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Work in Progress: Curricular Integration of Design and Material Standards in Engineering

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Introduction and Motivation

This paper discusses how the Departments of Mechanical and Industrial Engineering (MEIE) and Civil and Architectural Engineering (CEAE) at Texas A&M University-Kingsville (TAMUK) collaborated to create undergraduate and graduate certificate programs with an emphasis on design and material standards. The goal of the certificate programs is to increase student understanding of and appreciation for professional standards as relates to engineering design and material characterization. This paper will describe the components of the certificate programs and progress to date.

Standards play a crucial role in engineering practice. Material testing according to a standardized procedure is imperative to obtain reliable material properties. Design of engineering systems or structures involves appropriate use of relevant standards and codes. ASTM (American Society for Testing and Materials), AISC (American Institute of Steel Construction) and/or ISO (International Organization for Standardization) standards are used extensively for these purposes. However, the significance of standards may not be immediately apparent to students in a classroom or laboratory setting. Generally, in laboratory courses, students are asked to follow a given set of procedures without understanding the criteria or method by which the procedures were selected. Similarly, mechanical or structural design courses emphasize code requirements without providing a comprehensive picture of the development of codes and the relationship to core mechanics of materials concepts. This presentation leads to students who can perform calculations without understanding why. Hence, this method of instruction does not encourage deep thought or investigation into the significance of standards and standardization. The need for improved integration of professional standards in engineering education has been long recognized [1].

The inclusion of standards in the senior capstone course is part of the ABET accreditation process for engineering programs [2], and many students begin to develop a deeper understanding of the importance of codes and standards through the capstone experience. The certificate program described in this paper is designed to develop this deeper understanding of codes and standards earlier in a student's academic career. The certificate program focuses on the role of codes and standards within the engineering field as well as on the procedures for adopting and adapting codes to reflect new knowledge, both of which are significant to students' professional development [3]. While much existing engineering curriculum is standard or code-driven, the certificate program trains students to appreciate the importance of standards and standardization in a way that will promote life-long use of standards in their professional careers.

An additional benefit of the current work is creation of a certificate program that will be reflected on student transcripts. Transcripted certificates and similar mico-credentialling efforts improve student marketability [4-6]. Often, micro-credentialling programs are designed to be integrated into or used as a gateway to full degree programs [5;7]. The certificate program described in this work differs from traditional micro-credentials in that it requires completion of a capstone design project (undergraduate) or thesis (masters), thus placing emphasis on end-of-degree requirements.

Certificate Requirements

For the certificate program, the decision was made to emphasize the role of standards and codes as relate to material, material characterization, and the design process because these areas have shared relevance for students in MEIE and CEAE fields. As a small, regional, Hispanic Serving Institution, Texas A&M University-Kingsville frequently offers joint mechanics courses for undergraduate students in multiple majors. Thus, curriculum innovations affecting mechanical engineering (MEEN) students will also affect civil (CEEN) and architectural (AEEN) engineering students, and vice versa. Having both departments working together on this project increases its long-term impact.

The Certificate on Standards for Material Testing, Characterization, and Applications is a transcripted certificate offered at the undergraduate and graduate level. The undergraduate certificate became effective in Fall 2022 and appears in the 2022-2023 undergraduate catalog. The graduate certificate became effective in Spring 2023 and will appear in the 2023-2024 graduate catalog. The proposals for both the undergraduate and graduate certificates were routed simultaneously; the date of publication is a result of TAMUK internal processes. To earn the certificate, both undergraduate and graduate students are required to attend 6 standards-related seminars. The seminar series is described later in this paper.

Other requirements for undergraduate students include:

- Completing a total of 12 credits (4 lecture courses or a combination of lectures and labs) with a grade of "B" or better in each course. The certificate courses may be selected from a list of MEEN, CEEN, and AEEN courses.
- Completing a senior capstone project that has a significant component focused on standards.

Graduate student requirements are similar with the following differences:

- Completing a total of 9 credits (3 courses) with a grade of "B" or better in each course. The certificate courses are selected from a list of MEEN and CEEN graduate courses; there is no AEEN graduate program at TAMUK.
- Completing a thesis that has a significant component focused on standards.

Course Modules

A major component of the certificate program is developing content modules across a wide spectrum of courses. Table 1 summarizes the courses with embedded content modules that have been developed since the initiation of the project; the semester the course module was first developed is shown in parentheses. The original project goal was to embed course modules into a total of 19 courses offered by the MEIE and CEAE departments over four long (fall / spring) semesters. Spring 2023 represents the third semester of this effort, and 18 content modules have been developed or are being developed, although some require further refinement in future semesters. The remaining course is the capstone senior design course for industrial engineering, which is a new program at TAMUK.

A course module includes one or more assignments or lectures that discuss codes and standards in the context of materials (testing and characterization) or design. The goal of the course

modules is to go beyond content that would be expected in the curriculum. Course modules should challenge students to gain more familiarity with the standards and codes, whether this is through direct exploration of a code or standard (where it would otherwise be presented in summary form) or by a deeper understanding of the process for creating and updating codes.

Table 1. Course Modules Developed to Support Certificate Programs

Level	Mechanical Engineering	Civil and Architectural Engineering
Freshman	GEEN 1201: Engineering as a Career (Fall 2022).	
Sophomore	MEEN 3344 / 3145: Material Science and Laboratory (Spring 2022). CEEN 3311: Strength of Materials (Spring 2022).	CEEN 3311: Strength of Materials (Spring 2022).
Junior	MEEN 3349: Fundamentals of Manufacturing Processes (Spring 2022).	CEEN / AEEN 3303: Structural Analysis (Spring 2022). CEEN/AEEN 3304: Reinforced Concrete Design (Spring 2022). CEEN 3244 / 3145: Construction Materials and Laboratory (Spring 2022).
Senior	MEEN 4382: Polymer Science & Engineering (Spring 2022). MEEN 4385: Manufacturing of Composites (Spring 2022). Senior Design Project (Spring 2022).	CEEN/AEEN 4316: Structural Steel Design (Fall 2022). AEEN Senior Design Project (Fall 2022). CEEN Senior Design Project (Fall 2022).
Graduate	MEEN 5301: Advanced Manufacturing (Fall 2022). MEEN 5331: Advanced Materials Science (Fall 2022). MEEN 5333: Polymer Science (Spring 2022).	CEEN 5361: Advanced Structural Steel Design (Spring 2023).

Table 1 presents undergraduate courses according to the year in which they are anticipated to be taken by a student following published degree plans, rather than by the year indicated by course level. At TAMUK, as at many other institutions, the first number in a course title indicates its level (1000 = freshman, 2000 = sophomore, etc.) and the second number indicates the number of credit hours (1 = traditional laboratory meeting 3 hours a week; 3 = traditional lecture meeting 3 hours a week). To stay on track for graduation, MEEN, CEEN, and AEEN students typically take their first junior level (3000-level) courses in sophomore year. Also, in Table 1 linked lecture and laboratory courses are presented together; separate modules were developed for both the lecture and laboratory components of these courses. Lastly, structural engineering courses required for both CEEN and AEEN students are traditionally cross-linked and taught as a single course (due to limited number of faculty). These courses are not differentiated in Table 1.

Examples of course modules include:

- CEEN / AEEN 3303 (Structural Analysis) teaches students to calculate the effects of external loads on structural components. Key to student success in advanced structural design and capstone courses is development of a systemic view of a structure and the ability to specify ultimate structural demands. Use of loading standards increases students' conceptualization of how loads drive the design of a structure. The embedded content module discusses dead, live, and wind load calculations using ASCE 7.
- CEEN / AEEN 4316 (Structural Steel Design) is an inherently code-intensive course focused on the application of the *AISC Steel Construction Manual*. The embedded content module discusses the structure of AISC and the processes used to revise the steel manual. The Fall 2022 implementation of this course module was offered as an extra-credit opportunity and will be further developed in future course offerings.
- MEEN 4385 (Manufacturing of Composites) discusses traditional polymer and polymer-matrix composites production, additive manufacturing of polymer composites, etc. The Spring 2022 implementation of this course had a newly embedded section on the use of ASTM standards D5868, D1002, and D3165 in a lab module where various adhesives were tested. Some with fiber reinforcement and most with a neat resin. The impact of tab cleaning, preparation practices, and adhesive types were evaluated.

Preliminary Course Survey Data

Students enrolled in courses with an embedded content module are invited to complete an anonymous survey to measure the effectiveness of the content modules in developing students' awareness of and appreciation for standards and codes. The survey is designed to be completed twice: once at the beginning of the semester for a pre-course picture of understanding / engagement and again at the end of the semester to determine if there were significant changes. However, the survey was developed throughout the Spring 2022 semester, so only post-course survey results are available for Spring 2022. Pre- and post-course surveys are available for Fall 2022 and will be collected for subsequent semesters.

In Spring 2022, 14 students completed the post-course survey. Note that 478 students were registered in classes with embedded course modules in Spring 2022, so it is immediately clear that survey completion is a challenge. Of the respondents, 13 (93%) were male, and 1 (7%) preferred not to share gender information. The respondents were demographically and ethnically diverse: 3 (21%) identified as white, 4 (29%) identified as Hispanic/Latinx, 2 (14%) identified as

Asian, 3 (21%) identified as black, and 2 (14%) declined to respond. Table 2 summarizes Spring 2022 student survey responses.

As demonstrated in Table 2, the majority of students (86% or above on all questions) indicated improved understanding of or appreciation for industry standards at the "intermediate" level or higher, while less than 60% of students rated themselves at "high" or above on these questions. The strongest response (57%) occurred when students were asked to rate their understanding of standards for engineering design / materials. Similar responses (50%) were recorded for overall understanding of standards and ability to apply relevant standards.

Table 2. Spring 2022 Student Post-Course Survey Responses

Survey Questions: One a scale of 1 to 5, indicate your…	Very High	High	Intermediate	Low	Very Low	Responses High or Above
Overall understanding of standards	0	4	8	1	1	29%
Overall appreciation of standards	1	6	6	0	1	50%
Understanding of standards for engineering design / materials	0	8	4	1	1	57%
Appreciation of standards for engineering design / materials	0	6	7	0	1	43%
Ability to identify relevant standards	0	5	7	1	1	36%
Ability to apply relevant standards	0	7	5	1	1	50%

In Fall 2022, 276 students were registered in classes where standards related course modules were implemented. 23 students completed the pre-course survey, and only 13 students completed the post-course survey. Table 3 summarizes the pre-course and post-course survey results for Fall 2022. Table 3 data show that course modules had a net positive increase on student respondents' confidence and interest in the application of standards and codes. The degree of increase varied from over 30% (ability to identify relevant standards) to just 1% (ability to apply relevant standards).

Demographically, the Fall 2022 pre-course respondents were 87% male (20 students), 4% female (1 student), 26% white (6 students), and 65% Hispanic / Latinx (15 students). 2 students did not provide gender or ethnicity. Fall 2022 post-course respondents were 77% male (10 students), 23% female (3 students), 8% white (1 student), and 92% Hispanic / Latinx (12 students).

Table 3. Fall 2022 Student Survey Responses

Survey Questions: On a scale of 1 to 5, indicate your…	Responses High or Above		Change
	Pre-Course	Post-Course	
Overall understanding of standards	57%	77%	+20%
Overall appreciation of standards	69%	85%	+16%
Understanding of standards for engineering design / materials	57%	77%	+20%
Appreciation of standards for engineering design / materials	74%	85%	+11%
Ability to identify relevant standards	43%	77%	+34%
Ability to apply relevant standards	61%	62%	+1%

It is interesting to note that 87%-91% of pre-course survey responses and 84%-92% of post-course survey responses were at the "intermediate" or higher range for Fall 2022. This range is similar to the number of "intermediate" or higher responses reported in Spring 2022 (86-93%). These data suggest the importance of looking at the "high" and "very high" responses in tracking future survey results, since very little difference appears among intermediate, low, and very low responses.

Seminar Series

In addition to direct integration into existing courses, the certificate programs require students to attend at least 6 standards-related seminars. A seminar series was organized for Spring 2022 and Spring 2023 to enable students to meet this requirement. A total of 93 students attended seminars in Spring 2022; and a total of 54 students attended seminars in Spring 2023.

To date, 11 seminars have been conducted or planned. The paper authors have each given a seminar in their area of expertise (material engineering and structural design). External speakers from the Texas Department of Transportation, US Army Corps of Engineers, National Institute of Standards and Technology, and ASTM have discussed the use of standards in government agencies from the state to the international level. Industry speakers have addressed the use of standards in a range of engineering applications, and one additional TAMUK faculty member has discussed supply chain standards for business. Spring 2023 included two speakers with experience either developing a new standard or working in applications where standards have not yet been developed. These presentations highlighted the dynamic nature of standards and codes.

Each seminar has included both an in person and a virtual component, which offers several advantages. First, the opportunity to present virtually increases flexibility for guest speakers and enables seminar organizers to recruit presenters from more diverse fields. Several guest speakers have presented virtually who would not have been able to travel for an in-person presentation. The virtual component also increases participation among audience members and provides the ability to record presentations.

Students unable to attend a live presentation (either in person or on-line) are able to watch the recorded presentations for credit towards certificate completion. The students must submit a

short summary of two interesting points that they observed or learned when watching the recording. As of February 2023, 4 students have taken advantage of the recorded seminar option. In addition to allowing more students to participate, having recorded presentations increases the long-term sustainability of the seminar series and offers a wider range of topics to explore.

Senior Capstone and Thesis Projects

The last component of the certificate program requires students to complete a senior capstone project or master's thesis with a significant amount of standards / code-related content. A senior capstone project or a master's thesis will be considered as having a significant amount of standards / code-related content when the project and documentation include the design, manufacturing or construction, or characterization of one or more systems, components, or experimental processes using standards / codes.

As part of the graduation check-out process to earn the certificate, a student must submit a form to one of the program coordinators. One page of this form relates to the senior capstone project or master's thesis, and the form is completed in two stages. First, the student discusses their topic idea with their course instructor / advisor and then with one of the certificate program coordinators. If approved, both faculty members sign the form with an initial title for the project. A written project proposal is included at this stage. Once the capstone project or master's thesis is finished, the same two faculty members (instructor / advisor and program coordinator) review the completed work and sign to indicate fulfillment of certificate requirements.

The written proposal should include what standards or codes are likely to be used and how they are integral to and would advance the project. For a project focused on developing new standards or codes, the proposal should illustrate how the project will contribute to the development of new standards or codes and to which organization they will be submitted.

The final report / thesis must be approved by the same two individuals as the proposal (if possible) and should discuss in depth what standards / codes were used, how they were used, and how the applied standards / codes are distinct from specifications provided by a customer / instructor / advisor / funding sponsor, etc. If new standards or codes were proposed, they should be discussed in detail, and also how they were (or are planned to be) submitted to an appropriate organization and any feedback received.

In Spring 2023, 3 undergraduate students are expected to complete capstone design projects that have been approved as meeting certificate requirements. One senior design project includes applications of ASME codes for pressure vessels and process piping, such as ASME B31.3, ASME B31.12. The other senior design project involves applications of ASTM G99-17, ASTM G133-05, and ASTM F732-17 standards for design and development of a pin-on-disk Tribometer.

Conclusions and Continuing Work

The framework for the Certificate on Standards for Material Testing, Characterization, and Applications is complete, and the authors anticipate having the first students earn certificates in the 2022-2023 academic year. Major accomplishments to date include:

- Successful completion of the curriculum proposals to create transcripted certificates at both undergraduate and graduate level.
- Completion of two seminar series in support of the certificate program.
- Development and implementation of standards-related content modules across a wide spectrum of courses.
- Establishment of criteria defining “significant work” for senior capstone and master’s thesis students.
- Creation of a certificate check out process for graduating students.

Ongoing work includes continued implementation of content modules and improved advertising / awareness of the certificate program. These tasks include correlating and publishing the content modules on the project website. Another element to be completed is collecting and analyzing more data to measure the effectiveness of the certificate program in increasing student awareness of codes and standards in engineering practice. A significant challenge to data analysis is the low number of survey responses received to date, and a reconsideration of the mechanism for collecting feedback on the certificate program may be required.

As currently approved by the TAMUK Institutional Review Board (IRB), survey requests are distributed to students enrolled in courses with embedded content modules at the beginning and end of each semester. Students are contacted by the department administrative associates, since neither the project leaders nor the faculty members may distribute or discuss the surveys (to prevent any undue influence on students taking the course). In addition to the survey being completely anonymous and optional, this method of delivery places a very low priority on completion. Therefore, it seems likely that additional mechanisms are needed to measure program effectiveness. Possibilities include: adding a survey component to the seminar series; assessing student performance on course modules related to standards and codes; and assessing student performance on the incorporation of standards and codes in capstone projects / masters theses. These are areas for future exploration and would be subjected to IRB review before implementation.

Overall, however, preliminary results indicate that the certificate program is raising engineering students’ awareness of the role of codes and standards in material and design.

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