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Overview of ABET Accreditation from the Perspective of Two-Year Programs

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Abstract: Measuring the quality of education delivered by higher education institutions is an important indicator in presenting the value of degree-granting units to the external world. Accreditation authorization, known as the review and endorsement procedure of this quality measurement process, is handled by a number of accrediting bodies. In the U.S., ABET, a non-profit, non-governmental body with ISO 9001:2015 certification, is recognized as a leading organization accrediting higher education degree programs in the STEM field worldwide. This paper aims to provide an in-depth overview of ABET accreditation from the perspective of two-year programs.

Keywords: ABET, Accreditation, ETAC, CHEA, ISO, Program, Criteria

1. Introduction

Accreditation is a quality review term used in higher education to analyze and endorse the colleges, universities, and programs in terms of their quality assurance and continuous improvement. The entire accreditation review process is handled by an external organization (accreditation body) and it is a lengthy process [1].

According to Wikipedia, an authoritative body that performs accreditation is called an accreditation body. The International Accreditation Forum (IAF) and International Laboratory Accreditation Cooperation (ILAC) provide international recognition to accreditation bodies. In addition, there are many internationally-recognized accreditation bodies approved by the IAF and ILAC [2].

In the U.S., higher education institutions seek regional accreditation to illustrate the institution's quality by maintaining their compliance with the standards and processes of the accreditation body. These bodies are recognized by the Council for Higher Education Accreditation (CHEA) [3]. In CHEA, regional accrediting organizations are classified into six geographical zones, and shown in Figure 1.

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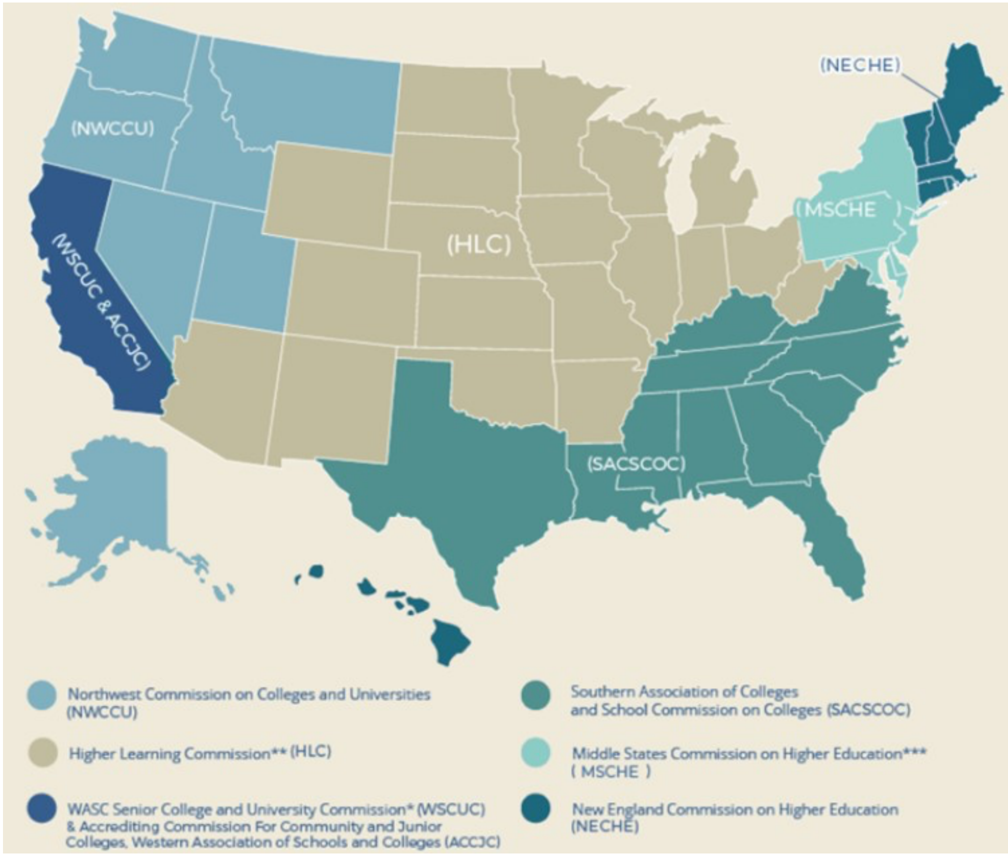

Fig. 1. Regional Accrediting Organizations in the U.S. (Courtesy of CHEA)

Internationally, there are a number of accreditation bodies. Some of the largest accreditation bodies are listed below [2]:

- The Emirates International Accreditation Centre (EIAC) in the Middle East
- The Pakistan National Accreditation Council (PNAC), National Accreditation Board for Testing and Calibration Laboratories (NABL), and Quality Council of India (QCI) in South Asia
- The China National Accreditation Board in East Asia
- The United Kingdom Accreditation Service (UKAS) in Europe
- The National Association of Testing Authorities (NATA) and the Joint Accreditation System of Australia and New Zealand (JAS-ANZ) in Oceania
- The South African National Accreditation System in Africa.

Most of the accreditation bodies use the international standards issued by the International Organization for Standardization (ISO). ISO is an independent, non-governmental, global organization with a membership of 167 national standardization bodies. Through its members, ISO brings together experts to share knowledge and develop voluntary, consensus-based, market-relevant international standards that support innovation and provide solutions to all global challenges [4].

There are agreements between accreditation bodies in their signatory countries and regions to recognize the programs accredited by these accreditation bodies as substantial equivalent for engineering and engineering technology programs. For example, the Washington Accord, the Sydney Accord, and the Dublin Accord focus on engineering and engineering technology programs.

The Washington Accord is an international accreditation agreement for undergraduate professional engineering academic degrees between the bodies responsible for accreditation in signatory countries and regions. Established in 1989, the full signatories as of 2020 are Australia, Canada, China, Costa Rica, Hong Kong, India, Ireland, Japan, Korea, Malaysia, New Zealand, Pakistan, Peru, Philippines, Russia, Singapore, South Africa, Sri Lanka, Taiwan, Turkey, the United Kingdom and the United States [5]. Another agreement is the Sydney Accord. The Sydney Accord is an agreement between the bodies responsible for accrediting engineering technologist qualification programs in each of the signatory countries. It recognizes the substantial equivalency of programs accredited by those bodies and recommends that graduates of accredited programs in any of the signatory countries be recognized by the other countries as having met the academic requirements for entry to the practice of engineering technologist [6].

In 2002, the national engineering organizations of Ireland, the United Kingdom, South Africa, and Canada signed an agreement that mutually recognizes the qualifications which underpin the granting of Engineering Technician titles in the four countries. The Dublin Accord is similar in operation to the Washington and Sydney Accords [7].

When we examine the accreditation process for Engineering, Engineering Technology, Applied/Natural Science, and Computing accreditation, the only internationally known and accepted quality authorization organization is ABET. ABET is a U.S. non-profit, non-government accreditation body. Although this organization is very well known for its bachelor of science degree accreditation, there is very little information about its coverage and services for the two-year degree programs. This paper presents the latest information about the ABET accreditation for two-year degree programs in engineering technology, applied/natural science, and computing.

2. ABET Accreditation Overview

Accreditation in higher education is a collegial peer-review process that occurs periodically. There are two types of accreditations, institutional-based and program-based. In general, institutional-based accreditation focus on faculty and student success [3]. Depending on the program's discipline, programs can also be accredited by national accreditation agencies such as ABET. ABET is a non-profit, non-governmental agency that accredits programs in natural science, computing, engineering, and engineering technology [8]. More than 2,200 academic, government, and industry volunteers participate in the accreditation activities. Volunteers go through extensive training on accreditation and are appointed by member societies. An ABET accreditation provides quality assurance that the program prepares graduates who meet the needs of the applicable profession. In addition, the review process verifies that students' education experience meets the global standard for technical education in the profession.

The accreditation activities of ABET are carried out by four different commissions: Applied and Natural Science Accreditation Commission (ANSAC), Computing Accreditation Commission (CAC), Engineering Accreditation Commission (EAC), and Engineering Technology Accreditation Commission (ETAC). ABET accredits Associate, Bachelor, and

Master level programs among the four commissions. ETAC was the first commission to accredit at the associate degree level (1947), followed by ANSAC (2000) and CAC (2019).

Seeking ABET accreditation is approximately a two-year process. This process includes a self-study report by the program, a peer review to gather evidence (accreditation visit), and a final judgment (accreditation action) by the commission on the accreditation status. The ABET accreditation process for a two-year associate degree program or a bachelor's degree program is the same. The accreditation review activities (peer review) are supported by volunteers from the related professional societies. The applicable professional society (member society) appoints volunteers to review the program's compliance with the criteria. The criteria are established and maintained by the professional community. There are differences between the requirements for an associate degree program and a bachelor's degree program. Details on these differences are described in the next section.

For students, there are many advantages to attending an ABET-accredited program [8]. In employment, ABET accreditation enhances employment opportunities within the country and internationally. Graduation from an ABET-accredited program is a minimum qualification for some licensure, registration, and certification. On the financial front, accreditation, both at the institution and program level, establishes students' eligibility for many federal student loans, grants, and scholarships [9]. In 2022, among the class of 2020, 55% of bachelor's degree recipients received student loans. ABET accreditation establishes students' eligibility for many federal student loans, grants, and scholarships. Many students earn their associate degree from an ABET-accredited program in transfer credits and then transfer to a bachelor's degree program. Although institutions have their guidelines for transfer credits, courses from ABET-accredited programs are often accepted as applicable for meeting degree requirements at the four-year level in a similar program.

ABET accreditation adds value to the program by ensuring that the program has met standards essential to prepare graduates to enter critical STEM fields in the global workforce. Two-year colleges serve a broad audience, from those seeking a traditional transfer program to a four-year institution, through the completion of associates in science or arts, to those looking for specialized courses or training that will lead to a job. Companies looking for the labor force needed to meet their needs will seek partnerships with two-year colleges because of their ability to adapt the curriculum to the company's needs. In return, companies will provide equipment or funding and assist the students in the program. For example, John Deere has several technician training partnerships with two-year colleges across the country. According to Georgetown University's Center on Education and Workforce, these middle-skill jobs are just some of the 16 million openings needed to be filled by 2024. These jobs require more than a high school diploma but not a bachelor's degree, and a two-year college is a place to meet those needs [10].

Two-year colleges in many states are also closely associated with career centers that offer education in the trades, both at the secondary and post-secondary levels. Two-year colleges are uniquely qualified to fill the skills gap with specialized training and coursework needed to meet the demands of employers. These agreements put two-year schools in a position to provide stackable credentials; a participant can take the minimum number of courses required to earn a certificate, leading to an entry-level position. From this point, students can expand their education with additional certificates or degrees, providing lateral mobility both in skills and financial rewards. The need to meet the demands of employers has inspired states like Tennessee and South Carolina to spend millions of dollars on improving their career technical programs and in the case of South Carolina, provide tuition-free enrollment into high-demand occupations. Employers need well-prepared workers and rely on an organization such as ABET to ensure that programs prepare graduates to be productive employees is beneficial for all involved [11][12].

3. ABET Accreditation Criteria

There are two sets of criteria that ABET-accredited programs must satisfy: General Criteria and Program Criteria.

General Criteria apply to all programs accredited by the applicable ABET commission. Each of these eight General Criteria must be satisfied:

1. Students (*) – This criterion deals with student enrollment, performance, progress, advisement, and graduation.

2. Program Educational Objectives (*) – Program educational objectives are broad statements that describe what graduates are expected to attain within a few years after graduation. Program educational objectives are based on the needs of the program's constituencies.

3. Student Outcomes (**) – Student outcomes describe what students are expected to know and be able to do by the time of graduation. These relate to the knowledge, skills, and behaviors students acquire as they progress through the program.

4. Continuous Improvement (*) – This criterion deals with the attainment of student outcomes using documented continuous improvement processes.

5. Curriculum (**) – This criterion deals with curricular topics that combine technical, professional, and general education components to support student outcomes but do not prescribe courses.

6. Faculty (**) – This criterion deals with the competence of the faculty, the sufficiency of their student interaction and advisement, and their ability to improve the program.

7. Facilities (*) – This criterion deals with classrooms, libraries, offices, laboratories, tools, computing resources, and associated equipment to support the attainment of the student outcomes and to provide an atmosphere conducive to learning.

8. Institutional Support (*) – This criterion deals with institutional services, financial support, and staff needed to meet program needs.

* = Harmonized General Criteria – These criteria are identical in language across all four of ABET's accreditation commissions.

** = Commission Specific (Non-Harmonized) General Criteria – These criteria are unique to each ABET Commission and contain language differentiating associates from baccalaureate programs from master's programs.

Program Criteria address discipline-specific requirements within areas of specialization. These criteria have been developed by ABET member societies and the commissions. Each commission has a different set of Program Criteria contained in each commission's criteria document posted on the ABET website [13]. Therefore, program Criteria are not written for every discipline.

In addition to the General Criteria and Program Criteria, all programs must adhere to the requirements in the ABET Accreditation Policy and Procedure Manual (APPM) [14].

For Two-Year (Associate) programs, the Program Criteria may add additional elements to the Curriculum and Faculty requirements specified in the General Criteria.

In ETAC, which accredits most of the associate programs under ABET, there are currently 24 Program Criteria [15].

Those Program Criteria are used in conjunction with the ETAC General Criteria to accredit 231 programs worldwide. Programs that do not align with any of the current Program Criteria may use the General Criteria only [16].

Table 1 lists the Lead and Cooperating Societ(ies) for each ETAC Program Criteria.

Table 1: Lead and Cooperating Societ(ies) for each of the ETAC Program Criteria

ETAC Program Criteria	Lead Societ(ies)	Cooperating Societ(ies)
Aeronautical Engineering Technology	AIAA	
Air Conditioning, Refrigerating, Heating, and Ventilating Engineering Technology	ASHRAE	
Architectural Engineering Technology	ASCE	
Automotive Engineering Technology	SAE	
Chemical/Refinery Process Engineering Technology	AIChE	
Civil Engineering Technology	ASCE	
Computer Engineering Technology	IEEE	IISE
Construction Engineering Technology	ASCE	
Construction Management Technology (NEW, under public review)	CMAA	
Electrical and Electronics Engineering Technology	IEEE	

Electromechanical Engineering Technology	IEEE	ASME, ISA
Engineering Graphics/Design/Drafting Engineering Technology	ASME	SME
Engineering Technology	ASEE	
Environmental Engineering Technology	AAEES	AIChE, ASCE, ASHRAE, ASME, SAE, SMME
Fire Protection Engineering Technology	SFPE	
Healthcare Engineering Technology	AAMI	ACS, AIChE, ASABE, ASME, IEEE
Industrial Engineering Technology	IISE	
Information, Information Security, Cybersecurity, Information Assurance Engineering Technology	IEEE	CSAB
Instrumentation and Control Systems Engineering Technology	ISA	
Manufacturing Engineering Technology	SME	
Marine Engineering Technology	SNAME	
Mechanical Engineering Technology	ASME	

Mechatronics Engineering Technology (NEW, under public review)	ASME, IEEE, SME	
Nuclear Engineering Technology	ANS	
Surveying and Geomatics Engineering Technology	NSPS	ASCE
Telecommunications Engineering Technology	IEEE	

Figure 2 shows how the 231 ETAC accredited associate degree programs align with the current 24 ETAC Program Criteria. The Electrical and Electronics Engineering Technology (EET) and Mechanical Engineering Technology (MET) Program Criteria account for more than half the ETAC accredited programs. Six other Program Criteria (Civil ET, Computer E.T., Construction E.T., Architectural E.T., Surveying and Geomatics E.T., and Engineering Technology) account for another 30% of programs. The other 15 Program Criteria account for 14% of the programs. The remaining 5% of the programs use General Criteria only.

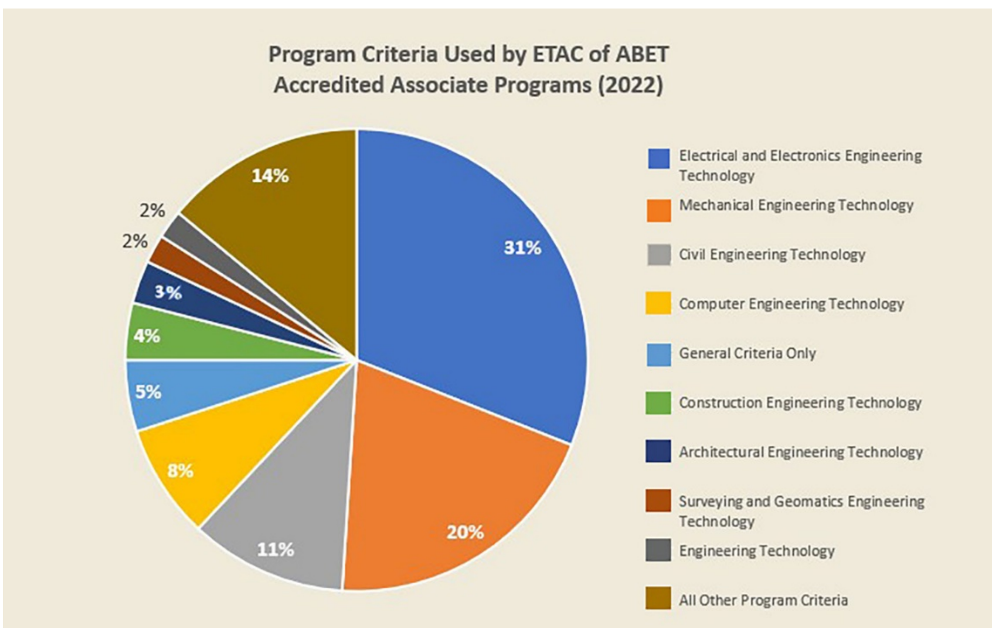

Fig. 2. ETAC accredited associate degree programs aligned with the Program Criteria

The key differences between the criteria for associate and baccalaureate programs in ETAC can be summarized in Table 2.

Table 2: Criteria Differences between Associate and Baccalaureate Programs

ETAC Criteria	**Associate**	**Baccalaureate**
3. Student Outcomes	Design **solutions** for, communicate and solve **well-defined** engineering problems Analyze and interpret test results Serve as a **member** of a technical team.	Design **systems** for, communicate and solve **broadly-defined** engineering problems Analyze and interpret test results **to improve processes** **Lead** a technical team
5. Curriculum	Math: Application of algebra and trigonometry	Math: Application of integral and differential calculus or other mathematics above the level of algebra and trigonometry Integration of Content: Provide a capstone or other integrating experience that develops student competencies in applying technical and nontechnical skills to solve problems.
Program Criteria	Curriculum elements added for **associate** programs.	Curriculum elements added for **baccalaureate** programs.

The processes for adding new or modifying existing General Criteria or Program Criteria are specified in the APPM. Suggestions for new or modified Program Criteria are submitted to a Lead, Co-Lead, or Cooperating Society assigned to that programmatic area. Changes are further divided into substantive changes (a new criterion or a revision to an existing criterion that modifies its prior meaning) and non-substantive changes (which do not modify the prior meaning of a criterion and is normally intended to improve clarity, structural consistency, syntax, or typography).

The process for determining the Lead, Co-Lead, and Cooperating Societ(ies) for new Program Criteria starts with the Criteria Committee. Societies submit position papers documenting their interest. Recommendations on lead, co-lead and cooperating societ(ies) by the Criteria Committee are based on analysis of the position papers, including alignment with the societies' curricular area strengths, membership involvement and expertise, publications, and other justification for the level of participation the societies have requested. The Criteria Committee also surveys existing programs to assess whether existing criteria can be used or modified instead. For designation as lead or co-lead, a technical curricular contribution from the society should be at least 1/3 of curricular content. Journals and conferences sponsored by the community, directly related to the programmatic area, and member data for those working in the programmatic area are also considered. Multi-disciplinary programs such as Mechatronics Engineering Technology may require more than one lead society. ETAC prefers no more than two societies designated as lead or co-lead, so the Program Criteria generation and update process is not unwieldy.

For new Program Criteria, the rationale should include letters of endorsement from a sampling of potential constituent programs. Once the proposed new or changed criteria are reviewed and approved by the appropriate bodies (the lead, co-lead, and cooperating societies, the sponsoring ABET Commission, and its Area Delegation), the proposed criteria are published on the ABET website for a period of public review and comment. During the review and comment period, proposed criteria will be published in the "Proposed Criteria" section of the appropriate criteria document. In addition, public comments are passed to the Criteria Committee of the sponsoring ABET Commission and reviewed with the Lead, Co-Lead, and Cooperating Societies. Finally, changes are incorporated into the proposed criteria and re-published on the ABET website for incorporation in the next available accreditation cycle [17].

In ETAC, there are currently two new and one substantive change to Program Criteria posted on the ABET website for public comment:

- Construction Management Technology (Lead Society: CMAA)
- Industrial Engineering Technology (Lead Society: IIISE)
- Mechatronics Engineering Technology (Lead Societies: ASME, IEEE, SME)

4. ABET Accreditation Cycle

The ABET accreditation process starts in January, with the program submitting a "Request for Evaluation" (RFE). In addition, already accredited programs must submit a copy of a transcript to ABET with the program's name. New programs seeking accreditation must have had at least one graduate in the previous academic year. Figure 3 shows the timeline of a typical General Review Evaluation (GRE).

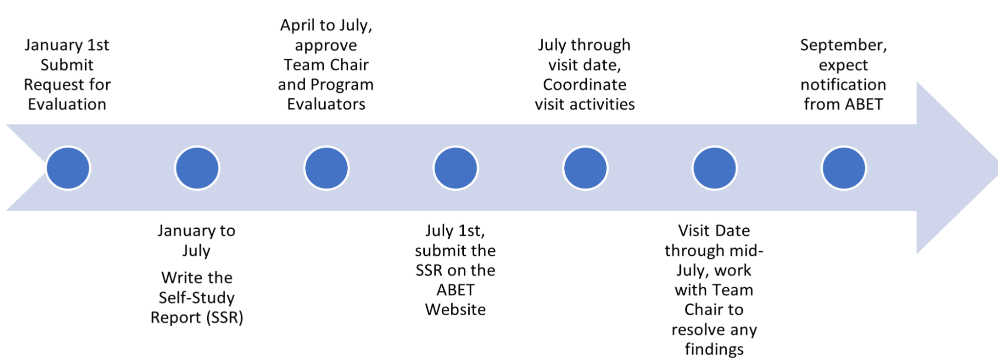

Fig. 3. Timeline of a typical ABET Accreditation Cycle's Timeline

The review process for an associate degree is the same as bachelors' degree programs. Still, there are differences in the criteria, such as student outcomes, the required curriculum, and the Program Criteria, if applicable, as it was highlighted in Table 2. There are some programs that do not have specific Program Criteria; in those cases, they are evaluated under the General Criteria.

As stated earlier, having an accredited program can be beneficial for associate degree programs that are working closely with the industry to meet their needs for middle-skill or technician level positions. The ABET criteria are flexible enough to meet the local industry requirements, even in the case of Program Criteria, but the employer must be part of the process. When it comes to participation on the industrial advisory council (IAC) for a program, those employers that hire graduates need to have a seat on the IAC and be active participants. During an accreditation review, program evaluators look for evidence demonstrating active participation of the IAC in the program's curriculum and educational objectives.

ABET accreditation is based on a six-year cycle. Programs are re-accredited once every six years with the same accreditation filing steps presented in Figure 3. If the programs face difficulties satisfying some criteria, shortcomings at different quality levels may be cited. Through an interim review, programs usually fix these shortcomings within two years (either a report or visit).

Associate degree graduates can go directly into the workplace, but those seeking to continue their education can do so by attending a four-year institution with programs that provide the next two years. In many states, only graduates from four-year ABET-accredited programs can sit for the Fundamental of Engineering (F.E.) Exam, the first step in the process of being licensed as a Professional Engineer (PE).

5. Current Statistics of the Accredited Associate Degree Programs in ABET

As indicated before, ABET is the recognized U.S. accreditation organization and also provides leadership internationally through memoranda of understanding and mutual recognition agreements, such as the Washington Accord and Dublin Accord. ABET evaluates programs offered in a 100-percent online format too [18][19].

The accreditation of these programs occurs all over the world, not only in the U.S. As of January 30, 2022, 4,361 programs are accredited, distributed over 850 institutions in 41 countries. This represents an increase of 54 programs and four institutions over 2020. Based on this data, 3382 programs and 653 institutions are located in the U.S. while 979 programs and 197 institutions are outside of the U.S. [20].

As of January 30, 2022, there are 240 accredited associate programs in 92 institutions in 7 countries. Figure 4 presents the geographic distribution of these seven countries. Two of these programs are accredited by the CAC. Seven of them are accredited by the ANSAC. The remaining 231 of them are accredited by the ETAC. The states with the ABET accredited associate degree programs are shown in Figure 5.

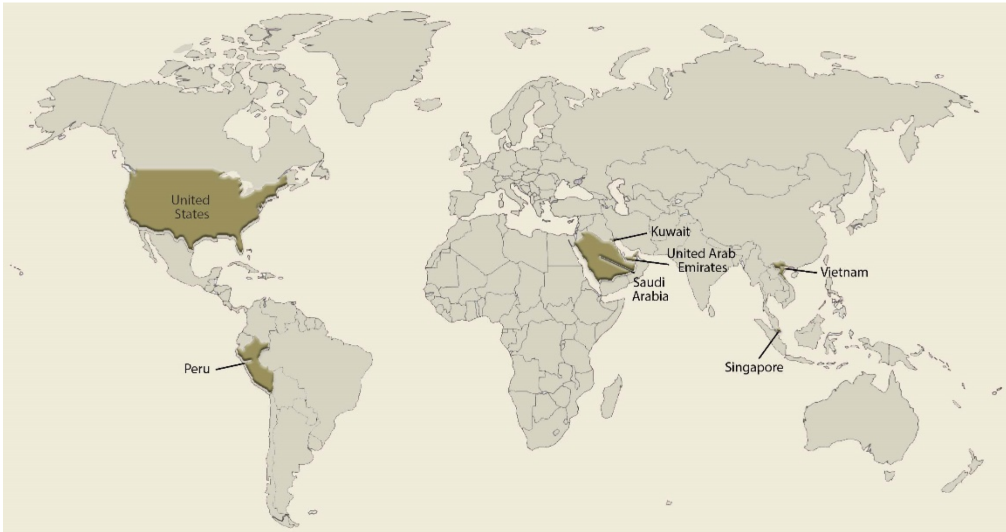

Fig. 4. Countries with ABET accredited associate degree programs

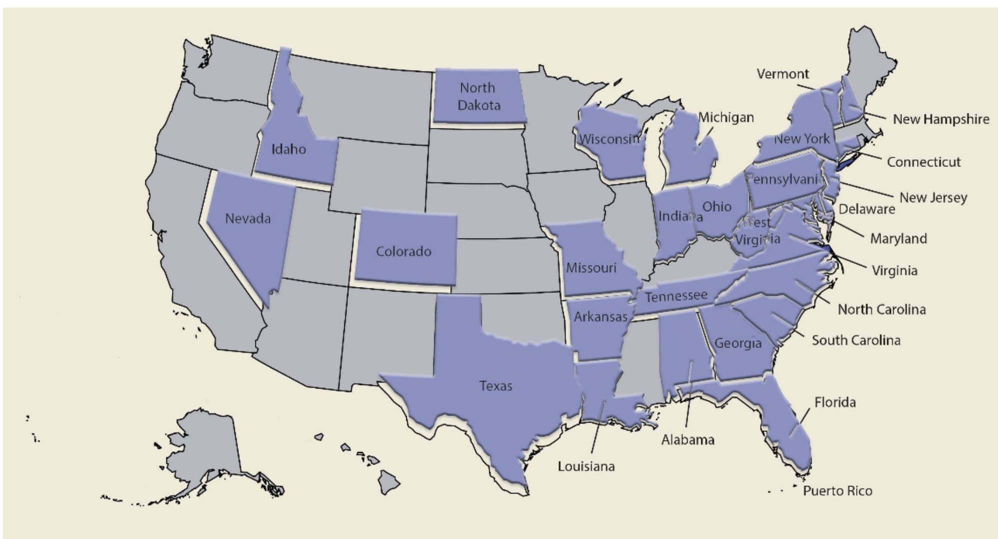

Fig. 5. States with ABET accredited associate degree programs in the U.S.

The table in Appendix A presents the latest statistics of ABET accredited associate degree programs. The data have been gathered using the ABET Accredited Programs [21].

6. Highlights from The ABET Accredited Programs

In this section of the article, readers will find some key points from several different community colleges, not only from the U.S. but also from some other nations, presenting their experiences with ABET.

Houston Community College, Texas, has kept its AAS (Associate in Applied Science) degree in Electronics Engineering Technology accredited by the ETAC of ABET since 1983 [22]. The program faculty, staff, and college administrators have been committed to delivering an educational program that meets the highest criteria required by industry and the ETAC of

ABET. The program's director indicates that "Students who enroll in our program can rest assured that they are receiving the highest standard of education provided by a program that has been thoroughly vetted for its quality and validity." [23].

At Hudson Valley Community College, New York, degree programs in Civil Engineering Technology, Electrical Engineering Technology, and Mechanical Engineering Technology have been accredited by ETAC of ABET since 1970 [24]. The school dean indicates that "The reaccreditation of these three programs speaks to the high academic standards we set for our graduates. We have consistently maintained programs that fully prepare graduates for their chosen careers." [25].

At Southwest Tennessee Community College, located in Memphis, Tennessee, Engineering Technologies Division offers four AAS degrees in Architectural Engineering Technology, Computer Engineering Technology, Electronic Engineering Technology, and Mechanical Engineering Technology accredited by the ETAC of ABET. Computer Engineering Technology Program has been accredited since 1978, although the other three have been accredited since 1971 [26]. All programs are regularly reviewed to ensure that the region's employment needs are being met. The program administrators anticipate that new and modified programs and certificates will be added to their college as the community's needs are assessed [27].

In Saudi Arabia, Jubail Industrial College has six A.S. programs that have held ABET accreditation since 2012 (Chemical Engineering Technology, Electrical Power Engineering Technology, Instrumentation and Control Engineering Technology, Manufacturing Engineering Technology, Mechanical Maintenance Engineering Technology, and Polymer Engineering Technology), plus Non-Destructive Testing and Evaluation Engineering Technology since 2015. Jubail Industrial College is the largest and most sophisticated technical institute governed by the Board of Directors of the Royal Commission in Saudi Arabia [28][29]. Jubail Industrial College is an outstanding example of how relevant modern education, in support of technology, transforms a rural society into a modern, vibrant one. It is a successful example of how, within a couple of decades, planned industrial and educational developments can work hand in hand [30].

Another college named Yanbu Industrial College in Saudi Arabia has six accredited AS degree programs accredited by the ETAC of ABET for almost 15 years [31][32]. The ABET accredited workforce education at Yanbu Industrial College helped the city grow the initial investments from industrial developers in the city to a current all-time high of more than 14 billion dollars. In almost twenty years, the College has become one of the major sources of manpower for the local economy, propelling Yanbu's industrial sector to becoming a major contributor to the nation's development [33].

7. Conclusion

The accreditation process can measure the quality of an associate degree program. ABET is one of the major accreditation bodies that accredit associate degree programs in the STEM field. There are few differences in the ABET accreditation process between a bachelor's degree and an associate degree program except for criteria, where there are different criteria for each degree program. As outlined in the criteria section and the accreditation cycle section, preparing for an accreditation visit can be a lengthy and resource-intensive process. However, there are significant advantages to students attending ABET-accredited programs, and there are advantages for programs seeking accreditation. This unique paper presents the accreditation process for the two-year programs without detailing all its benefits. The authors plan future studies to investigate the impact of accreditation.

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Disclosures

The authors declare no conflicts of interest. The opinions expressed are the authors' own and do not represent ABET's position on any issue.

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Appendix A: ABET accredited associate degree programs

School Name	City	State	Country	# of Programs	Accrediting Commission
Abu Dhabi Polytechnic	Abu Dhabi		United Arab Emirates	1	ETAC
Vaughn College of Aeronautics and Technology	Flushing	New York	United States	2	
Alfred State College	Alfred	New York	United States	5	
American College of the Middle East	Kuwait		Kuwait	4	
University of Arkansas at Little Rock	Little Rock	Arkansas	United States	2	
Augusta Technical College	Augusta	Georgia	United States	2	
Austin Peay State University	Clarksville	Tennessee	United States	3	
Bismarck State College	Bismarck	North Dakota	United States	1	
Bluefield State College	Bluefield	West Virginia	United States	3	
BridgeValley Community and Technical College	South Charleston	West Virginia	United States	3	
SUNY Broome Community College	Binghamton	New York	United States	3	
Rowan College at Burlington County	Mount Laurel	New Jersey	United States	2	
Cao Thang Technical College	Ho Chi Minh		Vietnam	2	
Central Ohio Technical College	Newark	Ohio	United States	4	
Central Piedmont Community College	Charlotte	North Carolina	United States	5	
Chattanooga State Community College	Chattanooga	Tennessee	United States	3	
Cincinnati State Technical and Community College	Cincinnati	Ohio	United States	1	
College of Technological Studies	Shuwaikh		Kuwait	11	
Columbus State Community College	Columbus	Ohio	United States	1	
Cuyahoga Community College, Metropolitan	Cleveland	Ohio	United States	4	
Georgia Piedmont Technical College	Clarkston	Georgia	United States	2	
Delaware Technical & Community College, Stanton	Newark	Delaware	United States	1	
Delgado Community College	New Orleans	Louisiana	United States	1	
Denmark Technical College	Denmark	South Carolina	United States	1	
Erie Community College, North Campus	Williamsville	New York	United States	4	
Essex County College	Newark	New Jersey	United States	3	
Universidad del Este	Carolina	Puerto Rico	United States	3	
Fairmont State University	Fairmont	West Virginia	United States	3	
Ferris State University	Big Rapids	Michigan	United States	2	
Gaston College	Dallas	North Carolina	United States	3	

Greenville Technical College	Greenville	South Carolina	United States	5	
The Higher Institute of Telecommunication & Navigation			Kuwait	4	
Houston Community College	Houston	Texas	United States	1	
Hudson Valley Community College	Troy	New York	United States	3	
Idaho State University	Pocatello	Idaho	United States	6	
ISIL	Lima		Peru	1	
Ivy Tech Community College, Bloomington	Bloomingto n	Indiana	United States	1	
Ivy Tech Community College, Columbus	Columbus	Indiana	United States	2	
Ivy Tech Community College, Fort Wayne	Fort Wayne	Indiana	United States	3	
Ivy Tech Community College, Indianapolis	Indianapoli s	Indiana	United States	2	
James A. Rhodes State College	Lima	Ohio	United States	2	
Jubail Industrial College	Jubail Industrial City		Saudi Arabia	7	
Kent State University, Tuscarawas Campus	New Philadelphi a	Ohio	United States	2	
Lorain County Community College	Elyria	Ohio	United States	2	
Southwest Tennessee Community College	Memphis	Tennessee	United States	4	
Miami University	Oxford	Ohio	United States	2	
Middlesex County College	Edison	New Jersey	United States	3	
Midlands Technical College	Columbia	South Carolina	United States	3	
Mohawk Valley Community College	Utica	New York	United States	3	
Monroe Community College	Rochester	New York	United States	1	
County College of Morris	Randolph	New Jersey	United States	2	
Morrison Institute of Technology	Morrison	Illinois	United States	1	
Zane State College	Zanesville	Ohio	United States	1	
Nashua Community College	Nashua	New Hampshire	United States	1	
Nassau Community College	Garden City	New York	United States	2	
Naugatuck Valley Community College	Waterbury	Connecticu t	United States	2	
NHTI-Concord's Community College	Concord	New Hampshire	United States	4	
State University of New York College of Technology at Canton	Canton	New York	United States	4	
State University of New York at Morrisville	Morrisville	New York	United States	1	
New York City College of Technology	Brooklyn	New York	United States	5	
State University of New York, College of Environmental Science and Forestry	Syracuse	New York	United States	1	

City University of New York, Bronx Community College	Bronx	New York	United States	1	
City University of New York, Queensborough Community College	Bayside	New York	United States	3	
Northeast Wisconsin Technical College	Green Bay	Wisconsin	United States	1	
Calhoun Technical College	Orangeburg	South Carolina	United States	1	
Paul Smith's College	Paul Smiths	New York	United States	1	
Pennsylvania College of Technology	Williamspo rt	Pennsylvan ia	United States	3	
Pennsylvania State University	University Park	Pennsylvan ia	United States	6	
Piedmont Technical College	Greenwood	South Carolina	United States	2	
University of Puerto Rico at Bayamon	Bayamon	Puerto Rico	United States	4	
University of Puerto Rico at Humacao	Humacao	Puerto Rico	United States	1	
University of Puerto Rico at Ponce	Ponce	Puerto Rico	United States	3	
Purdue University Fort Wayne	Fort Wayne	Indiana	United States	3	
Savannah Technical College	Savannah	Georgia	United States	1	
Sinclair College	Dayton	Ohio	United States	7	
College of Southern Nevada	North Las Vegas	Nevada	United States	2	
Spartanburg Community College	Spartanburg	South Carolina	United States	1	
St. Louis Community College at Florissant Valley	St. Louis	Missouri	United States	1	
Stark State College of Technology	North Canton	Ohio	United States	3	
Vermont Technical College	Randolph Center	Vermont	United States	5	
Waukesha County Technical College	Pewaukee	Wisconsin	United States	2	
The University of West Alabama	Livingston	Alabama	United States	1	
Yanbu Industrial College	Yanbu Al-Sinaiyah		Saudi Arabia	6	
York Technical College	Rock Hill	South Carolina	United States	4	
Youngstown State University	Youngstow n	Ohio	United States	3	
The University of Akron	Akron	Ohio	United States	2	ANSAC
Chattanooga State Community College	Chattanoog a	Tennessee	United States	1	
Embry-Riddle Aeronautical University - Worldwide	Daytona Beach	Florida	United States	1	
Ngee Ann Polytechnic			Singapore	1	
Temasek Polytechnic			Singapore	1	
Trinidad State Junior College	Trinidad	Colorado	United States	1	
Anne Arundel Community College	Arnold	Maryland	United States	1	CAC
Lord Fairfax Community College	Middletown	Virginia	United States	1	

ASSESSMENT OF THE EFFECTIVENESS OF USING DRONES FOR SMART MANUFACTURING EDUCATION

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Abstract: Recently, drones have become a useful tool in training and practicing the core of industry 4.0 for applications ranging from machine diagnostics to surveillance and detection of air leaks. In this work, train-the-trainer workshops were organized to train primarily STEM educators from Two-year higher education and secondary education institutions on Smart Manufacturing (SM) technologies. The hands-on activities during these workshops included assembling and coding drones. Four workshops were held between 2019 and 2021 with 114 participants from 20 states across the United States. The workshops included research, industry speakers, and hands-on activities with assembling and coding drones with Arduino, Python, or Blockly. The effectiveness of using drones for training in SM workshops was evaluated using retrospective surveys. Most participants reported that their knowledge of coding and smart manufacturing increased and that the knowledge gained from the workshops is applicable to their work. In addition, using statistical tools, 7,182 students ± 1,903 were exposed to the smart manufacturing concepts using drones six months after the workshops with a confidence level of 90%.

Keywords: Smart Manufacturing, Train-the-trainer workshops, Drones

1. Introduction

In the past 15 years, unmanned aerial vehicles (UAVs), more commonly known as drones, have grown from radio frequency (RF)-based drones that cannot go out of visible range to drones that can sense danger using their integrated vision systems, laser range finders, and other wireless communication capabilities [1,2]. These developments have allowed drones to be used in various industries, including agriculture, logistics, manufacturing, mail carriers, and education [1]. In addition, drones can effectively be used in Search and Rescue (SAR) operations in the aftermath of disasters such as hurricanes, explosions, and earthquakes in a timely and efficient manner [3,4]. UAVs have also found applications in mapping and observations [5,6], inspecting buildings and bridges [7,6], logistics [8,6], maneuvering around building sights [9,6], and exploring harsh environments unfit for humans [10].

The outbreak of COVID-19 has resulted in significant societal, industrial, and educational impacts that will last for generations [11,12]. Concerning the drone industry, the COVID-19 pandemic inspired the application of aerial thermal imaging to locate individuals in crowds that may exhibit covid-like symptoms, especially fevers. UAVs equipped with thermal imaging infrared cameras that detect COVID-19 are called Thermal Corona Combat Drones (TCCD). These TCCDs consist of an infrared thermal imaging camera to locate individuals with fever symptoms as well as cameras connected to Artificial Intelligence (AI)-enabled systems that aid in locating individuals via facial recognition [13].

Despite the exploding applications of drones, the utilization of UAVs indoors has been limited due to potential safety hazards. However, with recent developments allowing visually aided navigation, precise awareness sensors, and more precise attitude control, drones are safer than ever to use indoors [14]. Consequently, drones have found many indoor applications such as performing light-weight part and material delivery between workstations in manufacturing plants [15], detecting problems in manufacturing equipment [16], conducting routine inspections in areas that are difficult to reach [10], detecting gas leaks, overheating machinery, and fire [10,16], and providing surveillance of manufacturing facilities [10].

As a result, using drones in education has rapidly increased in the recent decade, such as in coding and programming education [17], robotics education [18], sustainable development and environment [19], and multidisciplinary projects [20]. However, the full potential of using drones in education has not yet been fully realized [19].

"Industry 4.0" came to describe the fourth industrial revolution [21], which primarily relies on technologies based on artificial intelligence (AI). In the United States, Industry 4.0 is more commonly known as Smart Manufacturing (SM) [21,22]. Some of the technologies of SM include intelligent industrial robotics [23], additive manufacturing, industrial internet of things (IIOT) [22,24], and the use of unmanned aerial vehicles (UAVs). The goal of this generation of industry is to be primarily driven by AI and to be made up of versatile machines that provide a more efficient and variable workspace [25].

Recent advances in UAVs include using Artificial Intelligence (AI)-based algorithms for object identification, path planning, and determining traffic movement which allow for them to safely navigate through a manufacturing plant, where there is significant mobility of machines and people [26]. Furthermore, swarm intelligence allows for swarms of robotic drones to be used in these situations to aid in the process. Next-generation Swarm Intelligence (SI) can significantly revolutionize the use of drones in everyday applications. SI is inspired by insects such as bees and ants that naturally coordinate to accomplish tasks that otherwise would not be possible to accomplish alone [27]. All these advances increase the demand for next-generation technicians that are knowledgeable in programming and running drones.

Despite that increased demand, no program exists that provides training for using drones in the manufacturing industry. To answer the need for incorporating drones in advanced manufacturing education, train-the-trainer workshops were developed that included four components: speakers from industry, speakers on the latest advances in scientific research in the field, industry tours, and hands-on training on coding drones. Details on the contents of the workshops are described in reference [28]. The workshops were funded by the National Science Foundation's Advanced Technological Education program. In this work, we only investigate the effectiveness of one component of these train-the-trainer workshops, which is using coded drones for smart manufacturing education.

2. Methodology and Approach

Train-the-trainer workshops were carried out over three years, from 2019 to 2021. These workshops targeted educators from Science, Technology, Engineering, and Mathematics (STEM) backgrounds, from secondary education to two-year higher-education institutions. The first two workshops were offered on-ground in Smyrna, Tennessee (see Fig. 1) and in

Farmington, Connecticut, in the summer of 2019. Two more workshops were offered virtually in December 2020 and July 2021 to accommodate COVID-19 safety precautions; as previously noted, workshop contents are detailed in reference [28]. Each of the summer 2019 workshops included an industry tour to demonstrate real-world applications of SM to the participants.

The workshops included training with Arduino-coded drones, lectures, and invited speakers from research and industry. Each of the participants received an Arduino/Python coded Codrone Pro kit. The two-day workshop included hands-on training for participants to build the drones and write Arduino codes to fly the drone. At the end of the workshop, participants were given a post-workshop evaluation survey to measure the effectiveness of the workshops. The survey was voluntary in compliance with federal regulations; 105 out of the 114 (92%) participants completed the survey.

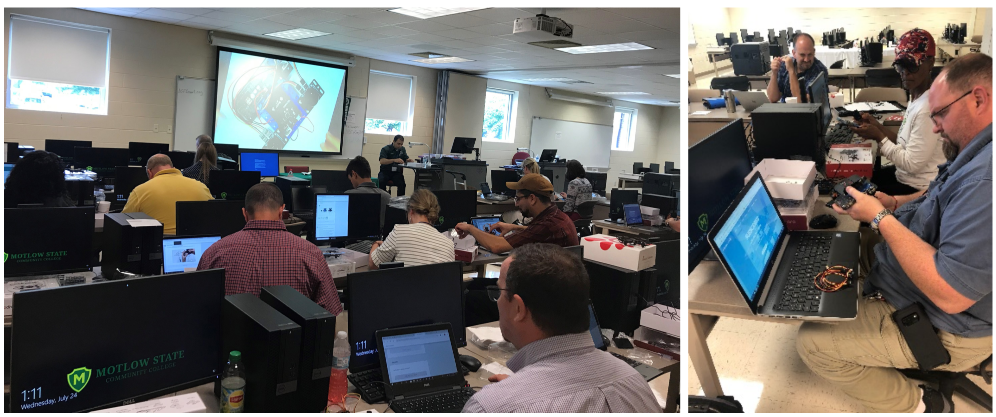

Fig. 1. Photos from the Second on-ground Smart Manufacturing Workshop in Smyrna, TN, July 2019

3. Results and Discussion

The Arduino-coded drones used in training can potentially be used to train students on numerous applications in the manufacturing industry, such as material transportation, inventory monitoring, production line observations, monitoring of confined and restricted spaces, and simple pick-and-place operations.

The effectiveness and overall impact of using drones was assessed in the workshops. Data were collected through three instruments:

- Pre-workshop application forms that include voluntary demographic data
- Post-Workshop evaluation surveys
- Follow-up surveys were given to participants about six months after completing the workshops.

A total of 114 educators participated in the workshops, 36 participants in the 2019 on-ground workshops, and 39 in each of the two virtual workshops in 2021 and 2022. In the 2019 workshops, 83% of the participants who responded to the survey reported that they had a better general understanding of SM after the workshop. After the hands-on exercise where the participants built a Codrone Pro from a kit and wrote an Arduino-based code to fly the drone, 93% of the participants reported having a better understanding of coding. In addition, 97% reported that the information learned in the workshop would be useful in their work.

In the 2020 virtual workshop, 49% of the participants reported significantly improving their understanding of SM after the workshop and 77% of the participants stated that the information obtained would be useful in their STEM courses.

In the 2021 virtual workshop, 95% of the participants reported that they gained a stronger understanding of SM after the workshop and 87% reported that the knowledge attained in this workshop would be useful in their lecture and laboratory practices.

Overall, a significant majority of participants surveyed indicated a substantial improvement in their knowledge of SM and coding with drones. As part of the continuous improvement process of the workshops, some of the question statements were changed slightly from one workshop to another to ensure clarity and accuracy. A summary of the results of the surveys are shown in Table 1.

Table 1. Participant Ratings on Overall Workshop Experience.

Assessment Criterion	% Agree	% Neutral	% Disagree	Total
The time allotted for each session was sufficient.	87.6 % (92)	4.8 % (5)	7.6 % (8)	105
The training materials/handouts distributed were helpful.	86.7 % (91)	5.7 % (6)	7.6 % (8)	105
The objectives of the training were clearly defined.	84.9 % (90)	6.6% (7)	7.6 % (8)	105
The quality of instruction was exceptional.	85.6 % (89)	5.8% (6)	8.6% (9)	104
The training experience will be useful in my work.	88.5 % (92)	4.8% (5)	6.7% (7)	104

Some of the comments received for the open-ended question: "What is your major take-away from this workshop" include:

- "I will build the drone and look at the lessons. I want to adapt this for my Capstone Project course at a technical college."
- "[Learned] the how–to for the drone."
- "Smart Manufacturing and Drone Programming."
- "I would say that technician skills (from M. Barger presentation). And of course, very useful information to help incorporate drone programming into curriculum."

In order to assess the direct impact of the workshops on under-represented groups in engineering (Black, Hispanic, American Indian, and women) and on economically-disadvantaged populations, demographic data of the participants were collected, including race, sex, and highest degree achieved. The same demographic categories used by the U.S. Census Bureau to collect the data for the workshops. The demographic data of the workshop participants are shown in Table 2.

Table 2. Participant Demographics

Demographic Data	2019 (On-ground)	2020 (Virtual)	2021 (Virtual)	Total
Race/Ethnicity				
Black	3	5	4	12 (10.5%)
White	27	22	28	77 (67.5%)
Hispanic	2	1	0	3 (2.6 %)

Other	2	10	6	18 (15.8 %)
No Answer	2	1	1	4 (3.5 %)
Total	36	39	39	114 (100 %)
Sex/Gender				
Female	7	16	9	32 (28.1 %)
Male	29	20	28	77 (67.5 %)
No answer	0	3	2	5 (4.4 %)
Total	36	39	39	114 (100 %)
Highest Degree Earned:				
High School Degree	3	0	7	10 (8.8 %)
Associate Degree	1	3	6	10 (8.8 %)
Bachelor's Degree	6	3	4	13 (11.4 %)
Master's Degree	23	17	15	55 (48.2 %)
PhD/Doctoral Degree	3	16	7	26 (22.8 %)
Total	36	39	39	114 (100 %)

Most faculty with high school degrees as the highest achieved degree are located in remote areas and economically-disadvantaged regions. To increase their presence for the following workshop, we increased outreach activities to the economically-disadvantaged regions and far rural areas in the State of Tennessee. This effort helped in improving the participation of this category of participants during the 2021 virtual event.

One impact of the COVID-19 pandemic was to help the increase diversity of the participants after workshops switched to virtual. This was evident in the significant increase in participants from states other than Tennessee and Connecticut. Table 3 shows the distribution of participants by state.

Table 3. Workshop Participant Distribution by State

State	2019	2020	2021	Total
Tennessee	14 (38.9 %)	3 (7.7 %)	25 (64.1 %)	42 (36.8 %)
Connecticut	16 (44.4 %)	8 (20.5 %)	1 (2.6 %)	25 (21.9 %)
Other States	6 (16.7 %)	28 (71.8 %)	13 (33.3 %)	47 (41.2 %)
Total	36 (100 %)	39 (100 %)	39 (100 %)	114 (100 %)

Follow-up surveys were sent to the participants six months after completing the workshops to assess the long-term impact of the workshops. The primary focus of the surveys was to determine the extent to which the lessons learned in the workshop were integrated and/or implemented in the classrooms.

About 31% of participants in the first year responded to the six-month follow-up surveys (11 out of 36). Of the surveys answered, on average, 64% indicated that they started implementing the concepts learned in their classrooms, and 36% indicated that they have already integrated concepts learned in their classes. In addition, 82% of respondents indicated that they used the drones they received in the workshop in their classrooms. Implementations with the drones ranged from student demonstrations to teaching coding with the drones to fly through obstacles. On average, 63 students per instructor have been exposed to the Smart Manufacturing concepts using drones six months after the workshop.

By applying the rules of statistics to determine the margin of error for a population of 114 participants, it can be shown that we can state with a 90% confidence level that 82% of participants implemented or integrated the drones in their classrooms within six months of the workshop with a margin of error of ± 18.25%

The number of students per instructor exposed to the Smart Manufacturing concepts is 63 students per instructor with a 90% confidence level and a margin of error of ±26.5%
It should be noted that the margin of error here increased to ±26.5% due to the reduction in the sample size since only 82% of the 31% who responded to the six-month follow-up surveys indicated that they integrated the drones in their classrooms.

Therefore, we can estimate that 7,182 students ± 1,903 were exposed to the smart manufacturing concepts using drones six months after the workshops with a confidence level of 90%.

From the discussion above, we conclude that the hands-on activity with the drones was one of the significant components successfully implemented in the classrooms of participants, as evidenced from the results of the six-month follow-up surveys.

4. Conclusion

In this work, we investigated the effectiveness of drones as a hands-on training application for training on SM. The training took place through two-day workshops conducted over the period from 2019 to 2021. Although the first two workshops were on-ground and took place in the states of Tennessee and Connecticut, the workshops for 2020 and 2021 were switched to virtual mode after the outbreak of the COVID-19 pandemic. Assessment of the effectiveness of the workshops showed that the workshops significantly increased the knowledge of the participants in the SM field. Using statistical analysis, it was found that the total number of students that were exposed to Smart Manufacturing training using drones as a result of these workshops was 7,182 ± 1,903 students with 90% confidence.

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Disclosures
The authors declare no conflicts of interest.

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