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Board 18: Work in Progress: Implementation of a Junior-level Biomedical Engineering Design Course Focused on the Manufacturing of Electrospun Nanofibers.

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Work-in-Progress: Implementation of a junior-level biomedical engineering design course focused on the manufacturing of electrospun nanofibers.

Abstract: In this work-in-progress (WIP), we describe the implementation and evaluation of a new junior-level design course in bioengineering that focuses on the manufacturing of electrospun nanofibers at a public, R1 institution. Electrospinning is a fiber production method that uses high voltages to draw polymer solutions into thin threads at the nanometer scale. This ability to easily produce materials at a biological size has led electrospinning to find applications in various biomedical applications such as tissue engineering and drug delivery [1, 2]. However, several parameters can greatly affect the production quality of fibers, such as concentration of the polymer solution, voltage, feed rate, and ambient conditions [3]. Controlling the manufacturing of electrospun fibers presented a unique engineering problem that could integrate concepts from multiple bioengineering courses including biomechanics, circuits, computer aided design (CAD), thermodynamics, and biomaterials into a single engineering design project with real-world applications. This project served as the basis for a new junior-level design course that will better prepare students for their senior capstone experience. In the future we plan to evaluate assignments and course evaluations to assess learning outcomes and student satisfaction.

Introduction: Students graduating from biomedical engineering (BME) programs have expressed frustration and difficulties when competing for industry positions against traditional engineering graduates, such as mechanical, chemical, or electrical engineers [4, 5, 6]. Seeing a similar frustration in our students we sought a way to adapt our program to ensure our students could meet the demands and requirements of future employers. One way BME programs can adapt to industry demands is by increasing the amount of design experiences for students [7]. This can be done by including sophomore and junior-level engineering design projects into a BME curriculum as they increase students' engineering design knowledge and confidence in approaching design projects [8]. Using this knowledge, we developed a new required junior design course, "Biomedical Engineering Fundamentals and Design" with the goal of providing students with additional engineering design opportunities prior to their senior capstone course, while also integrating concepts from previous biomedical engineering courses. The course learning outcomes (CLOs) were: 1) Apply engineering design principles to a bioengineering problem, and 2) Fabricate and assemble a solution that meets a client's specifications.

Electrospinning: Several projects were considered for this design course including bioreactors, spectrophotometry, and wearable sensors. Electrospinning was ultimately chosen as the core project because it was found to be affordable and allowed us to develop skills in CAD, microcontrollers, fabrication, and material testing, areas where graduating students felt underprepared. It also integrated the most concepts from courses offered by our department such as biomechanics, circuits, feedback systems, and cell and molecular engineering.

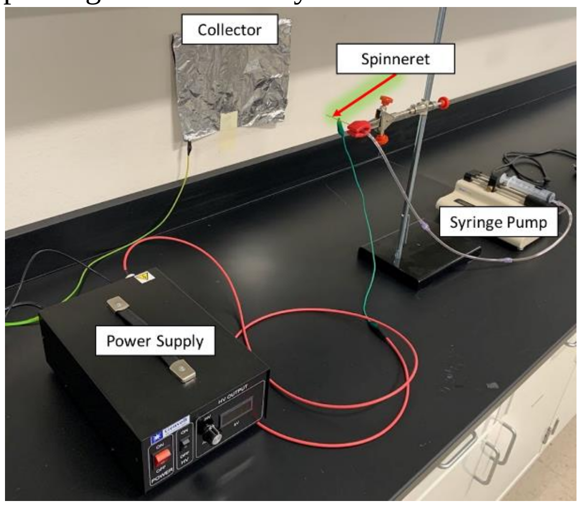

Figure 1: *Electrospinning setup used in course.*

The basic setup for an electrospinning device includes a high voltage power supply, syringe pump, spinneret, and conductive collector. (Fig. 1) [9, 3]. During electrospinning a charged polymer dissolved in a solvent is pumped through an electrified spinneret creating a cone shaped jet known as the Taylor Cone. The cone is then pulled towards a grounded collector (aluminum foil). As the cone extends away from the spinneret the solvent evaporates and the polymer solidifies into thin fibers. The fiber diameter and mechanical properties are heavily influenced by parameters such as concentration of the polymer solution, power supply voltage, and pump feed rate [3, 9]. However, even when these parameters are tightly controlled ambient conditions such as temperature and humidity can influence the polymer's ability to solidify [3, 9, 10]. Poor control of ambient conditions could lead to the production of electrospun fibers with improper diameters or material properties [9, 11, 12].

Course Implementation: The foundation for this new design course was based on previous implementations of electrospinning in senior design projects [13, 14], educational modules [15, 16, 17], and research courses [18, 19, 20]. However, the novelty of this course was its goal of controlling ambient conditions to improve manufacturing electrospun fibers. Specifically, students in teams of 4-5 were tasked to design an electrospinning system that could monitor temperature or humidity and regulate the appropriate ambient parameter to stay within an ideal range.

The course was designed to be a required 2-credit hour course that would be held once a week during a standard 3-hour laboratory period with ~20 students (5 teams). The course was led by one primary instructor and one teaching assistant. Additionally, to parallel the senior capstone course a professor who was not the instructor for the course acted as a client for the groups. This role was to act as primary stakeholder whom student contact to ask questions, gather design requirements, and receive feedback related to the project.

Most of the materials were provided to the students, however teams did have an option of purchasing up to $100 worth of equipment for themselves. The major components that were purchased for the course included, high voltage power supplies (*Genevolt, 73030*) and syringe pumps (*Fisherbrand, 14-831-200*), $1,500 and $1,300 respectively. For maximum safety polyethylene oxide (PEO) (MW = 400,000 Sigma-Aldric, 372773) was chosen as the electrospinning polymer because it could be dissolved in water [21], avoiding use of more harmful solvents such as acetone or acetic acid. Additional expenses for electrospinning consumables (PEO, syringes, tubing, etc.), circuit components (e.g. cooling fans, heating pads, atomizers, sensors, etc.) and building materials (e.g. plexiglass, wood, etc.) were ~$1,000 per team. The course also utilized the university's machine shop to acquire necessary equipment so students could fabricate their own prototypes. The total startup cost for a single class was $20,00 or $4000 per team. However, since power supplies and syringe pumps can be shared across multiple class sections, scalability is not seen as prohibitive. Recuring yearly costs for PEO, building materials, and other consumables are expected to be about $200 per team.

To ensure students were prepared for the project and meet CLOs, the schedule was divided into three main sections: Design Lectures, Training Modules, and Project Build Time (Appx. Table A1). Design lectures were used to guide students through the design process while providing them with necessary tools at each stage. After a foundation for the design process was properly established, the project was introduced. Training modules were then provided to develop student skills in various areas that would assist in completion of the project. These included training at the machine shop, and labs on electrospinning, microcontrollers, and material testing. Lastly, the final weeks of the semester were devoted to teams building their prototype at the university's machine shop and iterating their design based on testing.

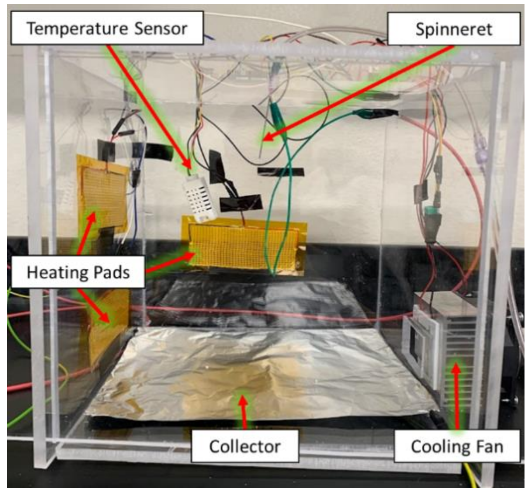

Figure 2: *Example of a student-built electrospinning chamber that controls*

Assessments: Assessments for the course were broken up as follows: Client Evaluations (5%), Peer Evaluations (10%), and Individual Assignments (35%), Team Assignments (50%), (Appx. Table A2). All assessments were mapped to CLOs and designed to parallel those in the capstone course, so students knew what to anticipate when entering senior design. Client evaluations were used to determine if the teams were meeting the client's requirements and expectations, and peer evaluations were used to ensure accountability among team members. Individual assignments consisted of reflections about the design process and assessments related to training modules, while Team Assignments consisted of assessments related the to design project.

Team assessments were scaffolded using periodic "Design Updates (DU)", in which teams would work on a small section of the project and get feedback before any major presentations. For example, students would have to complete updates related to their Problem Definition/ Requirements (DU1) and Concept Generation/ Down-selection (DU2) prior to presenting their Preliminary Design Review (Appx. Table A3).

Evaluation and Future Work: The first offering of "Biomedical Engineering Fundamentals and Design" was in Fall 2022 and had a single class section. The second offering with three class sections is occurring in Spring 2023. Teams from the first offering were able to create functional electrospinning devices which could modulate temperature or humidity (Fig. 2); however, they were unable to test electrospun fibers due to issues with the material tester used in the course.
Overall students seemed to enjoy the course commenting the following in a survey:

- "I liked how [the class] built upon itself and taught skills that are unlike other classes."
- "I found the problem we were attempting to solve to be very interesting and the lecture concepts to be very useful in application to senior design."
- "This semester has been an incredibly rewarding experience… I was able to strengthen my problem-solving abilities, allowing me to approach any situation with confidence."

For the future we are planning to add new electrospinning projects to give students a greater variety of options. We are also planning to evaluate the course and its longitudinal effect on the capstone class. This proposed study will analyze how well students meet CLOs for the junior and senior design courses offered by the department. The study will employ a combination of qualitative and quantitative methodologies to examine student performances on various assessments, both formative and summative.

Contributions: I would like to thank Dr. David Schmidtke, Dr. Gu Kang, and Chunya Wu for their help in developing the "Biomedical Engineering Fundamentals and Design" course.

Appendix

Table A1: *Example Course Schedule. The course was divided into 3 primary sections: Design Lectures (Blue), Training Modules (Green), and Project Build Time (Orange)*

Week	Lecture Topic(s)	Labs
1	Syllabus Overview, Intro to Design	
2	Problem Statements and Stakeholders	
3	Requirements	
4	Conceptual Design and Down-selection	
5	Project Introduction	Machine Shop Training
6	Team Building and Project Management	Electrospinning Lab
7	Presentation Skills	Microcontroller Lab Day 1
8		Microcontroller Lab Day 2
9	**Preliminary Design Review**	
10	Prototyping	Material Testing Lab
11	Testing and Verification	Build and Test Day 1
12		Build and Test Day 2
13		Build and Test Day 3
14		Build and Test Day 4
15	**Final Design Demonstrations and Presentations**	
16	**Final Design Report**	

Table A2: *Assessment Breakdown for Course. Assessments were divided into the four categories: Client Evaluations, Peer Evaluations, Individual Assignments, and Team Assignments.*

Client Evaluations (2)	**5%**
Peer Evaluations (2)	**10%**
Individual Assignments	**35%**
Attendance	5%
Safety Training Requirements (8)	4%
Reflections (3)	6%
CAD Tutorials (2)	8%
Pre-labs (3)	12%
Team Assignments	**50%**
Post-Labs (3)	12%
Design Updates (4)	8%
Preliminary Design Review	5%
Final Prototype	5%
Final Design Review	10%
Final Design Report	10%

Table A3: *Timeline and description of assignments related to the design process. Design updates (green) acted as formative assessments and were used to give feedback to students prior to summative assessments (orange).*

Timeline

Assignments	Description
Design Update 1: Problem Definition and Requirements	From your own research, your team should have developed an understanding of the scope for your project. One of the most important things to do at this point in the project is to capture and summarize all relevant project information. This document should summarize the team's understanding of the project background, problem, objectives, stakeholders, and requirements.
Design Update 2: Conceptual Design and Down-selection	Now that your team has developed an understanding of the problem and requirements of your project, you can now begin coming up with potential solutions. Create several conceptual designs which will solve the problem you are given, then use down selection tools to determine which designs best meet your requirements.
Preliminary Design Review	The Preliminary Design Review (PDR) is a formal meeting involving the major project stakeholders (e.g. client, instructors, and team members). This meeting provides an opportunity for everyone involved in the project to review the progress to date. For this presentation you will be presenting what you have accomplished in Design Updates 1 and 2. We will then discuss which conceptual design would be best to pursue. The PDR should be viewed as a tool that will help your team keep the project on track by finalizing key project decisions and identifying any gaps or deficiencies in the design.
Design Update 3: Embodied Design	Now that your team will be creating one of the conceptual designs from your PDR it is important to refine the details of the design. For this assignment your team will create a CAD model, functional model, circuit diagram, and pseudocode diagram for your embodied design.
Design Update 4: First Prototype	Now that your team has finalized many of the details of the design you can begin prototyping to determine if your design will meet some of the requirements you proposed and what modifications you may need to make.
Final Prototype Demonstration	You will show the client and instructors the functionality of your prototype and how it meets 4 of your top requirements.
Final Design Presentation and Report	The Final Design Review (FDR) and Final Design Report is the conclusion of the design process. Your overall objective is to demonstrate how you solved the problem given to you and how your design has met the requirements that you defined.

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