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Innovative Delivery of 3D Printing

Dr. Ismail Fidan, Tennessee Technological University

Currently, Dr. Fidan serves as a Professor of the Department of Manufacturing and Engineering Technology at Tennessee Technological University. His research and teaching interests are in additive manufacturing, electronics manufacturing, distance learning, and STEM education. Dr. Fidan is a member and active participant of SME, ASEE, ABET, ASME, and IEEE. He is also the Associate Editor of IEEE Transactions on Components, Packaging, and Manufacturing Technology and International Journal of Rapid Manufacturing.

Dr. George Chitiyo, Tennessee Technological University

George Chitiyo is a Professor of Educational Research and Evaluation at Tennessee Tech University. He teaches courses in research methods, statistics, and program evaluation. He is involved in designing and implementing evaluation initiatives of different types of educational programs and interventions in PreK-12 and higher education settings. His evaluation work includes projects in Advanced Technological Education (ATE), STEM education programs, and health related research.

Dr. Perihan Fidan, Tennessee Technological University

Dr. Perihan Fidan is a faculty member at the Curriculum and Instruction department at Tennessee Tech University. Her current research interests include STEM education, 3D printing, and incorporating literacy into STEM classrooms. She is a member of the American Educational Research Association, National Science Teaching Association, International Congress of Qualitative Inquiry, and the National Association of Multicultural Education.

Mr. Ankit Gupta, Tennessee Technological University

Mr. Ankit Gupta is PhD candidate and Graduate Research Assistant at Mechanical Engineering Department in Tennessee Technological University with the expertise in additive manufacturing processes (Laser sintering and Fused Filament Fabrication) and advanced materials (metal alloys, ceramics and high temperature polymers). He has graduated from Indian Institute of Technology (Indian School of Mines) Dhanbad with a Master's Degree in Mechanical Engineering. During the course of this studies, he has gained solid and hands-on experiences on continuous and short fiber composite 3D Printing and low-cost metallic printing, their fabrication, characterization, computational modeling and analysis. He is member and active participant of Society of Manufacturing Engineers (SME-S215) student chapter for 3 years.

Mr. Seymur Hasanov, Tennessee Technological University

Seymur Hasanov finished his bachelor and master's degree in industrial engineering at Qafqaz University. He joined the mechanical engineering department of Qafqaz University as a faculty member in 2015. During this time, he taught various engineering courses including Engineering Graphics, Solid Modeling, CAD/CAM, and Civil Engineering Drawing for industrial, mechanical, and civil engineering students. Currently, he is a Ph.D. candidate and graduate research assistant at the mechanical engineering department of Tennessee Tech University. His research areas are in design for additive manufacturing, composite 3D printing, and functionally graded materials. Seymur is a member and active participant of SME and ASME engineering societies.

Dr. Allen Munyaradzi Mathende, Tennessee Technological University

Dr. Mathende is a recent graduate from the College of Education at Tennessee Tech University. His research interests are in the use of technology in educational settings, data use in education policy development, conducting program evaluations, institutional research, and building stakeholders' evaluation capacity. Dr. Mathende is a member and active participant of the AEA. He is also the Editorial Board Member of the Frontiers of Contemporary Education journal.

Mr. Zhicheng Zhang, Tennessee Technological University

Mr. Zhicheng Zhang is a PhD researcher at the Additive Manufacturing Research and Innovation Laboratory of Tennessee Technological University. His first degree is Bachelor of Science in Physics from Shandong Normal University, China. Then, he also received a second Bachelor of Science degree in Physics from East Tennessee State University in May 2015. He entered Tennessee Technological University in August 2017 and received a Master of Science degree in Mechanical Engineering in August 2019. Currently, he is a PhD student in Mechanical Engineering. Mr. Zhang is an active member of TTU SME chapter.

Innovative Delivery of 3D Printing

Abstract

3D Printing (3DP), also known as Additive Manufacturing (AM) is the latest production technology. Its popularity in fabricating functional parts in all fields is growing day by day. The range of 3D printed products is limitless, including glass frames to hearing aids. It is thus important to train educators and students regarding this cutting-edge technology so that they become familiar with the functionality and implementation of it in several courses, laboratories, and projects. This paper reports several novel developments which have been implemented in the past few years, including details of these unique practices and feedback received from the educators and students.

1. Introduction

This paper will focus on the innovative delivery of 3DP in few different formats under the COVID-19 educational environment faced in 2020 and 2021 [1]. The study will present the development and implementation of AM techniques in the flipped classroom (FC), online/on-ground workshop format, and Massive Open Online Courses (MOOCs).

In FC, concepts are learned out of class and the laboratories or problem-solving activities are worked out in practical settings under the supervision of the instructor or assistant [2]. Several benefits of FC have been reported in other fields, but not in the 3DP field. One FC study has shown that integration of 3DP and Industry 4.0 (known as the fourth industrial revolution for the cutting-edge automation of traditional manufacturing practices using modern smart technologies) could be successfully implemented in multi-disciplinary engineering teaching [3]. One case study performed at the Massachusetts Institute of Technology reported that flipping the classroom as well as the activities and examples used were impactful for student learning [4]. The study's evaluation results showed that students preferred the FC and were more comfortable asking questions and engaging themselves in this environment.

In the past few years, the authors have successfully conducted studio workshop-based learning of 3DP [5][6]. The educational practices of this method were framed around the hands-on workshop experiences. After the delivery of curricular content, the participants had a chance to engage with setup, design/innovation, fabrication, teamwork, and presentation activities. Workshop-based learning of 3DP has been shown to provide a creative and engaging environment for both students and teachers so that they could collaboratively work together [7].

MOOCs are free and easily accessible online courses are readily available for anyone to enroll and learn. They provide an inexpensive and convenient way to learn new skills, advance individuals' careers, and deliver value-added educational experiences at scale. Several short and long format courses are available on YouTube and LinkedIn Learning platforms. Several higher educational institutions and organizations have also developed courses to deliver the latest trends and technologies in this field [8].

2. Development and Implementation

2.1. FC Delivery of 3DP

CAD for Technology is a junior-level required engineering technology course covering a broad spectrum of 2D and 3D design contents and rules using AutoCAD and SolidWorks software tools. Students taking this course are required to complete a freshman-level Graphics course so that they can learn the fundamentals of design and its implications for engineering and technology.

The course has been delivered in both online and on-ground settings in the past. In Fall 2020, the course was offered in a FC format to 40 students. Recorded lecture notes and laboratory practices for each lecture were placed on the course's media tab at least two days before the online lectures and laboratory practices so that students could access and learn the content before attending the live online delivery hours. Figure 1 shows the sample views of the recorded lecture and laboratory snapshots.

Throughout the lecture hours and laboratory hour practices conducted in online formats, special emphasis was given to the extra hands-on practices, troubleshooting, and extra questions. This way, students were able to have an opportunity to freely ask the questions directly to the course professor regarding the problems they faced during their design practice.

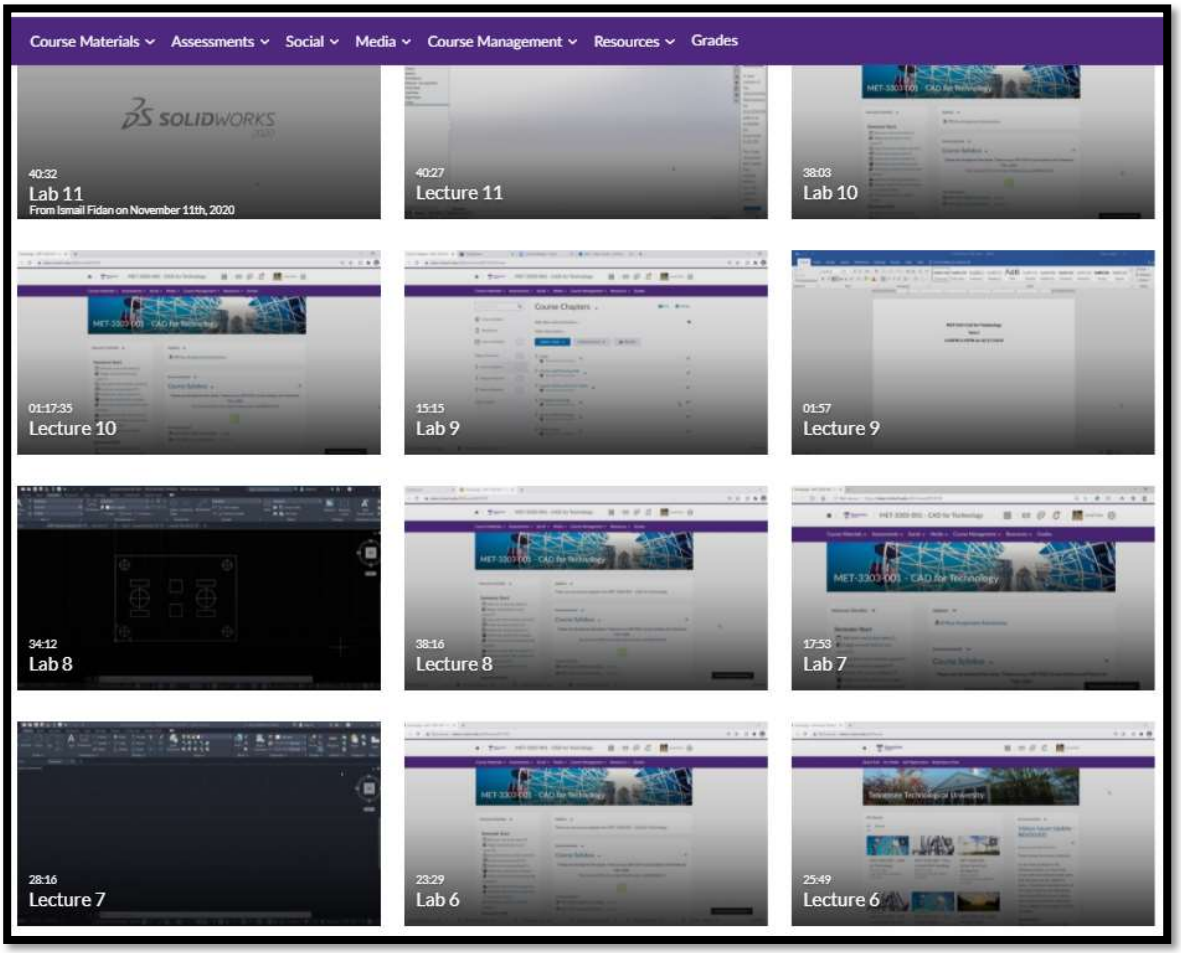

Figure 1: Recorded lectures and lab practices were made available before the live online delivery

The most impactful part of the course was the delivery of its hands-on component via a course term project. Eight student teams were formed and they were trained using cutting-edge 3DP technologies in on-ground formats. Course student assistants spent extra hours to support the students' learning and success in running, troubleshooting, and post-processing the 3D printed parts in the Additive Manufacturing Research and Innovation Laboratory. Figure 2 shows a training session conducted for a group of students in a 3DP laboratory. Each team presented their projects at the end of the semester. The key findings of this practice will be reported in the upcoming evaluation section.

Figure 2: CAD for Technology students are receiving 3DP instructions from the course assistants

2.2. Hands-on 3DP Workshop in Online and On-ground Settings

It is essential to train the STEM educators with the latest trends and technologies of 3DP. As part of an NSF funded workforce development project, some of the authors have been conducting several workforce development workshops in different parts of the continental US. It was evident that the STEM educators and their students received advanced knowledge blocks throughout these well-structured programs.

Due to the COVID-19 pandemic, the latest workshop was conducted in both online and on-ground settings to ensure participants' health, and safety. Six participants attended the event via the Zoom webinar tool, and five chose to attend in person.

The theme of this hybrid event conducted in early 2021 was to deliver the latest trends and technologies and also help the participants to practice the 3DP technologies using 3Doodler 3D printing Pens. Figure 3 shows a snapshot from the 2021 workshop.

Figure 3: 3DP Workshop participants in online and in-person settings

Figure 4 presents a snapshot of the workshop agenda. The participants were able to practice what they have learned with the equipment shipped before the event.

INFORMATION SESSIONS

9:15AM-9:45AM	*Additive Manufacturing-A new way of 'Making'* Ismail Fidan, TTU Conventional Manufacturing, Advanced Manufacturing, Smart Manufacturing, Additive Manufacturing, 3D Printing, Additive versus Subtractive Technologies, AM-WATCH
9:50AM-10:05AM	*Fundamentals of Design* Seymur Hasanov, TTU Solid Modeling, Reverse Engineering, Design for Additive Manufacturing, Professional CAD Software Tools, Free CAD Software Tools, Required skills and tools.
10:10AM-10:25AM	*Core skill – Visualization* Kim Grady, BehaveHeuristics, LLC Provide demo of 3D visualization skills using a demo with a simple cube. Skills demonstrated: Right-hand-rule, Orthogonal Cartesian Coordinate System, rotations and orienting an object on a build platform. Discussion of terms used.

Figure 4: A sample portion of the training program

2.3. 3DP MOOCs and Webinars

As part of a funded NSF Advanced Technological Education (ATE) Project, several MOOCs have been developed in the past few years. The recorded sessions are available on YouTube, as well as on the project site am-watch.org. The MOOCs that are currently available are listed below:

- Introduction to Additive Manufacturing
- Additive Manufacturing Process Chain
- The Business of Additive Manufacturing and Startups
- How to set up the Monoprice Maker Select
- Design for Additive Manufacturing
- Safety in Additive Manufacturing
- Monoprice Maker Select Drive Motor Assembly
- Metal 3D Printing

As part of the same NSF ATE Project, the project team also offers several short webinar series every semester and they are hosted by Tennessee Tech University [9]. These webinars deliver the latest trends and technologies in the 3DP field. Figure 5 shows the sample flyer of the Spring 2021 webinar series [10]. 3DP lectures are also available in the category of MOOCs and easily accessible to anybody who needs quick and specific information on the hot topics of 3DP from 'Wire Arc Additive Manufacturing' to 'Design for Additive Manufacturing'.

Figure 5: Virtual Short 3DP Lecture Series held in Spring 2021

3. Evaluation

3.1. Evaluation of FC CAD for Technology Course

In Fall 2020, the design course was offered in an online setting. Its hands-on project component was delivered by the author team and course assistants. Figure 6 provides the key findings of the course provided by the university IDEA course evaluations.

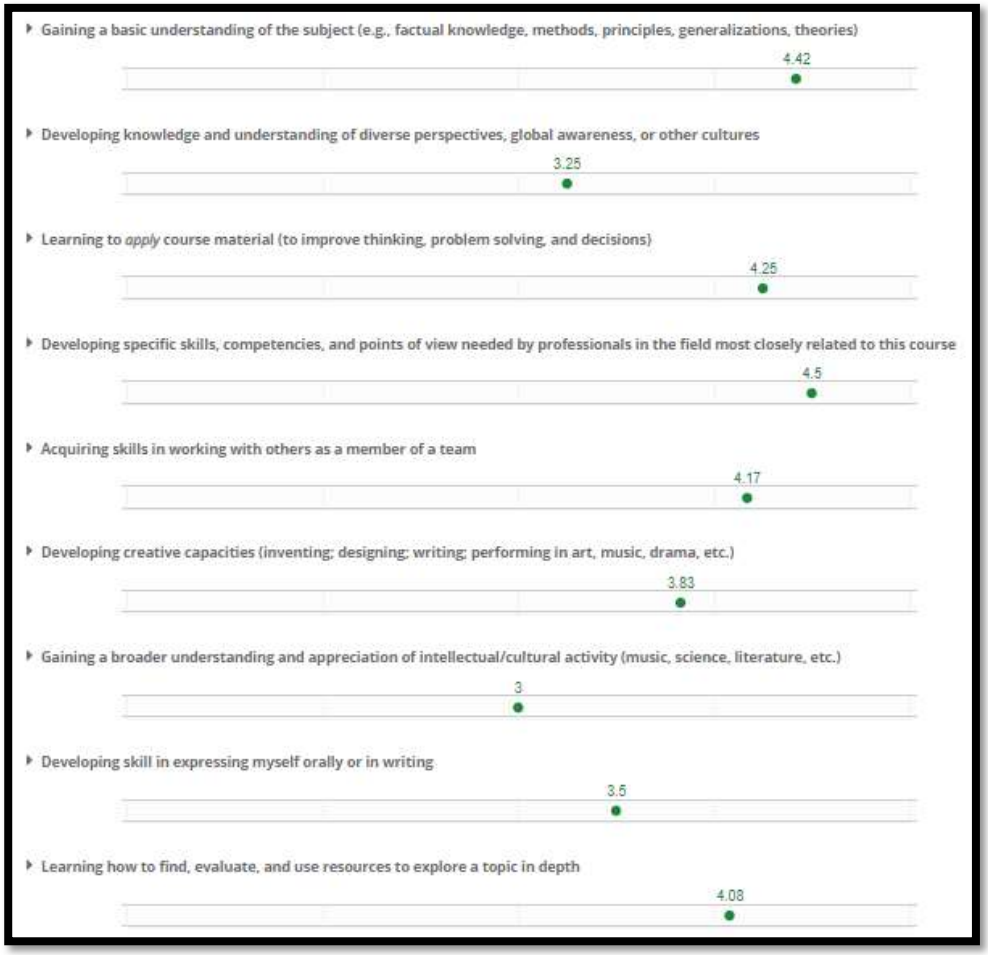

Figure 6: Evaluation of FC Delivery of Design Course enhanced with 3DP

The essential and important focus of the course was selected as 'Gaining a basic understanding of the subject' and 'Learning to apply course material.' In both categories, the majority of the course students showed a high satisfaction rate.

The qualitative responses provided by the students are also summarized below:

- The instructor does a good job teaching AutoCAD and SolidWorks. He also does well in encouraging students to get involved with the material.
- Wonderful Class! Thank you, professor!
- Thank you for being a kind, supportive professor during this semester.

- Professor did an excellent job instructing this class!
- I really enjoyed the class. I appreciated the real-world examples and advice, and I believe what was taught in class will be very applicable and valuable in my career. Thank you.

3.2. Evaluation of the Hands-on Online/On-ground 3DP Workshop

This section presents the main findings from the evaluation survey completed by 11 participants who attended the project workshop in January of 2021, at Tennessee Tech University.

Five of the participants attended in person, and six attended virtually via Zoom. Of the 11 participants, nine (82%) were male, and two (18%) were female. The racial breakdown was 64% White (n = 7), 27% (n = 3) Black or African American, and 9% (n = 1) Hispanic.

3.2.1. Workshop Content

With regards to workshop content, the items assessed were quality of instruction, the relevance of topics covered to the respondents' work, the content of the training, and the extent to which the objectives were met. Most of the participants had very high ratings on all these items. These findings are illustrated in Figure 7.

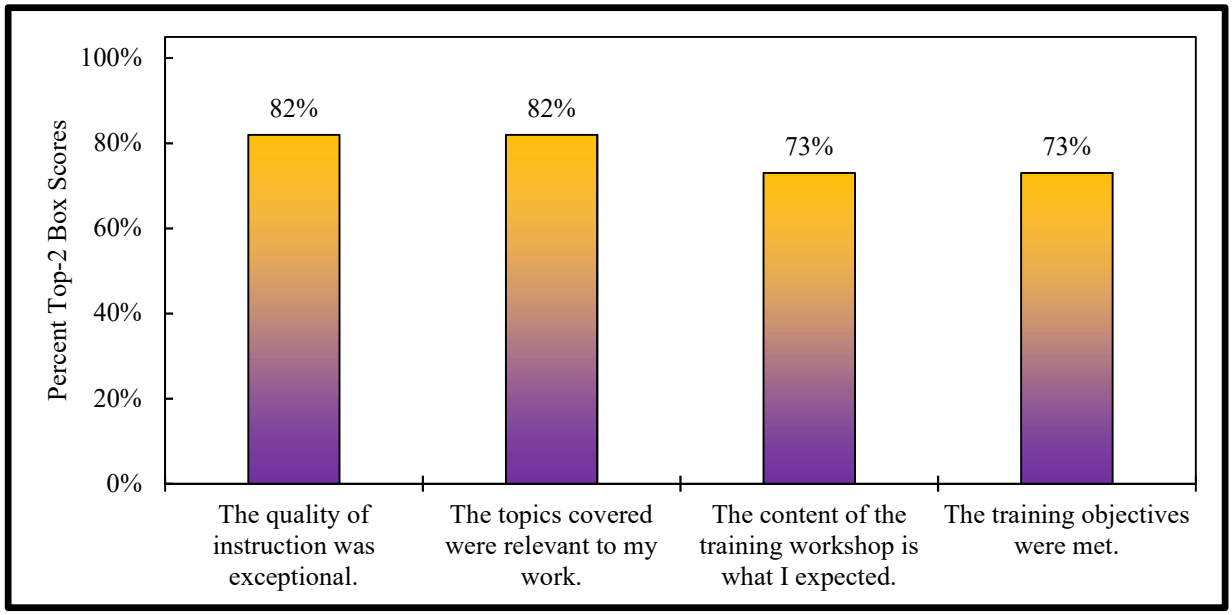

Figure 7. Percent of Positive Responses on Workshop Content

3.2.2. Workshop Experience

Participants were also asked about their overall workshop experience. As shown in Figure 8, the majority of responses (82%) were positive across all six items. A couple of items under this component are important to highlight, and these are: (i) the training experience will be useful in my work, and (ii) participating in this workshop provided me with the opportunity to network with

other educators. These specific items directly address the main goal of the training workshop and thus attest to the effectiveness of the training.

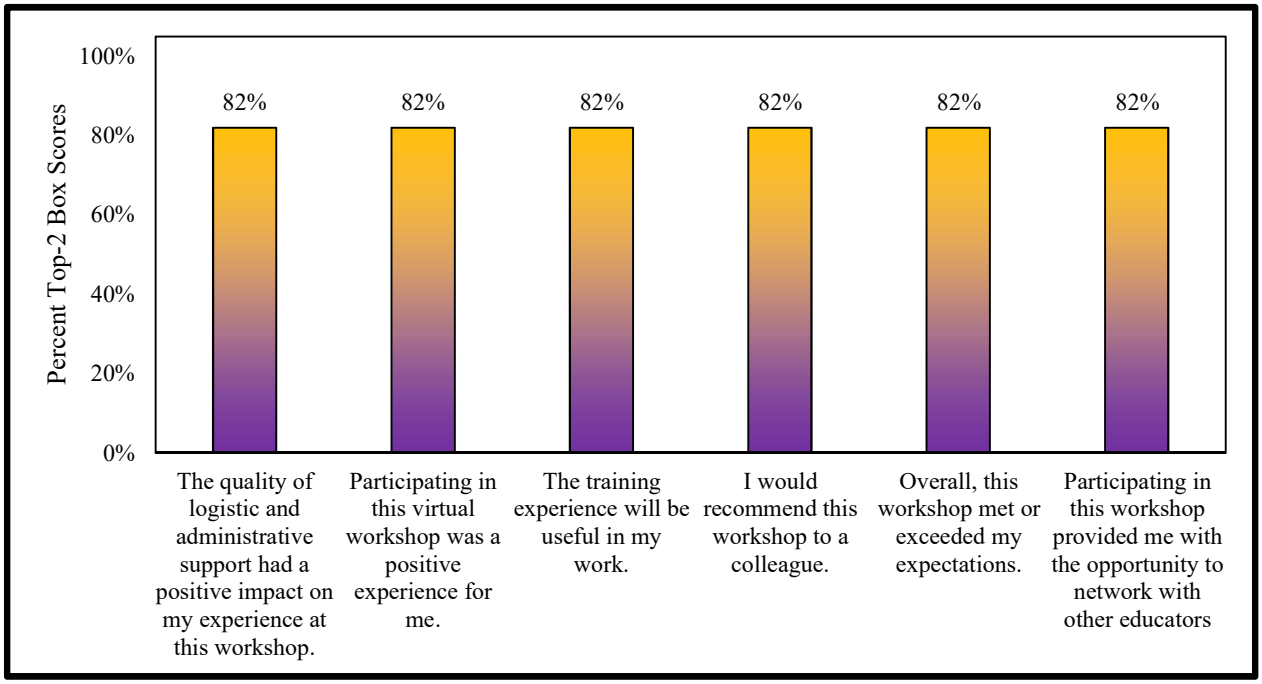

Figure 8: Percent of Positive Responses on Workshop Experience

3.2.3. Participants' Understanding of AM Concepts

Participants were asked to rate their level of understanding of specific concepts related to AM. Using a retrospective pretest, they were asked to rate their current understanding of four specific concepts compared to before the workshop. The findings are given in Table 1.

***Table 1**: Participants' Level of Understanding of AM Concepts Compared to Before the Workshop*

	About the same as before	A little better than before	A lot better than before
The basics of AM	27% (3)	18% (2)	55% (6)
The difference between Additive and Subtractive Manufacturing	27% (3)	45% (5)	`27% (3)
The fundamentals of design	27% (3)	55% (6)	18% (2)
The materials used in Additive Manufacturing	18% (2)	18% (2)	64% (7)

3.2.4. Participants' Knowledge of 3D Printing Concepts

Using a retrospective pretest, participants were asked to rate their level of knowledge of certain aspects related to 3DP. Specifically, they were asked to rate their current understanding compared to before the workshop. The findings are presented in Table 2.

Table 2: Participants Level of Knowledge of 3DP

	About the same as before	A little better than before	A lot better than before
The basics of AM	18%	27%	55%
3D printer parts	36%	36%	27%
3D printer operating principles	27%	36%	36%
Different types of software	27%	55%	18%

Participants were also asked to rate their overall knowledge of the content presented during the workshop using a 4-point Likert scale. Before the workshop, 54% (n = 6) had basic or advanced knowledge of the 3D printing content. This percentage increased to 100% after the workshop.

3.2.5. Proficiency with 3DP

Figure 9 shows the change in participants' proficiency to perform 3D printing tasks, comparing their ability before and after the workshop. Top-2 box scores were computed for each of the items, which were rated on a 4-point Likert scale with the levels of minimal, basic, proficient, and advanced. There was an improvement in all the aspects measured. The biggest change (45%) was on two items (i) how to create templates and, (ii) using stencils and templates. The three remaining items showed an improvement of 37% each from pretest to posttest.

3.2.6. Likelihood and Confidence to Use Content Learned During the Workshop

All 11 participants indicated that they were both (i) likely to use what they have learned during the workshop, and (ii) confident that they can successfully use what they have learned during the workshop. For the likelihood to use what they have learned, the net promoter score was 82% with a detractor score of zero. Similarly, for confidence to successfully use what they had learned, the net promoter score was also 82%, with a detractor of zero.

3.2.7. Summary

Findings from the evaluation of the training workshop pointed towards a successful training experience. The educators largely expressed that they benefited from the training and were looking forward to begin implementing what they had learned from the workshop by engaging their students. The participating teachers (who are from the community colleges and high schools) expressed that they had learned a lot from the workshop. Before the training, slightly more than half (54%) had basic or advanced knowledge of the 3D printing content. This percentage increased

to 100% after the workshop. All 11 participants indicated that they were both (i) likely to use what they have learned during the workshop, and (ii) confident that they can successfully use what they have learned during the workshop. The teachers also expressed that their proficiency level with regards to specific 3D printing tasks had improved, with the biggest improvements being in terms of how to create templates and using stencils and templates. In response to open-ended questions, the teachers also provided suggestions for areas of improvement in the future.

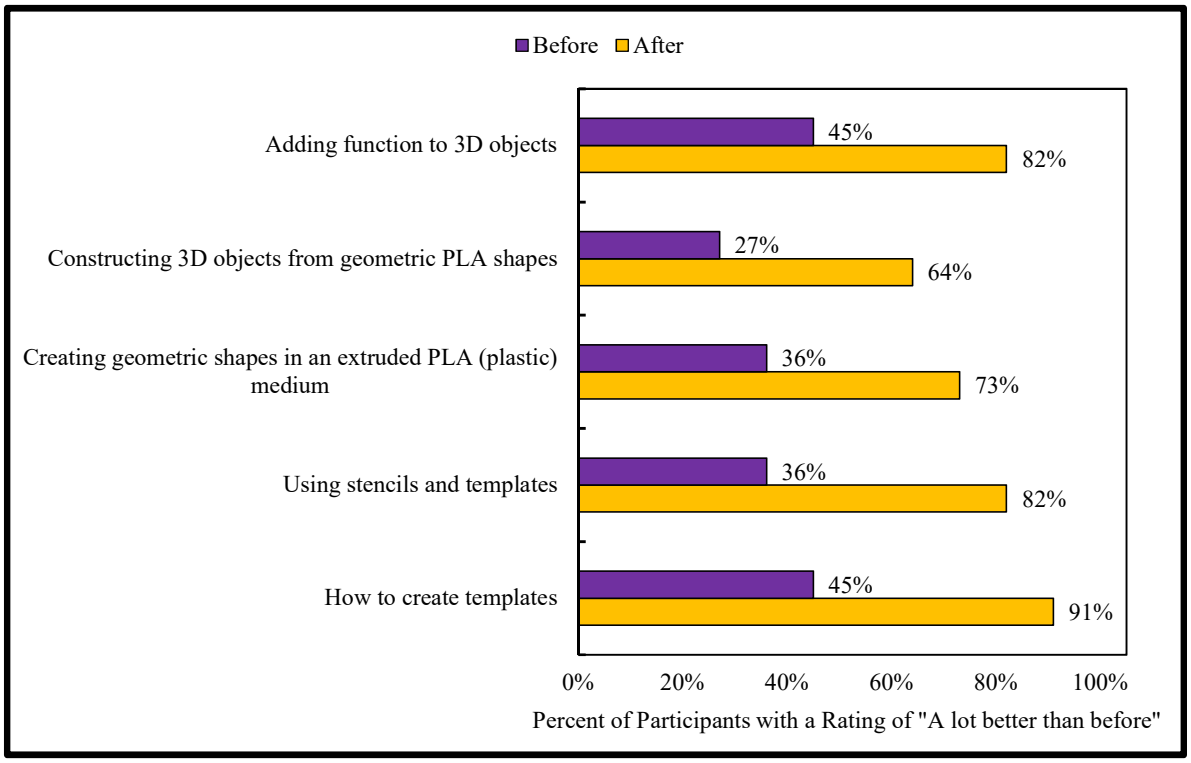

Figure 9: Participants Proficiency with 3DP

3.3. Evaluation of the 3DP MOOCs

Although there was no formal survey instrument prepared to measure the success of the developed MOOCs and their implications on users' practices, several positive statements were reported to the development team. The educators who attended the 3DP studio workshops reported in 2.2. were the major users of these developments. Also, the students of the project management team used the developed MOOCs quite a bit. The qualitative responses provided are based on the following points;

They are developed from a diverse group of people from university, community college, and a national laboratory.

The information provided is factual, focused, and well-prepared.

MOOCs are easily accessible and could be used as an educational aid.

The development of specific modules on different 3DP technologies could be great future work since the technology is continuously evolving.

In Fall 2020, the Additively Innovative Virtual Lecture Series were evaluated. This brief section summarizes survey responses collected from participants at the end of three lectures:

1. Mass Production and Decision Making with Low-Cost Additive Manufacturing for Institutions and Small Businesses with Eric Wooldridge
2. New Product Development for Additive Manufacturing: Methods and Tools with Steinar Killi
3. Machine Learning in Additive Manufacturing with Ian Gibson

The survey at the end of each lecture was very brief. Among other things, participants were asked to report on their understanding of the topic before and after the lecture. Figure 10 shows that most participants expressed an increased understanding of each of the topics, particularly the first two.

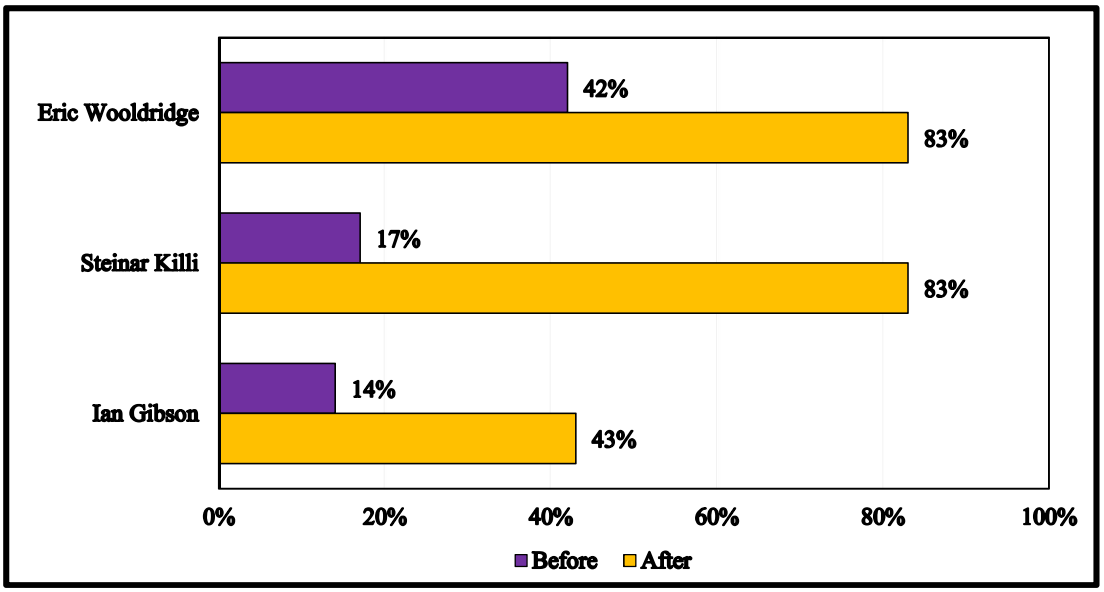

Figure 10: Percentage of Respondents who reported a Proficient/Advanced Understanding of the Topic Before and After Each Lecture

Conclusions

Today, the number of innovations reported in 3DP is limitless since the use of this technology is growing every day. Scientists have been discovering that 3DP could take them to new heights in cutting-edge education, engineering, and medicine. The importance of teaching this technology with innovative methods and showing its best practices are also essential to increase the adaptation and implementation of 3DP. This paper has reported the development and implementation of 3DP in three unique approaches. The evaluation reports have proven that such kind of unique educational tool is well received by the educators. It is expected that more tools will be developed and implemented to increase the adaptation and implementation of 3DP in the future.

Acknowledgements

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