Final Report for
Development of Standards Education Modules for Additive Manufacturing
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Executive summary

In this project, we developed four online modules focusing on the use of standards in additive manufacturing design, process development, and evaluation. These modules, which can be incorporated into various learning management systems, include videos, assignments, activities, and project descriptions and rubrics. The modules have been incorporated into the curriculum of three additive manufacturing courses in the College of Engineering at the University of Arizona across three distinct departments. To date, 88 students have engaged with the updated standards curricula. We observed significant increases in these students' competency and confidence in using standards, with large effect sizes. We have identified 118 faculty who teach additive manufacturing courses across the US who will receive a link to our resources to incorporate them into their courses. Our results have been disseminated in two conference presentations and a conference publication, which has been downloaded 65 times in the 7 months since publication.

1. Motivation and Approach

1.1 Project Motivation

Identifying and utilizing technical standards to guide design and evaluation of new products and processes is a fundamental skill for engineers. Given the rapidly evolving nature of additive manufacturing (AM), it is important that engineering students who will utilize AM understand relevant standards and how to incorporate them into their work. We have identified AM courses at over 90 institutions nationwide, and many of these courses have developed in the past 5 years. There is a need to support educators at our institution and institutions across the US in best practices for teaching students to identify and utilize AM standards.

1.2 Project Approach

Current curricula provide students with limited opportunities to practice finding, reading, and applying standards in general, and AM standards in particular. To address this gap, we updated three UArizona courses to include the online learning modules we develop in this project and disseminate the modules and our findings widely. Specifically, we had five project objectives:

1. Develop 4 e-learning modules.
2. Deploy each of the developed modules in one or more courses at UArizona.
3. Improve UArizona students' ability to identify, locate, evaluate, and effectively use standards for technical problems related to additive manufacturing.
4. Distribute e-learning modules to other institutions of higher education with guidance for how other institutions can replicate our methods.
5. Disseminate project results in a final summary paper to a wide audience.

Our module development and course deployment focused on designing activities and projects which provide direct practical experience with students in utilizing standards. By structuring our modules as a collection of different activities and modalities (e.g., readings, videos, activities, projects), we ensured maximum flexibility for other instructors to pick and choose the content they would like to use. Additionally, this range of formats ensures the content can be incorporated for distance, online learning, incorporated into flipped classroom modalities, or assigned as homework in traditional lecture courses.

2. Outcomes and Evaluation

The overall goal of our project was to improve students' ability to effectively use standards. In order to achieve this goal, we developed five performance objectives. We developed a project evaluation plan, which included interim and final indicators. Relevant interim and final indicators will be described in the results of each corresponding objective below.

2.1 Objective 1: Develop four e-learning modules.

The content of the four learning modules (Table 1, Fig. 1) has been iteratively developed over the course of the project, with continued updates still underway as we continue to teach courses which utilize the modules. We monitored the timeline of module development as a project evaluation indicator. Two modules were developed in Fall 2022, with the remaining

two modules developed in Spring and Fall 2023. Content which was incorporated into the modules has been developed continuously throughout the project period of performance.

Table 1. Description of the four learning modules developed in this project

Learning module focus	Topics and relevant standards
Module 1: Introduction to engineering standards	**Topics**: Standards development organizations; standard development process; How to identify and access standards; ASTM F42 committee
Module 2: Use of standards in the design for additive manufacturing process	**Topics**: AM terminology; Design and data formats; AM test samples; GD&T; AM applications **Relevant standards**: ISO/ASTM52900-15, ISO/ASTM 52921-13; ISO 17296-4; ISO/ASTM 52915-13; ASME Y14.5
Module 3: Additive manufacturing process development	**Topics**: AM processes; AM feedstocks; Preparing and testing test specimens **Relevant standards**: F2971-13; ISO/ASTM52904-19; F3049-14
Module 4: Testing and evaluation for additively manufactured parts	**Topics**: Mechanical properties; Requirements for purchased AM Parts **Relevant standards**: ISO/ASTM52901-16

Each module has three or move videos with PlayPosit interaction, which helps engage students by testing their understanding of video content as the video progresses. Most of this content is videos we recorded in our One Button recording studio on our campus, which enabled us to record high quality lecture-style videos (Fig. 1). In keeping with recommendations provided to us by our online learning instructional designers, we have kept videos short (typically below 8 minutes) to ensure student engagement. The videos are coupled with readings of standards, reading of news articles and case studies, and short assignments and design prompts. We have also compiled project materials to use in tandem with the modules, with three examples of AM-related projects which incorporate AM standards. Additional project resources include rubrics to assess design reports for competence in identifying and utilizing relevant standards.

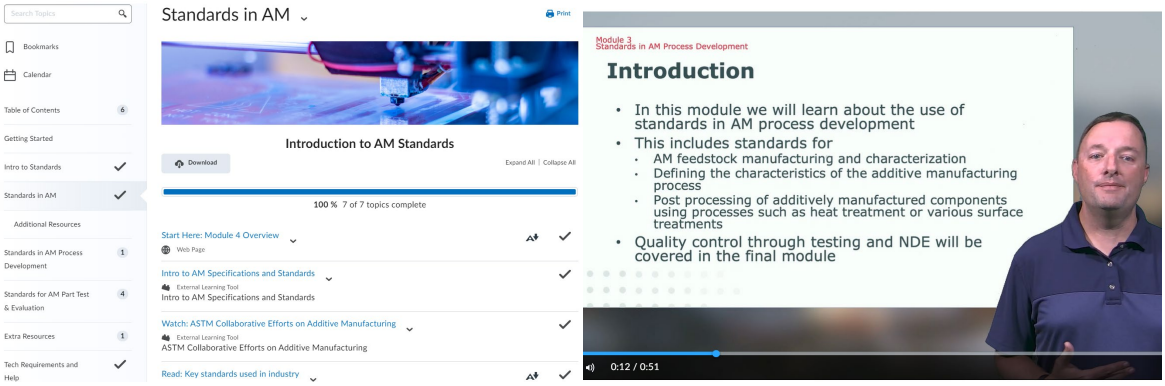

Figure 1. Screenshots of the learning management module (left) and video content (right)

2.2 Objective 2: Deploy each of the developed modules in one or more courses at UArizona. Our materials were deployed in three courses in the College of Engineering at UArizona. SIE 481/581: Design for Additive Manufacturing; AME 410: Introduction to Additive Manufacturing; and MSE 440/MSE 540: Metal Additive Manufacturing. SIE 481/581 (taught by Dr. Budinoff) is an introduction to the engineering design process with a focus on understanding constraints and opportunities associated with AM. Students learn to exploit AM to manufacture parts with complex geometry, while also considering economic viability and manufacturability. AME 410 (taught by Dr. Chan) describes the general AM process chain and specific AM processes (e.g., photopolymerization, powder bed fusion process), and also surveys materials properties and design and optimization. MSE 440/MSE 540 (Dr. Wessman) focuses on industrially-relevant metal AM processes, and introduces interactions between manufacturing process parameters, alloy chemistries, metallurgical structures, post-processing operations and application. The relevant courses have continued to be taught approximately once per year and are seeing good enrollment (Table 2), indicating that students are interested in this topic. Despite not being able to offer each course once per year due to enrollment issues or instructor availability, we have still taught 88 students over the course of the project.

Table 2. Description of the four learning modules developed in this project

Course	Semesters taught	Enrollment during project
SIE 481/581: Design for AM	Fall 2022 (not taught in Fall 2023 due to instructor availability)	2 undergraduate students in-person 10 graduate students in person 6 graduate student in online section Total: 18 students
AME 410: Intro to AM	Spring 2023; Spring 2024	16 undergraduate students in UArizona microcampus in Sampoena University in Indonesia 12 undergraduate students in main campus in-person Total: 28 students
MSE 440/540: Metal AM	Fall 2022; Fall 2023	24 undergraduate students in-person 15 graduate students in person 3 graduate student in online section Total: 42 students

To evaluate our progress for Objective 2, we asked for student feedback on the learning modules. In Fall 2022, we asked students enrolled in SIE 481/581 to provide us with written feedback on the modules. The feedback was generally positive, but also gave us ideas for improving our modules. Some example quotes are included below (note: these quotes were originally featured in our conference proceeding [1]:

> *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.

Another 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…

Students appreciated the self-paced lecture of modules:

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.

Specific suggestions for improvement included:

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 specific comment for improvement was:

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.

Additional evaluation criteria was to assess any difficulties instructors faced in incorporating the learning modules into their courses, and variations in implementation in the three courses. Summaries of these evaluation criteria for each class are discussed separately below.

SIE 481/581: In the first implementation of the updates in this course, we asked students to bring laptops to class and to complete the two most relevant modules (module x and x) during class time. The main difficulty in adapting the learning module into the class was the self-paced and online nature of the modules. This format was a little odd and slightly out of place from the typical lecture format. In future, we will assign the online modules as homework assignments. The online, self-paced nature of the modules worked very well for students enrolled in the online section of the course, who completed the modules rather than the typical activity of watching a pre-recorded lecture. We also asked students to use guidance from standards and cite specific standards in their final project report. Submitted projects and reports show that students are able to identify and reference relevant standards. These course updates have worked well and will

continue to be implemented in future semesters. We will continue to adjust the implementation to ensure students engage more deeply with the standards throughout their design projects.

AME 410: The first full implementation is still underway in Spring 2024 and so data is limited on this course implementation. The instructor is planning on introducing the testing module as a course project, assigning students to engage with the modules and incorporate the new knowledge and skills into an open-ended design and evaluation project.

MSE 440/540: This course has been taught fall semester for the last 4 years, and has typically included an in-person cohort of ~25 students per term. In the most recent term, the course was also offered remotely for students enrolled in online master's degree courses, broadening the reach of the course beyond the local region. The course includes discussion of all aspects of metal additive manufacturing, from raw materials production through the AM process itself and evaluation of the material properties and quality that results. Engineering standards education is present throughout the course, with examples of relevant engineering standards and their use incorporated into each topic. To provide a more focused emphasis on the importance of these standards, a full lecture towards the end of the course is also used to provide a comprehensive overview of the available standards, and to discuss potential future standards development that will improve metal AM process design and control. The lecture includes content developed for inclusion in the online modules, and with the recent adaptation of the course for an online program the modules will be used directly instead of recorded lectures to deliver this information. MSE440/540 develops engineering careers skills that will be useful for students upon entering the workforce. One way of accomplishing this is through the use of a semester long term project where students develop an additive manufacturing process plan to produce a part of their own selection. The use of engineering standards in developing their process is a required project element, and students are graded on having used and included these resources in the project. In addition to the lecture content presented to the students, the students are also given example templates and a grading rubric for the project that dictates the use of engineering standards in their report. Homework assignments throughout the course include tasks that lead the student to information gathering for the report, and this includes learning how to find and retrieve appropriate standards. By including this early in the course, it prepares students to be able to find these resources as they need them for the project. Submitted projects have shown that students have developed these skills, and post course survey responses indicate they find value in this information and recognize its importance for later use in their careers.

To summarize, *we successfully incorporated increased content on AM standards into three courses across our College of Engineering and received good feedback from students*. Students have demonstrated an ability to identify and reference standards in course assignments and projects. The *total number of students enrolled in the updated classes is 88 since the project implementation began* and the number of students impacted at our institution will continue to grow as we teach these courses in future semesters.

2.3 Objective 3: Improve UArizona students' ability to identify, locate, evaluate, and effectively use standards for technical problems related to additive manufacturing.

In order to assess how students progressed at identifying, locating, evaluating, and using standards in our courses, we used a pre- and post-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). Our survey questions were inspired by a prior study that evaluated students' increase in understanding of standards [2]. This survey was administered in Fall 2022, Fall 2023, and we have pending results for Spring 2024. A total of 49 students took the pre-test and 32 students took the post-test. To test if the differences in scores between pre and post scores were significant, we used a Wilcoxon rank sum test and we used Cohen's delta to quantify the effect sizes (Table 3).

Table 3. Scores for students' rating of their competency with standards improved over the semesters where they took our updated courses

Question	Pre-test mean (SD)	Post-test mean (SD)	*p*	Effect size, d
I feel that I can define what a technical standard is	3.07 (1.20)	4.31 (0.82)	***p* < .001**	1.16
I feel that I can locate technical standards in online databases	2.96 (1.26)	4.09 (0.89)	***p* < .001**	1.01
I feel that I can determine what type of technical standard to use as I conduct engineering work	2.82 (1.25)	3.72 (1.02)	***p* = .002**	0.77
I feel confident that I can utilize technical standards as I conduct engineering work	3.05 (1.40)	3.91 (0.93)	***p* = .008**	0.69
Average of all four above listed items	2.95 (1.13)	4.01 (0.79)	***p* < .001**	1.04

The average scores and all four individual 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. In summary, to evaluate this objective, *we found that students had significant increases in their self-reported ability to define, locate, identify, and utilize standards after taking our updated courses*.

2.4 Objective 4: Distribute e-learning modules to other institutions of higher education with guidance for how other institutions can replicate our methods.

For this objective, we wanted to reach other instructors at other institutions who may be interested in using the resources we developed in their own courses. We compiled a list of 118 instructor email addresses from 64 AM courses at 95 US universities (Table 4). Our evaluation criteria for this objective was the number of relevant instructors who we contacted. We will email the 118 instructors once the technical issues described in Section 4 are resolved.

Table 4. Examples of university courses related to AM

Institution	Examples of relevant AM courses
Northwestern	MECH_ENG 495: Introduction to Additive Manufacturing
UC Santa Barbara	MATRL 186B. Introduction to Additive Manufacturing
Ohio State	WELDENG 7027: Introduction to Additive Manufacturing
Texas A&M	MMET 281: Manufacturing and Assembly Processes II

The email to instructors will provide a link to our project website [3], which contains helpful information about how to import the modules into various learning management systems. Specifically, we utilize the Common Cartridge system which is able to be imported into learning management systems including D2L, Canvas, and Moodle. We provide links describing how to import our materials into these and additional systems on the course website.

2.5 Objective 5: Disseminate project results to a wide audience.

The final project objective and corresponding outcome was the dissemination of our project implementation and results to a broader audience beyond the AM instructors identified in Objective 4. As a final evaluation of this objective, we evaluated stakeholder engagement and questions raised during dissemination. We have focused on two primary means of dissemination of our results: conference presentations and publications, and a final summary paper submitted to NIST. We presented a paper titled “Using online learning modules to improve students’ use of technical standards in additive manufacturing courses and projects” [1] which described our modules and student feedback at a session organized by the Manufacturing Division of the American Society for Engineering Education Annual Conference & Exposition held in Baltimore, MD in June 2023. The session had attendees who were manufacturing instructors from many different institutions. These instructors were enthusiastic about the presentation and mentioned that their institutions also had a need to better incorporate standards, especially in manufacturing programs. Several instructors expressed interest in getting access to our materials. Our paper is in the conference proceedings.

We also collaborated on a panel presentation with other NIST Standards Curricula Development Program awardees at the Deshpande Symposium on Innovation and Entrepreneurship in Higher Education held in Phoenix, AZ in June 2023. Dr. Budinoff attended the panel and shared our experience with developing modules and educating students about standards. Several attendees

asked for advice about incorporating standards into their curricula and asked for links to our materials. We provided them with our contact information so they could obtain the resources once they have been finalized. Questions raised during dissemination was an evaluation criteria for us, and the focus of questions on obtaining our resources indicated successful dissemination.

Our final means of dissemination is the final summary paper submitted to NIST. The final summary paper (this document) will be shared on NIST's Standards Coordination Office's website along with other project presentations and documents. To summarize our evaluation of meeting this objective, we have disseminated via *2 conference presentations with approximately 25 audience members, 1 9-page conference paper which has already been downloaded 65 times, and a 10-page final summary document.* Dissemination will be enhanced further when the final email blast is finished, pending technical issues which will be described in Section 4.

3. Lessons Learned

This project has helped us understand the importance of hands-on and active-learning activities for supporting engineering students in learning how to utilize standards. Initially, we planned to record lecture videos of the similar length to a class. Based on advice from our digital learning team, we decided to scale down the length of videos to be more appropriate for online learning, targeting more 5-10 minute videos rather than lengthy 50-75 minute videos. We also made sure to provide activities that asked students to search for and reference standards, with a focus on project-based learning.

In implementing our developed material in our own classes, we learned that each class content required different implementation. The online modules worked well for online sections, but content could be either adapted to a live classroom with similar lecture content or could be assigned as homework. Also, having short modular activities in the modules made it easier for us to pick and choose the content and activities that made the most sense for our respective classes' learning objectives.

4. Scalability and Dissemination

To expand the impact of our work beyond the results described above, we are conducting outreach to other instructors who teach similar courses to those at UArizona who can utilize our materials. We have identified 77 instructors at institutions nationwide who teach similar AM courses as the existing UArizona courses (i.e., introducing additive manufacturing processes, design for additive manufacturing, and additive manufacturing material science). The overlap between their courses and our courses will make it straightforward for these instructors to adopt our learning materials in their courses. For each institution, we will email identified faculty who have taught these relevant courses with a description of our resources, summary of the evaluation of the developed curriculum, and link to our website so they can access and utilize our learning modules in their own courses.

With support of UArizona instructional designers, the modules are being exported from D2L in a format that allows them to be directly imported into other learning management systems such as Canvas. Because some of our enabling instructional technology has experienced technical issues (namely, the professional recording studio where we recorded our videos is experiencing difficulties with exporting the final recorded videos), we are planning on emailing instructors at the end of the Spring 2024 semester, once the technical issues are resolved and final videos are uploaded to our project website.

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References

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