Curriculum Innovation through the Integration of Manufacturing Related Materials and Quality Control Standards for Different Level Engineering Students from Freshmen to Graduates

Project Final Report

Kai Jin (PI)
Mechanical and Industrial Engineering Department Texas A&M University-Kingsville

Hua Li (Co-PI)
Mechanical and Industrial Engineering Department Texas A&M University-Kingsville

Abstract

The importance of standards is that they provide product manufacturers with clear material, mechanical, and dimensional requirements coupled with specific quality assurance and test methods used to ensure their quality and functionality. Manufacturing-related material standards provide a consensus regarding desired properties between both manufacturers and customers. Moreover, these standards provide analysis methods to measure the properties and leads to standard manufacturing procedures that ensure the quality. To fulfill the need of real-world systems, a curriculum innovation was planned and implemented into the industrial engineering graduate program at Texas A&M University-Kingsville with the aim to integrate manufacturing-related materials and quality management standards into graduate engineering education through innovative course modules and a certificate program. There are four major components in the framework, including (1) course module development on manufacturing-related material standards, (2) course module development on manufacturing related quality management standards, (3) graduate-level certificate program development, and (4) industrial experience sharing through webinars. ASTM and ISO standards were introduced to graduate students with hands-on experiences on applying standards to real-world case studies. It creates a systematic framework to strengthen graduate students' education and learning about manufacturing-related materials and quality management standards and standardization. Student surveys were used to collect their feedback, which show very positive impact on the students' knowledge and interests in standards and standardization.

Project Background and Motivation

Different engineering standards and standardization concepts are widely used in manufacturing and other industries as they provide manufacturers with clear material, mechanical, and dimensional requirements coupled with specific quality assurance and test methods to ensure the products meet specific standards. As the

Accreditation Board for Engineering and Technology (ABET) has started introducing standards into engineering program evaluation cri- teria,[1] many engineering undergraduate programs in United States have started to introduce different engineering standards in their capstone design projects and other core courses, such as material science. However, because the majority of engineering graduate students in the United States are international students,[2] they may not have a chance to learn engineering standards in their undergraduate programs. Most engineering graduate students have a lack of knowledge and training on how to locate and use standards properly because they may only get practical experiences with engineering standards and standardization in their thesis research, which is normally the last course in their degree plan. Therefore, it is critical and essential to integrate engineering standards and standardization training through a series of courses in engineering graduate education to strengthen students' understanding and knowledge.

The United Nations Economic Commission for Europe (UNECE) has developed a set of model curriculums related to sustainable development standards to help implement the United Nations' 2030 Sustainable Development Agenda and other related frameworks.[3] The Asia Pacific Economic Cooperation (APEC) has created an inventory of national standard education policies.[4] The American National Standards Institute (ANSI) has also developed the United States Standards Strategy (USSS), which points out the need for standard education pro- grams as one of the high priorities.[5] There is no question about the importance of introducing standards and standardization concepts into graduate education. However, standards and standardization consist of various aspects, including theoretical rules, applications, development process, etc. Because most engineering curriculums are well established with intensive technical courses, it is difficult (and there is little room) to make significant modifications by introducing engineering standards and standardization concepts into existing engineering curriculum. Moreover, it is a challenging process for engineering faculty to develop new courses or modify existing courses.[5] As the engineering standards are changing fast to meet the industrial needs, it is also very challenging for an engineering faculty to get familiar with the most recent standards because of a lack of practical experience of developing engineering standards.[5] For example, since ISO 9000 was first released in 1987, referred to as quality assurance standard, it has been revised significantly for at least four different times regardless of many minor changes.[6] In addition, many standards-developing organizations (SDOs) have developed various online training materials. However, most engineering graduate students in the United States are not aware of these online training materials because they are difficult to find and understand.[7]

A new curriculum innovation framework to integrate manufacturing-related materials and quality management standards into master-level industrial engineering graduate curricula was developed in order to better prepare graduate students for their engineering careers. Hands-on activity-based learning modules were carefully designed and introduced into three graduate-level courses in the industrial engineering graduate program at Texas A&M University-Kingsville (TAMUK). These new course materials cover the different aspects related to

engineering standards, including theoretical rules, applications, and development processes. Although it is not possible to cover all kinds of engineering standards in these new course materials, it is important to expose engineering graduate students to the fundamental knowledge related to engineering standards and standardization. Student surveys were conducted to collect their feedback on the acceptance and effectiveness of our course modules. The survey also asked about the students' progress and improvement on the knowledge and skills related to standards and standardization in manufacturing-related materials and quality management fields.

Program and Course Design

The purpose of this curriculum design is to develop innovative course modules to use in current TAMUK industrial engineering graduate engineering curriculum to improve students' career readiness, and to advance students' professional preparedness. A graduate-level certificate program was also created to enhance the education and learning impacts. In this curriculum innovation, two existing industrial engineering graduate courses are modified by introducing standard learning modules to the current course content, and one new industrial engineering graduate course, Standards of Product Design and Manufacturing, was created.[8] By completing these three courses with grade of B or above, students are also able to get a Manufacturing Standards and Standardization Certificate. It allows full time students to complete it in one regular semester and industrial professionals to complete it as a nondegree student without applying to any degree programs at TAMUK. The last component is a webinar. Webinars are held three times a year (spring, summer, and fall) and are offered by invited industrial professionals. Each webinar lasts 45 minutes to one hour and is free to students, which focuses on real-world application of standards and standardization in industry.

The first course modification is to introduce ISO 9000:2015 to the existing IEEN 5333-Six Sigma graduate course. The ISO 9000 family of quality management systems standards is designed to help organizations ensure that they meet the needs of customers and other stakeholders while meeting statutory and regulatory require- ments related to a product or program.[9,10] It is critical for engineering students to understand and implement ISO 9000 and other standards. In this course, the history and overview of ten sections of ISO 9000:2015 are introduced. After that, ISO 9000:2015 sections 4 to 10 are discussed in detail, and the implementation of ISO 9000:2015 and audits are introduced. Students also work on a case study as a group project to complete the course require- ment. As the course learning objectives, students are expected to be able to (a) understand and discuss the aims of the audits, which is to verify a system is working as it is supposed to, finding out where it can improve, and to correct or prevent problems identified; (b) lead or participate in a team to prepare for the internal and external audits; and (c) identify the opportunities and strategies of continuous improvement. The detailed course module design is shown in Table 1.

The second course modified is IEEN 5332-Manufacturing System Design. Manufacturing-related material standards provide a consensus regarding desired properties between both manufacturers and customers. Moreover, these standards provide analysis methods to measure the properties and leading to standard manufacturing procedures that ensure the quality. Accordingly, there is an urgent need to develop course materials that provide students with related knowledge.[11] The course modules of manufacturing-related material stan- dards are designed to polish students' skills on the development of standards if there is no standard to deal with a specific project. These modules cover the topics on procedures of standard development and influence of material selection on manufacturing process and system design. A practical course project is designed within the course module to allow students to develop the standards of material selection, preparation, and testing to gain valuable hands-on experience. As the course learning objectives, students are expected to be able to
(a) develop standard procedures if there are no available standards for a product; (b) identify either one ASTM or one ISO standard test procedure (or both) that correlates with the developed procedure; and (c) evaluate the developed standard procedure and give suggestions on manufacturing system design.
Table 2 shows the course module design.

Table 1 Course module design used in IEEN 5333

TOPIC COVERED	CLASSES USED
INTRODUCTION AND HISTORY OF ISO 9000:2015 AND OVERVIEW OF ITS TEN SECTIONS	Half Week
ISO 9000:2015 SECTION 4 CONTEXT OF THE ORGANIZATION	Half Week
ISO 9000:2015 SECTION 5 LEADERSHIP AND SECTION 6 PLANNING	One Week
ISO 9000:2015 SECTION 7 SUPPORT AND SECTION 8 OPERATION	One Week
ISO 9000:2015 SECTION 9 PERFORMANCE EVALUATION AND SECTION 10 IMPROVEMENT	One Week
IMPLEMENTING ISO 9000:2015 AND AUDITS WITH CASE STUDIES	One Week

In addition, a new graduate course, Standards of Product Design and Manufacturing, was developed. This course provides an overview of materials and processes standards in manufacturing and covers the material se- lection, system design, and use of equipment in manufacturing, from small-scale operations to massive automated plants. The course provides students with a comprehensive understanding of standards use in manufacturing, polishes students' skills to develop standard procedures, and prepares students for evaluation of new standards for modern production. This course aims to establish the concept of standards and standardization among students and offer students the skills of searching and interpreting standards. As the course learning objectives, students will be able to (a) discuss types of standards and standards organization; (b) develop critical thinking toward standards and their impact and value; (c) search and browse standards; and (d) incorporate accounts of stand- ardization into industrial projects. The detailed course schedule is shown in Table 3.

Table 3
Course schedule of the new Standards of Product

Design and Manufacturing course

Topics Covered	Class Time Needed
Importance of Standards and Standardization	One week
Standardization and Mass Production	Two weeks
Standards Development and Modification	Two weeks
Major Types of Standards	Two weeks
Mandatory and Voluntary Standards	Two weeks
Standard Database and Searching Standards	One week
Standards Structure with case study (ISO 10303-240:2005)	Two weeks
Characteristics of a good standard	Two weeks

Note: ISO 10303-240:2005, *Industrial Automation Systems and Integration – Product Data Representation and Exchange – Part 240: Application Protocol: Process Plans for Machined Products*.

Survey Results and Discussion

As of the spring 2020 semester, each of the aforementioned three courses has been offered twice in the industrial engineering graduate program at TAMUK. A student survey was recently conducted to collect students' feedback on course modules, certificate program, and webinars. The survey results are summarized next. The survey results show that most students rated their overall experiences with the new curriculum as good (6 %), very good (56 %), and excellent (38 %), and most students (around 90 %) think that they have good knowledge about standards and standardization in manufacturing and quality management after completing the new curriculum program. In addition, all the students agree that it will help them to find a job after graduation by obtaining the manufacturing standards certificate. Table 4 shows that the students like these course modules better than the webinars. One possible reason is the case studies provided by webinars' speakers may be a little bit difficult for the students to understand within the limited amount of time. It is suggested to use these case studies for further discussion in the classroom.

Tables 5–7 show the detailed responses related to each of the three courses, and most students think these modules have helped them improve their knowledge related to engineering standards and standardization. Each task listed in Tables 5–7 is extracted from internal course evaluation rubric of each course. Comparing the survey results of IEEN 5333 with those of the other two courses, it shows less percentage of good/great increases. Because IEEN 5333 was offered during summer semester, the same amount of course contents was taught in five weeks while there was class every day. Considering most students have little experience and knowledge with standards and standardization, it is challenging for the students to fully understand the new course contents in such short time. So the impact of IEEN 5333 would be less positive than the other two courses, which were offered in Spring or Fall semesters with 15 weeks. Meanwhile, since the new course is designed to teach standards, it has the most positive survey results.

Table 4 Overall satisfaction on different components

	Valuable Levels		
Components	Very Valuable	Valuable	Somehow Valuable
IEEN 5333	71 %	29 %	0 %
IEEN 5332	87 %	13 %	0 %
New Course	67 %	13 %	0 %
Webinars	50 %	19 %	31 %
Certificate	63 %	25 %	12 %

Table 5
Survey results related to revised IEEN 5333-Six Sigma and ISO Standards course

Confidence/Knowledge to Perform Each Task	Results*
(1) Understand ISO 9000 standards	0/0/0/6/38/54
(2) Understand other standards	0/0/6/0/38/54
(3) Implement ISO 9000 standards for audits	0/0/15/0/54/31
(4) Implement other standards for audits	8/0/8/15/31/38
(5) Participate in a team to prepare for internal or external audits	0/0/8/23/23/46
(6) Lead a team to prepare for internal or external audits	8/0/8/38/31/15
(7) Identify the opportunities of continuous improvement to meet ISO standards	0/0/0/15/46/39
(8) Seek for a position that requires knowledge in ISO standards	0/0/0/23/39/38
(9) Seek for a position that requires knowledge in other standards	0/0/0/15/46/39
(10) Work in a project that requires to use ISO standards	0/0/0/15/39/46
(11) Work in a project that requires to use other standards	0/0/0/15/46/39

Note: * Results presented in percentage as "Not sure/No Increase/A little increase/Some increase/good increase/great increase."

Table 6
Survey results related to revised IEEN 5332-Manufacturing System Design course

Confidence/Knowledge to Perform Each Task	Results*
(1) Identify ASTM or ISO standard, or both, for materials Selection	0/0/0/8/38/54
(2) Identify ASTM or ISO standard, or both, for material Preparation	0/0/0/8/38/54
(3) Identify ASTM or ISO standard, or both, for material Testing	0/0/0/15/39/46
(4) Develop standard procedures if there is no available standards for a product	8/0/0/0/54/38
(5) Evaluate standard procedure and provide suggestions on manufacturing system design	0/0/0/15/31/54
(6) Select materials for manufacturing processes based on a specific standard	0/0/0/15/31/54
(7) Participate in a team to prepare for manufacturing system design	0/0/0/15/39/46
(8) Lead a team to prepare for manufacturing system design	0/0/8/8/46/38
(9) Seek for a position that requires knowledge in ASTM standards	0/0/0/15/46/39
(10) Seek for a position that requires knowledge in other standards	0/0/0/8/54/38
(11) Work in a project that requires to use ASTM standards	0/0/0/0/67/33
(12) Work in a project that requires to use other standards	0/0/0/0/62/38

Note: * Results presented in percentage as "Not sure/No Increase/A little increase/Some increase/good increase/great increase."

Table 7
Survey results related to new Standards of Product Design and Manufacturing course

Confidence/Knowledge to Perform Each Task	Results*
Identify standards for materials Selection	0/0/0/0/82/18
Identify standards for manufacturing Process Selection	0/0/0/0/64/36
Identify standards for manufacturing System Design	0/0/0/9/45/46
Identify standards for manufacturing Equipment Selection	0/0/0/0/64/36

Evaluate standard procedure and provide suggestions on manufacturing system design	0/0/0/18/45/37
Develop standard procedures if there are no available standards for a product	0/0/0/9/73/18
Apply materials standards for metal, ceramic, polymer, and composite	0/0/0/18/55/27
Lead a team to prepare for manufacturing process design	0/0/0/9/64/27
Participate in a team to prepare for manufacturing process design	0/0/0/9/45/46
Seek for a position that requires knowledge in standards	0/0/0/9/55/36
Work in a project that requires to use standards	0/0/0/18/36/46

Note: * Results presented in percentage as "Not sure/No Increase/A little increase/Some increase/good increase/great increase."

The PIs also checked the changes on students' interests in jobs or careers related to standards and standardization before and after participating in the curriculum program. The results in Tables 8 and 9 clearly show that the new curriculum program has significantly positive impact on students' awareness and interests in jobs and careers related to standards and standardization, which is critical because of the workforce shortage in this field. It will also help increase the number of future workforce who may be interested in joining technical committees in different SDOs to continue developing and improving engineering standards.

Table 8
Changes in students' interests in work for a position related to standards and standardization

Available Choices	Before Participation	After Participation
Never thought about it	12.50 %	0.00 %
Not interested in it	18.75 %	0.00 %
A little interested in it	43.75 %	6.25 %
Interested in it	12.50 %	43.75 %
Very interested in it	12.50 %	50.00 %

Table 9
Changes in students' interests in careers related to standards and standardization

Available Choices	Before Participation	After Participation
Never thought about it	31.25 %	0.00 %
Not interested in it	0.00 %	0.00 %
A little interested in it	50.00 %	6.25 %
Interested in it	12.50 %	50.00 %
Very interested in it	6.25 %	43.75 %

It should be pointed out that all the students' surveys were totally anonymous and conducted after students received their course grades or certificate. So the students' responses should reflect their actual perspectives and opinions on the new curriculum materials. Most students also expressed that receiving a certificate helped them a lot during the job-hunting process, which attracts more and more students to take these three courses when there are many other available elective courses.

Conclusion

The students' feedback is very positive on the design and effectiveness of the new

curriculum program. According to another recent student survey targeted at students who have not participated in the new curriculum program (52 responses as of February 4, 2020), 52.08 % of students are very interested in the new certificate program, and 29.17 % of students are interested in the certificate program. There are 16.67 % students who are not sure at this moment, and there are only 2.08 % of students who are not interested. Because all the course modules, certificate courses, and recorded webinars are available for both in-class and online formats, the impacts of the new curriculum program can be sustained by sharing these materials within TAMUK and with other educators. It will also give the other educators the flexibility to decide how much of each topic they would like to include in their own courses. Material science and quality management are the core curriculum contents for mechanical engineering, industrial engineering, manufacturing engineering, and system engineering, so the learning modules can be directly used by instructors in these major in their courses. For the other engineering majors, instructors can easily use part of the modules in their senior design projects to solve product- and process- related engineering problems.

Although the new curriculum program shows positive impacts, most students (81.25 %) still think that they need more information about careers in standards and standardization. Considering the less positive responses on the webinars, most information related to careers in standards and standardization should be included in the webinars instead of technical knowledge about how to apply standards and standardization in industries. More online resources should also be introduced to the students. Compared with the new course materials, the newly developed certificate program is much more effective for attracting students to take the three courses. In order to increase the credibility of the certificate program, the new curriculum materials should be frequently updated to reflect the latest information and knowledge in engineering standards and standardization. Adopting latest UNECE, APEC, and USSS general educational guidelines and materials is also needed.

References

1. ABET, "ABET Accreditation Criteria & Supporting Documents," ABET, 2020, https://web.archive.org/web/20201009030953/https://www.abet.org/accreditation/accreditation-criteria/
2. H. Okahana and J. Allum, *International Graduate Applications and Enrollment: Fall 2015* (Washington, DC: Council of Graduate Schools, 2015).
3. L. Jachia, S. Kouzmine, and H. Xu, "UNECE Initiatives on Education on Standardization," in *Sustainable Development: Knowledge and Education About Standardisation*, ed. S. O. Idowu, H. de Vries, I. Mijatovic, and D. Choi (Berlin: Springer International Publishing, 2020), 151–152.
4. D. Choi, H. de Vries, and D. Kim, "Standards Education Policy Development: Observations Based on APEC Research," *International Journal of IT Standards and Standardization Research* 7, no. 2 (2009): 43–63, https://doi.org/10.4018/jitsr.2009070103
5. J. L. Gbur and D. Solomon, "Promoting Technical Standards Education in Engineering," in *2016 Annual Conference and Exposition* (Washington, DC: American Society for Engineering Education, 2016), 14882.
6. B. Lahidji and W. Tucker, "Continuous Quality Improvement as a Central Tenet of TQM: History and Current Status,"*Quality Innovation Prosperity* 20, no. 2 (2016): 157–168, https://doi.org/10.12776/qip.v20i2.748

7. A. S. Khan and A. Karim, "Importance of Standards in Engineering and Technology Education," *International Journal of Educational and Pedagogical Sciences* 10, no. 3 (2016): 1050–1054.

8. H. Li, K. Jin, and Y. Zhang, "A Curriculum Innovation Framework to Integrate Manufacturing-Related Materials and Quality Control Standards into Different Level Engineering Education," in *2018 Annual Conference and Exposition* (Washington, DC: American Society of Engineering Education, 2018), 21404.

9. S. Cai and M. Jun, "A Qualitative Study of the Internalization of ISO 9000 Standards: The Linkages among Firms' Motivations, Internalization Processes, and Performance," *International Journal of Production Economics* 196 (February 2018): 248–260, https://doi.org/10.1016/j.ijpe.2017.12.001

10. Y. Lu, K. C. Morris, and S. P. Frechette, *Current Standards Landscape for Smart Manufacturing Systems, NISTIR 8107*
(Gaithersburg, MD: National Institute of Standards and Technology, 2016).

11. M. Despeisse and T. Minshall, "Skills and Education for Additive Manufacturing: A Review of Emerging Issues," in *IFIP International Conference on Advances in Production Management Systems* (Cham, Switzerland: Springer, 2017), 289–297.