variety of programs and projects undertaken by faculty members from K-12 to college, by students at all levels, by administrators, and by engineers and scientists, all in concert with a number of external organizations. Many of the ideas in these programs and projects can be used by new organizations utilizing the experience of MatEdU and its partners. MatEdU has introduced materials selection and processing into existing programs such as guitar building (materials selection, electronics), aerospace technology (composites, materials properties), additive manufacturing (materials interactions, materials selection) and others. There are so many connections between materials concepts and these related fields that collaborative programs are inevitable with the right leadership.

MatEdU has also developed a case study outlining the development of the materials program at Edmonds College [16]. This stands as a "blueprint" for developing a materials educational learning environment and includes an outline with details and an inventory of what is needed. The blueprint has been presented to many colleges across the U.S. and has drawn considerable interest.

Specific follow-on ideas based on MatEdU's experience are different for different programs. First, of course, is the website and the information thereon. As noted, the website in its 2023 configuration is being migrated to become a part of the Micro Nano Technology Education Center (MNT-EC) at www.micronanoeducation.org. While it is expected that MNT-EC will utilize this partnership for their programs, there is much from MatEdU that can be utilized to develop other programs related to materials and technology education. MNT-EC also sponsors the Journal of Advanced Technological Education, where this article appears.

Technology Education Workshops for Instructors

One clear opportunity for wide application is related to the M-STEM programs that were noted above [8]. These hands-on workshops have generated considerable interest and connections among technology instructors in STEM-related areas. The conference's focus has always been communication: **Educators talking with Educators**. Participants want to talk about their best labs, demonstrations, or case studies and easily share their ideas with others. Unfortunately, due to the time constraints of their jobs, these educators have not been as good at writing up a lesson dealing with their ideas. As seen in the appendix to the M-STEM section [8], many simply provide their PowerPoint presentations. Development of modules from these instructors' ideas would bring recognition to them and could be a focus of further programs in curriculum development.

One advantage of this sort of workshop is that it is often possible to apply for separate funding to put on the workshop. Depending on the funding agency or institution, this can be for workshop operations or sometimes for participant stipends or travel. Finding the participants for whom the subject content is directly related to their background can lead to outstanding presentations and the enthusiasm needed for self-perpetuation.

Technician Education in Additive Manufacturing

The advance of additive manufacturing (AM) technologies has added to the curriculum in a variety of areas. As new materials are developed, and 3D printers are increasingly capable of utilizing multiple materials, it is imperative that technicians understand these material's properties and how they interact with other components of the system involved. MatEdU has addressed this potential gap in the convergence of additive manufacturing and materials through the Technician Education in Additive Manufacturing & Materials (TEAMM) project [17], which has included the identification and adaption (or adaptation?) of ASTM skills standards to keep pace with advances in research and development. TEAMM is supported through the utilization of social networking technologies, proactive identification and communication with key stakeholders, and improved access to professional development.

The National Science Foundation's Guitar Building Workshops

The NSF ATE Guitar Building Workshop program has provided an excellent example of hands-on learning and methods to infuse materials into a curriculum. Instructors at all levels benefit from this program to help their students build an electric guitar by applying scientific, engineering, and technological principles. Participants are presented with methods to teach applied learning techniques that help engage students and spark enthusiasm to learn STEM subjects. This had been a national program funded by NSF ATE and hosted by various institutions across the U.S.

Guitar building is a perfect means of demonstrating the need to apply materials concepts [18]. The specific type of wood identified to provide the guitar's tone is critical and has been the subject of a recent detailed investigation [19]. To design and build a guitar, materials properties of wood and the process of working the wood must be considered, along with properties and types of metals, properties of polymers, and the behavior and application of polymers in the system. Building a guitar also requires other STEM-related concepts, including;

- Mathematics: geometry of the body design, fret spacing, musical scales;
- Physics: frequency, string tension, waves, tones;
- Electronics: solenoids tolerances, intonation;
- Acoustics: body design, wood selection, intonation.

The STEM Guitar Project is still significantly impacting the ATE community. ATE Central is working with the former P.I. to create an ATE Impacts video. The NSF ATE Impacts coordinator will highlight the project through a video of ATE successes that have continued beyond the grant. The project team continues to collaborate with three of the most well-recognized guitar companies: Fender, Taylor, and Gibson. The video intends to highlight the project's long-standing industry linkages, their partnerships with educational institutions nationally, and the overall long-running project impacts. The goal of the video is to show the country the interaction and support of the guitar manufacturing community and the impact of STEM guitars on students. The video is expected to be released in early 2024.

Technology Curriculum Development

Developing educational lessons, labs, and related activities has been a principal focus of MatEdU [20]. To make it easier for new authors, MatEdU developed an outline that could be followed in lesson development. The lessons were called "modules" to emphasize that all types of lessons, labs, and other related curricula were to be included. All modules, after receipt and an initial review by the MatEdU Editor, were peer-reviewed by an expert in the field who could determine if the science or technology was correct and whether the presentation was such that it could be used in a classroom by an instructor who was not intimately knowledgeable with the content.

Many educators have taken the opportunity to develop curricula, usually related to presentations they had made at meetings, lessons they have used in their teaching, or related opportunities. Hands-on lessons, labs, and case studies were encouraged. When a specific need became clear, MatEdU put out a call for authors. This yielded authors from high schools, colleges, and universities and from engineering and technology companies where there were interested individuals. College instructors, in particular, were interested because it allowed them to add a peer-reviewed publication to their resume.

Various organizations, such as the nanotechnology center "NACK" [housed at Penn State University], provide curriculum development opportunities for college instructors. However, at pre-college and community college technology levels, not many instructors take the time to develop hands-on technology modules that others can use. This is a significant gap since technology instruction in high schools, in particular, needs top-quality, up-to-date curricula. Opportunities exist to build technology instruction into some high school science classes by introducing hands-on technological concepts needed to demonstrate science principles. High school science is an excellent venue for introducing technology in applying the science presented in the curriculum.

One collaborator of note is the ASM Materials Education Foundation, which has developed a curricular program that introduces K-12 teachers to materials science [2]. Workshops are provided annually in a hands-on format that allows participating instructors and teachers to experience activities that they can use in their classrooms. This enhances teachers' understanding and makes science, technology, and engineering classes more exciting for students. A wide variety of lessons are available but without the formality of MatEdU modules.

MatEdU partner Colorado School of Mines has tackled the question of how best to provide STEM resources to students in multi-lingual classrooms. The CSM Critical Materials Institute focused on developing lessons based on current and relevant STEM research topics for students in K-12 classrooms who are just learning English [21]. Lessons are structured in a supportive manner for students using visuals, fill-in-the-blanks, and word banks. Teachers are also provided with step-by-step guides, quick visuals, graphs, and engaging activities to help them teach the concepts and terminology to multi-lingual learners. Collaborating with Rocky Mountain Mathematic Engineering Science Achievement (RM MESA), they are pleased to say that they have just "delivered a lesson to teachers who are going to be reaching 600 underserved students this year!"

One of the limitations of developing and publishing hands-on curricula related to technology is a lack of incentive. At the community college level, in particular, there are no incentives for faculty to publish that there are at the university level. The MatEdU program has benefitted from the use of small financial incentives provided by an outside contractor, which allowed community college instructors to develop useful modules in areas such as critical materials and composites. Also, through collaboration with the Nano-Link, an NSF ATE-funded regional center, the MatEdU module collection included listings of 18 nanotech modules in English plus their translation into Spanish.

Information on student internships and the innovative use of competency-based apprenticeship programs developed using MatEdU curricula have been successful and are expanding. Students are recruited from high schools and community colleges in areas of interest to a company and work and learn in specific areas focused on core competencies for that area. This type of opportunity is often appropriate for students who are not 4-year college-bound and often can be used to enhance the diversity of the company's technician workforce. Core competencies in numerous areas are available for faculty and student use [11]. College-bound students are provided basic information on the many available options under the Student Resources tab.

Enhancing Undergraduate Research in Community Colleges

Research opportunities are widespread at universities and 4-year colleges, but community college students often lack this opportunity. As noted above, faculty have little incentive to develop and publish papers or curricula on their new ideas in curriculum. One way to help faculty provide research opportunities for students is to introduce short, course-based undergraduate research projects. This can help broaden students' ideas and be a good introduction to solving problems in industry. Such projects can be based on the subject at hand and can provide faculty with subject content for a published paper.

One way of introducing such research into courses is through "hackathons" [22], in which a small group of students with mentors from academia or industry undertakes creative problem-solving. Hackathons are a way to offer short-duration projects that often fit easily into course curricula and allow the students to be creative and learn something new that is perhaps tangential to the course curriculum. Short-term projects created by engineers and scientists in local industries can provide a source for such projects.

MatEdU collaborators have been involved in generating undergraduate research in community colleges using the hackathon approach. One example is an investigation as to means of reducing the weight of paint used on an aircraft. The weight of paint on a large aircraft can be substantial and will increase if a second coat is required [23]. A student project focused on using technology to enhance coverage of the first coat to reduce the need for a second, thus reducing aircraft weight. Another looked at tools used in antibody engineering, involving both computational work and laboratory measurements [24]. Getting students into short-term research opens up a wide variety of potential options for students and creates ways for instructors to broaden their curricula. Reporting on hackathons and other projects at the community college level is critical for the advancement of technological education.

Faculty Mentoring for Grant Writing

MatEdU collaborates in developing peer mentors for faculty wanting to develop programs within the National Science Foundation's Advanced Technological Education (ATE) program. Mentoring of faculty by experienced project investigators "broadens participation in ATE and develops the next generation of leadership to ensure the advancement of technician education in support of our nation's economy" [25]. Personal mentoring will be critical in developing new programs in areas such as energy, environmental, and transportation technologies, which can involve critical and rare earth materials and their practical ramifications in transportation systems, high-power batteries, and clean energy.

One example here is the maritime technology program at Skagit Community College. Mentoring from MatEdU included the development of programs that benefit both entities, with curriculum development relevant to both and collaborative programs. Developing connections between program developers has been critical. Continual communication on all aspects of MatEdU has enhanced programs and developed faculty members who can design and handle programs as they expand.

The mission of these mentoring programs is to help community colleges find and develop grant funding using real-time leadership development and technical assistance. Over the past several years, this program has generated a variety of ATE proposals from many community and technical colleges across the U.S. Some programs have had success by adding a coaching component to the grant-writing process [26]. Mentoring and coaching techniques apply well to collaborative projects and are enhanced by a mentor's experience in networking among peers and colleagues at other institutions.

Discussion and Conclusions

Tremendous advances in technology have been made over the past few years in many areas. These advances are widely reported in the science and technology literature and often in the popular press. At the level of technician education, one could expect an accompanying set of literature discussing how programs have been developed to affect the needed training. Unfortunately, such advances in education and training are not always available. This is most acute at the community and technical college level, where programs such as the NSF Advanced Technological Education (ATE) Program accomplish much of this critical work.

MatEdU has operated successfully for over eighteen years and has pointedly attempted to provide information on its programs using the internet, op-ed articles in technical journals, and scholarly publications [4,27-29]. MatEdU personnel have also been involved with undergraduate research and mentoring for grant writing, where incentives from colleges and industry could be used to enhance the reporting of successful projects.

While MatEdU has seen considerable progress in the programs discussed earlier, a significant impact of the program has been the implementation of the infusion of materials technology into multiple areas, from technology and electronics education to advanced manufacturing, clean energy, and critical materials utilization. This includes enhanced faculty knowledge and an overall faculty understanding of the role of science in technology and engineering. It has also provided ideas for increased student interest and for updated workforce training programs. Numerous partnerships and collaborations have enhanced MatEdU programs and many other institutions.

The National Educators Workshop and the M-STEM workshops were highly impactful to those instructors who attended. The attitude was that "if you (a presenter) can do this in your classroom, I should be able to do the same" - that is, these programs developed trust and confidence among participants and helped all to expand their ideas. In a survey, M-STEM participants estimated that their work would impact over 3000 students per year. However, a focus needs to be made on female instructors, as only 39% of the participants were female during the most recent three years.

Other means of developing faculty involvement included Showcases, NSF events, Elementary School STEM nights, and the Latino Leadership Initiative. Over 2000 instructors and up to 7800 individuals were reached using these programs in the most recent 3-year period.

Data on website use, provided by Google Analytics, show that multiple visitor sessions of 500 or more were recorded during the past several years, realizing a new visitor gain of about 1000 each year. Website discovery and traffic were enhanced by including the most-used keyword search terms, resources, and types of materials. In the site's metadata, these terms account for 47% of all visits, with an average time on related pages of 3 minutes, well over the average duration reported by Nielsen Norman Group.

Among the top website targets by visitors are the curriculum modules. During 2022, there were 154 downloads, with the Materials Science Educational Handbook chapters dominating; 65% of visits turned into downloads. Organic sources (searches from a search engine) yield the most visits, 71% of all traffic, while direct sources (where MatEdU is bookmarked from an external source) yield 24%, and referrals (where MatEdU is linked from an external source) yields 4% of the total website traffic. These observations indicate that users have grown to trust and are interested in the content on the website, and signifies an increasing use in the future. The website is easily discoverable and has content that the users want, leading to its success. Search engine results consistently put www.materialseducation.org in the top tier of websites used in searches. Over 6000 users annually accessed 100 social media postings, enhancing audience impact.

A wide variety of instructors have indicated that using the MatEdU instructional modules in the classroom has led to increased student learning. Recent enhancements to include rare earth elements, critical materials, and composite, natural, micro, and nano-materials make the module collection valuable. Expanding the scope of available instructional materials would continue to make the website even more valuable to instructors and students.

Materials Science is a rapidly expanding area, and numerous colleges are interested in starting an academic program in the area. MatEdU's recent case study provides a blueprint for a learning environment in Materials Science. This blueprint has been presented at a wide range of conferences and secondary and post-secondary institutions [16], resulting in considerable interest being developed in several institutions and organizations. While Materials Science is the focus of this case study, the principles involved could easily be adapted to other subjects and the expanding world of materials.

The MatEdU program has provided means whereby instructors can publish their curriculum modules under rigorous rules (with peer review) and has provided means for instructors to present and publish the results of their educational activities. The new Journal of Advanced Technological Education, J ATE, in which this article appears, is specifically designed to provide a means for such reports to appear in print. Using the models provided in this paper, subsequent programs can further develop the ideas presented here, present the results in future publications, and provide future generations of faculty and students with enhanced educational programs in technology.

Acknowledgments. The authors thank all who have been involved in the National Resource Center for Materials Technology Education – MatEdU - over the past eighteen years for their time, ideas, support, and creativity, all of which made this program successful. This work was sponsored in part by NSF DUE grants #0501475, #0903112, #1400619 and #2000347.

Disclosures. The authors declare no conflicts of interest.

References

[1] R. Roy, “The Relationship of Technology To Science and the Teaching of Technology,” vol. 1, no. 2, Art. no. 2, Mar. 1990, doi: 10.21061/jte.v1i2.a.5.

[2] “Home,” ASM Materials Education Foundation. Accessed: Mar. 08, 2024. [Online]. Available: https://www.asmfoundation.org/

[3] T. Stoebe, G. Whittaker, and K. Hinkley, “Materials Technology Education Program: Impact on Secondary Teachers and Students,” *Journal of Materials Education*, vol. 24, pp. 23–30, Jan. 2002.

[4] T. G. Stoebe and J. M. Rusin, “Materials Science and Technology: A curriculum that works,” *MRS Online Proceedings Library*, vol. 861, no. 1, pp. 54–59, Dec. 2004, doi: 10.1557/PROC-861-PP1.2.

[5] T. Stoebe, F. Cox, and I. Cossette, “Future Outlook for materials Technology Education,” *Journal of Engineering Technology*, vol. 30, pp. 24–30, Sep. 2013.

[6] A.-S. Bauer et al., “Cereal and Confectionary Packaging: Background, Application and Shelf-Life Extension,” *Foods*, vol. 11, no. 5, p. 697, Feb. 2022, doi: 10.3390/foods11050697.

[7] R. L. Mott, R. J. Bennett, M. J. Stratton, M. Cossette, T. G. Stoebe, and F. Z. Cox, “Integration of Materials Instruction in the Field of Manufacturing,” presented at the 2014 ASEE Annual Conference & Exposition, Jun. 2014, p. 24.789.1-24.789.15. Accessed: Mar. 08, 2024. [Online]. Available: https://peer.asee.org/integration-of-materials-instruction-in-the-field-of-manufacturing

[8] “Materials in STEM” Conference Programs and Archives at http://materialsinstem.us/ and http://materialsinstem.us/archives

[9] R. L. Mott, T. G. Stoebe, R. Simoneau, and I. Cossette, “Core Competency Needs in Materials Technology,” *Journal of Materials Education*, vol. 29, no. 3–4, p. 259, 2007.

[10] T. Stoebe, F. Cox, and I. Cossette, “Educational Needs for Personnel in Nanotechnology: Core Competencies for Technicians,” *Journal of Nano Education*, vol. 4, no. 1–2, pp. 57–62, Mar. 2013, doi: 10.1166/jne.2012.1024.

[11] “Core Competencies Pocket Reference,” National Resource Center for Materials Technology Education, https://materialseducation.org/docs/MatEdu_CoreComp_2019.pdf

[12] “Standards for Technological and Engineering Literacy,” International Technology and Engineering Educators Association. Accessed: Mar. 08, 2024. [Online]. Available: https://www.iteea.org/stel

[13] *Next Generation Science Standards: For States, By States*. Washington, D.C.: National Academies Press, 2013. doi: 10.17226/18290.

[14] *A Framework for K-12 Science Education: Practices, Crosscutting Concepts, and Core Ideas*. Washington, D.C.: National Academies Press, 2012. doi: 10.17226/13165.

[15] T. J. McCue, “MatEdU Materials Science Educational Handbook 2021 Published,” Materials Education (MatEdU). Accessed: Mar. 08, 2024. [Online]. Available: https://materialseducation.org

[16] M. Cossette, “So You Want To Be in Materials Science: Blueprint of a Learning Environment,” Material Science Technology Education (MatEdU), 2022. [Online]. Available: https://materialseducation.org/resources/instructional-resources/#blueprint

[17] “Technician Education in Additive Manufacturing & Materials (TEAMM).” Accessed: Mar. 08, 2024. [Online]. Available: http://www.4teamm.org/about

[18] "The National Science Foundation STEM Guitar Project." Accessed: Mar. 08, 2024. [Online]. Available: http://guitarbuilding.org/

[19] J. D. Cotton and J. D. Wolodko, "Identification of Sustainable Tonewoods for Acoustic Guitars Using Materials Selection Software," A*M&P Technical Articles*, vol. 181, no. 5, pp. 13–18, Jul. 2023, doi: 10.31399/asm.amp.2023-05.p013.

[20] National Resource Center for Materials Technology, "MatEdU Modules," Materials Education (MatEdU). Accessed: Mar. 08, 2024. [Online]. Available: https://materialseducation.org/educators/matedu-modules/

[21] Mel Cossette, Cynthia Howell, and Danielle Ladd, "Real-time Research and Resources for the Multilingual Classroom," MatEd and Critical Materials Institute (CMI) at the Colorado School of Mines, Aug. 2023. [Online]. Available: https://materialseducation.org/docs/resources/Case_Study-Multilingual_Classroom_Resources.pdf

[22] Joshua Tauberer, "How to run a successful Hackathon." Accessed: Mar. 08, 2024. [Online]. Available: https://hackathon.guide/

[23] M. A. "Vitriol" Gagné, Gould Mcintyre, and Suade Bergemann, "How much weight does paint add to an airplane?," Quora. Accessed: Jan. 22, 2024. [Online]. Available: https://qr.ae/pshioT

[24] S. Porter et al., "Igniting Creativity: Hackathons for Developing Undergraduate Research Projects in Antibody Engineering," *Journal of Advanced Technological Education (J ATE)*, vol. 2, no. 2, Jul. 2023, doi: 10.5281/zenodo.8124853.

[25] "Mentoring STEM Faculty for NSF ATE Grant Writing and Implementation." Accessed: Mar. 08, 2024. [Online]. Available: https://www.mentor-connect.org/

[26] L. Pfeiffer, "Mentorship vs. Executive Coaching to Address the Leadership Crisis in Community Colleges," *League for Innovations Conference*, vol. 35, no. 1, Jan. 2022, [Online]. Available: https://www.league.org/leadership-abstracts/mentorship-vs-executive-coaching-address-leadership-crisis-community-colleges

[27] T. Stoebe, "Making STEM Work for Students," *Journal of Mineral and Material Science*, vol. 4, no. 1, Mar. 2023, doi: 10.54026/JMMS/1055.

[28] T. Stoebe, F. Cox, and I. Cossette, "Future Outlook for materials Technology Education," J*ournal of Engineering Technology*, vol. 30, pp. 24–30, Sep. 2013, [Online]. Available: https://materialseducation.org/docs/resources/Future_Outlook_for_Materials_Technology_Education.pdf

[29] M. Cossette and T. Stoebe, "Innovative Education," https://www.materialseducation.org/docs/features/Intl_Innovation_164_Research_Media.pdf

KonnectVR: Pioneering an Open-sourced, Educational, Collaborative Virtual Reality Platform

DAVID ANDERSON[1]*, MARK GILL[2]

[1]*Biology Department, St. Cloud Technical & Community College, St. Cloud, MN, 56303, USA*

[2]*Visualization Laboratory, St. Cloud State University, St. Cloud, MN, 56301, USA*

**David.anderson@sctcc.edu*

Abstract: Virtual reality (VR) technologies are transforming educational paradigms by enabling highly immersive, interactive simulations that increase engagement and cognition. This paper presents KonnectVR (KVR), an innovative, open-source platform designed to mitigate common barriers in educational VR. Barriers such as high costs, limited content customization, and the absence of real-time assessments. The system, constructed by undergraduate students, facilitates experiential learning, real-time collaboration, and assessment delivery, empowering educators with an unprecedented degree of accessibility and customization. Employing a case study methodology, we provide unique insider perspectives into KVR's architectural design, underlying pedagogical framework, development processes, challenges encountered, and future directions. Findings reveal technical hurdles overcome by undergraduate student teams like VR-specific programming, user interface design, networking, and cybersecurity integration. The analysis uncovers key themes around project-based skill acquisition, problem-solving perseverance, cross-team knowledge gaps, and the benefits of an agile, user-centric approach. Ultimately, KVR demonstrates how emerging technologies and open-sourced solutions can converge to innovate learning, pushing boundaries while serving an egalitarian educational mission. The platform sets the foundation for a new generation of community-driven tools democratizing access to interactive, distributive, collaborative VR experiences that maximize knowledge construction.

Keywords: virtual reality, VR, educational technology, Open Source, collaborative learning, real time assessment, immersive learning

Introduction

The transformative impact of Virtual Reality (VR) technology is being felt across a multitude of industries, from healthcare [1] to real estate [2], from gaming [3] to tourism [4]. Yet, its potential is arguably most transformative in education [5], a realm traditionally fraught with limitations such as rigid curricula, varying learning styles [6], and the lack of real-time assessments [7]. Addressing these limitations, KonnectVR (KVR) emerges as a ground-breaking solution: an open-source, educational, distributive, collaborative VR platform with built-in assessments to revolutionize the very fabric of modern learning experiences.

While VR technologies have been used in higher education since the early 2000s [8], classroom implementation of VR remains a challenge. In addition to the cost, deployment, and maintenance of individual head-mounted displays (HMDs), limited content is available for direct instruction. Existing commercially available VR applications directly focused on delivering higher education content are priced at a premium. Organon is a human anatomy application [9], SimX Patient is a nursing simulation [10], EngageVR is a social VR platform where instructors can develop and hold virtual classes [11], and Virbella is another social VR platform to hold virtual classes [12]. All these applications are limited when considering faculty content and assessments. Estimated costs for one 24-student section range from $3,400 (SimX Patient) to $12,000 (Virbella). As more faculty look to VR for content, these costs scale quickly and become exorbitant. Few colleges or universities, and even fewer students, have funds to support these additional fees.

There is a distinct lack of quality and customizability for more cost-effective VR solutions. Free and open educational content is rarely well-vetted by discipline experts and, therefore, usually unsuitable for educational use. Additionally, most VR applications are made for personal use, so they rarely include assessment tools or collaborative activities. While some applications have assessments, they are seldom customizable without significantly adding to the cost. Finally, few of the currently available VR applications have functionality for instructors to customize content.

Being an open-source platform, KVR democratizes educational technology by offering unprecedented accessibility and customization [13]. Educators, developers, and learners can contribute to the platform's continuous development, thus fostering a community-driven, scalable, adaptable, and ever-evolving approach to education. This feature differentiates KVR from other proprietary educational solutions and sets the stage for limitless pedagogical techniques and content delivery innovations.

KVR is not simply a conceptual vision but a functional platform primed to be community-driven to cohesively integrate immersive educational content, real-time collaboration, and data-backed assessments. With VR's capacity for creating highly realistic simulations, KVR enables instructors to contextualize complex topics interactively and experientially. Imagine a history course where students can virtually explore the streets of Ancient Rome or a chemistry module that allows learners to manipulate atomic structures in real time. These are not mere gimmicks but pedagogical tools designed to enhance cognition and retention.

The platform's distributive capabilities transcend traditional geographical and institutional boundaries, offering learners worldwide equal opportunities to access high-quality education. KVR's open-source nature further amplifies this by encouraging the contribution of educational modules from diverse cultures and disciplines, thereby enriching the global repository of knowledge and learning methods.

Central to KVR's mission is the facilitation of real-time collaboration. Traditional learning management systems (LMSs) focus learners on a specific learning flow where the faculty and administrator control the content [14]. While LMS platforms have recently focused on improving user interfaces and incorporating personalized learning, they still promote solitary learning with limited interactivity [15]. In contrast, KVR's collaborative features are designed for collective problem-solving, group experiments, and interactive discourse within a virtual environment. This promotes the acquisition of academic knowledge and the development of essential teamwork and communication skills.

A primary driving force behind KVR's development has been integrating formative and summative assessments into a VR environment. Real-time evaluation empowers educators to adapt their instructional strategies responsively while students benefit from tailored learning pathways that cater to their unique needs and abilities. Figure 1 visually represents where KVR sits in the educational XR environment.

As we navigate through this article, we will delve into the creation process for KVR. After setting foundational terms, we will begin with the project's motivational factors behind its conception. We will describe the architectural design structure as well as the project-based learning approach implemented during KVR's construction. Next, we will explain each team's contributions to the project, including challenges, successes, and failures. We will finish with KVR's pedagogical potential and the far-reaching implications of this open-source VR platform.

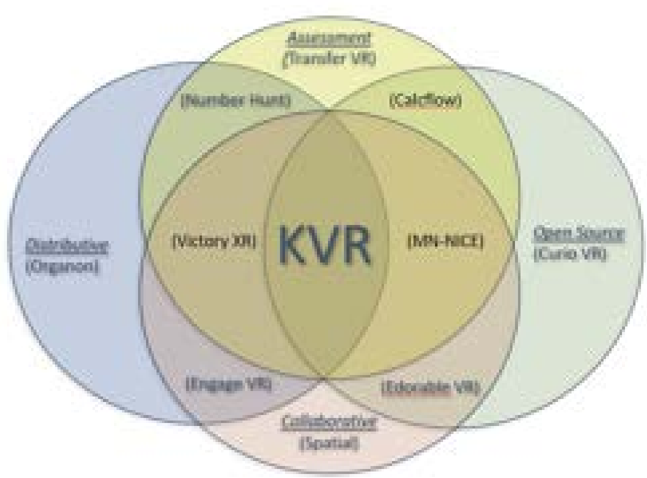


Fig. 1. Ven Diagram showing convergence of Distributive Learning, Collaborative Learning, Assessments, and Open-Source Tools.

Background & Foundation

We will use terminologies and constructs in the following sections, which are fully defined in Supplemental A.

Motivational Factors

1. Democratizing Education. Open education resources (OER) have been increasingly adopted over the past decade, yet a small percentage of textbooks and resources are used in higher education [16]. They are broadly defined as "the open provision of educational resources, enabled by information and communication technologies, for consultation, use, and adaptation by a community of users for non-commercial purposes" [17]. These resources have a significant impact on reducing student financial risk and debt while also improving student course completion [16].

Open source takes OER to a deeper level. Beyond releasing a resource for use free of charge, open source releases the code that also creates the product [13]. Formed by UNIX, GNU, and Linux development, the open-source movement has been closely linked with academia since its inception [13]. To be open source, software must meet the ten requirements relating to author rights, distribution policies, and restrictions set forth by the Open Source Initiative [13]. As an open-source platform, KVR is free to use and provides opportunities for others to extend the platform, creating modules or adding new features.

2. XReality (XR) Educational Technologies. XReality technologies (XR), including VR, are a variety of digitally simulated environments [18] that provide users with a sense of immersion and presence [19]. VR can be both immersive and non-immersive. In immersive VR (IVR), the user is immersed in a digitally simulated environment created by a head-mounted display (HMD), which disconnects them from the physical world [19–22]. In non-immersive VR (NiVR), the digitally simulated environment is displayed on a computer screen and manipulated by a computer mouse or joystick [23, 24].

Two hallmarks of VR are its ability to create a sense of immersion and presence. Immersion relates to the user's disconnection between the real world and the immersive environment, and presence is a sense of "being there" [25–27]. Both immersion and presence directly contribute to the believability and relatability of a virtual situation. IVR has been consistent in its ability to induce physiological and emotional reactions more than screen-based or NiVR learning experiences [28–30]. The unconscious reactions stimulate feelings of immersion and presence, which lead to autobiographical memory encoding like real experiences rather than laboratory memory encoding, which most traditional, screen-based learning experiences (including NiVR) produce [26,27,31]. However, NiVR allows for increased accessibility by using PCs and tablets, which are ubiquitous in education.

Existing technology-enhanced teaching methods often fail to provide the believability and relatability possible using VR, especially IVR. These new, immersive technologies can provide students with collaborative, inquiry-based, problem- and case-based, and discovery learning experiences in visually rich, personalized environments [23, 31–34]. Research has shown that students have significantly higher motivation, satisfaction, and performance scores after IVR experiences [24, 35]. In higher education settings, IVR technology can increase knowledge retention [36, 37], improve abstract and spatial understanding of complex objects such as the heart [38], as well as enhance student motivation and interest in the course material [39, 40]. Additionally, studies have demonstrated that students feel IVR enhances both motivation and enjoyment for learning, as well as finding the course content more engaging [39, 41]. The significance of this aspect lies in previous studies demonstrating that students across various age groups when motivated, tend to achieve higher levels of academic success [42–44]. Similar results on motivation (although not memory encoding) have also been achieved using NiVR [24, 35].

3. Project-based Learning. KVR implemented a project-based learning approach during its construction process, engaging undergraduate computer science and software engineering students to develop the platform. Each year, a new team of students was recruited to add new functions to KVR, building upon previous teams' work. The students met with the stakeholders bi-weekly during the academic year to discuss progress, challenges, and next steps. While the stakeholders gave each student capstone team direction and support, they were also given autonomy to explore potential solutions as they encountered challenges.

Project-based learning (PBL) is increasingly recognized as a pedagogical approach that is well-suited for college-level computer science and software engineering student learning [45, 46]. In traditional lecture-based settings, theoretical concepts are often taught in isolation, limiting students' ability to grasp their application in real-world scenarios. However, PBL promotes the practical application of theory by developing software projects that simulate industry challenges [45, 46]. Students are typically assigned to small groups responsible for conceptualizing, designing, implementing, and testing a software solution to a given problem [45, 46]. This process enables them to gain hands-on experience in various phases of software development, including requirement analysis, system design, coding, testing, and project management [45, 46]. Moreover, students are encouraged to integrate and apply concepts from different areas of their curriculum by engaging in projects that often require multidisciplinary knowledge – such as machine learning applications, mobile app development, or cloud computing solutions.

The collaborative nature of PBL is particularly beneficial in the context of computer science and software engineering, given that teamwork, communication, and cross-functional collaboration are critical skills in the tech industry [47]. Working in groups simulates the collaborative dynamics of real-world software development, thereby giving students a glimpse into what professional work entails, including the need to coordinate with team members, troubleshoot issues collectively, and manage version control. Additionally, the iterative process of PBL, where review and refinement are ongoing, mirrors methodologies commonly used in the software industry, thereby familiarizing students with prevalent best practices [45, 46]. Students are assessed not only based on their technical deliverables but also on their ability to work in teams, communicate their ideas clearly, and adapt to changing requirements or feedback, thus creating a more holistic educational experience beyond mere coding skills.

Collaboration in VR in the context of learning is not a widely implemented concept. While many multiplayer games exist [48], collaborative VR learning experiences are much less common. Social VR use did increase significantly during the COVID-19 pandemic [49]. Yet, these platforms offer little in the way of hands-on learning opportunities. Instead, they aim to create a sense of community in VR. Instructors can use social VR in a remote classroom, but the educational value is limited to verbal interactions. EngageVR does provide opportunities for experiential learning as well as customization and is used by content developers such as VictoryXR [50]. However, as is common with proprietary platforms, EngageVR is priced at a premium, making it cost-prohibitive for most institutions.

Methods

This is a case study undertaken by KVR's primary stakeholders to explore its creation process, architectural nuances, and pedagogical potential. Our unique insider perspective provides insights into the multifaceted challenges and solutions that encapsulated the journey of KVR.

This case study method provides an in-depth, contextually rich examination of KVR, allowing us to unravel the complexities of building an integrated educational platform. We dissect the platform's genesis, from initial conceptualization and motivation to minimum viable product (MVP), exploring the technical decisions and design considerations that guided its development and the pitfalls and setbacks the project has encountered. The aim is to provide insights into the functionalities of KVR and the systemic thought processes and collaborative efforts that contributed to its inception and refinement.

Given our first-hand experience with KVR, our data collection was retrospective and iterative. We first contacted each capstone team and collected the working and final documents they had submitted for their capstone courses. We then reviewed these documents to analyze each team's initial goals versus completed outcomes, barriers encountered, solutions employed, and results. Beyond document analysis, we reviewed different code iterations to identify reusability, compatibility with current versions, and effectiveness.

It is critical to acknowledge the potential for research team bias as the primary stakeholders of KVR. We aimed to mitigate this by continually seeking external reviews and feedback and grounding our analysis in empirical evidence. Furthermore, the dynamic nature of XR technologies signifies continuous evolution of the platform, and as such, future iterations might exhibit differences from the version explored in this study.

Results

KVR was constructed over three years by senior computer science and software engineering students at St. Cloud State University (SCSU). Each team member was enrolled in a capstone course that spanned two standard academic semesters. The capstone course aims to teach students how to manage software engineering projects with real-world stakeholders.

The capstone teams employed a two-week sprint cycle, a component of the Agile methodology designed to accelerate product development and improve responsiveness to stakeholder feedback. In a sprint cycle, the team meets initially to review the backlog, a list of tasks and features prioritized by the stakeholders, and plan the sprint. The students work collaboratively over the next 14 days to develop, test, and iterate software features, aiming for specific deliverables by the sprint's end. The cycle concludes with a sprint review, where developed features are showcased to stakeholders, including the course instructor, who provide feedback [51]. The cycle is repeated, with the team planning new tasks and working to complete them in the next two weeks. Each standard academic semester provides space for up to seven sprints, for a maximum of 14 sprints for each capstone team. Each team completed a total of 12 sprints, five in each fall term and seven each spring.

St. Cloud State University Visualization Laboratory (SCSU VizLab)

Founded in 2014, the SCSU VizLab's primary mission is to explore visualization techniques and how they can be used to improve learning experiences, data analysis, and industry workflows, emphasizing student collaboration, experiential learning, and innovation. The lab actively engages with industry and educational stakeholders, allowing undergraduate students to learn how visualization can be leveraged. It hosts cross-disciplinary projects with local communities and private industries, enriching students' learning experiences in a rapidly evolving field. KVR has been an active project at the VizLab since 2020, providing undergraduate students with opportunities to learn on a real-world project.

2019-2020: Minnesota (State) Networked Immersive Collaborative Experience (MN-NICE)

The spark that launched KVR began in an SCSU VizLab public demonstration of Minnesota (State) Networked Immersive Collaborative Experience (MN-NICE) (Figure 2). As a leader of XR technology construction and integration in the upper Midwest, the SCSU VizLab has held many different demonstrations since its inception to raise awareness of the usefulness of these technologies in education. These have included two workshops related to a grant awarded to SCSU by Minnesota State Colleges and Universities (Minnesota State) called MN-NICE. One demonstration targeted educators interested in XR adoption, and the other was a deliverable specific to the grant award for the public. It was at one of these workshops that Anderson conceptualized KVR.

The Minnesota (State) Networked Immersive Collaborative Experience (MN-NICE) was designed as a collaborative, collocated, educational VR platform where students could engage with virtual environments and their classmates in a shared experience. Virtual objects and settings were mapped to and aligned with the real world, which enabled a blending of the different realities. Unfortunately, because it required people to be in the same physical space, MN-NICE was untenable during the COVID-19 pandemic. The collaborative portions of MN-NICE were repurposed into the first iterations of KVR.

Fig. 2. Public demonstration of MN-NICE in the SCSU VizLab.

2020-21: Integrating OER Anatomy & Physiology Texts with VR

In 2020, Anderson secured another Minnesota State grant award to create OER anatomy & physiology experiences in VR. Anderson and Gill explored options to deploy these laboratory experiences and, after finding none, engaged undergraduate software engineering students to begin developing one. All six members of this first KVR capstone team were an integral part of the development of MN-NICE, so they had experience working with Unity, the primary VR creation software. The team was provided with a scope of work that included 12 requirements (Figure 3). The students chose to break into three sub-teams of two, each tackling one aspect of the requirements, focusing on the VR input system, interaction design, avatars, and multiplayer networking.

User Management	User data for assessment & reporting captured
Networking	Multiple users in shared VR experience
Avatars	Visual representation of users
Modular	Supports 3rd party content
Assessment	Track user progress
Feedback	Notify user of success & progress
Reporting	User data stored
UI/UX	User interface & user experience
Documentation	Hand-off to next team
FERPA compliant	Secure log-in & reporting
Unit testing	Discrete testing of code units
Lab builder	Instructor created experiences

Fig. 3. KVR Scope of Work Requirements

1. VR Input System. Sequencing and connecting objects were identified as primary functions of an educational platform. The students implemented a system so objects can be connected at a given point. Using a skeleton assembly lab as a use case, they created identifying display spheres where objects could be connected that change color based on whether it was correctly or incorrectly connected (Figure 4). They also worked to implement User Interfaces (UIs) in the form of a VR keyboard and tablet (Figure 5). The keyboard was for users to input usernames or question answers, whereas the tablet, which could be free-standing or worn on the arm, served as a system navigation interface.

Fig. 4. Bones with spherical connectors at the ends that were used as a use case throughout development: A. Bones are unconnected, and spheres are clear. B. Bones are correctly connected, and spheres glow green. C. Bones are being placed incorrectly, and the sphere glows red.

A. Original Tablet B. Keyboard

Fig. 5. Original tablet and keyboard created as user interfaces (UIs) by Team 1.

2. Interaction Design. The students used the first several sprints to brainstorm and plan how to construct the interaction and quiz system, finally deciding the platform would need an online database and cloud server access. While they could begin with student-level Microsoft accounts, they quickly determined more robust access would be required for long-term platform sustainability.

The team encountered significant challenges while connecting the Unity project with the online database. While resolved in the end, it was a significant impediment to progress during the early spring sprints. The performance assessment functionality development proved challenging, as this foundational work needed significant time to explore different avenues and options. By the end of the spring term, Team One had completed an assessment framework. It was exported to a spreadsheet file stored locally on the headset that an instructor could access and download.

3. Avatars. Initially, the work on the avatars was slow due to the delayed procurement of VR headsets. While the students worked on the development, it was difficult to assess the work accurately without access to VR headsets to test. They began with rudimentary avatars that had hands and a sphere as a head. By the spring semester, they improved functionality enough to have facial and hand animations and more realistic bodies. Name tags were created so collaborators could easily identify each other and a camera feature so an individual could see how their avatar presented. They also implemented haptic feedback and sounds when certain actions were performed. The final avatar configuration for Team One was a robot-like figure (Figure 6).

A. Spheres & hands avatars B. Robot avatars

Fig. 6. Team 1 Avatars: A. Initial avatars were only hands and spherical heads. The final avatars were robots with smiley faces.

4. Multiplayer Networking. A primary requirement for the platform was that it had the capacity for several users to interact and collaborate in the same experience. Over the year, the team evaluated several options to incorporate this feature. While Unity had a new solution for multiplayer networking, it was not stable and ready for implementation. The students explored a third-party solution, but determined it was not feasible due to cost and timeline. By the end of the third sprint, they had found a potential solution; however, this system required standing up an online server, which became a significant barrier to overcome over the remainder of the academic year. It was finally solved mid-way through the spring term when the stakeholders could secure an online multiplayer subscription.

Stable networking provided significant challenges to the students throughout the project. At different points in the spring term, they encountered various issues with how objects behaved in a collaborative environment. By the end of spring term, though, the students had resolved enough issues to have four users in the same virtual environment, experiencing the same object actions and outcomes.

5. Challenges & Problem Solving. Over the academic year, two significant challenges outside the team's control became evident. First was the lack of VR headsets available for testing. While the students could test on a flat screen, it does not always accurately display the issues that need to be remedied. Confounding this issue was that the VizLab was shut down due to COVID-19, preventing students from utilizing headsets that would normally have been available. The stakeholders finally provided each team member with a headset by mid-fall. The second significant challenge was robust online server access. Early on in the fall term, the team identified this as a sustainability requirement, but there were significant complexities encountered by the stakeholders securing this access. In the end, the stakeholders navigated the processes and secured the required access by mid-spring.

The students noted two significant challenges within their control over the course of the year: underestimating time to complete tasks and the complexity involved with laying foundational work that others would continue. Beyond seeking stakeholder input, they used mostly online resources to solve problems, including general search engines, YouTube tutorials, documentation found in an online software repository, and Unity Discord communities.

6. Products. The first capstone team was able to complete a functional, collaborative, educational VR platform with built-in assessment capabilities they dubbed KonnectVR (KVR). The platform did have glitches that needed refining, but the foundation was laid for future work. Team One also constructed a *Content Creation Manual* for content creators to understand how to efficiently create and upload modules for the platform.

2021-22: Expanding Access for a VR Learning Platform

The second capstone team was comprised of five members, all of which worked as student workers in the VizLab during the summer of 2021 and so had a working knowledge of KVR and its existing capabilities and shortcomings. As Team Two had five members, it was not as easily split into pairs, so at times they worked individually, at times in pairs, and sometimes as a trio. They regularly noted the importance of comprehensive documentation, which was not always provided by Team One.

Initially, Team Two was to be tasked with creating a two-dimensional interface (2D Client) for KVR so one could access the modules on a standard PC rather than a VR headset. However, one of the team members had taken the initiative over the summer to begin adapting the input and output functions, allowing the scope for Team Two to broaden. The final scope included adding general platform functionality improvement, making avatars more life-like, and expanding capabilities for instructors to create experiences without the need to code.

1. 2D Client. The initial application as a 2D client was ready by mid-fall. However, the stduents found many different areas that needed addressing over the rest of the year with moving to a PC version. General inputs and outputs were straightforward. Integrating grabbing, manipulating, and general hand movements were more complex problems to resolve. Spawning location as well as maintaining object border integrity were also issues the students found and resolved by early spring.

2. Avatar Improvement. Team One created a placeholder avatar with the expectation that future teams would improve upon the design. Team Two implemented a new, more life-like customizable avatar structure that could enhance user agency. They created a new UI that included a color palette selector that changed an avatar's hair, skin, and clothing color (Figure 7). They also created animations for facial expressions and mouth movements when talking. Finally, hand and arm animations were added to indicate when someone was talking.

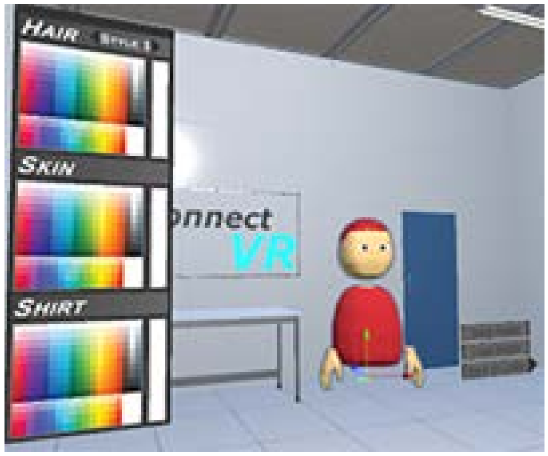


Fig. 7. Customizable Avatar UI: Users can modify their avatar's appearance.

3. Lab Builder. Creating an experience while in a virtual environment added a new degree of complexity to the project, including object manipulation; new UIs; and Upload, Load, Save, Delete, and Search functions for objects and assessments. Each summer, the VizLab engages student interns, which are predominantly SCSU computer science and software engineering students. Expanding on work done by these interns over the summer, Team Two initially focused on creating a process where an instructor could upload, spawn, and manipulate an object while in the VR environment. Object movement was accomplished by selecting the arrow that moved the object in the specific cardinal direction as well as rotation (Figure 8). Additionally, they included a function to resize objects.

The complexity of lab development required a full revision of KVR's existing UIs, which were built more for navigation and basic input. This new UI needed to have a file explorer framework which would allow the user to spawn objects; upload, delete, and search for files; and load, save, and search for lab modules. Additionally, the UI needed options to switch between different modes of operation. To reduce the instructor time burden, the students explored and implemented the concept of asset bundles, which are groupings of objects that can be uploaded into the environment all at once, rather than individually.

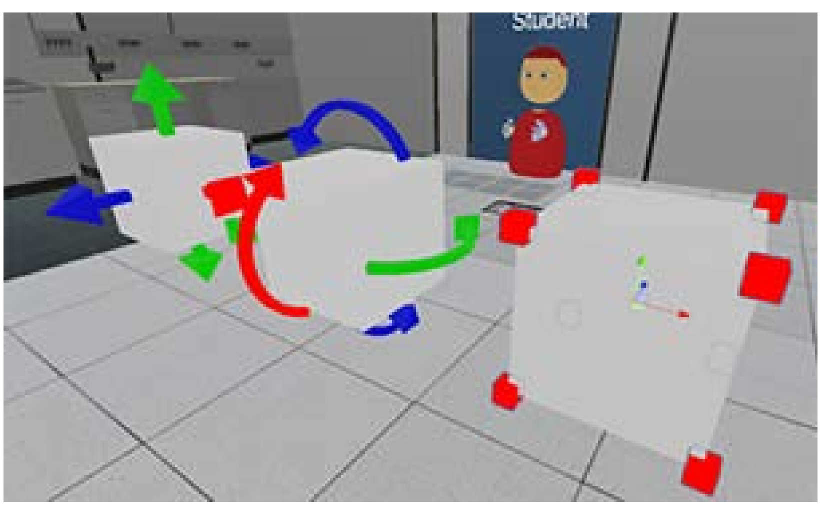


Fig. 8. Lab Builder: The blocks are placeholders for 3D models. The instructor can spawn a model into an environment and manipulate the object using the arrows for location and position as well as the blocks for size.

4. Challenges & Problem Solving. As with Team One, Team Two found unexpected challenges throughout the project, with three seen consistently: version control, understanding complexity, and artistry. Both teams used the free version of GitHub as a version control system. Where Team One did not seem to have issues, Team Two consistently had problems with GitHub losing new versions or creating merging errors. In fact, the team was unable to showcase their work in their final presentation due to breakage when merging everyone's final versions. Understanding just how complex a project will be is challenging for experienced developers, so it is not surprising that senior students would struggle with forecasting how complex a project would be. Finally, all members of Team Two were senior software engineer students that were tasked with creating 3D models, a new avatar, and user interfaces. None of the students considered themselves well versed in art or UI techniques and they all struggled with this aspect. A final challenge for Team Two was implementing networking capabilities. While they searched through KVR's documentation and online resources, they were never able to replicate Team One's networking capabilities.

5. Products. The second team was able to complete their required scope, although some core functionalities (like networking) broke and were not able to be fixed. Modules in KVR could now be experienced in either a VR headset or on a PC and the user could customize their avatar. Additionally, instructors could experiment with creating their own laboratory experiences and not rely solely on developers.

2022-23: Unique User IDs and Security

At the end of the summer of 2022, stakeholder Gill took a sabbatical from the SCSU VizLab to work with Meta Reality Labs (Facebook). This created significant reservations in the next potential capstone team. There were discussions regarding the continuation of the project and in what direction it should move. In the end, the third capstone team moved forward, comprised of four members which all worked as interns in the VizLab during the summer of 2022. With only four members, Team Three loosely split into two pairs that changed based on who had most confidence tackling specific tasks.

Team Three was tasked with implementing a secure log-in system that would be compatible with learning management systems (LMSs), stabilizing the networking capabilities, and improving the avatar customization feature. To begin the year, stakeholder Anderson connected the students with the Minnesota State College and Universities' IT Department (MN State) to provide the team with insights into how an LMS sends and receives secure data. While the process was in transition at the time, the students learned that the new standard for software to connect with an LMS was to implement Learning Tools Interoperability Core Specification 1.3 (LTI 1.3). MN State IT also created an LMS shell so the development team could test processes against a live course.

1. LMS Cybersecurity. To secure data packets over the Internet, public and private key cryptography is employed, where a public key is used to encrypt data, making it accessible only to the holder of the matched private key, who can decrypt it (Figure 9). In LTI 1.3, these public and private keys are pivotal for establishing trust between the tool and the platform. The tool's public key is shared with the LMS, which uses it to verify messages from the tool signed by its private key. Conversely, the LMS has a private key to sign messages and a public key that the tool uses to verify. This ensures secure message exchange.

Fig. 9. Cybersecurity Basics: The sender encrypts the data with a public key, and the recipient decrypts the data with a matched private key.

Implementing a secure log-in system that was LTI 1.3 compliant was by far the most challenging task for Team Three. As none had cybersecurity training, they needed to learn the basic concepts and apply them in a new arena. While VR games have secure log-in capabilities, this is handled differently than LTI 1.3 requires. At the beginning of the term, the stakeholders were unaware of any VR application that had successfully implemented LTI 1.3.

Over the year, Team Three was able to successfully implement a log-in system that securely sent information to an online database and received verification of whether that information matched a user account. When a user enters KVR, they land in a lobby scene. Team Three created a UI requiring users to enter an ID, password, and access code to move into any module. If the user does not have an account, they can select "Create an account" and do so. They also successfully implemented a password recovery system that sends an email to a user if requested so they can reset their password. Additionally, Team Three added error messages that display incorrect field inputs (Figure 10) and a reporting function that sends results to an instructor via email tied to the access code and includes the student ID.

Fig. 10. Secure Log-in: UI requiring User ID, Password, and Access Code with password error message.

2. Networking. The team restored basic networking functionality and fixed issues with how the tablet UI displayed when in a collaborative environment.

3. Avatars. Over the summer, VizLab gained access to a Unity package called AutoHands, which provides for easy implementation of various interactions. Team Three succeeded in replacing the traditional Unity commands with *AutoHands* to enhance the user experience and reduce the burdens on module creators.

4. UI/UX. While not in the scope of Team Three, they created a whiteboard that allows the user to write in a variety of colors and highlighters in the VR space.

5. Unit Testing. Unit tests verify individual software components in isolation, ensuring functionality and reliability. Essential to software development, they aid in maintaining code, reducing bugs, and facilitating test-driven development. These tests act as checks and documentation, improving design and long-term maintenance. Through Team Three's fall term, no one had constructed any unit tests for KVR. Once Team Three understood the importance of unit testing, especially to cybersecurity, they began to implement a unit testing process to validate the software design.

6. Challenges & Problem Solving. Team Three's scope significantly differed from the previous two, moving squarely into cybersecurity and LMS integration. As stated, none of the students had experience with this aspect of software engineering, which significantly slowed progress. Although MN State IT helped by setting up a course shell and providing input, they were not versed on how to create a new system that implemented LTI 1.3, only how to determine whether a system met the standards after being built. The students reached out to SCSU faculty but received little relevant help. After fall, stakeholder Anderson connected the students with a former MN State IT cybersecurity specialist who was able to help identify issues and potential solutions.

Working in both immersive and 2D environments also creates challenges. As a game development engine, Unity is not built with tools to easily implement standards such as LTI 1.3. Where standard desktop operating systems provide a wide array of tools (e.g., LTI 1.3), immersive environments do not. The students found no resources to guide them in implementing LTI 1.3 with Unity, and the resources were tangential systems that would not work in both environments. The team worked diligently to find online resources and tested several iterations, but in the end, KVR was not quite ready for LMS integration.

While Team Three did have some challenges with revision control like Teams One and Two, the project was moved to Unity's PlasticSCM revision control system over the summer, which significantly decreased conflict issues.

7. Products. As the smallest team with one significant challenge, Team Three had fewer deliverables than Teams One or Two. By the end of the year, the structure to implement LTI 1.3 was in place, including a log-in UI connected to an online database that could verify the validity of log-in credentials. KVR also now sends results via email to an instructor rather than having to access the file directly on the headset. Scope creep involved the team developing a functional whiteboard and implementing the *AutoHands* feature. Team Three also created a unit test framework for future teams to implement.

Table 1 summarizes the efforts and accomplishments of each team over the three academic years inspected.

Table 1. KVR Scope of Work Requirements and Team Completion

Requirement	Team 1 2020-21	Team 2 2021-22	Team 3 2022-23
User Management	Implemented		
Networking	Implemented		Stabilized
Avatars	Implemented	Improved	Improved
Modular	Implemented		Improved
Assessment	Implemented	Extended	
Feedback	Implemented		
Reporting	Implemented		Extended
UI/UX	Implemented	Extended	Extended
Documentation	Minimal	Extended	Extended
FERPA compliant			Initiated
Unit testing			Implemented
Lab Builder		Implemented	

Discussion

The discussion and analysis of creating the KVR platform over three academic years reveals a trajectory of increasing complexity and enhancement of educational technology. Several key themes emerged regarding the student learning and development process:

Collaborative Development Process

The capstone teams exemplify collaborative project-based learning, working in small groups with distinct responsibilities to construct components of KVR. This cooperative approach mirrors real-world engineering teams and enables skill-building in communication, task coordination, and teamwork. However, collaboration was sometimes hindered by documentation gaps between teams. More robust cross-team knowledge sharing could improve project continuity.

Overcoming Technical Complexity

The students faced substantial technical challenges inherent in crafting an innovative VR platform, including networking, UI/UX design, VR-specific development, and cybersecurity integration. Students gained first-hand experience grappling with complex systems. Each team persisted in problem-solving, seeking creative solutions through self-directed research and stakeholder support. However, underestimating task complexity frequently leads to delays.

Bridging Theory and Practice

The project provided an authentic context for students to bridge classroom knowledge with practical application. Students combined their expertise in areas like databases, software design, and security to construct a functional product. This reinforced technical learning and preparedness for industry. However, some skill gaps like cybersecurity and UI design were apparent; targeted supplemental training could be valuable.

Agile, Responsive Development

The scope evolved over the three years based on accomplishments, challenges, and emerging priorities. This agility allowed the platform to expand meaningfully each year. However, changing goals also caused fragmentation. Explicitly mapping long-term objectives at project onset may have improved continuity. Formal user testing and feedback loops could have also helped guide responsive development.

Future Work

The KVR platform, while functional at the end of each academic year, still requires significant work before it is ready for release and widespread adoption. Capstone Team Four is currently advancing the platform forward. In light of the experiences of past capstone teams, future work should focus on several key areas to fully realize the platform's potential.

- Enhanced documentation and knowledge transfer. It is imperative to establish a robust knowledge transfer system to mitigate the collaboration issues due to documentation gaps. This system would ensure team continuity and preserve institutional knowledge for future developers.
- User-centric development. Moving forward, incorporating regular user testing and feedback will be crucial. This will help create a responsive development environment where user experience drives the platform's evolution.
- Advancing LMS integration. Given the complexities of integrating with learning management systems, especially with LTI 1.3, further work should focus on achieving seamless interoperability and ensuring the platform meets educational standards for data security and privacy.
- Unit testing and quality assurance. Establishing a comprehensive unit testing framework will be vital for future development. This framework will guarantee that new features function as intended and maintain the overall integrity of the platform.
- Scalability and performance optimization. As the platform grows, optimizing performance and ensuring that KVR can scale to support an increasing number of users and complex simulations will be important.
- Enhanced accessibility. VR both restricts and expands user access to learning experiences. While a 2D client is a significant advancement in ensuring all students can access the content, exploring additional accessibility challenges like voice interaction and screen-reading functionalities will create an even larger educational impact of KVR.

Conclusion

Overall, KVR demonstrates how student-led project teams can construct complex software systems collaboratively, learning immensely in the process. It points to project-based learning's capacity for instilling professional skills and complementary knowledge. While challenges emerged, they also offered formative experiences in analytic troubleshooting and perseverance. With enhancements to cross-team continuity, intentionally responsive design, and supplemental training on emerging skills, this instructional approach shows immense potential to prepare future technologists.

The construction of the KVR platform presents a multifaceted narrative of growth, challenge, and learning, showcasing the potent blend of collaboration, technical acumen, and problem-solving capabilities fostered through project-based learning. The platform is a testament to the efficacy of hands-on educational experiences in preparing students for real-world technology landscapes.

By converging the domains of immersive technologies and open-sourced educational solutions, KVR provides educators with learning experiences that are interactive, collaborative, and accessible. While the journey was fraught with hurdles, each was a steppingstone towards significant learning outcomes, culminating in a platform that serves educational purposes and empowers its creators with a profound understanding of the software development lifecycle. This case study provides unique insider perspectives into the realities of crafting an ambitious platform like KVR. Future enhancements, guided by the lessons learned, are set to propel KVR into a new echelon of educational technology tools, bridging the gap between theoretical knowledge and practical applications and molding adept future technologists equipped to navigate and shape the technological frontiers of tomorrow.

Acknowledgements. This work was supported by the Minnesota State System of Colleges and Universities Innovation Funding Program and the National Science Foundation (NSF) under awards #2202206 and #1902574.

Disclosures. The authors declare no conflicts of interest.

Supplemental Materials: Please see https://micronanoeducation.org/wp-content/uploads/2024/03/Supplemental_D.-Anderson_KonnectVR.pdf

References

[1] M. M. T. E. Kouijzer, H. Kip, Y. H. A. Bouman, and S. M. Kelders, "Implementation of virtual reality in healthcare: a scoping review on the implementation process of virtual reality in various healthcare settings," *Implementation Science Communications*, vol. 4, no. 67, Jun. 2023, doi: 10.1186/s43058-023-00442-2.

[2] G. Pleyers and I. Poncin, "Non-immersive virtual reality technologies in real estate: How customer experience drives attitudes toward properties and the service provider," *Journal of Retailing and Consumer Services*, vol. 57, Nov. 2020, Art no. 102175, doi: 10.1016/j.jretconser.2020.102175.

[3] F. Wallace, "VR Gaming and the Technology's Impact on the World," HeadStuff, Oct. 2018, Accessed: Aug. 31, 2023.[Online]. Available: https://headstuff.org/entertainment/gaming/vr-technology-and-the-gaming-world/

[4] M. Melo et. al., "Immersive multisensory virtual reality technologies for virtual tourism: A study of the user's sense of presence, satisfaction, emotions, and attitudes," *Multimedia Syst.*, vol. 28, no. 3, pp. 1027–1037, Jun. 2022, doi: 10.1007/s00530-022-00898-7.

[5] U. Dakeev and F. Yildiz, "Design and Development of Mixed Reality (MR) Laboratory Tools to Improve Spatial Cognition, Student Engagement, and Employee Safety," J ATE, vol. 2, no. 1, pp. 37–48, 2023, doi: 10.5281/zenodo.7332034.

[6] R. Gentry, A. P. Sallie, and C. A. Sanders, *Differentiated Instructional Strategies to Accommodate Students with Varying Needs and Learning Styles* (2013).

[7] E. Gustafsson-Wright, S. Osborne, and A. Sharma, “How can real-time performance data lead to better education outcomes?,” Brookings, May 6, 2021. [Online]. Available: https://www.brookings.edu/articles/how-can-real-time-performance-data-lead-to-better-education-outcomes/

[8] E. Drake-Bridges, A. Strelzoff, and T. Sulbaran, “Teaching Marketing Through a Micro-Economy in Virtual Reality,” *Journal of Marketing Education*, vol. 33, no. 3, pp. 295–311, Dec. 2011, doi: 10.1177/0273475311420236.

[9] “The Leading XR Medical Anatomy Platform,” 3D Organan. Accessed: Aug. 31, 2023. [Online]. https://www.3dorganon.com/

[10] “SimX Virtual Reality Medical Simulation,” Virtual Reality Medical Simulation | SimX. Accessed: Aug. 31, 2023. [Online]. Available: https://www.simxvr.com/

[11] “EngageVR,” ENGAGE. Accessed: Aug. 31, 2023. [Online]. Available: https://engagevr.io/

[12] “Virbela: A Virtual World for Work, Education & Events,” Accessed: Aug. 31, 2023. [Online]. Available: https://www.virbela.com/

[13] S. E. Lakhan and K. Jhunjhunwala, “Open Source Software in Education,” EDUCAUSE Review. Accessed: Aug. 31, 2023. [Online]. Available: https://er.educause.edu/articles/2008/5/open-source-software-in-education

[14] A. Terehin, “How to Create a Learning Experience Platform [LMS to LXP] | Agente,” (2021). Accessed 10/3/2023.

[15] A. Terehin, “How to Design and Redesign a LMS,” Agente Blog. Accessed: Oct. 03, 2023. [Online]. Available: https://agentestudio.com/blog/transforming-lms-into-lxp

[16] N. B. Colvard, C. E. Watson, and H. Park, “The impact of open educational resources on various student success metrics,” *International Journal of Teaching and Learning in Higher Education*, vol. 30, no. 2, pp. 262–276, 2018.

[17] “Forum on the Impact of Open Courseware for Higher Education in Developing Countries, UNESCO, Paris, 1-3 July 2002: final report,” UNESCO, Paris, CI.2002/CONF.803/CLD.1, 2002. Accessed: Apr. 06, 2024. [Online]. Available: https://unesdoc.unesco.org/ark:/48223/pf0000128515

[18] P. A. Rauschnabel, R. Felix, C. Hinsch, H. Shahab, and F. Alt, “What is XR? Towards a Framework for Augmented and Virtual Reality,” *Computers in Human Behavior*, vol. 133, Art no. 107289, Aug. 2022, doi: 10.1016/j.chb.2022.107289.

[19] P. Rubin, Future Presence: *How Virtual Reality Is Changing Human Connection, Intimacy, and the Limits of Ordinary Life*. New York: HARPERONE, 2020.

[20] M. J. W. Lee, M. Georgieva, E. Craig, B. Alexander, and J. Richter, “State of XR & immersive learning outlook report 2021,” Immersive Learning Research Network, 2021.

[21] A. K. Noor, “The Hololens revolution,” Mechanical Engineering, vol. 138, no. 10, pp. 30–35, Oct. 2016, doi: 10.1115/1.2016-Oct-1.

[22] S. Lessick and M. Kraft, “Facing reality: The growth of virtual reality and health sciences libraries,” *J Med Libr Assoc*, vol. 105, no. 4, pp. 407–417, Oct. 2017, doi: 10.5195/jmla.2017.329.

[23] D. F. Angel-Urdinola, C. Castillo-Castro, and A. Hoyos, “Meta-Analysis Assessing the Effects of Virtual Reality Training on Student Learning and Skills Development,” The World Bank, Policy Research Working Paper WPS9587, Mar. 2021.

[24] N. R. Dyrberg, A. H. Treusch, and C. Wiegand, “Virtual laboratories in science education: Students’ motivation and experiences in two tertiary biology courses,” *Journal of Biological Education*, vol. 51, no. 4, pp. 358–374, Oct. 2017, doi: 10.1080/00219266.2016.1257498.

[25] J. J. Cummings and J. N. Bailenson, “How immersive is enough? A meta-analysis of the effect of immersive technology on user presence,” *Media Psychology*, vol. 19, no. 2, pp. 272–309, 2016, doi: 10.1080/15213269.2015.1015740.

[26] A. Suh and J. Prophet, “The state of immersive technology research: A literature analysis,” *Computers in Human Behavior*, vol. 86, pp. 77–90, 2018, doi: 10.1016/j.chb.2018.04.019.

[27] J. Parong and R. E. Mayer, “Cognitive and affective processes for learning science in immersive virtual reality,” *J Comput Assist Learn*, vol. 37, no. 1, pp. 226–241, 2021, doi: 10.1111/jcal.12482.

[28] J. Kisker, T. Gruber, and B. Schöne, “Behavioral realism and lifelike psychophysiological responses in virtual reality by the example of a height exposure,” *Psychol Res*, vol. 85, no. 1, pp. 68–81, Feb. 2021, doi: 10.1007/s00426-019-01244-9.

[29] L. B. Cadet and H. Chainay, “Memory of virtual experiences: Role of immersion, emotion and sense of presence,” *International Journal of Human-Computer Studies*, vol. 144, 2020, doi: 10.1016/j.ijhcs.2020.102506.

[30] G. A. Wilson and M. McGill, “Violent video games in virtual reality: Re-evaluating the impact and rating of interactive experiences,” in Proceedings of the 2018 *Annual Symposium on Computer-Human Interaction in Play*, in CHI PLAY ’18. New York, NY, USA: Association for Computing Machinery, Oct. 2018, pp. 535–548. doi: 10.1145/3242671.3242684.

[31] J. Radianti, T. A. Majchrzak, J. Fromm, and I. Wohlgenannt, “A systematic review of immersive virtual reality applications for higher education: Design elements, lessons learned, and research agenda,” *Computers & Education*, vol. 147, p. 103778, Apr. 2020, doi: 10.1016/j.compedu.2019.103778.

[32] B. Wu, X. Yu, and X. Gu, “Effectiveness of immersive virtual reality using head-mounted displays on learning performance: A meta-analysis,” *British Journal of Educational Technology*, vol. 51, no. 6, pp. 1991–2005, 2020, doi: 10.1111/bjet.13023.

[33] Y. Zhao and K. A. Frank, “Factors affecting technology uses in schools: An ecological perspective,” *American Educational Research Journal*, vol. 40, no. 4, pp. 807–840, Jan. 2003, doi: 10.3102/00028312040004807.

[34] H. Luo, G. Li, Q. Feng, Y. Yang, and M. Zuo, “Virtual reality in K-12 and higher education: A systematic review of the literature from 2000 to 2019,” *Journal of Computer Assisted Learning*, vol. 37, no. 3, pp. 887–901, 2021, doi: 10.1111/jcal.12538.

[35] C. Koh, H. S. Tan, K. C. Tan, L. Fang, F. M. Fong, D. Kan, S. L. Lye, and M. L. Wee, “Investigating the effect of 3D simulation based learning on the motivation and performance of engineering students,” *Journal of Engineering Education*, vol. 99, no. 3, pp. 237–251, 2010, doi: 10.1002/j.2168-9830.2010.tb01059.x.

[36] K.-T. Huang, C. Ball, J. Francis, R. Ratan, J. Boumis, and J. Fordham, “Augmented Versus Virtual Reality in Education: An Exploratory Study Examining Science Knowledge Retention When Using Augmented Reality/Virtual Reality Mobile Applications,” *Cyberpsychology, Behavior, and Social Networking*, vol. 22, no. 2, pp. 105–110, Feb. 2019, doi: 10.1089/cyber.2018.0150.

[37] E. Krokos, C. Plaisant, and A. Varshney, “Virtual memory palaces: immersion aids recall,” *Virtual Reality*, vol. 23, no. 1, pp. 1–15, Mar. 2019, doi: 10.1007/s10055-018-0346-3.

[38] H.S. Maresky, A. Oikonomou, I. Ali, N. Ditkofsky, M. Pakkal, and B. Ballyk, “Virtual reality and cardiac anatomy: Exploring immersive three-dimensional cardiac imaging, a pilot study in undergraduate medical anatomy education,” *Clin. Anat*, vol. 32, no. 2, pp. 238–243, Mar. 2019, doi: 10.1002/ca.23292.

[39] S. Kavanagh, A. Luxton-Reilly, B. Wuensche, and B. Plimmer, “A systematic review of Virtual Reality in education,” *Themes in Science and Technology Education*, vol. 10, no. 2, pp. 85–119, 2017.

[40] G. Makransky and L. Lilleholt, “A structural equation modeling investigation of the emotional value of immersive virtual reality in education,” *Education Tech Research Dev*, vol. 66, no. 5, pp. 1141–1164, Oct. 2018, doi: 10.1007/s11423-018-9581-2.

[41] H.-M. Huang, U. Rauch, and S.-S. Liaw, “Investigating learners’ attitudes toward virtual reality learning environments: Based on a constructivist approach,” *Computers & Education*, vol. 55, no. 3, pp. 1171–1182, Nov. 2010, doi: 10.1016/j.compedu.2010.05.014.

[42] M. Boekaerts, “Successful Schooling,” in *Motivation to Learn*, D. Bhaskara Rao, ed. (Discovery Publishing House, 2002), pp. 101–120.
Available: https://unesdoc.unesco.org/ark:/48223/pf0000128056

[43] J. Hattie, *Visible Learning*, 1st edition. London ; New York: Routledge, 2008.

[44] Y.-G. Lin, W. J. McKeachie, and Y. C. Kim, “College student intrinsic and/or extrinsic motivation and learning,” *Learning and Individual Differences*, vol. 13, no. 3, pp. 251–258, 2001, doi: 10.1016/S1041-6080(02)00092-4.

[45] E. Ceh-Varela, C. Canto-Bonilla, and D. Duni, “Application of Project-Based Learning to a Software Engineering course in a hybrid class environment,” *Inf. Softw. Technol.*, vol. 158, no. C, Jun. 2023, doi: 10.1016/j.infsof.2023.107189.

[46] W. Intayoad, “PBL Framework for Enhancing Software Development Skills: An Empirical Study for Information Technology Students,” *Wirel. Pers. Commun.*, vol. 76, no. 3, pp. 419–433, Jun. 2014, doi: 10.1007/s11277-014-1715-1.

[47] “51 In-Demand Tech Skills for Technology Careers,” Indeed Career Guide. Accessed: Sep. 01, 2023. [Online]. Available: https://www.indeed.com/career-advice/career-development/in-demand-tech-skills

[48] “Steam Store,” Steam. Accessed: Aug. 31, 2023. [Online]. Available: https://store.steampowered.com/

[49] B. Kelley, “The Rise of the ‘Quarantine Bar Simulator’: The Uses and Gratifications of Social VR During the COVID-19 Pandemic,” in 2021 *4th International Conference on Information and Computer Technologies (ICICT)*, Mar. 2021, pp. 216–221. doi: 10.1109/ICICT52872.2021.00043.

[50] “Home Virtual Reality VR Education Software & Augmented Reality Learning - VictoryXR,” Accessed: Apr. 06, 2024. [Online]. Available: https://www.victoryxr.com/

[51] M. Frydenberg, D. Yates, and J. Kukesh, “Sprint, then Fly: Teaching Agile Methodologies with Paper Airplanes,” *Information Systems Education Journal*, vol. 16, no. 5, p. 22, 2018.

Makers by Design: Helping Teachers Integrate Design Thinking Into Instruction Through a Sustained Professional Learning Fellowship

CHRISTOPHER RUSSELL[1]*, AMANDA GONCZI[2]

[1]*Northern Virginia Community College, Fairfax VA, USA*

[2]*Michigan Technological University, Houghton MI, USA*

**crussell@nvcc.edu*

Abstract: This paper investigates the extent to which participants in a professional learning (PL) program learned and implemented design thinking principles within their instruction. In 2022, 17 educators from the northern Virginia region were recruited to an NSF-funded PL fellowship, including K-12 teachers, post-secondary faculty, and public librarians. During the project, fellows completed 20 hours of design thinking PL, practiced teaching at digital fabrication summer camps for elementary and middle school youth and developed and implemented a lesson plan that integrated design thinking into their subject area. Data sources included surveys, teacher-generated lesson plans, and lesson reflections. A mixed methods approach was used for data analysis.

Keywords: design thinking, professional learning, STEM education

Introduction

Integration of makerspace technologies and the practice of *making* has drawn attention as an active learning intervention to cultivate student interest in STEM in an interdisciplinary context. To promote STEM literacy among students, K-12 and post-secondary institutions are integrating STEM pedagogies across the curriculum [1]. The culture and practice of *making* is one approach to STEM integration that centers around student-directed project-based learning, interdisciplinary problem-solving, and collaborative effort [2]. In this context, making typically entails using digital fabrication technologies (e.g., 3D printing, laser cutting) alongside design software (e.g., TinkerCAD, Adobe Illustrator) to design physical objects that solve a given problem. Integrating these techniques into classroom instruction can improve student attitudes toward and interest in STEM disciplines [3]–[5]. However, studies of classroom implementation of digital fabrication technologies also report that teachers struggle to move beyond "keychain syndrome," the tendency to fall back to reproducing simple objects, such as a keychain or coaster, that entail little to no student-driven problem-solving or engagement in authentic design thinking [6], [7].

Design thinking encompasses a set of principles that, when coupled with *making*, may provide a more authentic and meaningful experience for students and help teachers move beyond the "keychain syndrome". Design thinking is a non-linear cognitive strategy used to approach the design of systems and solutions through collaborative and user-focused practices [8]. In the classroom, preliminary research suggests that design thinking is an effective model for teaching "21st century skills" that are also crucial to the development of science and engineering practices (e.g., collaboration, creativity, communication) [9]–[12]. As an engineering design process, design thinking organizes product creation around an empathetic understanding of the end-user's needs [8], [13]. An understanding of the user is intentionally developed through a variety of data sources, including surveys, interviews, and observations. Rather than moving prescriptively through a rigid series of steps, design thinking allows a designer to move fluidly between stages in response to changes in the users' needs or the extent to which those needs are understood [14].

Teacher PL focused on *making* has generally centered on machine operation, and not pedagogy, cognitive strategies, and processes to situate the technology [15]. This project, Makers by Design (MBD), represents an effort to build teachers' understanding of design thinking so making can be situated within meaningful design activities for students that foster interest and skills development. From a STEM workforce development perspective, it is essential students develop proficiency in design-related skills for future success in STEM careers, including technical positions that require problem-solving, communication, collaboration, and other aspects of design thinking.

This paper presents results from an NSF-funded Advanced Technological Education (ATE) project that aimed to help in-service educators integrate design thinking into their practice. Seventeen educators from the Northern Virginia region were recruited to a 9-month fellowship consisting of a) 20 hours of professional learning in design thinking at Northern Virginia Community College's (NVCC) makerspace, b) practice teaching design thinking at a digital fabrication summer camp with middle and high school students, and c) lesson planning to facilitate design thinking into their instructional setting. This cohort of educators had representatives from K-12, public libraries, post-secondary institutions, and a wide range of disciplinary backgrounds. Data collection and analysis were designed to answer two questions:

1. To what extent does participation in the professional learning fellowship foster the integration of design thinking elements into instruction?
2. To what extent does the fellowship improve participants' confidence in implementing design thinking and digital fabrication?

Methods

Effective Professional Learning. Research on PL suggests that interventions that foster sustainable changes in teaching practice include (a) modeling, (b) lesson plan development, (c) practice teaching, (d) coaching, and (e) building a community of practice. Modeling desirable instructional practices provides teachers with the opportunity to experience exemplary, authentic instruction as learners [16]. *Modeling* has shown utility in several areas of STEM education, including engineering instruction [17], digital technology use [18], [19], and reform-based science instruction [20]. *Lesson planning* allows teachers to revisit and apply what they learn in an active way that is relevant to their own instructional context (e.g., grade, student ability, content) [16], [21]. Teachers value opportunities to *practice* using new instructional strategies in conditions without repercussions if a lesson does not go as planned [22]. Individualized coaching allows PL implementers to differentiate support based on teachers' needs [23].

Program Recruitment. Educators were recruited for the PL fellowship through contacts with local school districts and library systems and internally at NOVA. The application process required demographic data and brief narratives of prior experiences with design thinking, engineering, and common makerspace technologies. Of the 32 applicants, 17 fellows were accepted to the program using a rubric prioritizing racial and ethnic diversity of students taught, geographic representation across NVCC's service area, and quality of narrative responses. (Table 1).

Table 1. Participant demographics (n=17)

Teaching Environment	
K-12	59% (n=10)
Post-secondary	29% (n=5)
Library	12% (n=2)
Gender	
Female	65% (n=11)
Male	35% (n=6)
Race / Ethnicity	
White	41% (n=7)
Other	24% (n=4)
Black	18% (n=3)
Hispanic / Latino	12% (n=2)
Asian	6% (n=1)
Pacific Islander	0% (n=0)

Program Structure. From a content perspective, MBD sought to help participants understand *design thinking* and distinguish it from *engineering design*. *Design thinking* proceeds through a 5-step process, beginning with identifying a general problem experienced by a group of people (Table 2). As an engineering design practice, design thinking emphasizes gathering and analyzing information from users (*empathize*) prior to the formation of problem statements (*define*). Prior to developing prototypes, a number of solutions are developed (*ideate*) and evaluated against existing constraints and specifications. Initial prototypes are typically low-cost and low-fidelity, designed to gather more information from users through testing that can be used to refine (*ideate*) potential solutions further.

Table 2: Design thinking process and descriptions

Process	Description
Empathize	Gather data about end-users experiencing a particular problem. Use a variety of methods (e.g., interviews, observations) to ensure an accurate understanding of how users feel about and interact with the problem.
Define	Analyze collected data to produce an actionable and refined problem statement. Statements refine the problem and identify specific user needs that must be met for a solution to be effective.
Ideate	Produce a wide range of potential solutions to the new problem statement. Ideation should alternate between divergence (thinking of a broad range of solutions) and convergence (narrowing down those solutions according to the problem statement).
Prototype	Develop a working prototype of the chosen solution. Prototypes should be low-cost and quick to produce.
Test	Test the prototype in a working environment, preferentially with the user or a designer acting as the user.

Spring PL consisted of online and face-to-face instruction (Table 3). In the workshop, the commonly used bridge challenge was used to distinguish design thinking and other forms of engineering design in the PL. As traditionally taught, bridge-building challenges typically involve students using limited time and materials to build a bridge of a defined length and then testing its load-bearing capabilities. This activity typically defines the problem exactly (e.g., the bridge must be 12 inches long) and defines the parameters for success similarly (e.g., a successful bridge will hold 500 grams without breaking). By comparison, a version of the bridge-building activity centered around design thinking would provide information about users first, asking students to consider users' needs as a foundation for the design process. The results of a "bridge building activity" using design thinking as a cognitive strategy might not involve a bridge at all. Instead, students might propose an alternative means of conveyance (e.g., ski lift) or another creative solution. In other words, the users' needs and constraints are crucial in identifying the problem and subsequent solution. These two variants of the bridge challenge were compared and discussed in the first meeting (Table 3).

Fellows then were assigned interdisciplinary groups to consider a design challenge. Specifically, fellows were tasked to develop a storage and sorting solution for a fictional LEGO hobbyist. During each session, fellows were introduced to a concept or strategy in design thinking (e.g., interview users, journey map), applied that strategy to their project, and then observed a guest teacher delivering a model lesson using the strategy in a particular educational context (e.g., middle school science, introductory college engineering). Each session roughly corresponded to one of the five steps of the design thinking cycle (Table 3).

Table 3. Structure of the design thinking PL

DT Step	Description	Model Lesson
Empathize *Virtual,* *2 hours*	• Facilitators introduce fellows to design thinking. • Overview of the LEGO design challenge. • Develop an interview protocol for their users.	N/A
Empathize *Virtual,* *2 hours*	• Implement interview protocols. • Expand user profiles.	Build-A-Bridge: adds users to an engineering bridge-building exercise.
Define *Virtual,* *2 hours*	• Formulate a user-focused problem statement.	Citizen Science: challenge students to identify the problems with a failed science outreach project.
Ideate *In-person,* *6 hours*	• Develop a journey map that follows their user's experiences. • Ideate several solutions to their user's problems.	Board Game Design: play a prototype board game, then propose new rules and test them.
Ideate *Async,* *2 hours*	• Fellows evaluate their solutions using a rubric.	N/A
Prototype & Test *In-person,* *6 hours*	• Fellows develop a physical rough prototype using paper, cardboard, and glue. • Peer testing of prototypes.	Camp Practice: rapidly prototype a LEGO transport method for Suresh, an elementary school student.

After completing the spring PL, fellows planned for and then practiced teaching design thinking during a week-long summer camp run by NVCC. During camp days, the morning focused on introducing digital fabrication technologies (e.g., 3D printer, laser cutter) and design software (e.g., TinkerCAD, Adobe Illustrator). The afternoon (approximately 2.5 hours) was devoted to design thinking workshops. The MBD fellows led the camp students through a design challenge during these workshops. The camp students were provided with a bio of a user who experienced trouble transporting LEGO creations from one place to another. For example, campers might work with the fictional Suresh, a 12-year-old boy who transports his LEGO sets between his divorced parents' houses on a scooter. Fellows were given broad latitude to structure this time, with the general guidance to try to include each step of the design thinking process. During fellows' practice of design thinking instruction, PL facilitators observed and provided feedback at the end of the day during structured debriefs that lasted approximately 30 minutes. Table 4 provides an overview of the structure of the design thinking portion of the summer camp.

Table 4. Camp design thinking framework

Activity and Time	Design Thinking Step	Description
Challenge Overview *5 minutes*	N/A	Explain the challenge to students. On days 2 and 3, use this time to recap previous events.
Meet Your User *15 minutes*	Empathy	Pass out user dossiers to students. Have students review dossiers in their groups. Students may "interview" their users, with facilitators acting as users.
How Might We…? *10 minutes*	Define	Provide students with the How Might We Chart. Explain that students should use the chart to determine what their user requires for the solution to solve the problem.
Brainstorming *15 minutes*	Ideate	Now that students have completed the How Might We chart detailing the requirements of their solution, they should ideate designs. Students should take 5 minutes to draw their designs – encourage students to label and explain their thoughts. Then ask students to converge their designs into one group plan using the Group Design worksheet.
Prototype *60 minutes*	Prototyping	Using the provided materials, groups should prototype their chosen design. While groups are prototyping, facilitators should move around to resolve issues with the prototyping process.
Test *30 minutes*	Test	Using the provided testing worksheet, help teams develop a testing protocol. You may have teams switch prototypes with one another if time permits.
Debrief & Cleanup *15 minutes*	N/A	Teams should take the time to review the results of their testing and decide how they would continue with their prototype (e.g., new design, refine, etc..).

For the last stage of their fellowship, fellows developed a lesson plan integrating design thinking into their classroom instruction. After testing out lessons in their classrooms, fellows provided NVCC with a copy of their lesson plans (required) and a brief reflection (optional) explaining how their lesson went and what advice they would give another educator who wanted to use their ideas.

Data Collection and Analysis. Data sources included participant lesson plans and surveys. Submitted lesson plans were coded for the steps of the design thinking process (*empathize, define, ideate, prototype, test*) as described above, along with three additional codes (*overall process, iteration, and failure*). *Overall process* refers to statements describing the overall process of design thinking, either by explaining the strategy's goals or outcomes. *Iteration* refers to statements that reference the iterative nature of design thinking or the necessity of producing multiple versions of a given product to find the best possible solution. *Failure* refers to statements that reference the necessity of failure in order to gather data on what doesn't work as well as what does. The first author coded the lesson plans. Validity of frequency counts was established by the second author, who coded a subset of the lesson plans (20%). Any disagreements in codes were resolved through discussion.

Patterns in self-reported confidence in implementing four instructional practices (design thinking, human-centered design practices, 3-D printing, laser-cutting) were analyzed through descriptive statistics (Mean, standard deviation). Participants were assigned de-identified numeric identifiers.

Results

Of the 17 educators selected for the program, 13 completed the fellowship, produced design-thinking lesson plans, and provided responses to all survey instruments. Participating educators completed a pre-and post-survey intended to measure their confidence in integrating elements of digital fabrication, design thinking, and user-centered methods into their instruction. Descriptive statistics indicate the mean confidence increased for design thinking, human-centered design practices, and 3-D printing (Table 5).

Standard deviations were above .5 for all measures and all time points, indicating quite a lot of variability in participant responses, with variability highest for 3D printing and laser cutting. Design thinking was the construct that showed the greatest mean confidence change and the greatest decrease in standard deviation from pre to post indicating the participants consistently chose a greater Likert confidence score compared with participants on the presurvey. Due to the low sample size, inferential statistics could not be performed.

Table 5. Confidence[a]

Instructional Component	Pre-fellowship (n=15) Mean (SD)	Post-fellowship (n=12)
Design Thinking	3.06 (0.89)	3.5 (0.52)
Human-centered design practices	3.23 (0.62)	3.42 (0.51)
3D Printing	2.60 (1.30)	2.67 (1.23)
Laser Cutting	2.33 (1.23)	2.0 (1.34)

[a]4-point Likert scale, 1 = not at all confident, 4 = Highly confident

Table 6 provides an overview of the lesson plans produced by participating educators. For each lesson, the subject area, grade band, and a brief description of the lesson content are provided. Educators were encouraged to submit a lesson that addressed the context of their teaching practice; as such, the format and content of lesson plans are highly variable across participants.

Table 6. Overview of participant lesson plans

ID	Discipline	Lesson Description
1	Career & Technical Education High School	Taught design thinking as a winter break elective, running 2 hours a day for 5 days. Much of the lesson content is reused from PL workshops.
2	Career & Technical Education Middle School	Lesson is a 9-class sequence in which students create a custom sign for a teacher at their school. Students are required to structure their groups as a pretend business; practicing pre-professional skills.
3	Career & Technical Education High School	Lesson is a design challenge to develop a reaching tool for elderly clients who are vertically challenged.
4	Engineering High School	Lesson involves the creation and fabrication of a board game for 4th grade mathematics students and takes place over 4 90-minute blocks. Lesson has a very rigid structure, with the requirements for the game (e.g., types of pieces, rules, learning objectives) have already been predetermined by the instructor.
5	Biology Post-secondary	Lesson plan is a redesign of the laboratory section of an advanced microbiology course and intended to allow students freedom to design and structure their own research lab.
6	STEM Resource Teacher Elementary	Lesson involves reading students a fable, then asking them to use the design thinking process to think of a solution to the problems experienced by the characters in the fable.
7	Engineering High School	Lesson is a collaboration with the Biology teacher for 10th grade students. Students receive a case study of users impacted by dirty water and must create a filtration solution.
8	Physical Education Post-secondary	A workshop for volunteer faculty and staff to brainstorm ideas for a wellness campaign to be prototyped in Fall 2022.
9	Librarian	Lesson is a workshop for a cub scout troupe visiting the makerspace to earn their engineering badge. Scouts build an attachment for a Sphero that can carry a 3D printed container full of candy through an obstacle course.
10	Career & Technical Education Middle School	Lesson is structured as 6, 45-minute blocks and asks students to develop an ankle brace for a child with cerebral palsy. Budgeting and financial constraints are a major part of the instruction.
11	Photography High School	Lesson plan is a revised plan from summer camp instruction. Lesson is a two-part workshop, the first being a bridge-building icebreaker and the second a design challenge focused on building a chair for a specific user.
12	Librarian	Project is a train-the-trainer workshop for librarians who develop public-facing programs. Over the course of a 2.5-hour workshop, participants develop a structure for a library program starting with a packet of feedback gathered from prior programming.

Table 7 provides an overview of the frequency of each code identified in each participant's lesson plan. The frequency of each code found in lessons demonstrates the degree to which lessons focused on a particular element of the design thinking process or, in some cases, did not address a portion of the process at all. The overall prevalence of each code among all plans is provided to show the likelihood that participants utilized an element of design thinking in their lessons.

Table 7. Frequency of design process codes in lesson plans

ID	Empathize	Define	Ideate	Prototype	Test	Overall Process	Iteration
1	4	2	2	1	2	0	2
2	2	1	1	2	1	1	2
3	2	0	2	0	0	0	0
4	1	0	1	0	1	0	1
5	1	1	0	0	0	1	0
6	1	2	3	1	1	1	1
7	3	3	0	2	1	0	0
8	2	1	0	0	0	1	0
9	0	0	2	2	2	0	2
10	3	0	1	0	2	0	0
11	2	3	2	2	1	0	1
12	4	1	2	2	1	0	1
Overall Prevalence	**11(91.7%)**	**8 (66.7%)**	**9 (75%)**	**7 (58.3%)**	**9 (75%)**	**4 (33.3%)**	**7 (58.3%)**

Discussion

Collected lesson plans and survey results indicate a small increase in educator confidence and integration of the principles of design thinking within their instruction. Of the 17 participants, 16 (94%) included sections on empathizing with users in their lesson plans. Teachers also taught specific techniques to develop empathy with a user, such as interviewing (1, 2, 3, 12), bodystorming (1, 8), and developing a list of user needs (12, 11, 7). Teachers worked around the lack of immediate users by inventing their own, such as 6, who used an established fairy tale with simplistic characters as a way for elementary schoolers to practice empathy.

Likewise, nearly all educators integrated prototyping and testing into their teaching of design thinking. Following the emphasis on rough prototyping in design thinking, educators frequently used prototyping and testing data to gather more user data. For instance, 2 asked students to send rough drafts and drawings to their clients as soon as possible. Seven instructed his engineering students that their solution "could be a proof of concept, a model, a working device, or any combination of these" as long as it served the function of communicating their idea to their assigned user. Nearly all educators (83%) included a testing plan that involved gathering data from other stakeholders interacting with student work. Some (4, 6, 10, 12) had students test each other's prototypes, while others brought in users outside the classroom (1, 2, 10). Educators also used the prototyping and testing stages as an opportunity to include iteration and redevelopment of successful prototypes, though these gestures towards iteration were tempered by concerns over time constraints.

Teachers were less likely to include a focus on ideation in their lesson plans compared with empathy, frequently preferring to place constraints on the types of products that students could create. Several projects (e.g., an ankle brace for a child with cerebral palsy (8), a water filter for remote use (7)) were constructed to allow students to proceed directly from the empathy stage to the prototyping stage by simply telling students what they had to make. Teachers placed constraints on ideation even with projects that could be open-ended - for example, 4 had students create a board game to teach 4th-grade fractions but strictly required what game elements (e.g., dice, cards, spinners) had to be included. Educators who successfully integrated ideation acknowledged constraints given to students but emphasized what parameters students should have complete control over. For instance, 2 had students create custom classroom signs for other teachers in their school. two's students were required to conform to a certain size and material restriction but were otherwise free to use whatever artistic techniques were available to them as long as their final product was satisfactory to their client.

Future research should investigate explanations for patterns in the lesson plan data. Specifically, why were some aspects of design thinking included more frequently than others? Furthermore, what benefits of using design thinking as a pedagogy do teachers identify? Educators could also integrate testing, prototyping, and iteration into their plans effectively. However, gaps in integration remained, especially with regard to ideation.

Conclusion

The Makers by Design fellowship showed promise as a PL method to help educators integrate engineering design through design thinking into their instructional practice. In particular, participants successfully included empathy in their submitted lesson plans. This outcome is promising in an age where teachers are increasingly encouraged to foster 21st-century skills, including collaboration and communication. Participants' almost unanimous integration of empathy highlights that focusing on user needs may be an element that resonates with teachers from various disciplines and a facile strategy to promote empathic habits of mind and authentic engineering in classrooms.

Acknowledgments: This work was supported by the National Science Foundation (NSF) under the award 2055324.

Disclosures. The authors declare no conflicts of interest.

References

[1] K. C. Margot and T. Kettler, "Teachers' perception of STEM integration and education: a systematic literature review," *Int. J. STEM Educ.*, vol. 6, no. 1, p. 16, Dec. 2019, doi: 10.1186/s40594-018-0151-2.

[2] E. R. Halverson and K. M. Sheridan, "The maker movement in education," *Harv. Educ. Rev.*, vol. 84, no. 4, pp. 495–504, 2014, doi: 10.17763/haer.84.4.34j1g68140382063.

[3] P.-N. Chou, "Skill Development and Knowledge Acquisition Cultivated by Maker Education: Evidence from Arduino-based Educational Robotics," *Eurasia J. Math. Sci. Technol. Educ.*, vol. 14, no. 10, 2018, doi: 10.29333/ejmste/93483.

[4] I. Lyublinskaya and S. Sheehan, "Effect of the Collaboration Between MakerSpace, University, and Elementary Schools on Student STEM Attitudes," pp. 78–98, 2018, doi: 10.4018/978-1-5225-6951-0.ch005.

[5] K. A. Peppler, E. Halverson, and Y. B. Kafai, *Makeology. Volume 1, Makerspaces as learners environments*. New York: Routledge, 2016.

[6] P. Blikstein, "Digital Fabrication and 'Making' in Education The Democratization of Invention," in *FabLab*, transcript Verlag, 2014. doi: 10.14361/transcript.9783839423820.203.

[7] M. Eisenberg, "3D printing for children: What to build next?," *Int. J. Child-Comput. Interact.*, vol. 1, no. 1, pp. 7–13, Jan. 2013, doi: 10.1016/j.ijcci.2012.08.004.

[8] T. Brown, "Design Thinking," *Harv. Bus. Rev.*, vol. 86, no. June, pp. 1–9, 2008.

[9] L. R. de Campos, "Design Thinking in Education: A Case Study Following One School District's Approach to Innovation for the 21st Century," University of San Francisco, 2015. Accessed: Sep. 28, 2020. [Online]. Available: https://repository.usfca.edu/diss/116

[10] S. Goldman, Z. Kabayadondo, A. Royalty, M. Carroll, and B. Roth, "Design thinking research: Building innovation eco-systems," in *Design Thinking Research: Understanding Innvation*, H. Platner, C. Meinel, and L. Leifer, Eds., Springer Interational Publishing, 2014, pp. 11–34. doi: 10.1007/978-3-319-01303-9.

[11] C. Noweski, A. Scheer, N. Büttner, J. Von Thienen, J. Erdmann, and C. Meinel, "Towards a paradigm shift in education practice: Developing twenty-first century skills with design thinking," in *Design Thinking Research: Measuring Performance in Context*, Springer Berlin Heidelberg, 2012, pp. 71–94. doi: 10.1007/978-3-642-31991-4_5.

[12] I. Rauth, E. Köppen, B. Jobst, and C. Meinel, "Design thinking: An educational model towards creative confidence," *66-2 Proc. 1st Int. Conf. Des. Creat. ICDC 2010*, no. December, pp. 1–8, 2010.

[13] T. Brown and J. Wyatt, "Design Thinking for Social Innovation," *Stanf. Soc. Innov. Rev.*, pp. 30–35, 2010, doi: 10.1111/j.1348-0421.1982.tb00269.x.

[14] H. G. Nelson and E. Stolterman, *The design way : intentional change in an unpredictable world*. The MIT Press, 2012.

[15] R. C. Smith, O. S. Iversen, and M. Hjorth, “Design thinking for digital fabrication in education,” *Int. J. Child-Comput. Interact*., vol. 5, pp. 20–28, Sep. 2015, doi: 10.1016/j.ijcci.2015.10.002.

[16] D. K. Capps, B. A. Crawford, and M. A. Constas, “A Review of Empirical Literature on Inquiry Professional Development: Alignment with Best Practices and a Critique of the Findings,” *J. Sci. Teach. Educ*., vol. 23, no. 3, pp. 291–318, Apr. 2012, doi: 10.1007/s10972-012-9275-2.

[17] G. J. Kelly, C. M. Cunningham, and A. Ricketts, “Engaging in identity work through engineering practices in elementary classrooms,” *Linguist. Educ*., vol. 39, pp. 48–59, Jun. 2017, doi: 10.1016/j.linged.2017.05.003.

[18] R. L. Bell, J. L. Maeng, and I. C. Binns, “Learning in context: Technology integration in a teacher preparation program informed by situated learning theory,” *J. Res. Sci. Teach*., vol. 50, no. 3, pp. 348–379, 2013, doi: 10.1002/tea.21075.

[19] M. Pope, T. Jayne, D. Franz, and B. Hamil, “Teacher candidates and technology: Making integration happen,” *Natl. Forum Appl. Educ*. Res., vol. 21, no. 3, pp. 1–9, 2008.

[20] J. L. Maeng, B. A. Whitworth, R. L. Bell, and D. R. Sterling, “The effect of professional development on elementary science teachers’ understanding, confidence, and classroom implementation of reform-based science instruction,” *Sci. Educ*., vol. 104, no. 2, pp. 326–353, Mar. 2020, doi: 10.1002/sce.21562.

[21] W. R. Penuel, B. J. Fishman, R. Yamaguchi, and L. P. Gallagher, “What Makes Professional Development Effective? Strategies That Foster Curriculum Implementation,” *Am. Educ. Res. J*., vol. 44, no. 4, pp. 921–958, Dec. 2007, doi: 10.3102/0002831207308221.

[22] C. A. Bell et al., “Improving Observational Score Quality,” in *Designing Teacher Evaluation Systems*, John Wiley & Sons, Ltd, 2015, pp. 50–97. doi: 10.1002/9781119210856.ch3.

[23] K. Varma, F. Husic, and M. C. Linn, “Targeted Support for Using Technology-Enhanced Science Inquiry Modules,” *J. Sci. Educ. Technol.*, vol. 17, no. 4, pp. 341–356, 2008.