

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 $\pm$ 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

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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 $\pm 18.25\%$

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 $\pm 26.5\%$. It should be noted that the margin of error here increased to $\pm 26.5\%$ 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 $7,182 \pm 1,903$ 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 $7,182 \pm 1,903$ students with 90% confidence.

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Disclosures

The authors declare no conflicts of interest.

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