Multi Institutional Collaboration in Additive Manufacturing: Lessons Learned

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Abstract

One of the fastest growing fields in the broad field of engineering is Additive Manufacturing (AM), also known as 3D Printing. AM is being used in many fields including, among others, design, STEM, construction, art, and healthcare. Many educational institutions however, do not have the requisite capacity and resources to effectively educate students in this area particularly when it comes to rapid transition from design to small-volume level production. A coalition of several higher education institutions under a National Science Foundation (NSF) funded Advanced Technological Education (ATE) Project has been working towards providing educators with the skills and material resources to effectively teach their students about 3D printing. The ultimate beneficiaries are high school and post-secondary students and include those in vocational fields. Before and during Fall 2019, Train the Trainer Studios (TTS) were conducted to train instructors, drawing participants from many institutions across neighboring states designed to provide hands-on instruction to participants. In addition, Massive Open Online Courses (MOOC) and webinars have also been made available to all participating instructors and other collaborators to openly share the information being generated through this ATE AM coalition. Evaluation of the TTS revealed many positive results, with the participants sharing many success stories after implementing the learned concepts at their institutions. From the evaluation findings, participants were largely satisfied with the delivery and quality of instruction they received from all the TTS presenters, with almost all of them, in all instances, indicating that the training they received would be useful in their programs. The current paper

and proposed presentation will report on the lessons learned through this process, including sharing some of the success stories from the instructors and their students.

Background

The far-reaching impact of AM on many industries has been essential to modern innovation and is continuing to expand [1]. The effects of AM, or 3D Printing as it is commonly known, can be seen in a variety of fields ranging from visual art to healthcare. Effective education programs designed to teach others about AM are vital to the growth and support of this technology as it becomes increasingly ubiquitous [2]. Despite its economic importance, many educational institutions lack the means to teach this emerging subject. To this end, a coalition of higher education institutions partnered under an NSF ATE project grant to teach current and aspiring STEM educators. This program, which ultimately benefits student learners, targeted teachers affiliated with high schools and colleges including vocational schools. The following list provides the accomplishments made by this coalition:

- Multi-institutional AM collaboration in teaching, laboratory practices and research [3],
- Framework developed to measure the attainment of ABET Student Outcomes through AM curricular practices. [4],
- Smart phone accessible AM laboratory platform for multi-institutional collaboration [5],
- Up to date skills required of AM technicians [6],
- TTS: studio-based AM training [7],
- Using AM as an innovation tool to enhance the student learning and success [8-9],

- Up to date MOOC AM Resources [10],
- Additively Innovative Virtual Lecture Series [11].

Although coalition members developed a number of AM best practices [12-20] the core of this paper is the evaluation of TTS as a unique tool for AM education. Overall, TTS is a learning approach designed to give hands-on instruction to AM instructors [3-4]. Webinars and MOOCS were also used to teach content and engage with AM educators. TTS sessions were held before and during the Fall of 2019 in several states. Evaluation of the TTS was ongoing throughout their delivery. The main coverage points of TTS-based AM learning were as follows.

- Build your own printer, operate it, print some entrepreneurial parts and learn the key maintenance steps.
- Grasp the concept of ABET accreditation and let the participants learn the attainment of student outcomes.
- Access AM resources and review the coverage of the content.
- Learn the studio type of instructional delivery and practice it in setting up the 3D Printer and printing an entrepreneurial project.
- Learn and practice the importance of teamwork and communication in an interactive hands-on project environment.

This paper highlights the understandings and lessons learned from this evaluation.

Evaluative Findings at Three Workshop Sessions

Session A of the TTS was conducted at Sinclair College in Dayton, OH with 15 STEM educators who were affiliated with public and vocational schools. The instructional foci of these educators were varied and included STEM, makerspace focused, computer science, and other

areas. Approximately five different content areas were covered including design, generative design, 3D printing in multi-disciplinary analysis and optimization (MDAO), and environmental costs comparisons of AM. Two AM focused sites were toured as part of the TTS.

Session B was held at the University of Louisville in Louisville, Kentucky. There were 19 participants at this session. Just like the TTS at Sinclair College, the instructional foci of these participants were similar to Session A with many having a STEM focus but also art, theatrical design, social studies, and special education. These participants were affiliated with public middle and high schools, a community college, and a four-year college. The content covered during Session B was related to design, printer control software, and an AM institute affiliated with the university where the session was held. A site tour of an AM training center was also conducted.

Session C was held in Cookeville, Tennessee at Tennessee Technological University. A total of fifteen participants attended and were affiliated with either high school or a community college. Associated content areas for these potential AM educators included STEM fields and also machining, non-destructive testing, and machine tool technology. The content areas covered at Session C were related to CAD, practical AM applications, math class integration, AM safety, and maintenance, and troubleshooting.

Several aspects of all of the TTS sessions were evaluated. Educator participants were requested, to retrospectively, give a rating (1 minimal; 2 basic; 3 average; 4 proficient; 5 advanced) of their understanding of a topic before and after each one was covered. Participants were also asked about their overall workshop experience by indicating their level of agreement (1 strongly agree; 2 somewhat agree; 3 neither agree nor disagree; 4 somewhat agree; 5 strongly

agree) with several survey items. Shown in the following pages are the data collected from these evaluations.

Evaluation Results

Table 1 shows the proportions of the 49 participants who agreed or disagreed with statements related to the training sessions. The majority of trainees agreed with all statements posed to them.

Table 2 displays some of the results of two open-ended questions asked of the educator participants taken from all three trainings. The findings were overwhelmingly positive and indicated the broadness of applicability of AM, depending on the backgrounds of the participants.

Some educators indicated more interest in current AM trends while others were more drawn to software for student use. When the participants were asked about what changes they would like to see at the workshops, the responses were also varied and potentially tied to the background of the educator as well. Some wanted a more in-depth technology focused teaching approach while others requested alternating hands-on activities with lecture presentations to vary the pace of the workshop~~s~~.

Table 1

Combined Bottom and Top Two Response Choices for All Sessions

	Disagree	Agree
The objectives of the training were clearly defined.	-	(94%) 46
The training objectives were met.	-	(100%) 49
Each session stated the objectives clearly.	-	(100%) 49
The content of the training workshop was what I expected.	(2%) 1	(88%) 43
The topics covered were relevant to my profession.	(2%) 1	(98%) 48
The training materials/handouts distributed were helpful.	(2%) 1	(94%) 46
The training experience will be useful in my work.	(2%) 1	(98%) 48
The quality of logistic and administrative support had a positive impact on my experience at this workshop.	(2%) 1	(96%) 47
The quality of instruction was exceptional.	(2%) 1	(96%) 47

Table 2
Selected Open-ended Responses to the Question: "What did you like most about this workshop?"
· *I was impressed with the Generative Design, I have never seen it. I liked everything else, but I really got impressed with this topic because I never did anything like that.* · *I liked the instructors and the participants. I like getting a 3-D printer and learning how to use it. I like getting insight into the real world and how the 3-D printer is being used in industry.* · *I loved the mini presentations on current trends in additive manufacture. I learned a lot about current trends that I can share with my students. This was truly wonderful.* · *What I appreciated most about this workshop (other than getting a FREE 3D printer for our school!) was the realization that so much is possible with this type of equipment, and with equipment that is not completely out of reach financially when it comes to initial cost or consumables cost. With the software that is available free to educational organizations being as well-featured as it is, we can do much with this. The students at our school will love it. The teachers and university students who assisted were very helpful, as well. The breakfast was good, too, so thanks for that!* · *The presentations were great. The students were of great service and really were able to explain their areas as well as help to troubleshoot as needed. It also allowed for a large amount of networking and connections that I feel will be useful in the upcoming year and beyond.*
Selected Open-ended Responses to the Question: "What would you recommend changing?"
· *I liked hearing from the speakers and thought what they had to say was very interesting, but I struggle to stay sitting that long without drifting off. I don't know exactly how to fix it. Maybe more variety or alternating speakers with other activities, instead of back to back speakers?* · *If I were to change one thing, I would say try this: Right off the bat, go to a computer and pull up a 3D file from the web, open it in the slicer, and save a print job. Take that micro SD card straight to a printer already set up, calibrated, primed, and tested. Start a print job from the file that the attendees just watched you download. After doing a roughly half-hour introduction lecture, take the class back out to see the half-printed object. Go back to the classroom & finish the session (1/2-hour or more later). Go back out to see the finished product less than 1.5 or so hours after the training starts. Then, go over all the steps that you did to make that happen. It might be cool that way.* · *It would be useful, for someone like myself who is technically literate to have some time to work with the design software. We had almost no time to work on the software, and if we didn't have a person in our group who knew how to use it, we would have been lost.* · *Give us mistakes to fix. What are common troubleshooting examples? How do we know when we damage or how to clean the nozzle?*

Summary of Findings

The teaching of AM is an effective way to teach others about a variety of subjects (including AM itself) as it is often viewed as an interesting subject that stimulates learners and impacts a number of content areas [21]. Even though AM is effective in this regard, there currently exists no agreed-upon singular model to teach about it or with it [22]. The evaluative approach taken to examine the TTS was multifaceted and sought to look at the sessions from the perspectives of the participants. Frequently, participants at all three sessions indicated having an overall positive experience. All participants at all sessions agreed (at least somewhat) that the goals of the workshops were met. It is interesting that the majority of all participants felt that the content covered was relevant to their profession given that such a diverse range of foci were reported. Similar to what is shown for Session A in this paper, a comparable trend was seen at all three sessions where the respondents typically reported a limited understanding of the AM topic covered before and then an increase after.

Teaching AM through hands-on activities is commonly seen as an effective instructional approach [23-24]. Frequently the responses to the open-ended survey items at all three sessions showed that the hands-on activities were some of the most well-regarded by participants. The TTS delivery format promoted networking and collaborative learning. The participants were very eager to be able to apply this technology directly to their classroom; the majority of participants indicated their desire for more information related to their specific content area or knowledge and about best practices for teaching AM in a classroom environment.

Conclusions

AM education is multidisciplinary and can be used in a myriad of ways regardless of the subject being addressed. The participants were very eager to learn with and about AM. Putting learners in hands-on learning situations where they were able to use AM technology was beneficial to the participants understanding, and they all expressed enthusiasm to apply it to their own specific content foci.

Acknowledgement

This project has been funded by NSF Award Number 1601587 entitled 'AM-WATCH: Additive Manufacturing – Workforce Advancement Training Coalition and Hub'.

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