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Using online learning modules to improve students' use of technical standards in additive manufacturing courses and projects

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Abstract: Engineers in a variety of industries use engineering standards to guide their work. However, many engineering students have little awareness of relevant standards or codes, especially in cutting-edge fields with rapidly developing standards such as additive manufacturing. To address this gap, we have developed four online learning modules focused on the topic of additive manufacturing which are deployed in our university's learning management system. These modules can be incorporated into manufacturing and design courses throughout the engineering curriculum. The covered topics include an introduction to engineering standards, an introduction to standards in additive manufacturing, how standards are used during additive manufacturing process development, and using standards during testing and evaluation of additively manufactured parts. Examples of standards covered include ASME Y14.46 and ISO/ASTM 52900-21. The modules are applicable for all types of AM processes but focus most on material extrusion and powder bed fusion. We describe the process of designing the modules, guided by best-practices for online learning and a backwards design strategy, use of a variety of online learning technologies, and interactive course activities. The modules have been deployed into the curriculum of several additive manufacturing-related courses offered at a large public university in the southwestern United States starting in Fall 2022. The impact of our modules is assessed using a survey-based instrument that measures students' confidence in identifying, locating, and using standards for a sample of approximately 30 students. We found a significant large difference in students' self-reported ability to utilize standards from the beginning to end of the semester. We discuss differences in survey responses and explore trends for varying levels of industry experience. The learning modules, which include interactive videos, interviews with industry representatives, and readings, activities, and quizzes, are freely available to any interested instructors to incorporate into their courses.

Keywords: Additive manufacturing; online learning; standards

Introduction

A fundamental skill for engineers is to identify relevant standards (i.e., technical documents that provide best practices and establish uniform procedures across different organizations) and appropriately use these standards to guide their work. The use of standards is so central to engineering that the Accreditation Board for Engineering and Technology (ABET), which accredits colleges and universities that offer engineering degrees, requires that an accredited program "incorporates appropriate engineering standards and multiple constraints" into a capstone design experience [1]. Standards are valued in industry, as well. A survey of managers in technical sectors showed that the managers viewed standards as essential to daily operations, regardless of their company's specific sector [2]. Despite the importance of standards to engineering practice, standards often receive only cursory coverage in engineering curriculum. A survey of engineering industry representatives showed that 73% of those surveyed felt that recent engineering graduates lacked knowledge of engineering codes and standards [3].

In recent years, there have been several efforts to increase engineering students' competency with standards. The National Institute of Standards and Technology (NIST) has the Standards Services Curricula Development Cooperative Agreement Program, which provides funds for

institutions to develop innovative materials and methods to incorporate standards into their curricula. Examples of past projects include Green Buildings and Sustainable Materials [4] and Digital Forensics [5].

One area that had not been the focus of prior significant curriculum development for standards is additive manufacturing (AM). Because AM technologies have matured and increased in industry adoption only recently, curricula which include AM standards are still developing. Many universities began incorporating AM into engineering curricula in the past 5 to 10 years. However, the technology has expanded rapidly, and related coursework has followed with over 70 courses being offered in AM coursework, according to a recent search by the authors of this work.

The AM standards landscape has seen fast-paced changes along with the rapid evolution of AM technology. Standards developing organizations including ASTM, ISO, and ASME have all developed standards relating to designing, producing, and testing parts fabricated using AM. The number of relevant standards has increased quickly: a recent search in ASTM's Compass standards database using the search key "additive manufacturing" identified 361 ASTM standards. It is necessary to prepare students to identify and use relevant AM standards so they are prepared for industry employment in fields that utilize AM. Additionally, the rapidly evolving AM standards landscape presents an interesting case study for students to learn more about standards development.

For these reasons, our team decided to prepare a set of learning modules on AM standards to incorporate into relevant courses at our university. Specifically, we decided to develop four distinct but interrelated learning modules, focusing on usage of standards in general, introduction to AM standards, standards for AM process development, and AM standards for testing (Table 1). These modules have been or will be incorporated into three courses at our institution: Design for Additive Manufacturing (offered by the Department of Systems and Industrial Engineering), Additive Manufacturing (offered by Aerospace and Mechanical Engineering) and Metal Additive Manufacturing (offered by Material Science and Engineering).

Table 1. Description of e-learning modules

Module name	Description	Examples of standards covered
Introduction to technical standards	Students will learn about the role and importance of technical standards. They will explore the range of technical standards available and experience locating and utilizing technical standards.	
Introduction to AM standards	Students will be introduced to the major categories of AM processes so they can identify differences between the processes, using standard terminology. They will understand what information is contained in relevant standards that can help guide the design and fabrication of parts using AM. They will use standards as they scope the design of a new product.	ISO/ASTM52900-21 ISO/ASTM 52910 ISO/ASTM52901-16 ASME Y14.46
Standards in AM process development	The various types of AM processes will be defined and classified using standard terminology. Students will learn about current published standards relating to AM processes and feedstocks. We will discuss industry-specific guidance and limitations with data sharing.	ASTM F3049-14 ISO/ASTM52904-19
Standards for testing and evaluation of AM parts	Students will understand the types of tests that are frequently conducted to evaluate AM part properties and will be able to describe the corresponding test specimens. They will gain a high-level understanding of why such evaluations are performed and how much variation there can be in AM part performance.	ASTM F3122-14 ASTM F2971-13 ISO/ASTM52902-19

Our goal was to make the content of our modules general to all AM processes, so the modules can be incorporated into a wide variety of courses. Throughout the modules, we used the seven classifications of the latest AM technologies under ISO/ASTM 52900:2021: Binder Jetting, Directed Energy Deposition, Material Extrusion, Material Jetting, Powder Bed Fusion, Sheet Lamination, and Vat Photopolymerization.

Impact on manufacturing education

The incorporation of standards is an important goal for engineering courses given the industry-relevance as standards, as detailed above. Specifically for manufacturing, there has been little illustration in literature as to how standards can be incorporated into manufacturing courses, with only a few published examples, e.g., [6], [7]. Our modules can serve as a guideline for others to incorporate standards into their manufacturing courses, either by directly adapting our materials or by using it as a framework for types of activities they can use.

Development of modules

The modules were developed as online learning modules, used in online courses, assigned as out-of-class assignments, or presented during in-person courses. The modules were developed with the support of an instructional designer from our institution's University Center for Assessment, Teaching, and Technology. We used a "backward design" approach with three general steps: identify the desired results of the modules (i.e., what will students be able to do after engaging with the module), determine acceptable evidence (i.e., how can we assess student understanding), and plan learning activities (i.e., plan the activities students will engage in in the

modules) [8]. Using this approach, we focused on defining student learning outcomes for each module before choosing the content and assessments in each module.

We also used guidance from the instructional designer to make our content suitable for online learning by combining a variety of content such as readings, videos, and student activities. We used PlayPosit to create more interactive videos, with short questions to test students' understanding interspersed within each video. We included interactive activities, such as tasking students to find and summarize relevant standards using various standards databases. Each module included an introduction previewing the learning objectives of the module and providing students with an activity list (Fig. 1). Although the modules were developed in D2L, we plan to export the modules in a way that they can be uploaded to other learning management systems as well, such as Canvas and Blackboard, to encourage adoption of our materials in other AM-related courses across the US.

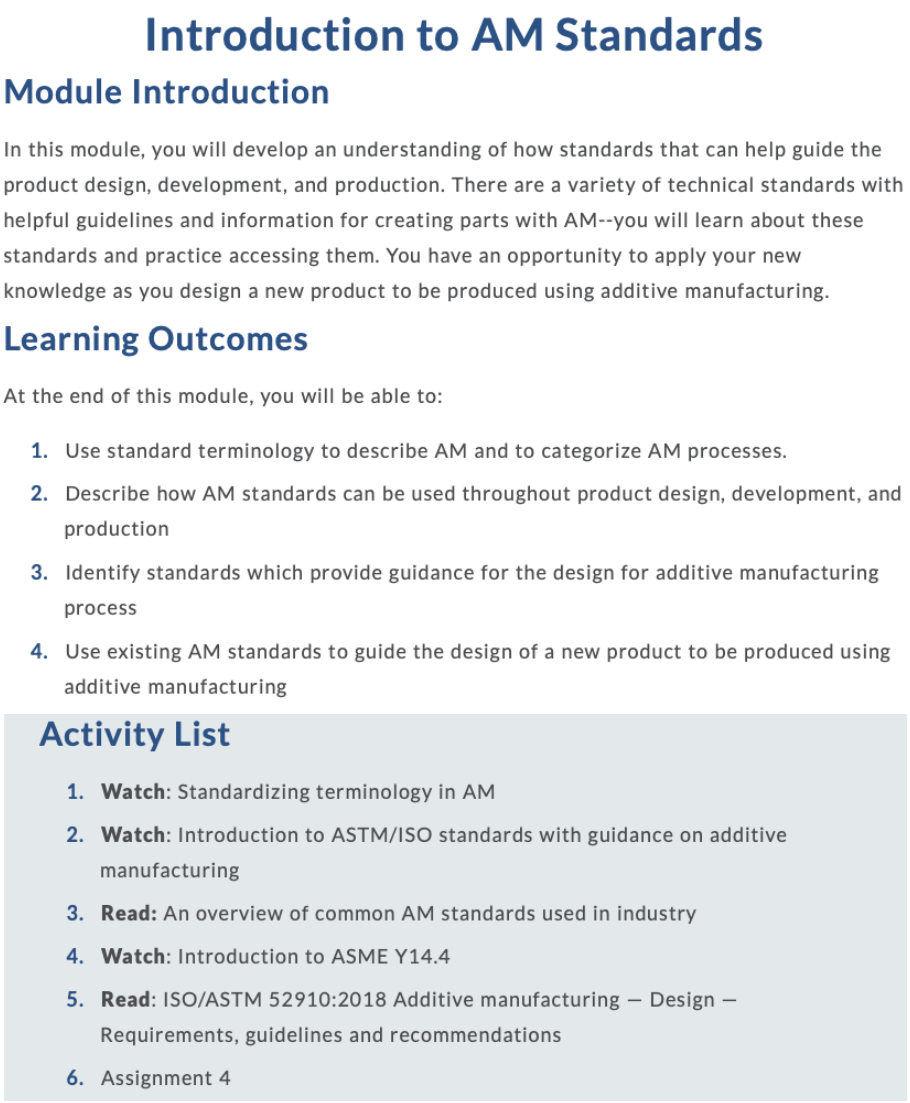

Figure 1. Screenshot of the overview of Module 2: Introduction to AM Standards from our learning management system

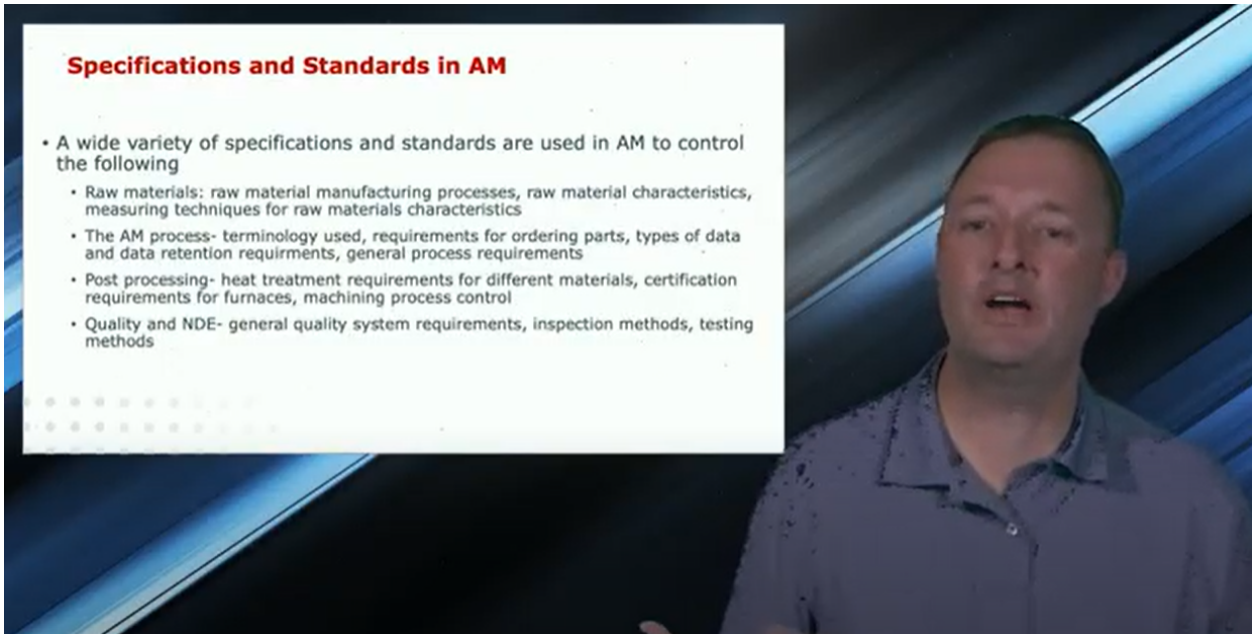

Figure 2. Example of video included in Module 3

Modules 1 and 2 were deployed in the Design for Additive Manufacturing course at our institution and content from Module 3 was incorporated into the Metal Additive Manufacturing course in Fall 2022. This pilot allowed us to evaluate the impact of the content and to identify areas in which we should improve our modules in the year ahead. The full content of the modules is still under development and will be shared at the end of 2023.

Feedback on modules

To evaluate the impact of our content, we asked students to take a pre- and post-test/survey at the start and beginning of our courses. The test asked students to rate their competency with technical standards, with responses ranging from 1 to 5 (where 1=strongly disagree and 5=strongly agree). We took inspiration for our survey questions from a prior study that evaluated students' increase in understanding of standards [9]. In Fall 2022, A total of 32 students attempted the pre-test; 24 students attempted the post-test. The differences between pre- and post-test are shown in Table 2. To test if the differences in scores were significant, we used a Wilcoxon rank sum test. Cohen's delta was used to quantify the effect sizes.

Table 2. Results from survey to evaluate students' perceived competency with standards

Question	Pre-test mean (SD)	Post-test mean (SD)	p	Effect size, d
I feel that I can define what a technical standard is	2.96 (1.22)	4.27 (0.83)	**p < 0.01**	1.22
I feel that I can locate technical standards in online databases	2.80 (1.27)	4.14 (0.94)	**p < 0.01**	1.16
I feel that I can determine what type of technical standard to use as I conduct engineering work	2.71 (1.27)	3.68 (1.09)	**p < 0.01**	0.81

I feel confident that I can utilize technical standards as I conduct engineering work	3.11 (150)	3.86 (1.04)	p = 0.086	0.57
Average of all four above listed items	2.88 (1.16)	3.99 (0.87)	**p < 0.01**	1.06

Students felt more strongly at the end of the semester that they could define technical standards, locate them in online databases, and determine what types of standards to use in their work. The only item that did not see a significant increase was "I feel confident that I can utilize technical standards as I conduct engineering work," indicating the students may need more practice using standards in engineering projects. The average scores across all four items were significantly different at the end of the semester, with a large effect size, indicating that exposure to the content on standards in AM helped students to feel more confident in their use of technical standards.

We asked students in the post-survey to tell us the number of years of experience they had working in industry. Interestingly, we found that students with less than 1 year of experience reported more certainty in their ability to use standards at the end of the semester (n=11, M=4.20, SD=0.71) than students with 1 to 5 years of experience (n=8, M=3.44, SD=0.90). Students with 6 or more years of experience expressed the highest certainty in their abilities (n=3, M=4.67, SD=0.58).

We asked students to provide us with written feedback on the modules, as well. The feedback was generally positive, but students also gave comments for improvement that we plan to incorporate. Students enjoyed the mix of content offered in the videos, and gave positive feedback on the interactive videos, reading, and activities, with one student commenting:

> *I liked watching the videos about the standards and how they are useful. They helped me get a better understanding about why and how standards are used. The activities on finding standards for a specific application was also useful since it gave us an example of how we might go about applying standards in our careers.*

Students valued having hands-on experience with standards and suggested having more opportunities to incorporate standards into their coursework. One student commented:

> *I also enjoyed the mix of videos and readings that were applicable to the material throughout the module. My own thought is to maybe have more activities to apply and look at technical standards…*

In the Design for Additive Manufacturing course, students were asked to complete the modules in class in a self-paced activity. This self-paced format seemed to be a good fit for students exploring standards, with one student saying:

> *Personally, I really preferred this type of module for AM standards over the typical lectures. Not to say that technical standards and AM standards aren't important, but it would be difficult to fully learn and understand them by just sitting through lectures about them. I thought the reflections and case study were the best activities to have gone through in the modules. Showing how to find standards and then trying to apply them and give reasoning to where they can be used was a good exercise, and made the overall topic*

of standards and their importance to different parts of the design process easier to understand.

Some specific suggestions were given to improve the modules. One student said:

> *I think the reflection activities were a good bolster for the learning material and the modules flow pretty well. I would recommend moving them up earlier in the coursework though. Some of the newer standards (see ASTM F3530-22) have a lot of really helpful DFM guidance.*

Another student echoed the need to incorporate standards throughout the semester, rather than just in one week of the course:

> *I think it would be sort of helpful to identify the standards as you taught the class. Just a brief mention, just to know they exist. Like the lattice tolerance standard. I didn't even know there was a standard until today but pointing that out when we had our lattice lectures might point to the fact that there is a standard. I sort of thought it was like freehand or the machine software calculated it by itself.*

In the coming year, we hope to improve on the design and implementation of our modules and to conduct a final roll out in Fall 2023. We found that students engaging with the self-paced activity liked a variety of short activities and videos rather than long videos or a single type of content, which agrees with the guidance of our instructional designer. Students also wanted to have the content of standards spread throughout the class, rather than taking several modules together. We plan to spread out the modules throughout the semester in the future. We also plan to provide more opportunities for students to apply their knowledge of standards into open-ended design projects, in hopes of increasing students' confidence in utilizing technical standards as they conduct engineering work, which was the only item in our survey where we did not observe a significant increase across the semester.

Conclusion

AM technology and the AM standards landscape are rapidly evolving. The novelty of the field and the quick pace with which AM standards are being developed makes this topic a perfect fit for introducing engineering students to standards and the standards development process. We have incorporated learning modules on a variety of AM-standards topics into several undergraduate and cross-listed courses at our institution. Students show increased understanding and confidence in their ability to interact with standards after taking the revised courses with standards content. The variety of activities in the modules helped keep students engaged but students wanted more references to standards and opportunities to apply standards throughout the semester, beyond the context of the four modules. Student feedback helped us to identify ways to improve and change our content, such as increasing the range of activities included and providing students with many opportunities to incorporate standards into open-ended and hands-on projects. We plan to share these modules with the broader manufacturing education community soon so other instructors can incorporate this material into their own courses.

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