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Preparing industry for additive manufacturing and its applications: Summary & recommendations from a National Science Foundation workshop

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ABSTRACT

Accompanying the increasing advances and interest in Additive Manufacturing (AM) technologies is an increasing demand for an industrial workforce that is knowledgeable about the technologies and how to apply them to solve real-world problems. As a step towards addressing this knowledge gap, a workshop was held at the National Science Foundation (NSF) to discuss the educational needs to prepare industry for AM and its use in different fields. The workshop participants – 66 representatives from academia, industry, and government – identified several key educational themes: (1) AM processes and process/material relationships, (2) engineering fundamentals with an emphasis on materials science and manufacturing, (3) professional skills for problem solving and critical thinking, (4) design practices and tools that leverage the design freedom enabled by AM, and (5) cross-functional teaming and ideation techniques to nurture creativity. This paper summarizes the industry speakers and presentations from the workshop, along with several new educational partnerships identified by small working groups. Based on the presentations and partnerships, the following recommendations are offered to advance the AM workforce. First, ensure that all AM curricula provide students with an understanding of (i) AM and traditional manufacturing processes to enable them to effectively select the appropriate process for product realization; (ii) the relationships between AM processes and material properties; and (iii) "Design for AM", including computational tools for AM design as well as frameworks for process selection, costing, and solution generation that take advantage of AM capabilities. Second, establish a national network for AM education that, by leveraging existing "distributed" educational models and NSF's Advanced Technology Education (ATE) Programs, provides open source resources as well as packaged activities, courses, and curricula for all educational levels (K-Gray). Third, support K-12 educational programs in STEAM (STEM plus the arts) and across all formal and informal learning environments in order to learn the unique capabilities of AM while engaging students in hands-on, tactile, and visual learning activities to prepare them for jobs in industry while learning how to think differently when designing for AM. Fourth, provide support for collaborative and community-oriented maker spaces that promote awareness of AM among the public and provide AM training programs for incumbent workers in industry and students seeking alternative pathways to gain AM knowledge and experience. Recommendations for scaling and coordination across local, regional, and national levels are also discussed to create synergies among the proposed activities and existing efforts.

1. Introduction

1.1. Motivation for the workshop

Additive Manufacturing (AM) is leading a rebirth of interest and activity in advanced manufacturing in the United States. The hype

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and promise for AM has been driven as much by technological advances (e.g., the ability to manufacture fully-dense metal parts for production) as by the commodification of existing AM technologies (e.g., desktop-scale 3D printers). Many of these AM and 3D printing (3DP) advances lie on opposite ends of the Technology Readiness Scale, yet together they are generating unprecedented interest in this decades-old technology.

While enthusiasm for AM has grown substantially recently, widespread use and industrial adoption of AM for production of end-use products has been tempered. In addition to the technical challenges (e.g., lack of metrology and production standards, limited working materials, uncertainties in part qualification), one acknowledged barrier to AM adoption is the workforce's unfamiliarity with the technologies' capabilities, their working materials, and techniques for designing products to take full advantage of the potential offered by AM.

The need to educate future design and manufacturing engineers was a core focus of the 2009 Roadmap for Additive Manufacturing [1–3], as unfamiliarity with AM technologies is a significant hurdle for industrial adoption. The roadmap urges the development of university courses and "programs for educating the general population to enhance the interest in AM applications and generate some societal 'pull' for the technologies" [1]. Fundamentally, to realize the full potential of AM, engineers must (i) fully understand AM technologies and AM materials, (ii) know how to design products for fabrication via AM, (iii) be able to synthesize AM's economic and environmental impacts on a manufacturing value chain, and (iv) understand how to effectively communicate and ultimately qualify AM parts.

While some AM courses at the undergraduate and graduate levels do exist (see, e.g., [4,5]), their limited quantity does not match the recent interest in, and national importance of, AM technology. Recent textbooks on AM (e.g., [6,7]) will satisfy some of this interest and provide overviews of AM technology, but providing scalable hands-on experiences to train thousands of students and incumbent workers is a challenge. For instance, the Center for Innovative Materials Processing through Direct Digital Deposition at Penn State offers 4-day industry practicum sessions that combine lectures with hands-on activities in their AM facilities. They have trained more than 240 industry practitioners in the past three years, but participation is limited to 40 people per class due to space constraints and safety concerns. Many AM facilities face similar challenges and must balance the time spent training against time spent doing research and work for their industry partners.

Numerous workshops have been held in the past year to address AM's critical research and technical challenges [8–10]. Specifically, these workshops have focused on (i) assisting newcomers in becoming familiar with the technology, (ii) presenting research opportunities to those communities that have yet to interface with AM, and/or (iii) presenting updates on the dynamically changing technologies.

To date, none of these workshops have convened experts from industry, academia, non-profit organizations, and government agencies to discuss the specific educational needs and opportunities – and corresponding partnerships – for the AM workforce. To address this gap, we organized a Steering Committee (see Acknowledgements) with support from NSF and America Makes to hold a 1.5-day workshop on AM education and training at NSF in Arlington, VA. The goals and objectives for the workshop are discussed next.

1.2. Workshop goals & objectives

While there is clearly a need to educate a workforce that is capable of intelligently employing AM technologies, the means for appropriately addressing this gap are not well defined. Advancing the understanding, utilization, and adoption of AM and will require an interdisciplinary workforce that has the knowledgebase for synthesizing new materials, integrating advanced process controls, establishing quality control standards, and formulating new design and communication methodologies. The knowledge, skills, and abilities necessary to work effectively with AM technologies are not well understood – and are changing quickly – given how rapidly the field is evolving. What should we be teaching students about AM? What do graduate students need to know versus undergraduates? What technical training should be offered at community colleges? What types of AM-related skills are needed in industry? How best to capture and integrate the interdisciplinary knowledge needed to take full advantage of all of AM's capabilities? There are unlimited opportunities given the promise of AM, but what are the real needs, and subsequently, what are the knowledge, skills, and abilities that we should be teaching our students to work in this rapidly changing environment?

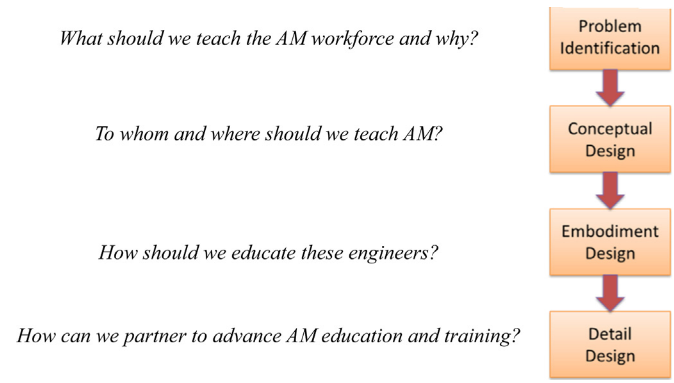

Fig. 1. Workshop Structure as a Process of Design.

Addressing these issues was the primary goal for the workshop. Specifically, the goal of the workshop was to *bring together participants from academia, industry, and government agencies to actively engage in discussions related to, and develop efforts for, enhancing the AM workforce through new and novel educational and training partnerships.* Workshop objectives for achieving this goal included:

- Providing a foundation for preparing the workforce for AM;
- Identifying new ways to work effectively across a wide spectrum of educational needs–graduate, undergraduate, community colleges, technician training, industry practitioners, and 'makers'; and
- Identifying synergies between existing AM educational efforts and funding to realize new education and training partnerships.

An overview of the workshop is presented in Section 2. The results from the workshop's breakout session are presented in Section 3. We close the paper with a summary of the key workshop outcomes and recommendations for enhancing the AM workforce. A detailed description of the workshop and its outcomes can be found in the workshop report [11].

2. Methodology: workshop overview

Faced with the broad overall workshop goal to identify efforts for enhancing the AM workforce through novel educational partnerships, the authors chose to approach the organization of the workshop in the framework of the engineering design process (see Fig. 1). Thus, the first workshop activity was to define the problem. In the context of AM education, the task was to discuss what should be taught to the future AM workforce at all educational levels (e.g., first to senior year in both university and community colleges).

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