International Journal of Research in Engineering and Science (IJRES)
ISSN (Online): 2320-9364, ISSN (Print): 2320-9356
www.ijres.org Volume 11 Issue 1 ǁ January 2023 ǁ PP. 347-353

Additive Manufacturing Training Needs Assessment

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Abstract
This paper, a continuation of the work presented in an Automation Alley article [1], elaborates on the additive manufacturing training needs study methodology, research questions, research results, and conclusions. Additive manufacturing (AM), also known as 3D printing, is a critical component of manufacturing competitiveness. Additionally, as seen most recently with the COVID-19 pandemic, AM can be a critical component of the supply chain for many industries and customers. While new engineering graduates typically have some experience with AM or 3D printing, many engineers in the field do not. As a result, there is a shortage of degreed engineers with appropriate AM experience representing a threat to manufacturing and the supply chain. This research study identifies the AM education needs of engineers in the field and proposes a corresponding training curriculum.
Keywords:*Additive manufacturing, 3D printing, engineering design, engineering education*

Date of Submission: 11-01-2023 Date of acceptance: 27-01-2023

I. INTRODUCTION

This paper, a continuation of the additive manufacturing (AM) work presented in an Automation Alley article [1], elaborates on the AM training needsstudy methodology, research questions, research results, and conclusions.Additive manufacturing, as defined by ISO/ASTM 52900, is a process of joining materials to make objects from 3D model data, usually layer upon layer as opposed to subtractive or formative processes [2]. The AM industry, including printing systems, materials, software, and services, has grown from $4.1 billion dollars in 2014 to approximately $10.2 billion dollars in 2018 and continues to grow[3]. Consequently, the need for an AM fluent engineering workforce has grown proportionately. However, many sources report there is a talent gap in additive manufacturing. An article from Deloitte Consulting suggests the gap is due to three broad areas: recruitment and hiring, training, and retention [4]. Of those three, this research study focuses on training. Previous studies such as the one conducted by Colletti in 2016 entitled “Positions Available in Additive Manufacturing/3D Printing and the Education and Skill Requirements for These Positions” focused on the AM skills colleges and universities should provide students thereby qualifying students for open AM positions [5].

In addition to colleges and universities, AM processes can be found in a variety of high school or secondary education applications. While schools have abandoned traditional shop classes such as metal shop and wood shop, they have adopted 3D printing. For example, there are schools participating in First Robotics who have incorporated 3D printing to manufacture their parts thus allow them to compete which would have been impossible without 3D printing. Additionally, professional organizations, such as the Society of Manufacturing Engineers (SME) implemented certification exams, such as the Additive Manufacturing Fundamentals certification exam to validate AM training at the high school level or secondary education level and beyond. Stratasys has similar certification exams.

Many community colleges have developed courses and programs in additive manufacturing to address the AM skilled workforce gap. In 2018, the U.S. Department of Labor’s Office of Apprenticeship approved the industry-vetted Additive Manufacturing (AM) Technician Registered Apprenticeship [6].

While schools are adding additive manufacturing content, this does nothing for engineers currently working in the field. According to Jimmie Beacham, chief additive engineering leader for GE Healthcare, “ 99 percent of the company’s engineers did not study AM in college and most engineers’ perception of it was developed from exploring simple rapid prototyped plastic parts [3].Mr. Aaron Howard, sales engineering manager at Voxeljet in Canton Michigan, USA, reports that his engineering staff spends a significant amount of time teaching their customers about design for AM, AM materials, and the advantage of AM for their respective companies. He reports that many engineers and companies think they are missing something by not integrating AM but do not know how to take advantage of it.

II. METHODOLOGY

To investigate this need further, the author conducted a qualitative study of the training needs of engineers currently working in AM in the state of Michigan, USA in 2019-2020. The purpose was to verify that working engineers need AM training and identify the training topics, amount of training needed, and preferred delivery method and schedule. In addition, the value of earning credentials and certifications was studied along with determining if and how companies could support AM initiatives at Eastern Michigan University (EMU).

The study consisted of an online survey emailed to approximately 3,900 additive manufacturing professionals and members of the Society of Manufacturing Engineers in the state of Michigan,USA. Questions were grouped into five categories.

1. Respondent background
2. Company size and use of AM
3. AM training topics needed and duration
4. AM training delivery method, schedule, and credit/certification
5. Support for AM initiatives at Eastern Michigan University

2.1 Research Questions

1. Are you personally involved with additive manufacturing/3D printing processes either directly or indirectly?
2. What is your job title?
3. Describe how you are involved with additive manufacturing/3D printing at your company.
4. How many years or additive manufacturing experience do you have?
5. What additive manufacturing/3D printing training have you attended?
6. Are there engineers <u>currently working</u> in your company who could benefit from additive manufacturing/3D printing training or related training such as CAD, generative design, design for AM, etc.?
7. Does your company provide additive manufacturing/3D printing training either internally or from a 3rd party (i.e. vendor training, SME, UL, MIT, etc.)?
8. Please describe the additive manufacturing/3D printing training provided by your company and/or from a 3rdparty.
9. Please indicate your overall company size.
10. What additive manufacturing/3D printing processes does you company currently use in-house or outsource?
11. On average, how much does your company spend on additive manufacturing/3D printing equipment, materials, training, and related activities combined per year?
12. Has your company ever donated money, time, materials, and/or equipment to schools to support their additive manufacturing/3D printing?
13. What CAD/Design software does your company use?
14. What software does your company use to repair, modify, and/or prepare files for additive manufacturing/3D printing?
15. For each topic, please estimate the amount of training that would benefit engineers <u>currently working</u> in your company.
16. Please rank your company's preferred training delivery method.
17. For <u>in-person training</u>, please rank your company's preferred class schedule.
18. For <u>in-person, multi-day training</u>, please rank your company's preferred class scheduling.
19. How important is onsite training for your company?
20. How important is it for training to be "hand’s on" using additive manufacturing/3D printing equipment and software?
21. How important is it for engineers to receive college credit or continuing education units for additive manufacturing/3D printing training?
22. How important is it for engineers to receive additive manufacturing certifications from SME or Stratasys
?
23. Does your company have an office and/or plant in Michigan?
24. Please estimate the number of engineers at your company <u>AND</u> working in Michigan who could benefit from additive manufacturing/3D printing or related training such as CAD, generative design, design for AM, etc.
25. What is your age
26. What is the highest degree you earned, major, and date earned.
27. What other degrees have you earned, major, and date earned
28. Where do you currently reside?
29. Would you or your company be interested in <u>learning</u> about additive manufacturing initiatives/activities at Eastern Michigan University?

30. Would you or your company be interested in supporting additive manufacturing initiatives/activities at Eastern Michigan University?
31. Please select how you or your company would like to support additive manufacturing initiatives at Eastern Michigan University.
32. Would you like to discuss your company's additive manufacturing/3D printing training needs or related training needs in more detail with a representative from Eastern Michigan University?
33. Based on your positive response to one or more of the previous questions, please provide your contact information so that we may follow up with you.

III. RESULTS

Of the approximately 3,900 surveys sent via email, there were 484 unique email opens, with 70 unique clicks on the survey link. Of the 70 unique clicks, 47 total responses were collected. Listed below are results pertinent to this paper.

3.1 Respondent Background

The respondents age, AM experience, highest degree earned, and previous AM trainingare illustrated in Tables 1, 2, 3, and 4respectively.

Table 1: Age of respondents.

Age	Respondents
Prefer not to answer	10%
18-25	10%
26-30	10%
31-40	19%
41-50	16%
51-60	29%
61-70	3%
Over 70	3%

Table 2: Years of AM experience.

Years of AM Experience	Respondents
0	2%
1-5	60%
6-10	17%
11-15	2%
16-20	8%
More than 20	11%

Table 3: Highest degree earned.

Highest Degree Earned	Respondents
Associates(AA, AS)	9%
Bachelors (BA, BS, BSE)	67%
Masters (MA, MS, MSc, MSE)	14%
Doctorate (PhD, EdD)	10%

Table 4: Previous AM training.

AM Training Previously Attended	Respondents
University/Community college classes	13%
Manufacturer sponsored training	23%
Professional organization sponsored training	19%
One the job training	32%
Other	10%
None	3%

3.2 Company Information

Tables 5 thru 9 provide company specific information such as size, AM expenditures, software used, and number of employees who could benefit from AM training. Not described in the tables is that43% of the respondents indicated their company has donated money, time, materials, and/or equipment to schools to support their additive manufacturing/3D printing initiatives. 58% of the respondents indicated their company provides AM/3D printing training either internally or from a 3rd party. 92% of respondents reported they were directly involved with AM or 3D printing, either directly or indirectly, at their company.

Table 5: Company size.

Number of Employees	
1-25	23%
26-50	4%
51-100	6%
101-200	9%
201-500	8%
More than 500	50%

Table 6: Annual company AM expenditure (materials, equipment, training).

Annual Company AM Expenditure (USD)	Respondents
0-$100,000	26%
$100,000-$250,000	10%
$250,000-$500,000	7%
$500,000-$1,000,000	7%
Over $1,000,000	21%
Don’t know	29%

Table 7: CAD software used.

CAD Software Used by Company	Respondents
Inventor	9%
Fusion 360	8%
Solidworks	19%
Catia	15%
Siemens NX	18%
Pro E	4%
Creo	6%
Altair Inspire	9%
Rhino	3%
Other	8%
Don’t know	1%

Table 8: Software used to repair, modify, and/or prepare files for AM/3D printing.

Software	Respondents
Netfabb	10%
Meshmixer	8%
Materialise	15%
Cura	8%
GrabCad	15%
Insight	8%
Eiger	6%
Polyworks	6%
Meshlab	2%
Simplify 3D	8%
Other	8%
Don’t know	6%

Table 9: Number of engineers at your company in Michigan who could benefit from AM training.

Number of Employees	
1-10	30%
11-20	14%
21-30	14%
31-50	2%
More than 50	35%
Don’t know	5%

3.3 AM training topics, delivery method, scheduling, and credit/certification

Tables10 illustrates recommended AM training topics and duration based on 8-hour days. Tables 11 thru 13 describe the recommended delivery method and scheduling. Tables 14 and 15 illustrate the relative importance of onsite training and hands-on training respectively.

Table 10:Average days (8 hours/day) of training recommended.

Training Topic	Average Days (8hours/day) of Training Recommended
Design for AM	3.1
AM materials	2.2

AM quality	2.2
AM technologies and applications	2.1
Advanced solid modeling	2.0
AM toolmaking, i.e. rapid tooling	1.8
Basic solid modeling	1.7
Generative design	1.6
Economics of AM	1.5
stl file repair and manipulation	1.2
AM safety	1.0

Other training topics recommend by the respondents were metallurgy, jidoka, advanced manufacturing, testing, cost estimating, supplier quality, and just-in-time.

Table 11: Preferred delivery method.

Delivery Method	1st choice	2nd choice	3rd choice	4th choice
Fully online	20%	24%	56%	0%
Hybrid	32%	52%	16%	0%
In-person	44%	24%	28%	4%
Other	4%	0%	0%	96%

Table 12: Preferred class scheduling.

Class Schedule	1st choice	2nd choice	3rd choice	4th choice
Training after work	11%	85%	4%	0%
Training during work	77%	5%	15%	0%
Training on the weekend	4%	4%	73%	19%
Other	8%	4%	8%	80%

Table 13: Preferred class scheduling for in-person training.

Importance of AM Certification	1st choice	2nd choice	3rd choice
One day per week for multiple weeks	24%	72%	4%
Consecutive days in the same week	72%	20%	8%
Other	4%	8%	88%

Table 14: Importance of Onsite Training

Importance of Onsite Training	Respondents
Very important	28%
Moderately important	31%
Slightly important	21%
Not important	10%
Don't know	10%

Table 15: Importance of hands-on training

Importance of Hands-On Training	Respondents
Very important	48%
Moderately important	39%
Slightly important	4%
Not important	4%
Don't know	5%

Table 16 shows the relative importance of AM certifications. These include the Society of Manufacturing Engineer's AM Fundamentals certification, Society of Manufacturing Engineer's AM Technician certification, and Stratasys's AM Certification. Table 17 lists the relative importance of receiving college credit or continuing education units for training.

Table 16: Importance of AM certification.

Importance of AM Certification	SME Certified AM Fundamentals Certification	SME AM Technician Certification	Stratasys AM Certification
Very important	7%	10%	7%
Moderately important	24%	17%	24%
Slightly important	17%	21%	21%
Not important	42%	42%	38%
Don't know	10%	10%	10%

Table 17: Importance of receiving credit for training.

Importance of AM Certification	Not Important	Slightly Important	Moderately Important	Very Important	Don't Know
College credit	30%	26%	15%	19%	10%
Continuing education units (CEU)	21%	24%	31%	10%	14%

Tables 18 and 19 describe the interest in working withEMU and also interest in supporting AM at EMU. In Table 19, the other responses include TBD, unknown, and discuss in person.

Table 18: Company interest in working with EMU.

Question	Yes	No
Would you or your company be interested in learning about additive manufacturing initiatives/activities at Eastern Michigan University?	47%	53%
Would you or your company be interested in supporting additive manufacturing initiatives/activities at Eastern Michigan University?	47%	53%
Would you like to discuss your company's additive manufacturing/3D printing training needs or related training needs in more detail with a representative from Eastern Michigan University?	39%	61%

Table 19:How you would like to support AM initiatives at EMU.

Method	Responses
Donate equipment	6%
Donate software	4%
Serve on curriculum advisory board	16%
Donate and designate	4%
Volunteer as guest speaker	18%
Sponsor student projects	8%
Sponsor student internships	10%
Sponsor faculty research	6%
Sponsor faculty internships	6%
Partner on grant proposals	14%
Other	8%

IV. CONCLUSION

The majority of respondents were between the ages of 31 and 60 indicating they have been out of school for at least 9 years or more. This is the target audience of the study, engineers likely not exposed to AM in college. Approximately 67% achieved a bachelor's degree as their highest degree earned.Approximately 62% of respondents possessedbetween 0 and 5 years of AM experience which demonstrates that many engineers in the field have minimal AM experience. Interestingly, many of the respondents have attended some form of AM training. While many respondents attended AM training, Table 9 demonstrates that there are many engineers in the field who could benefit from AM training. This validates the hypothesis that engineers in the field need AM training.

Regarding the specific training topics required, the top four training topics based on training time required are, design for AM, AM materials, AM quality, and AM technologies and applications. The training topics requiring the least amount of time areAM safety and stl file repair and manipulation. While some topics require more time than others, it does not necessarily indicate relative importance of the topics.

Regarding delivery methods and scheduling for training, the respondent's first choice was in-person training. However, hybrid was a close second indicating that a hybrid format would be acceptable. Based on the data in Table 14, in-person training should be onsite if possible. However, from Table 15, the in-person component should include hands-on activity. Maybe not surprisingly, the majority of respondents preferred training classes during working hours. Training after working hours is their second choice but definitely not on the weekend.

The results for certification and receiving credit for training reflected relatively low importance for both as shown in Tables 16 and 17 respectively. It does not mean they are viewed negatively but rather have low perceived value. This suggests it is not absolutely necessary to build certification and credit into AM training courses.

The responses to questions about working with EMU and supporting AM at EMU were very positive. The "yes" responses to the questions in Table 18 ranged from 39% to 47%. Additionally, many respondents expressed willingness to support AM initiatives at EMU in various forms.

4.1 Opportunities, Challenges, and Recommendations

The data clearly demonstrates the need for AM training, training topics, and length of training needed. There is an opportunity for a training partner to develop and offer such training. This also represents an opportunity for companies and organizations to fully leverage the benefits of AM. Training classes for each topic could be developed allowing companies to select which class(es) they want delivered. Each classcould be completely in-person or hybrid. In-person activities should be on-site, during the workday, and provide continuing education units if possible.

The largest challenge will be delivering the hands-on component of the training and doing it onsite if possible. For companies that have AM equipment, this could be possible. For companies without AM equipment, the trainer will need their own equipment offsite or partner with a 3rd party. This certainly increases the logistical complication and cost. The other challenge is identifying which topics to develop training for first.Does the length of training recommend by respondents correlate to its importance? The data does not answer that question. Which topics are most important may depend on the specific company.

If AM training for engineers in the field is to be offered, the next step is to identify a group of companies interested in AM training. Survey the companies to determine their most critical training needs based on topics in Table 10. The survey can also determine which, if any, AM equipment the companyhasonsite and if it is available for training. With that information, develop curriculum for the highest demand courses using durations listed in Table 10. The training will be hybrid with the in-person component conducted onsite as much as possible. If companies do not have AM equipment in-house, partnerships with vendors, resellers, manufacturers, or 3D printing service providers needs to be explored.

The School of Engineering at EMU, contains 3D printing lab with multiple printing technologies such as fused deposition modeling (FDM) and stereolithography (SLA) that could support AM training. The lab prints parts for all students in the School of Engineering. Exampleparts include prototypes, end-use parts, injection molding tooling, blow molding tooling, vacuum forming tooling, casting patterns, and core boxes just to name a few. Many respondents wanted to learn more about and support AM initiatives at EMU. There were a variety of ways in which respondents wanted to demonstrate their support of AM initiatives at EMU. Moving forward, the School of Engineering and other schools should pursue collaborations with companies to grow additive manufacturing capabilities and educational opportunities for students and faculty.

ACKNOWLEDGEMENT

The research project was funded byaBrickley Award from Eastern Michigan University.

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