Bridging Theory and Practice: The Impact of Senior Design Courses in Engineering Education

September - 2024

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Amir Saeidi is a passionate teacher who brings about innovative methods to make students get interested in material science and engineering. Amir conducts summer camps for school students encouraging them to take interest in material science and engineering.

In the 1990s, it was evident that engineering students struggled to transition smoothly into their professional roles. The education system at the time focused heavily on theories, presenting students with decontextualized, closed-ended problems that had only one correct answer. Although new graduates possessed theoretical knowledge, they lacked practical experience. The curricula did not emphasize teamwork, communication, or project management skills. This was in contrast with real-world engineering problems that are multifaceted, and open-ended, requiring engineers to find the best solution among various possibilities.

Around the same time, the Accreditation Board for Engineering and Technology (ABET) in the US shifted its accreditation criteria from inputs, such as course content, to outputs, including technical skills and other professional competencies like solving unstructured problems, effective communication, and teamwork.

In addition to industry concerns about the preparedness of the new workforce, recent graduates also faced challenges during their first few months on the job. They reported difficulties with technical tasks, teamwork, communication, self-directed learning, and adapting to their new identity as engineers.

These factors led to the introduction of senior design or capstone courses in most engineering programs in the US. These courses have become crucial, providing senior students with the opportunity to apply the knowledge they have gained during their undergraduate studies to solve real-world problems. In this article, I briefly describe how the senior design course is instructed in the Department of Materials Science and Engineering (MSE) at the University of California at Davis.

Senior design is a three-quarter course sequence for which industry clients provide problems that are important to them, but a solution to them is not urgent. Such projects are desirable as they provide an educational experience for the students while providing a solution to a problem that is valuable to the client. To help the students tackle the problems, the engineering design process is introduced and they are asked to implement the engineering design steps to suggest a solution and implement that.

The engineering design process is a systematic approach used to develop solutions to problems. It typically involves the following steps:

- Problem definition
- Background research and literature review
- Specifying requirements
- Brainstorming solutions
- Identifying the best solution
- Developing the solution
- Building a prototype
- Testing and evaluation
- Iteration and Improvement
- Implementation
- Communication of the results

Each step serves a specific purpose and should be followed to achieve an effective and feasible solution. Defining the problem sets the stage by clearly identifying what needs to be solved and what the constraints are while researching ensures that the solution builds on existing knowledge and technologies. Specifying requirements and brainstorming solutions help in shaping a focused direction and fostering creativity. By selecting the best solution and developing a prototype, the theoretical designs in practical, real-world scenarios are tested. This testing is critical for identifying unforeseen issues and areas for improvement, which might not be apparent in theoretical designs. The iterative nature of testing and redesigning refines the solution, making it more robust and tailored to meet the specific needs and constraints of the problem. Finally, implementing the solution and presenting it to stakeholders provides a chance to learn from the process and apply these insights to future projects.

On the other hand, as the students are going through these steps, they face challenges inherent to group work and open-ended problems such as working with their team members and managing conflicts, determining milestones, managing costs, etc. By the end of the project, the students' problem-solving skills are enhanced, and they have practiced how to approach complex challenges systematically, skills that are invaluable for any engineer. It also emphasizes collaboration, critical thinking, and creative problem-solving. In addition, the nature of these projects creates situations that resemble real-world working environments: disagreements with colleagues, finding resources for help, communicating with supervisors and clients, budget limitations, and meeting deadlines. The experiences gained in senior design directly address the concerns raised at the beginning of the article by equipping the students with the essential skills they need to thrive in their professional careers.

Our department collaborates with different companies on projects ranging from ceramics and batteries to e-textiles. Here, two of the projects are described to illustrate how the engineering design process can contribute to students' skill development.

1. Zinc-bromine battery: Zinc is used as an anode due to its high energy density of 150 Wh/kg and high volumetric capacity of 5854 mAh/cm^3; it also has a cell potential of 1.85 V, and is a widely available material and is inexpensive. However, it forms dendrites that puncture the separator in the battery and cause damage. After the literature review, the students identified different strategies to inhibit dendrite formation, including changing $ZrBr_2$ concentration in the electrolyte and using organic additives such as polyethylene glycol (PEG). After considering the needs of the client, Golden Gate Battery, and the budget and resources, a team of students investigated the effects of additives on the performance of a battery cell and the growth of dendrites. They specifically studied the columbic efficiency of the cells, and the evolution of dendrites by characterizing the anodes under a scanning electron microscope (SEM). Figure 1 shows some of the SEM images taken by the student teams.

2. Wound Vacuum-Assisted Closure (VAC): VAC is a medical technique that enhances wound healing by sealing the wound and applying negative pressure. While there are effective products for flat body areas like the chest, there are no commercial options available for hands. Current medical-grade gloves degrade quickly, resulting in holes that cause pressure leakage. Developing gloves that can maintain negative pressure for several days significantly reduces healthcare costs by decreasing the time for surgical interventions and enhancing patients' experiences. In a project defined by one of the surgeons at UC Davis Health, the students were tasked with evaluating materials suitable for a glove that can maintain negative pressure for several days. After defining the problem, the students identified criteria such as biocompatibility, strength, scratch resistance, and flexibility to select the right materials for this application. After a literature review, they determined tensile and puncture tests are needed to characterize the selected materials to screen them. Figure 2 shows the tensile and puncture test results.

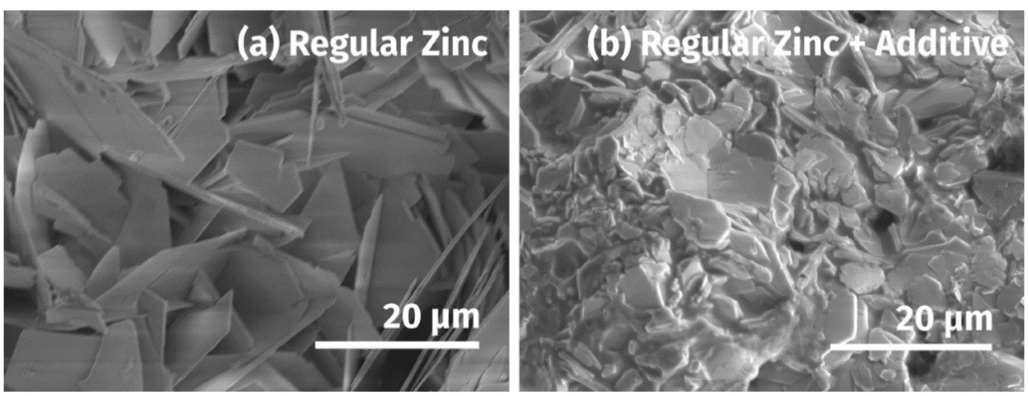

Figure 1. SEM micrographs from MSE students studying the effect of additives on dendrite growth on zinc anode by senior undergraduate MSE students at UC Davis.

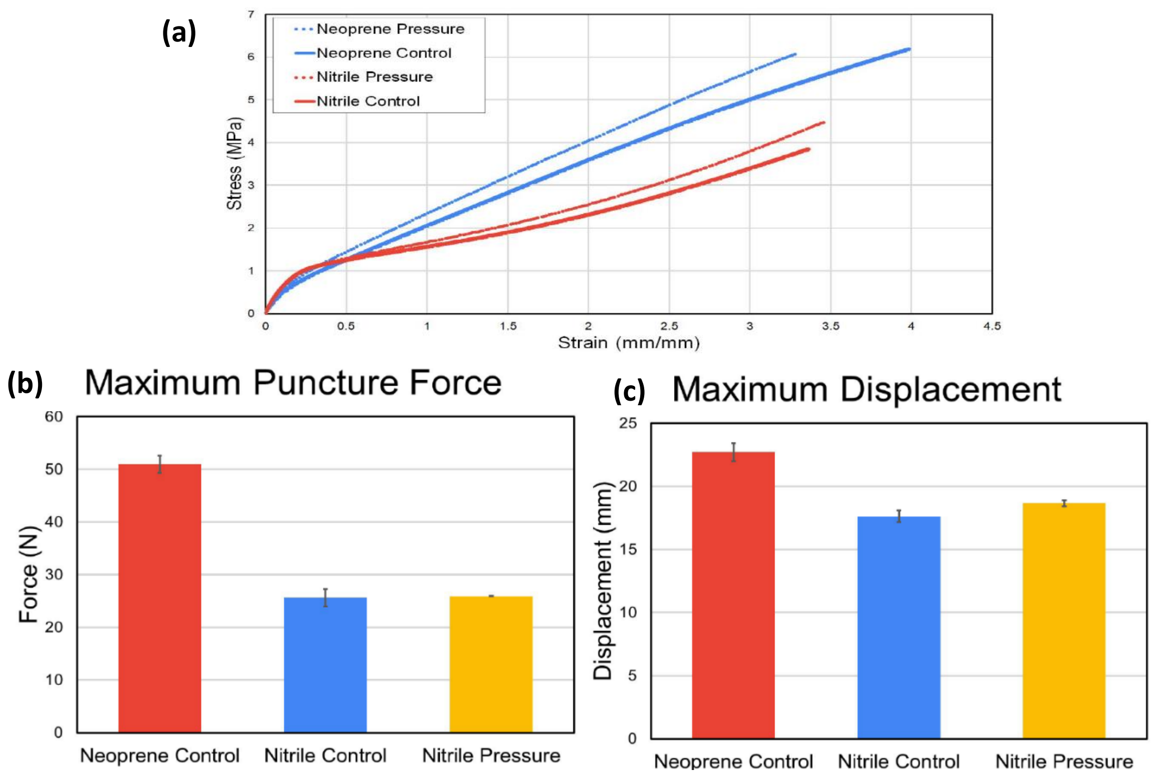

Figure 2. Stress-strain results (a) and puncture test results (b) and (c) of different polymers measured by senior undergradute MSE students at UC Davis.

What makes the success of these projects even more valuable is that our curriculum does not offer any course focused on electrochemistry or polymers. The students build on the knowledge they acquired during their studies and utilize the design process and the materials paradigm—processing, structure, properties, and function—to come up with solutions and criteria for success. In these examples, students encountered challenging situations that required them not only to apply their technical skills but also to rely on non-technical abilities like critical thinking and self-directed learning to solve the open-ended problems presented to them.

It must be emphasized that this educational opportunity is made possible by the participation of companies and individuals who are willing not only to share projects with us but also to mentor the students along the way. They dedicate half an hour of their time each week to provide feedback to the students and keep them on track, provide resources to them, and invite them to their facilities to conduct experiments. They generously give back to the community and contribute to the development of future engineers by providing projects and mentorship opportunities for the students. Having such partnerships is crucial in building a rich educational experience for the students. The capstone design course creates a culminating experience for engineering students and prepares them for success in their careers. It teaches them how to approach open-ended problems, how to present themselves as engineers and realize the need for lifelong learning.

You can learn more about our class in the MSE department at UC Davis, by checking out our website https://mse.sf.ucdavis.edu/senior-design

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