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Work-in-Progress: Design of a Material Science and Engineering Course to Promote Hands on Learning and Writing Proficiency

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Dr. Mansoor's research advances processing methods for novel alloys and material architectures, with two primary goals: (1) uncovering the intricate relationships between microstructure and environmental factors, and (2) designing lightweight, strong, and corrosion-resistant alloys. His work explores how these materials perform under extreme conditions, addressing challenges in critical sectors such as healthcare, energy, and transportation, while driving innovations in patient-specific medical devices, energy-efficient materials, and space manufacturing.

In engineering education, Dr. Mansoor is credentialed by the Association of College and University Educators (ACUE) in evidence-based teaching practices, emphasizing active learning and inclusive classroom environments. With over a decade of experience, he integrates active learning and experiential scaffolding into undergraduate and graduate courses on materials science and materials in design and manufacturing.

Beyond academia, Dr. Mansoor is a passionate advocate for the educational needs of children on the autism spectrum.

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Abstract
In today's rapidly evolving technical landscape, industry and academia demand an engineering workforce that can effectively communicate complex ideas besides solving challenging and complex engineering problems. Traditionally, engineering lab courses focus more on the technical side of experiments and less on communication skills. Although such courses require students to write reports, integrated writing instructions are missing. Due to lacking such training, students remained underprepared for the communication challenges they may encounter in the workplace. To bridge this gap, the newly established Materials Science and Engineering (MSEN) department at Texas A&M University has developed a course integrating hands-on experiments with structured writing instruction. In this paper, we present the design of the course and explain how the active learning approach creates an engaging, hands-on learning experience for MSEN undergraduate students to build both technical and writing skills in parallel. In the course, students complete three modules—metals, ceramics, and polymers—centered around the PSPP framework (processing, structure, properties, and performance), which teaches how processing-informed structure determines a material's properties and, thereby, its performance. Students also conduct a series of processing and synthesis experiments, such as heat treatment (metals), applying thin film coating (ceramics), and composite fabrication (polymers). To deepen their understanding, students conduct a range of characterizations on their prepared samples to explore the PSPP relationships. In addition to the hands-on experiments, the course has a mandatory writing-intensive component, where students receive writing instruction and prepare sections of a comprehensive lab report focusing on tasks such as memos and technical exhibits. Lastly, students combine these sections into a formal IMMRAD-C report and practice presenting technical results clearly and concisely. This paper describes the combined approach, which can serve as a model for future courses aiming to develop technical and writing proficiency in undergraduate engineering courses.

Introduction

Laboratory courses have been a part of the engineering curriculum for the last two centuries to provide students with a practical experience of applying the engineering concepts taught in lectures [1]. Generally, laboratory courses have been designed to address ABET student outcomes 3, 4, and 6. The ABET outcomes are:

- Outcome 3 - "an ability to communicate effectively with a range of audiences" [2].
- Outcome 4 - "an ability to recognize ethical and professional responsibilities in engineering situations and make informed judgments, which must consider the impact of engineering solutions in global, economic, environmental, and societal contexts" [2].
- Outcome 6 - "an ability to develop and conduct appropriate experimentation, analyze and interpret data, and use engineering judgment to draw conclusions" [2].

In addition to ABET-defined outcomes, lab courses need subject-based goals in MSEN programs. For this reason, the lab courses have been designed to emphasize integrating the PSPP (Processing-Structure-Properties-Performance) framework in a lab environment [3]. The PSPP framework gives students an overall picture of how materials perform due to their processing and resultant structure, which determines the material properties [3], [4]. In the past, efforts have been made to integrate the PSPP framework into lab courses effectively.

Some notable approaches to these integrations include assigning students open-ended projects [5], [6], integrating programming modules and computational modeling with the physical labs [7], [8], and bringing industry speakers for guest lectures [9]. These multiple approaches to designing MSEN lab courses highlight the continuous efforts to improve the lab experience for engineering students. However, another noteworthy aspect is to focus on developing students' ability to communicate the findings from the lab work to a general audience.

Laboratory writing is not only a task for documenting experiments but has also been used as a pedagogical tool for improving students' technical understanding and developing creative communication skills essential for engineering [10]. Writing for laboratory courses is not just for students to note down the steps performed in the lab and present the corresponding results of the experiments. Students should be able to synthesize data, relate their theoretical learnings in a practical environment, and communicate their findings eloquently [11]. The implementation of frameworks such as Writing Across the Curriculum (WAC), Writing-to-Learn, and rubric-based assessments have ensured that students' writing experience is purposeful and reflective of professional engineering standards[12], [13], [14]. Lab courses that have utilized such approaches in other disciplines have helped students not only reflect on the knowledge gained from the lab but also train them to be able to communicate their findings [12], [13], [14]. By integrating writing into lab courses, educators bridge the gap between technical knowledge and communication skills, equipping students with real-world challenges[15].

The paper aims to show that incorporating report writing with hands-on experiments can develop the technical and writing proficiency of students taking the course at Texas A&M University. This WIP showcases our commitment to advancing engineering education and ensuring that students are proficient in their technical and writing skills upon completing their studies. In the following sections of the paper, specific details of the experimental laboratories will be presented along with a discussion of the integration of technical writing and present expected outcomes from implementing this combined approach.

Methodology

This course integrates MSEN education by emphasizing a combination of hands-on experiments with technical writing. The course is offered to MSEN major undergraduate students who are usually in their 3rd year (junior year). The course's learning objectives ensured that students could prepare samples from metals, polymer, and ceramic materials for conducting various experiments upon completion. These objectives were achieved by having students perform different types of testing, such as mechanical testing for tensile properties, toughness, hardness, and dynamic mechanical analysis (DMA) for polymers. Students also performed microstructural analysis using scanning electron microscopes (SEM) and optical microscopes for samples prepared using different manufacturing processes. The course's primary focus is to encourage students to establish relationships between materials' structure, processing, and properties.

The course focused on achieving ABET student outcomes 3, 4, and 6 [2]. Figure 1 shows the implementation of the iterative active cycle used during the course. The course was administered to the students through two hours of lecture and three hours of lab time per week. Within the two hours of the lecture, the first hour was used to teach students the concepts they would use in their lab experiment that week. The second hour of the lecture was used to explain different aspects of technical writing. The course instructor delivered the theory and the writing lectures. Together with the course teaching assistants (TAs), the instructor provided feedback to the students for the presentations delivered by students for each lab. Per the feedback provided, the students incorporated the feedback into their memos and reports. Figure 2 shows a sample of the weekly breakdown that was followed for the course.

Figure 1: Active learning cycle implemented in the course showing the iterative process for enhancing students' technical and writing proficiency through the course

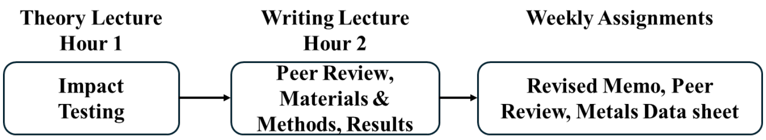

Figure 2: Sample schedule of one week of the course, showing the theory, writing lectures, and the assignment for the week for the students.

Concurrently, in-class activities are also conducted using the Canvas learning management system, with exercises such as spotting errors in existing graphs and tables, refining sentence structure, and group tasks in learning the use of plotting software such as Microsoft Excel. All announcements and relevant course information, such as assigned readings and assignment deadlines, were administered and posted using Canvas. Through the lectures and the in-class activities, students were provided the foundational knowledge necessary to explore various materials science concepts and how to convey their learnings to a general audience. The lectures and in-class activities mirror the "Abstract Conceptualization" step in Kolb's learning cycle, in which learners must engage with abstract ideas to develop their understanding [16].

For the lab component of the course, students were divided into groups of 3. For each lab, students were tasked with reading instruction manuals for the lab in which they were given information about the learning outcomes, background information, experimental procedure, and questions for the post-lab assignments. Upon completing their experiments, students are required to prepare memos and IMMRAD-C reports and present their findings to technical and non-technical audiences. Before the final submission of the reports, students are given feedback on their drafts through an iterative peer review process. Students can reflect on their experiments by preparing reports, memos, and exhibits, providing feedback to other groups, and synthesizing their work coherently. This process aligns with the "Concrete Experience" and "Reflective Observation" stage of active learning as students critically evaluate their experimental work and relate it to theoretical concepts [16]. Blending a course that utilizes traditional laboratory techniques with structured writing requirements, this methodology aims to allow students to enhance their understanding of MSEN concepts and communicate their findings proficiently.

Laboratory Schedule

Figure 3 shows the sets of experiments that were done during the course. The laboratory experiments were divided into three major groups of materials: metals, ceramics, and polymers. The total time spent on experiments with each group of materials is 4 weeks (refer to Figure 2). The relationship between the experiments and the different aspects of the PSPP framework is also shown in Figure 2, highlighting how the labs were designed to give students a practical understanding of the PSPP framework.

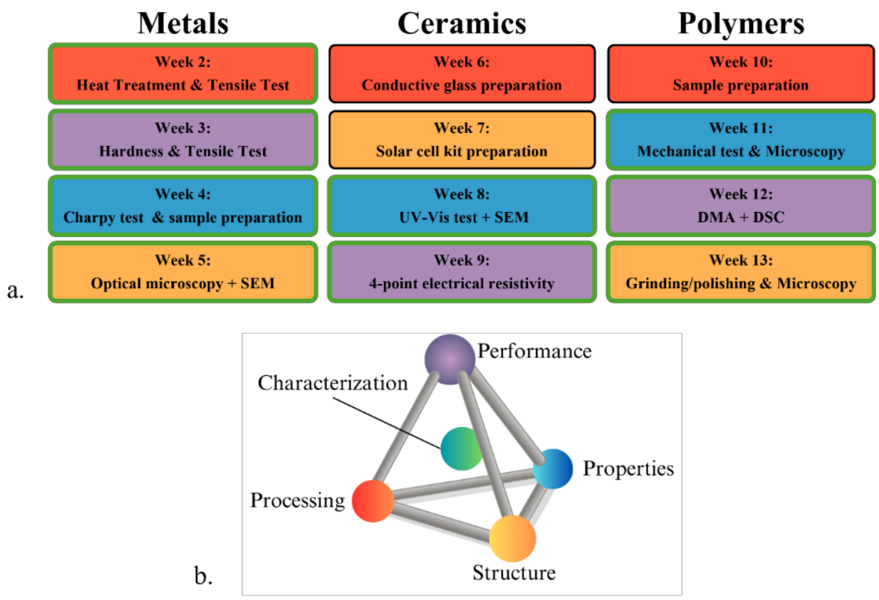

Figure 3: a. Schedule of laboratory experiments conducted for each group of materials during the course. The connection between the experiments and the different aspects of the PSPP framework (b.) is shown through the corresponding colors (labs with characterization have a green border) [3], [4].

The metal experiments aimed to familiarize students with the influence of thermal processing and deformation on commonly used metal alloys. The goal was achieved by having the students do 6 different experiments and tasks during 4 weeks. First, the students conduct heat treatments per industrial processing standards on Steel-4140 and Aluminum-6061 specimens. The students then measured the mechanical properties of the as-received specimens and the heat-treated specimens by conducting a tensile test followed by microhardness measurements and impact testing. After completing the mechanical tests, the students also assessed the microstructure of the metal specimens. The students prepared the specimens by mounting them in epoxy, followed by grinding, polishing, and etching. These specimens were then analyzed using Optical Microscopy (OM), Scanning Electron Microscopy (SEM), and

Energy Dispersive Spectroscopy (EDS). Students finally examined the fracture surfaces of the tensile-tested specimens using optical and electron microscopes to describe the morphology of the specimens.

After completing the metals module, the students conducted labs on ceramic materials to explore the functional properties and characterize the material using advanced techniques. Like the metals module, the students performed the experiments on ceramic specimens in a 4-week timeframe. Students began preparing ceramic samples using raspberry juice and TiO_2 nanocrystalline film to form solar cells. Their performance was measured under varying light conditions. The students then prepared conductive glass by applying the tin oxide coating, and the glass's resistivity was measured before and after coating. The resistivity of the glass was measured using a 4-point probe method. After measuring the glass's electric resistivity, the coated glass's transmittance was measured using UV-Vis, and SEM was done to capture images of surface particles on the glass. Energy Dispersive X-ray spectroscopy (EDS) was also done on the glass surface to study the composition of the coatings.

The final set of experiments for the laboratory part of the course focused on studying the mechanical, thermal, and structural properties of polymer composite specimens. Over 4 weeks, the students learned to fabricate a carbon fiber-reinforced polymer (CFRP) composite laminate using a prepreg lay-up and vacuum bagging technique. The fabricated specimens were cut into different fiber orientations (0°, 30°, 45°, 90°). The specimens made using this technique were then used for tensile testing and SEM imaging. After tensile testing, the thermo-mechanical behavior of the specimens at different temperature conditions was studied using Differential Scanning Calorimetry (DSC) and Dynamic Mechanical Analysis (DMA). Finally, the failure mechanism of the tensile tested specimens was examined using the SEM identifying features, including fiber pull-out, fiber breakage, matrix cracking, and delamination. Having students conduct hands-on experiments with different materials allowed them to apply their theoretical knowledge to the materials' properties directly, corresponding to the "Active Experimentation" stage of active learning [16]. This hands-on approach enabled students to work with materials directly, providing a real-world context to the theoretical concepts learned during the lecture component of the course.

Along with the experiments, students were tasked with completing assignments such as pre-lab quizzes, writing memos and lab reports, and preparing presentations. Pre-labs for each experiment were conducted in the form of a quiz on Canvas. There were videos for each lab that provided a demonstration and details about the experiment that students would perform in the lab. The pre-lab consisted of 3-5 questions, which were used to assess the students' conceptual understanding. After the lab, students submitted data reduction sheets upon completing each lab. Having students complete pre-lab quizzes encouraged them to think about how the experiment is supposed to be conducted, making them active participants during the learning process. The usage of pre-labs aligns with the "Abstract Conceptualization" stage of the active learning cycle as students are expected to hav an uncerstanding of the concepts before coming to the lab [16].

Integration of technical writing in the course

Along with the data reduction sheets, students were required to submit two memos and an IMMRAD-C (Introduction, Materials, Methods, Results, Discussion, and Conclusion) style report for the metals and polymer modules. Students were given instructions regarding the report's formatting and the minimum word count expected from the report, which is 2000 words. Students were asked to submit a technical exhibit document consisting of all the tables and figures that will be included in the report. Along with the templates, a guidance document was also provided to the students so they would have an idea about the required information in each section of the report. For the ceramics labs, the students were required to submit an abstract.

Feedback on all submitted documents was provided through a peer review process in which students were randomly assigned memos, exhibits, and reports of the other teams in the course for their review and feedback on the Canvas about the writing aspects. Rubrics were provided to all students so that they could provide constructive feedback on the writing aspects of the submission. The feedback was then collected and provided to the corresponding group of students so that they could incorporate the feedback and improve the quality of their submissions.

However, using Generative AI tools such as ChatGPT is changing how students write assignments [17]. Using AI tools has its benefits as well as problems [18]. While the AI tool may help students streamline their writing, a major issue can be that the AI tool makes the report look very generic and provides incorrect technical information [19], which is detrimental to the quality of the written work [20], [21]. To deal with the issue of the use of AI tools, a special lecture is given to the students about the use of AI, explaining how it should be used as a reference source and not as a crutch to complete writing assignments. Therefore, for the course, students were encouraged to ensure that the written work had originality and that AI tools were only used for making revisions, such as grammatical errors and diction. All assignments were screened through the Turnitin software to ensure no plagiarism and the large use of AI writing in the submitted assignments.

Through this course, students were expected to develop communication skills through writing-intensive components such as technical memos, IMMRAD-C reports, exhibits, and abstracts, which would improve students' ability to articulate their findings effectively. This outcome aligns with ABET student outcome 3, "an ability to communicate effectively with a range of audiences" [2]. As the lab experiments were performed in groups, students were allowed to refine their collaboration and leadership skills. Working in groups allowed students to coordinate tasks, achieve objectives, and address challenges, aligning with student outcome 4 [2]. Finally, the students also better understood the relationship between materials' structure, processing, and properties. By conducting experiments on metals, ceramics, and polymers, students better understand different types of materials and are exposed to advanced characterization techniques. This improved understanding of materials properties and technical writing aligns with student outcome 6, which is "an ability to develop and conduct appropriate experimentation, analyze and interpret data, and use engineering judgment to draw conclusions" [2].

Conclusion

Integrating technical writing in a traditional laboratory course represents an effort to bridge the gap between theoretical knowledge and practical application. Engaging the students in hands-on experiment preparation and execution and reflecting on the findings through analysis demonstrates the use of the active learning cycle in the course. Providing systematic guidance to the students through weekly writing assignments and lectures on different aspects of technical writing, the presented approach aims to show how technical writing can be incorporated into a laboratory course. This WIP reflects our commitment to advancing materials education and ensuring that future materials science and engineering graduates are equipped with the necessary skills that are in demand by the industry. Future development of the presented approach can focus on having students write journal article drafts to prepare students interested in research-oriented roles.

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