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WORKFORCE DEVELOPMENT STRATEGIES IN ADDITIVE MANUFACTURING

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Abstract: Additive Manufacturing (AM), also known as 3D Printing (3DP), is one of the newest manufacturing technologies with growing utilization in our daily life. Parallel to this growth, new materials, machines, and specific processes are being developed to produce parts in better-finished quality, at lower cost, and with shorter production time. However, workforce education in this evolving field has not advanced at the same pace as the technology, lacking proven curriculums, high-quality/accredited degree programs, and specialized advanced degrees. In this paper, some best practices established by the authors are introduced. The list is far from exhaustive but is proven to be effective in practice.

Keywords: Additive Manufacturing, 3D Printing, Workforce Development, Innovation, Training

1. Introduction

The products fabricated using AM technologies are usually geometrically complex with superior properties such as lighter weight and higher strength. It is clear that the trend will continue in this direction; new products will be manufactured with improved properties without being restricted by their geometric shapes.

Today, there are many technological advancements reported about the unique developments of the AM in every sector, from medicine to aerospace. For instance, a new AM method has been developed to produce nanoscale-level metal parts such as copper objects as small as 25 nanometers in diameter [1]. This new technique has great potential in electronics, automotive, sensor, and battery technologies. Scientists have also developed a number of new edible plant-based gel materials that can be used to 3D print meat-like foods [2]. These gels ingredients, such as soy protein and wheat gluten, are as nutritious as real meat. It is believed that such a solution will be very effective for high volume food production for hotels and army sites. In addition, AM has been used to build houses, bridges, and storage units. Engineers have worked with construction specialists to print substantial buildings with real concrete, such as a 2,100 sq. ft home with three bedrooms and three bathrooms [3]. Scientists have also developed a low-cost wire arc additive manufacturing (WAAM) machine that can be constructed with a $1,000 budget [4]. Their beta-testing results with carbon steel and Inconel 718 presented some excellent successes. In health care, researchers have also created smart health monitoring devices that could operate without being manually recharged [5]. Wearable biosensors were precisely designed and fabricated using AM to address the personalized monitoring applications [6].

Although there are significant needs, no well-established workforce development strategy prepares engineers and technicians for these new and challenging technologies. The development of AM workforce is an important priority for several funding agencies, too

[7][8][9]. Some funded projects are dedicated to developing AM-related curricular materials, MOOCs (Massive Open Online Courses), and training workshops. Specific course modules developed for AM instruction have been implemented in a number of design and manufacturing courses [10]. It was shown that the courses offered in Flipped Classroom (FC) model received a high satisfaction rating [11]. Hands-on AM training programs offered in-studio formats have shown higher learner satisfaction than the traditional in-person training formats [12]. During the CoVID-19 pandemic, several remote training solutions have been developed and successfully delivered [13][14]. Institutions sharing their capabilities in teaching remotely have presented higher student success rates, especially during the pandemic [15].

This unique paper will present the latest AM workforce advancement strategies reported and delivered in various higher education institutions.

2. Delivery Strategies

2.1. Strategy 1 - MOOCs: MOOC is one of the latest models for delivering instructional content online without attendance requirements to the learners [16]. Some organizations like *CourseRA* [17] and *LinkedIn Learning* [18] have adopted this innovative learning method to offer several curricular contents for their participants. The instructional modules available on *YouTube* also fall into this strategy. Some of the commonly used proven examples in this category are given below:

- Additive Manufacturing developed by John Hart, Massachusetts Institute of Technology [19]
- MOOC AM Resources developed by Ismail Fidan, Tennessee Technological University [20]
- Introduction to Additive Manufacturing, David Bourell, ASM International [21]
- Introduction to the Digital Manufacturing and Design Technology Series, Kemper Lewis, The University at Buffalo [22]
- Additive Manufacturing 101, Siemens Software [23]

2.2. Strategy 2 - Textbooks and Reports: Many AM books and reports have been written and are currently available. It was shown that *Additive Manufacturing Technologies* textbook published by *Springer* (3rd edition) is one such resource that has been highly adopted and used in higher education institutions [24]. This book has been downloaded more than 101000 times and used by thousands of institutions in higher education. The other most popular book is *Fabricated*, published by *Wiley*. This nine-year-old book has been widely used by many institutions in higher education and translated into several other languages [25].

The authority in reporting the annual AM innovations, trends, and technologies is the *Wohlers Report* [26]. This prestigious annual collection has been authored by many subject matter experts in the AM field and provides cutting-edge advancements in industry, higher education, research, and development. The report will continue providing the same level of cutting-edge information, although the international standardization society, *ASTM International*, announced the acquisition of *Wohlers Associates* at late 2021. It is expected that the quality and prestige of the report will even increase due to the acquisition [27].

2.3. Strategy 3 - Studios: Compared to the standard lecture format, studio-type learning and teaching pedagogy have become popular in courses requiring hands-on practice [28]. An appropriately managed studio classroom provides an active and cooperative learning environment in all subject matters. In AM, the training activities in studio format have shown high satisfaction rates in several AM workforce training practices [12][29].

The majority of the studio-type innovative AM workforce activities are reported in Maker Space practices. Some papers reported the innovations made in home institutions' maker spaces in providing an efficient and effective learning environment [30][31]. Figure 1 shows a team of participants building a 3D Printer in an AM Studio organized by Tennessee Technological University and Edmonds College.

Fig. 1. A diverse group of AM studio participants builds a 3D Printer

2.4. Strategy 4 - Virtual Lecture Series: One of the best ways to learn a specific subject matter is to learn from its expert. However, it is not always possible to conveniently find that expert. With the help of video conferencing solutions, in the last six years, additively innovative virtual lecture series has been developed and implemented by Tennessee Technological University. Several AM topics have been presented to hundreds of participants via this strategy [32][33]. Figure 2 presents the AM Virtual Lecture Series held in Spring 2021. The archive of the recorded lectures can be accessed at [34].

Some technical companies, such as *Solidprofessor* [35], developed a series of interactive video courses in different areas of AM supported by certification exams where students have to pass with a score of 80% to receive a certificate of achievement and complete the course. Massachusetts Institute of Technology has also developed a virtual course to help attendees learn the AM knowledge blocks from design to production in three months [36].

Fig. 2. Virtual AM Lecture Series held by Tennessee Technological University in Spring 2021

2.5. Strategy 5 - The Technician Education in Additive Manufacturing & Materials: The Technician Education in Additive Manufacturing & Materials (TEAMM) project established a unique coordination network of public and private sector stakeholders on AM [37]. This network addresses a critical gap in supporting a new direction of technician education, including identifying and adapting *ASTM skills standards* that keep pace with advances in research and development. TEAMM is supported by utilizing social networking technologies, proactive identification and expansion of key stakeholders, and improved access to workforce development.

AM News, published by the TEAMM project, highlights the latest developments and innovations in AM education workforce development efforts [38]. Subject matters and institutional affiliations tag news items. This news site has been proven to be a good and accessible resource for several institutions to read and learn the latest best practices in AM workforce.

2.6. Strategy 6 - FC: FC is one of several educators' new course delivery techniques. In FC, educators prepare educational materials via video conferencing tools and are released for students' convenient access 24/7. This way, educators spend more time answering students' questions than developing the course materials. The FC in AM instruction has shown some success [11][39].

The AM technologies have successfully supported the FC teaching model in several cases. It was proven that the students and participants of the classroom environment leave the learning activities with high satisfaction rates. Educators not only in engineering but also in medicine have reported their success stories [40]. Figure 3 shows the students' satisfaction with core learning outcomes collected from a *Computer-Aided Design* course in Fall 2020. This course was offered in FC format and enhanced with AM practices.

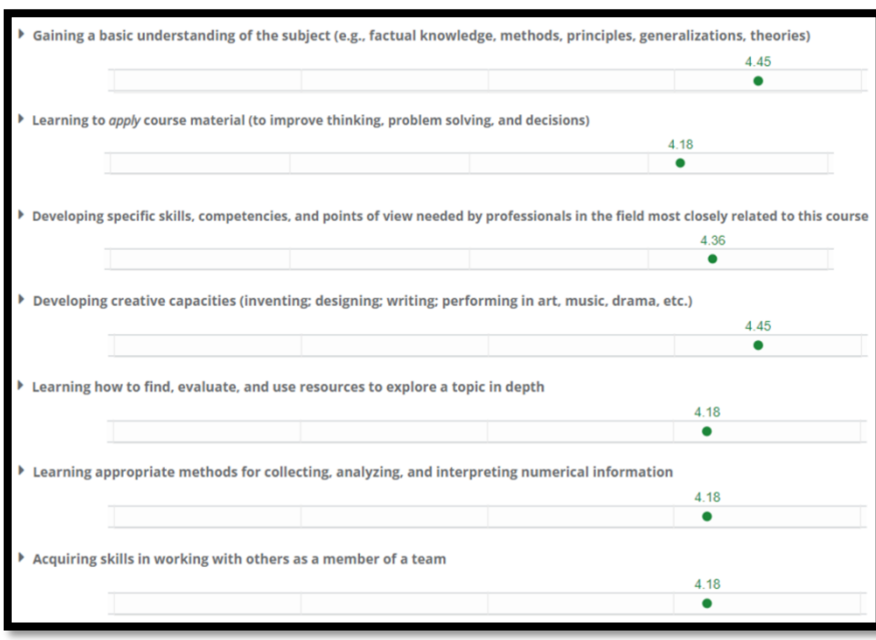

Fig. 3. Student Satisfaction Survey of Computer-Aided Design course offered in FC model in Fall 2020 over a 5.0 scale

2.7. Strategy 7 - Academic Centers of AM: Many universities established centers through funding from public and private sectors, which provide students with opportunities to practice and learn and do collaborative projects with the industry. A constantly increasing number of universities, colleges, and community colleges have adopted this strategy in the last few years. Among these academic institutions, Somerset Community College [41], Calhoun Community College [42], North Carolina State University [43], New York City College of Technology [44], and New York University [45] are the ones presenting some tangible workforce development activities.

2.8. Strategy 8 - Resources Developed by the 3DP Companies: Companies like Formlabs, Ultimaker, Desktop Metal, and Markforged have high-quality education and workforce development materials with videos and infographics on their website. Those informative materials are product-based, hands-on orientated, and up-to-date resources. Anyone interested can easily find information about maintenance, design guide, orientation analysis, and more in their documents. Some of the well-known AM Resources in this category are given below:

- 3D Systems [46]
- Stratasys [47]
- Markforged [48]
- Formlabs [49]
- Ultimaker [50]
- Desktop Metal [51]

3. Discussion

The growing trend of AM will continue with the advancements in new machines, materials, and technologies every day. It is also clear that the demand for training the workforce who could efficiently utilize these advancements will be a significant concern for many companies and institutions. The strategies highlighted in this paper will provide new opportunities for institutions and industries and students and workers.

The summaries of the eight strategies provide brief details about the specifics of each AM workforce training. These available strategies also have specific costs, timeframe requirements, and eligibility details. However, it was shown that each of them has a number of success stories provided by trained or educated individuals.

The manufacturing industry has progressed beyond traditional processes such as CNC, casting and injection molding, etc. AM technologies are emerging as critical enabling practices for modern design and end product development, revolutionizing manufacturing processes. In both consumer and commercial markets, the advancement of AM is highly dependent upon innovations that improve 3D printer capabilities, speed, and materials. As new materials are developed, and 3D printers are increasingly capable of utilizing multiple materials, it is imperative that technicians understand these materials' properties both individually and as they are combined during the AM process.

One of the challenges to AM is that most of the technology now is either FFF (Fused Filament Fabrication) or SLA (Stereolithography) since they are both affordable. Thus, most educational institutions provide training to students in these two areas. Other AM technologies are still far from academia, even though they can be used to fabricate good-quality components. Metal AM is still very expensive, and most schools cannot afford it. It is anticipated that its cost may drop down but not in the near future.

4. Conclusion

Conventional training methodologies of AM have been reported in many papers and reports. For example, hands-on training activities were conducted in a laboratory environment or train-the-trainer workshop. However, technological advancements in AM, distance learning tools, learning pedagogies have provided several more unique and flexible training solutions. This paper has shared some of them. Authors believe that the number of these training solutions will parallelly grow with the advancement of AM.

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- 1601522: Advanced Design and Fabrication of Prosthetic and Medical Devices

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