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Experiential Activities Demonstrating Mass Transfer in Porous Materials in an Introductory Bioengineering Course

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Abstract

This Complete Evidence Based Practice paper describes how hands-on experiential learning can be utilized in an introductory bioengineering course to teach complex topics and help students feel a sense of identity and belonging to the field. Bioengineering encompasses many multidisciplinary concepts, techniques, and applications from other disciplines; as such, students can feel underqualified or 'othered' compared to their peers. This is often observed especially in first-year students or those transferring from other fields.

Introduction to Bioengineering (BIOE 120) is a survey-style course offered to non-majors at the University of Illinois Urbana-Champaign. Students in this course wish to learn more about the field yet come from a variety of backgrounds, resulting in differing levels of knowledge and academic experience. However, as survey-style courses take a broad approach and often offer fewer credit hours, it can be difficult to teach technical concepts with their confines, especially to students who lack necessary prerequisites.

Transport and fluid dynamics are important bioengineering topics whose overarching concepts lend themselves to hands-on activities but can be difficult to implement on a smaller scale in a lecture classroom setting to first-year or transfer students without prior knowledge of the topic. One topic of interest is the transport of mass through a porous medium. We designed a low-cost protocol in which students in BIOE 120 tested the properties of soils that emulated other permeable materials relevant to bioengineering. Students in diverse teams quantified the flow dynamics of various soil types with different drainage properties, then planted seeds to compare plant growth and moisture levels. To conclude, students discussed the connection between their measurement techniques and engineering design in the context of biological systems.

Pre-, mid-, and post-project surveys assessed the activities' effectiveness in introducing the topics. Additionally, validated instruments were used to measure the impact on students' sense of belonging and identity in bioengineering. Finally, self-reflection allowed for an examination of the learning process.

Introduction

This Complete Evidence Based Practice paper describes how hands-on experiential learning can be utilized in an introductory engineering course to teach complex topics and introduce practices that help students feel a sense of identity and belonging to the field. Bioengineering is a multidisciplinary field of students and researchers with diverse backgrounds, academic experiences, and skills. Because the field encompasses so many concepts, techniques, and applications from other engineering disciplines as well as biology [1,2], students can feel underqualified in the depth and breadth of topics, or 'othered' compared to their peers. This is often observed especially in first-year students or those transferring from other fields [3,4].

Introduction to Bioengineering (BIOE 120, **Table 1**) is a 1 credit hour course offered to non-bioengineering majors at the University of Illinois Urbana-Champaign. Students in this course wish to learn more about the field yet come from a variety of backgrounds, resulting in differing levels of knowledge and academic experience. As survey-style courses take a broad approach and often offer fewer credit hours, it can be difficult to teach technical concepts, especially to students who lack prerequisite courses [5,6]. Moreover, in many engineering classroom settings, technical concepts are taught in a didactic, unidirectional manner [7]. Though students may practice applying the material in homework problems and exams, there is a general lack of hands-on experiences outside of labs [8,9], though the skills that engineering students may gain from such experiential activities can solidify concepts, connect to real-world situations, and aid in future environments such as design, graduate school, and industry [10,11]. Students in previous offerings of BIOE 120 indicated their desire for more hands-on activities in the course.

	Introduction to Bioengineering (BIOE 120)
Enrollment	50-60 students/semester
Course Objectives	● Identify real-world biomedical problems. ● Identify technology gaps and innovation needs. ● Propose problem solving strategies in the clinical context.
Grading	● Attendance and Participation: 40% ● Assignments: 60% ○ Post-lecture reflection questions (30%) ○ Seminar assignment (10%) ○ Project (20%) *[described in this paper]*
Project Breakdown	● Experiments: 50% ○ Question Set 1: 50 points ○ Question Set 2: 50 points ● Final Presentation: 50% ○ Presentation: 80 points ○ Documentation: 10 points ○ Peer evaluation: 10 points (individual)

Table 1: BIOE 120 information from course syllabus.

Transport and fluid dynamics are chief considerations in bioengineering. Porous materials (bone, tissue scaffolds, etc.) can transfer molecules, drugs, and other therapeutics [12,13]. Importantly, fluid flow underlies many physiological systems, including the circulatory and lymphatic systems, as well as engineered devices such as bioreactors [14,15]. These overarching concepts lend themselves to hands-on activities but can be difficult to implement on a smaller scale in a lecture classroom setting (as opposed to a large laboratory or outside environment, where most examples in this field take place) to first-year or transfer students without prior knowledge of the topic. Typically, at the University of Illinois Urbana-Champaign, mass transport is taught in a required junior level course, requiring differential equations related to fluid dynamics.

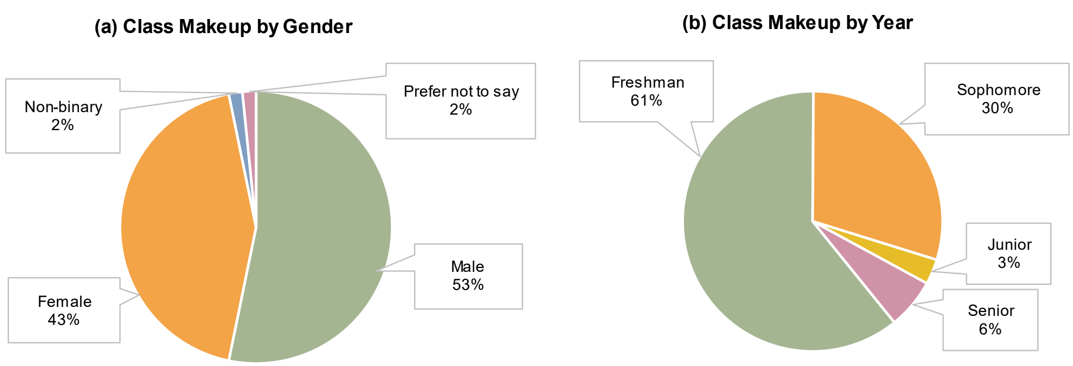
One specific topic of interest is the transport of mass through a porous medium, modeled by Darcy's Law. We designed a low-cost protocol in which students in BIOE 120 tested the properties of soils that emulated other permeable materials relevant to bioengineering. First, student teams were diversified by academic major, gender, and skill sets (such experience with data collection, analysis, and scientific writing), in order to build on each other's strengths. During the experiment, students quantified the flow dynamics of various soil types with different porosities and drainage properties, then planted seeds to compare plant growth and moisture levels over time. To conclude, students discussed the connection between their measurement techniques and physiological systems or engineered biomedical devices. Finally, to measure outcomes, we employed pre-, mid- and post-project surveys and validated instruments [16-18] that assessed the impact of the project on students' sense of identity and belonginess in the field of bioengineering, and on the development of certain technical skills.

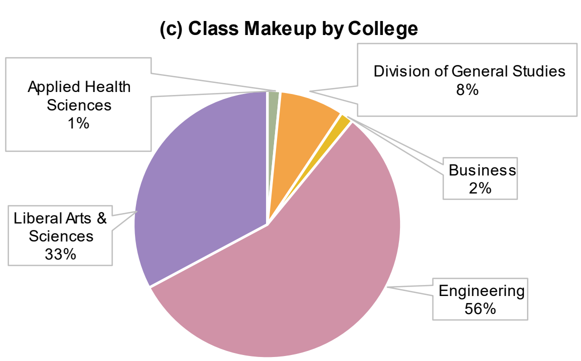
Methods

Course Backgrounds

Introduction to Bioengineering (BIOE 120, **Table 1**) meets once per week to offer lectures and discussions of recent trends in the field. Topics include cancer detection technologies, medical devices, biomaterials, biomechanics, neural engineering, and medical imaging techniques. Regardless of prior experience (there are no prerequisite classes), students gain an understanding of bioengineering's research topics, career paths, and coursework opportunities.

BIOE 120 is made up of approximately 50% first year students and 50% engineers, with the vast majority pursuing a STEM-related degree, a BIOE minor, or transferring into the BIOE undergraduate program. The course discussed in this paper was offered in Fall 2024 with an enrollment of ~70 total students (**Figure 1**). Classroom time is structured to consist of mini-lectures from experts in the field of bioengineering coupled with in-class discussions. Students visit research institutes on campus, participate in medical simulation activities, and converse with researchers and graduates in the field. Course assignments allow students to work on identifying real-world biomedical problems, technology gaps, and innovation needs.





(d) Major Breakdown

Bioengineering	16
Biology (Integrative/Molecular & Cellular), Neuroscience	13
Engineering Undeclared	10
Computer Science	9
Biochemistry, Chemistry	6
Other Non-STEM	5
Business, Economics	3
Undeclared Major	3
Physics, Astrophysics, Nuclear Engineering	3
Community Health, Psychology, Sociology	2
Electrical/Mechanical/Systems Engineering	2

Figure 1: BIOE 120 Class Demographics. (a) Course makeup by self-reported gender. **(b)** Course makeup by class year. **(c)** Course makeup by college. **(d)** Breakdown of majors in the course. (n = 62 students)

A project was introduced to complement course topics with a hands-on activity relating to fluid flow and mass transfer in biological systems. Students worked in teams to build confidence with experimental and analytical skills while deepening their understanding of biological systems. In this project, students tested the properties of soils that emulated other permeable materials relevant to bioengineering.

Forming Teams with CATME

CATME's Team-Maker software [19] was utilized to diversify teams of students in BIOE 120. Students completed a survey that requested data about their racial and ethnic identity, gender identity, college (e.g., Engineering, Liberal Arts and Sciences, Business), major(s), and class year (**Table 2a**). They were then asked to rate their experience level with various technical skills as well as their preferred leadership style and if they considered themselves to be a more detail-oriented or big-picture/idea thinker, on a spectrum (**Table 2a-b**). CATME formed teams of 4 students that emphasized diversity across these metrics. At the conclusion of the project, students used CATME's Peer Evaluation [20,21] to assess their teammates' contributions to the group.

Experimental Protocol

Before the experiment, materials were set up in group stations in a laboratory space by the course staff (**Figure 2a**). To begin the experiment (see protocol in **Appendix**), students first filled planter pots with different types of soil of varying intrinsic properties (e.g., density, porosity, material makeup) and components: Miracle-Gro Moisture Control indoor mix [Soil 1] and Miracle-Gro Organic potting soil [Soil 2] (**Figure 2b**). In their teams, students slowly poured a set volume of water into the pots while measuring the water volume that flowed out of the soil through the pot's drainage holes over 10-second time intervals (**Figure 2c**). At the end of the experiments, students planted 6 perennial lupine seeds into each pot of soil. These seeds were chosen for their quick germination and growth rate.

The course staff moved the pots in saucers to a south-facing windowsill (**Figure 3a**), where the plants grew over time. Pots were watered twice per week by the students and/or course staff and rotated regularly to ensure equal sun exposure.

(a) Group station setup **(b) Soil types used** **(c) Watering method**

Figure 2: Experimental Setup. (a) Group stations with project materials, including two pots, two measuring cups, two labels, a Sharpie, a ruler, and a wooden stick. **(b)** Two different soil types used, [Soil 1] and [Soil 2]. **(c)** The pouring method recommended in the protocol during the flow-through experiment.

<table>
<tr><th rowspan="1">Validated Instrument or Topic</th><th colspan="3">Survey</th></tr>
<tr><td>● Questions asked (rating scale)</td><td>Pre-</td><td>Mid-</td><td>Post-</td></tr>
<tr><td>(a) Demographics
● Racial/ethnic and gender identities
● College and major(s)
● Class year
● Leadership style (follower ... equal ... leader)
● Thinking style (visionary/ideas ... balanced ... detailed)</td><td>x</td><td></td><td></td></tr>
<tr><td>(b) Skill Development
(never used it before = none; some experience, basic skills = basic; lots of experience, basic skills = good; lots of experience, advanced skills = expert)
● Spreadsheets (Sheets, Excel, etc.)
● Scientific or technical writing (lab reports, abstracts, etc.)
● Scientific or technical presentations (making slides/poster, presenting to a class or group, etc.)
● Hands-on experiments</td><td>x</td><td></td><td>x</td></tr>
<tr><td>(c) Belongingness – modified from [16]
● Pre-project: I expect to fit right into BIOE 120 ... I expect to feel pretty out of place in BIOE 120 (1 ... 7)
● Post-project: I fit right into BIOE 120 ... I felt pretty out of place in BIOE 120 (1 ... 7)</td><td>x</td><td></td><td>x</td></tr>
<tr><td>(d) Science-Related Interests and Attitudes – from [17], question 31
Please rate your general interest in the following areas:
(1 = not at all interested ... 6 = very interested)
● Conducting your own experiments
● Understanding natural phenomena
● Understanding everyday-life science
● Explaining things with facts
● Using mathematics
● Telling others about science concepts
● Making scientific observations
● Wanting to know more science
● Graduating from college with honors</td><td>x</td><td>x</td><td>x</td></tr>
<tr><td>(e) Engineering Identity – modified from [18]
To what extent do you agree or disagree with the following statements?
(1 = strongly disagree ... 7 = strongly agree)
● My parents see me as a bioengineer.
● My instructors see me as a bioengineer.
● My peers see me as a bioengineer.
● I am interested in learning more about bioengineering.
● I enjoy learning bioengineering.
● I find fulfillment in doing bioengineering.
● I am confident that I can understand bioengineering in class.
● I am confident that I can understand bioengineering outside of class.
● I can do well on exams in bioengineering.
● I understand concepts I have studied in bioengineering.
● Others ask me for help in this subject.</td><td>x</td><td>x</td><td>x</td></tr>
</table>

Table 2: Questions and topics included on pre-, mid-, and post-project surveys. (a) Demographic questions asked. **(b)** Skill self-assessments were given pre- and post-project. **(c)** Sense of belongingness in the course was assessed pre- and post-project, modified from the Beginning-of-Term (BoT) Survey by Chin, et al [16]. **(d)** At all three timepoints, students were surveyed about their science-related interests and attitudes using a question from the Persistence Research in Science & Engineering (PRiSE) survey [17]. **(e)** At all three timepoints, students were surveyed about their sense of engineering identity, using Godwin's Measure of Engineering Identity [18].

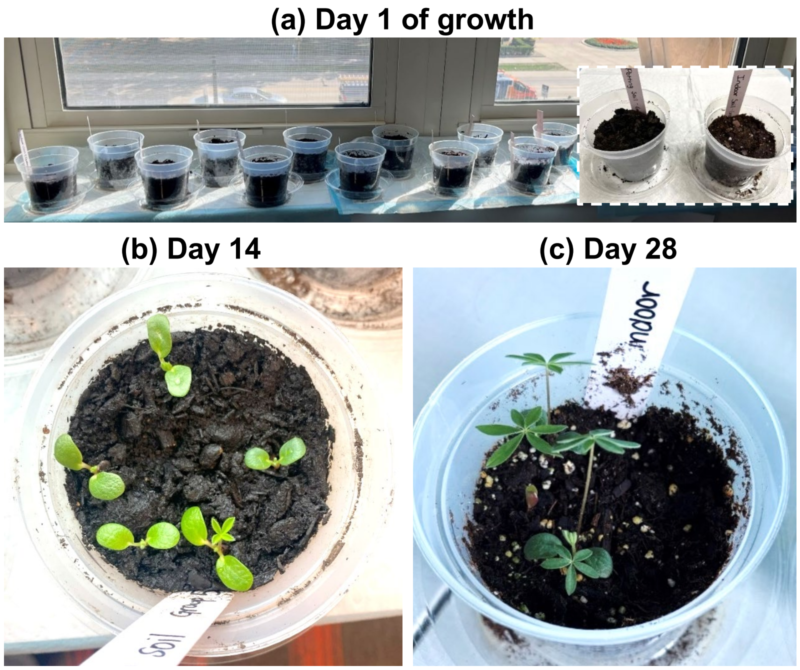


Figure 3: Plant Growth Phase. (a) Setup of pots on windowsill at beginning of growth phase. **(b)** Progress from Day 14, in [Soil 1]. **(c)** Progress from Day 28, in [Soil 2].

Students monitored plant growth conditions over time by measuring the number of sprouts and plant height, and then used color-based probes to read moisture levels in the two types of soil. Measurements were taken for 4 weeks (**Figure 3b-c**).

Project Assignments

Overall, the project was worth 20% of the final grade (**Table 1**). Two different question sets were assigned to students to reflect on and analyze their experiment. At the end of the project, students completed a final presentation.

Question Set 1 was assigned after the experiment. It engaged students quantitatively with their collected data, asking them to graph their results over time, determine the volume of absorbed water, and calculate the average flow rates. It also encouraged students to reflect on protocol instructions, considering why one methodology may be preferred over another. Moreover, it asked students to identify potential sources of error or differences when comparing data to other groups and challenged them to explore connections to real-world bioengineering applications.

Question Set 2 was assigned 4 weeks later. This assignment further expanded on the previous set, asking students to compare the differences in soil flow rates related to its material properties. It challenged students to formulate other relationships they could quantitatively represent, evaluate what graphs could best represent their data, and plot their results over time. Students also considered how different parameters could have affected the results of their experiment. Additionally, students were asked to reflect on their use of moisture sensors in the experiment.

The project culminated in a final presentation, in which groups expand upon their experiment to investigate mass transport and fluid flow in human physiology and bioengineering, utilizing their peers' wide variety of academic backgrounds. Teams formed by combining two previous groups (i.e., 7-8 students total) selected their topics from a given list, including:

- Flow through the lungs
- Intraocular fluid flow
- Lubrication of joints and transport in bone
- Flow through the kidney
- The lymphatic system
- Macrocirculation (heart, large blood vessels)
- Microcirculation (capillaries, small vessels)
- External (*in vitro*) biomedical devices
- Implantable biomedical devices

Each presentation lasted 5-6 minutes, and was evaluated on visual/oral presentation, slide content, peer evaluation, and documentation of research **(Table 1)**. Throughout the project, students were encouraged to work as a team so that they could learn from each other's diverse academic backgrounds and skill sets.

Project Surveys and Evaluation

Pre-, mid-, and post-project surveys assessed the project's effectiveness in introducing the topics of the experiment to students and enhancing their sense of belonging and identity. Validated instruments included Chin's Pre-Semester Concerns in First-Year Engineering Students [16], Goodwin's Measure of Engineering Identity survey [18], and the Persistence Research in Science & Engineering (PRISE) survey [17] (**Table 2c-e**). Though the course was also open to students at a local high school, these data (~7% of the class were minors) were excluded.

The pre-project survey aimed to better understand student demographics, feelings of belonging in the class and bioengineering field, and students' general interest levels in the different components of engineering (e.g., understanding natural phenomena, using mathematics, telling others about scientific concepts). Students completed this survey individually before beginning the experiment with their teams. Midway through the project (i.e., after the experiment and question sets), surveys again assessed student's science-related interests and attitudes and feelings of engineering identity (**Table 2d-e**).

Post-project surveys assessed students' science-related interests and attitudes and feelings of engineering identity, as well as feelings of belonging in the class. Students were asked to self-rate their experience levels for technical skills such as spreadsheets (Sheets, Excel, etc.), scientific or technical writing (lab reports, abstracts, etc.) and presentations (making slides/poster, presenting to a class or group, etc.) and hands-on experiments. Finally, self- and team-based evaluations through CATME at the end of the project allowed for the examination of group diversity on the learning process and effectiveness of team collaboration. Non-Human Subject Research determination was received from the Institutional Review Board at the University of Illinois Urbana-Champaign (Project IRB24-1426).

Data Analysis

For the course surveys, the instructor downloaded evaluation data from the learning management system, CATME, or online forms. Responses were then de-identified for the course staff to analyze blindly using Microsoft Excel. Likert-scale questions provided numerical ratings, which were aggregated to calculate averages and distributions for each prompt. Student responses to quantitative survey data were analyzed using descriptive statistics to summarize and interpret the results. A student's two-tailed unpaired t-test was used to determine significance between two groups at a time (e.g., feeling of belongingness pre- and post-project).

Results

Student Project Outcomes

Project outcomes were evaluated based on student performance in completing experimental tasks, data analysis on question sets, and final presentation. The outcomes demonstrated skill development in an understanding of mass transfer concepts among the students.

In Question Set 1, teams quantified the flow dynamics of various soil types utilizing protocols with measurable differences in water retention and drainage properties. They used their collected data to plot water collected vs. time and then calculate flow rate through each soil type (**Figure 4a**). Consistently, the Moisture Control indoor mix [Soil 1] retained more water. They identified potential sources of error including varying reaction times, uneven water spread, varying pour speeds, different depths of planted seeds, and inconsistencies or inaccuracies of volume measurements across pots or groups. When asked to relate the concepts to bioengineering, students made connections to cell membrane transport, flow rate optimization for medical devices, drug delivery, microfluidics, and nutrient flow throughout the body.

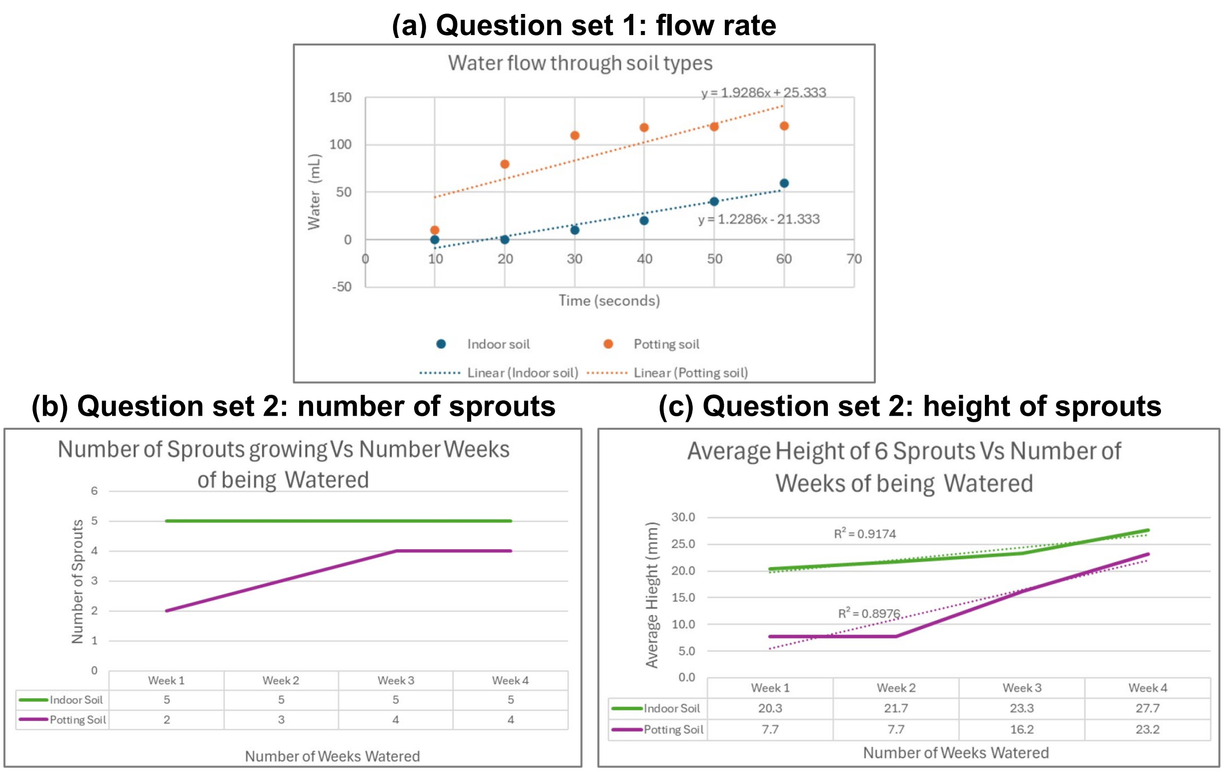


Figure 4: Representative Student Work. (a) In Question Set 1, students calculated flow rate and absorption volume for each soil. **(b,c)** In Question Set 2, students plotted the number and height of sprouts over 4 weeks.

In each subsequent week, student groups watered their plants and took measurements. For Question Set 2, students were asked to consider which types of variables could affect growth conditions; they responded that sunlight, room temperature, humidity levels, watering volume, and water source could have potential impacts on the experimental outcomes (**Figure 4b**).

Students' final presentations reflected their ability to connect experimental data with engineering applications in the context of biomedical systems. Two representative examples are described here. One group focused on how fluid dynamics and heat/mass transfer relate to biomedical devices which can be implanted (**Fig. 5a**). They explained the mechanisms of a biomimetic transcatheter aortic value and a bidirectional acoustic microfluidic pump, going into detail about design challenges, fluid dynamic modeling, and regulatory/safety considerations. Another team explained why the transport of fluid and mass is critical to the proper functioning of *in vitro* biomedical devices (**Fig. 5b**). To demonstrate applications, they detailed the measurements and functionality of devices such as over-the-counter blood glucose meters and pregnancy tests.

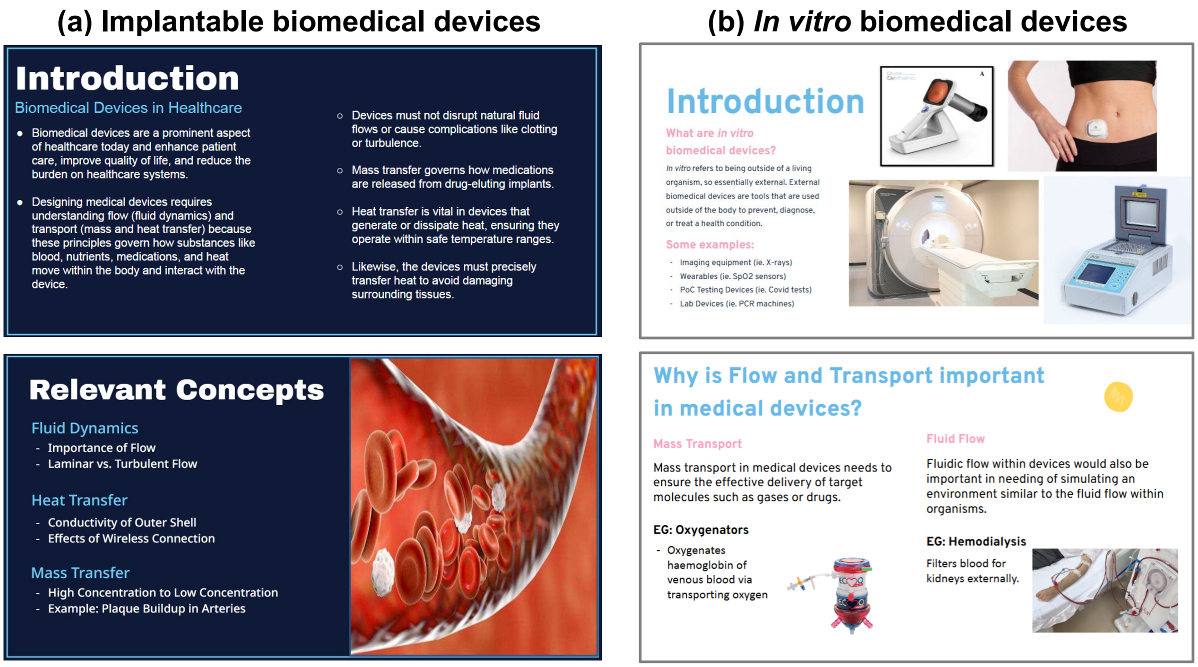


Figure 5: Representative Student Presentations. (a) Implantable medical devices. **(b)** *In vitro* medical devices.

Belongingness

Students' sense of belonginess in the course was quantified pre- and post-project using an item modified from the Pre-Semester Concerns (**Table 2**) [16]. Students rated themselves on the scale of "I (expect to) fit right into BIOE 120" (1) to "I (expect to feel)/(felt) pretty out of place in BIOE 120" (7). In the pre-survey, the average response was 3.1, which decreased significantly to 2.4 in the post-survey ($p = .015$), i.e., a shift in the direction of greater sense of belongingness.

Skill Development

Students were asked pre- and post-project to rate their skill level in four technical areas (**Table 3**). Based on half of the class who completed both skill surveys, the percentage of students who reported increases (from *none* to *basic*, *good*, and *expert* level) increased for spreadsheet skills (mostly *basic* to *good*), technical writing skills (slightly for *none* and more heavily for *expert*), technical presentation skills (slightly for *none* and more heavily for *good*), and experimental (from *basic* to *good*). 68.8% asserted that this skill development was in part due to BIOE 120 but mostly from other courses, while 15.6% believed the majority came from BIOE 120.

	Spreadsheets		**Technical Writing**		**Technical Presenting**		**Experimental**	
Skill Level	Pre-	Post-	Pre-	Post-	Pre-	Post-	Pre-	Post-
None (%)	3.1	0.0	3.1	6.3 ↑	0.0	3.1 ↑	0.0	0.0
Basic (%)	43.8	31.3	50.0	40.6	28.1	28.1	43.8	34.4
Good (%)	31.3	62.5 ↑	37.5	28.1	46.9	53.1 ↑	37.5	46.9 ↑
Expert (%)	21.9	6.3	9.4	25.0 ↑	25.0	15.6	18.8	18.8
Did this project (experiment + presentation) specifically help you develop any of the skills above?								
No								9.4 %
Some from BIOE 120, but the majority of skill development came from my other classes								68.8 %
The majority of skill development came from BIOE 120, but some from my other classes								15.6 %
Definitely								6.3 %

Table 3: Technical Skill Development. Comparison between pre- and post-project timepoints, with ↑ indicating an increase in percentage (n = 32 students who completed both surveys).

Measurement of Science-Related Interests and Attitudes

We utilized the Persistence Research in Science & Engineering (PRiSE) survey's Science-Related Interests and Attitudes metric [17] to gain insights into students' motivations before, during, and after the project (**Table 2, Figure 6**).

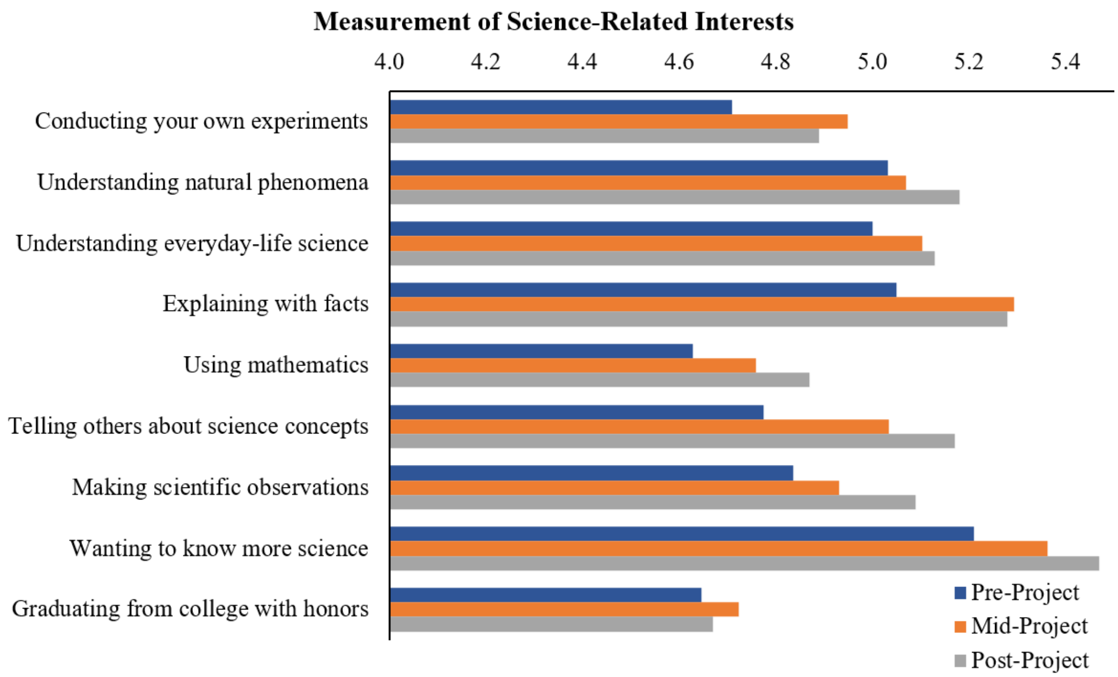


Figure 6: Measurement of Science-Related Interests. Students were surveyed pre-, mid-, and post-project (n = 62, 58, and 48, respectively) using an item from the PRiSE survey [17]. *(1 = not at all interested; 6 = very interested).*

The metrics demonstrated notable changes in students' commitment to pursuing STEM-related disciplines. Across all categories, students showed steady increases in average scores (4.2% average increase) across several key areas from pre- to post-survey, indicating enhanced interest and engagement with bioengineering concepts. The largest changes from pre- to mid-project and pre- to post-project were visible consistently in "Telling others about science concepts," increasing by 5.5% and 8.3% ($p = 0.052$), respectively. The largest standard deviations were observed in "Using mathematics" and "Graduating from college with honors."

Engineering Identity

The project's impact on students' engineering identity was also analyzed using responses to survey prompts derived from Goodwin's Measure of Engineering Identity, which was developed to probe the underlying self-beliefs in post-secondary students [18]. The analysis focuses on three pairwise comparisons between pre-, mid, and post-project timepoints (**Figure 7**).

Largest increases were seen between pre- and mid-project, when the students performed the experiment and Question Set 1. "My instructors see me as a bioengineer" and "Others ask me for help in this subject" increased significantly by 17.3% and 21.1% (both $p = 0.02$), respectively. "My peers see me as a bioengineer" increased substantially in the same range as well, though not significantly (13.7% increase; $p = 0.067$).

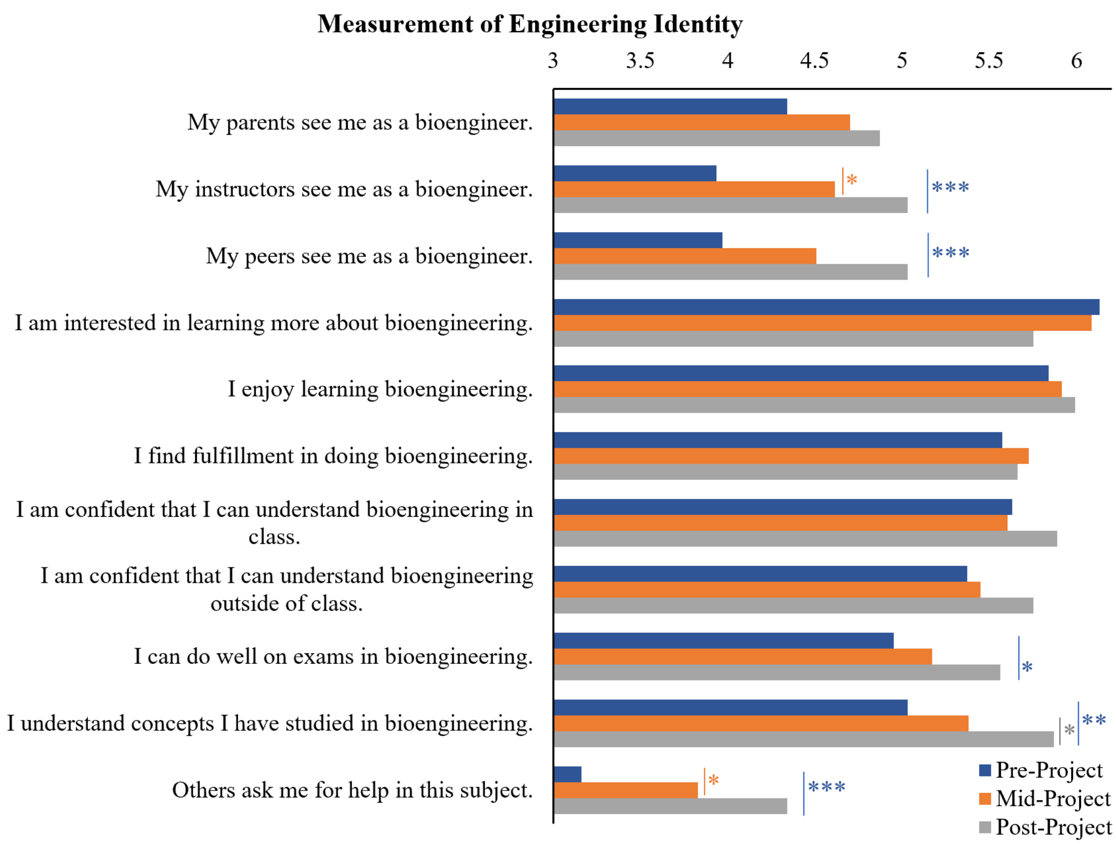


Figure 7: Engineering Identity. Pre-, mid-, and post-project results ($n = 62$, 57, and 50, respectively) of the prompts from Goodwin's Measure of Engineering Identity [18]. * = $p \leq 0.05$; ** = $p \leq 0.01$; *** = $p \leq 0.001$. *(1 = strongly disagree; 7 = strongly agree)*

Between the mid- and post-project surveys, i.e., the period in which students submitted Question Set 2 and completed the final presentations, the prompt "I understand concepts I have studied in bioengineering" had a statistically significant increase of 9.1% (p = 0.047).

When comparing the project overall between pre- and post-project surveys, five prompts exhibited statistically significant changes in measures of engineering identity: "Others ask me for help in this subject" increased by 37.3% (p = 0.0002), "My instructors see me as a bioengineer" by 27.8% (p = 0.016), "My peers see me as a bioengineer" by 26.8% (p = 0.0007), "I understand concepts I have studied in bioengineering" by 16.6% (p = 0.0018), and "I can do well on exams in bioengineering" by 12.3% (p = 0.02).

Finally, we compared measures of engineering identity between bioengineering (BIOE) vs. non-BIOE majors at each survey time point (**Table 4**). Significant differences were noted between groups at all time points for "My parents see me as a bioengineer" (p = 0.002 at pre-project) and "My instructors see me as a bioengineer." Many of the average measures increased for both groups throughout the project's duration. For the BIOE group, the largest change from pre- to post-project was observed in "My peers see me as a bioengineer" (which increased by nearly the same percentage for non-BIOEs as well). For the non-BIOE group, the largest change from pre- to post-project was observed in "Others ask me for help in this subject."

	Pre-Project Survey		**Mid-Project Survey**		**Post-Project Survey**	
Engineering Identity Measure	BIOE n = 8	non-BIOE n = 54	BIOE n = 6	non-BIOE n = 51	BIOE n = 8	non-BIOE n = 42
My parents see me as a bioengineer.	*6.0***	*4.1*	*6.7 *** ↑	*4.5* ↑	*6.0**	*4.7* ↑
My instructors see me as a bioengineer.	*5.4**	*3.7*	*6.0*** ↑	*4.5* ↑	*6.1** ↑	*4.8* ↑
My peers see me as a bioengineer.	5.0	3.8	5.0	4.5 ↑	*6.1** ↑	*4.8* ↑
I am interested in learning more about bioengineering.	6.5	6.1	*6.9** ↑	*6.0*	*6.6**	*5.6*
I enjoy learning bioengineering.	6.4	5.8	6.7 ↑	5.8	*6.8** ↑	*5.8*
Others ask me for help in this subject.	*4.6***	*2.9*	4.6	3.7 ↑	5.4 ↑	4.1 ↑

Table 4: Engineering Identity by Major. Pre-, mid-, and post-project averages of the Engineering Identity [18] prompts, separated for Bioengineering students (BIOE) versus those from all other majors represented in the class (non-BIOE). BIOE vs. non-BIOE were compared within each time point. *Italicized* averages indicate a significant difference between groups for that time point, with * = p ≤ 0.05; ** = p ≤ 0.01. ↑ indicates an increase in average score for that group compared to the previous time point. *(1 = strongly disagree; 7 = strongly agree)*

Discussion

Research on active learning and real-world applications in STEM education shows the potential of hands-on experiential learning to improve student engagement and outcomes [22,23]. Active learning approaches like project-based learning and collaborative group work can enhance engagement, understanding, and retention in STEM fields [24]. These methods, combined with real-world applications, foster relevance and motivation for sustaining student interest in STEM.

The experimental protocol demonstrating fluid flow and mass transport through a porous medium (see **Appendix**) effectively guided students through the activity with minimal confusion. The concise instructions, paired with pictures, helped ensure a smooth workflow. The course staff's preparation of the setup (**Figure 2a**), including pre-marking pot lines to standardize soil density, was helpful for time management. However, group sizes (4 students) were too large, leading to some students feeling left out or disengaged as there were not many distinct roles in the protocol. Staggering the start times would optimize the flow of the groups needing to fill their pots with the two soils at the onset. Measurements of engineering identity and science-related interest showed growth at both mid- and post-project timepoints, demonstrating the effectiveness of the experimental protocol in fostering these mindsets. A few students struggled to connect the project to bioengineering, focusing instead on soil or agriculture applications. Given more time, students could explore soil pH or biochemical properties.

This project aimed to address differences in student backgrounds through team-based learning and collaboration. By using CATME to diversify teams, students worked with peers from various academic and personal backgrounds. The project offered opportunities for mutual learning and skill development as students leveraged their diverse experiences to overcome challenges together, potentially reducing disparities in confidence and engagement. These skills are crucial for professional engineering environments.

It is interesting to consider the impact on collaborative learning beyond the project structure, which equipped students with basic experimental and analytical skills, as they communicated outside their comfort zones with like-minded peers. However, the diversity of the groups may have led to some students finding the experiment too easy or difficult, depending on their prior exposure to STEM topics, which may have led to natural leadership or follower roles. For example, a first-year biology student may have a different skill set than a fourth-year mechanical engineer, though both were pursuing the same course goal.

At the same time, it is important to note the myriad of other factors which could have impacted the results demonstrated in this paper. With nearly over a semester between the pre- and post-surveys, the timeline allowed students to develop from many other academic influences both inside the BIOE 120 course (e.g., guest speakers, research presentations, further investigation into the project topics) and outside (other courses or undergraduate research). For instance, though students demonstrated increases in skill level confidence (**Table 3**), over two-thirds cited other courses (including chemistry and physics) as the primary influence, with BIOE 120 contributing less to this development. One student stated:

> *"I have had a lot of classwork in this field in the past, which has helped me develop these skills. BIOE 120 was good practice especially because I haven't done much of that since high school; however, I wouldn't say it significantly helps students with more experience develop advanced skill[s]. Rather, I think it is very helpful for students just starting in the field - which is also a good thing - it just comes at the cost of being less helpful for students with more experience."*

Notably, the science-related interests and attitudes metrics (**Figure 6**) with higher standard deviations, including "Conducting your own experiments" and "Using mathematics," suggest that students entered the project with varying levels of confidence and interest in these areas.

This variability highlights the diverse backgrounds and prior experiences of the students (as visualized in **Figure 1**) in some instances, these may have led to disconnect among the group members if the differences were perceived as too large to overcome. However, the increases in areas including "Explaining things with facts" and "Telling others about science concepts" demonstrate how integrated communication and collaboration must be in STEM education. This connection was especially evident after students completed the oral presentations.

All in all, these results suggest that while the project succeeded in raising interest and engagement overall, it also highlighted unique strengths and growth opportunities for teams within a diverse cohort. Future project cohort repetition could explore targeted interventions, such as mentorship or learning opportunities, to address these disparities and further enhance persistence (especially in younger, first-year, or transfer students).

Nevertheless, when considering the measurement of science-related interests and attitudes, the increase in average scores indicates the perceived value of experiential, hands-on learning activities in fostering persistence and curiosity. By connecting the topics of fluid flow and mass transfer to real-world problems, students were encouraged to explore and appreciate the relevance of these concepts, and sustained motivation to engage with the field of bioengineering. For example, when students considered ways that the project helped them to develop connections across the material, answers ranged from associations with the course's guest speakers to examples of biological phenomena to group collaborations and discussions:

- *"The project helped me to see bioengineering's diversity."*
- *"[It] helped me talk to other [students] who talked about their majors."*
- *"The project allowed me to think of several different bioengineering applications [to] treat malfunctions in the lymphatic system. For example, lymphedema occurs when fluid doesn't properly drain, which connects to ideas of fluid flow and transport in the soil experiment."*
- *"My group covered topics related to other talks/readings we've done in class, so I had the opportunity to learn more in depth about [point-of-care] devices and connect it to both fluid flow and what we learned in class."*
- *"It helped me connect more to the presentations from [guest speakers] this semester."*
- *"Doing the work hands on gives you [a] perspective to realize that all of the content the [guest speakers] come speak about is real and tangible work."*

These results align with prior findings from PRiSE [17, 25], which show that students' early educational experiences significantly shape their STEM interests and self-efficacy. As PRiSE was designed to examine the connection between the exposure of high school students to a variety of interventions and their later persistence in selection of courses and majors, especially for those underrepresented in STEM careers, we believe it was appropriately translated to this course in which many students could feel 'othered' or in the minority by a multitude of metrics.

Engineering identity is a key factor for success in STEM fields. Increases in perceptions of being recognized as a bioengineer by both instructors and peers reflect the value of structured and collaborative learning environments. To quantify these perceptions, we utilized Goodwin's Measure of Engineering Identity, which was developed to probe the underlying self-beliefs in post-secondary students [18]. The significant increase in ratings for prompts between pre- and mid-project surveys suggests that early engagement in the project positively influenced students' confidence and perceived recognition (**Figure 7**). This could be due to instructor interactions during the initial project stages as well as a collaborative team environment. Both factors could have likely fostered peer support and substantially increased these feelings of confidence.

The pre- to post-project comparisons showed the most variation in engineering identity, indicating the project's overall impact. Significant increase in ratings for prompts including "My peers see me as a bioengineer" and "I can do well on exams in bioengineering" highlight how hands-on learning activities have the impact to transform students' self-perceptions and confidence; additionally, presenting their work to peers and instructors likely reinforced these perceptions. Along this same timeline, we observed a significant shift towards a greater sense of belongingness in the course (and, presumably, the field of bioengineering).

These findings suggest that collaborative projects with real-world applications are important in fostering engineering identity and emphasize the important of recognition by instructors and peers in shaping students' identities, which aligns with existing frameworks. The results of this project also encourage reflection on the importance of integrating learning activities with more challenging technical concepts in STEM curricula (especially for first year and transfer students).

Conclusion

Outcomes of this study validate the effectiveness of incorporating experiential activities to teach complex engineering concepts traditionally difficult to demonstrate in the classroom, within the confines of an introductory course. By engaging with relatable, tactile, real-world applications through soil and water, students bridged the gap between theoretical concepts and biomedical applications of fluid and mass transport.

With project deliverables such as quantitative measurements, monitoring plant growth, and group presentations, students demonstrated the development of technical skills through group work, data presentation, and relating experimental results to broader applications. Finally, by applying classroom knowledge to real-world bioengineering challenges, this project helped students understand the relevance of engineering concepts while connecting them to personal and professional goals. This approach maintained motivation and strengthened persistence in pursuing STEM fields, as seen by the positive shift in survey results for this group of students.

Though this format allowed students to tie their activity results to bioengineering topics related to fluid flow and mass transport (including the cardiovascular system, porous tissues, bioreactors, artificial organs, and drug delivery), the concepts could be translated across other technical courses commonly experienced by first-year students, complementing traditional lectures with experiences connecting complex engineering topics to familiar or real-life objects.

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References

[1] M. Flytzani-Stephanopoulos, K. Lee, H. Saltsburg, G. Botsaris, and D. Kaplan, "Seamless Integration of Chemical & Biological Engineering in the Undergraduate Curriculum," in *Proceedings of the 2003 Annual Conference*, Nashville, TN, Jun. 2003. https://doi.org/10.18260/1-2--12645

[2] M. McConkie, T. Taylor, and D. Britt, "Redefining a Biological Engineering Undergraduate Curriculum: Profits, Pitfalls, and Practicality," in *Proceedings of the 2006 Annual Conference & Exposition*, Chicago, IL, Jun. 2006. https://doi.org/10.18260/1-2--1322

[3] R. Ochia, "Development of an undergraduate bioengineering curriculum that mirrors the breadth of the field," in *Proceedings of the 2014 Fall ASEE Middle Atlantic Section Conference*, Swarthmore College, PA, Nov. 2014.

[4] H. Boone and A. Kirn, "First Generation Students Identification with and Feelings of Belongingness in Engineering," in *Proceedings of the 2016 ASEE Annual Conference & Exposition*, New Orleans, LA, Jun. 2016. https://doi.org/10.18260/p.26903

[5] M. Nowak, A. Ronald, and D. Leone, "An Undergraduate Biomedical Engineering Curriculum First Principles First," in *Proceedings of the 2002 Annual Conference*, Montreal, Canada, Jun. 2002. https://doi.org/10.18260/1-2--11148

[6] R. J. Voigt, "Introducing Information Technology Fundamentals into the Undergraduate Curriculum," in *Proceedings of the 2000 Annual Conference*, St. Louis, MO, Jun. 2000. https://doi.org/10.18260/1-2--8510

[7] J. Wang, "Bidirectional and Collaborative Feedback Between Instructors and Students for Scholarship of Teaching and Learning (SoTL)," in *Proceedings of the 2020 ASEE Virtual Annual Conference Content Access*, Virtual Online, Jun. 2020. https://doi.org/10.18260/1-2--34215

[8] N. D. Fila, J. L. Hess, P. D. Mathis, and S. Purzer, "Challenges to and Development of Innovation Discovery Behaviors Among Engineering Students," in *Proceedings of the 2015 ASEE Annual Conference & Exposition*, Seattle, WA, Jun. 2015. https://doi.org/10.18260/p.23677

[9] K. A. Connor, B. H. Ferri, and K. Meehan, "Models of Mobile Hands-On STEM Education," in *Proceedings of the 2013 ASEE Annual Conference & Exposition*, Atlanta, GA, Jun. 2013. https://doi.org/10.18260/1-2--22295

[10] Aglan, H.A. and Ali, S.F., "Hands-on Experiences: An Integral Part of Engineering Curriculum Reform," *Journal of Engineering Education*, pp. 327-330, Oct., 1996.

[11] J. Bridge, "Incorporating Active Learning in an Engineering Materials Science Course," in *Proceedings of the 2001 Annual Conference*, Albuquerque, NM, Jun. 2001. https://doi.org/10.18260/1-2--9369

[12] J. F. Al-Sharab and M. Benalla, "Fabrication of Nanofibers for Tissue Engineering and Regenerative Medicine," in *Proceedings of the 2016 ASEE Annual Conference & Exposition*, New Orleans, LA, Jun. 2016. https://doi.org/10.18260/p.26877

[13] Y. Khan, W. Sun, M. Attawia, M. Marcolongo, F. Ko, D. Katti, and C. Laurencin, "Towards an International Tissue Engineering Curriculum: The Drexel Initiative," in *Proceedings of the 2002 Annual Conference*, Montreal, Canada, Jun. 2002. https://doi.org/10.18260/1-2--10992

[14] S. Pal, J. Rahman, S. Mu, N. J. Rusch, and A. J. Stolarz, "Drug-Related Lymphedema: Mysteries, Mechanisms, and Potential Therapies," *Frontiers in Pharmacology*, vol. 13, art. no. 850586, Mar. 2022. https://doi.org/10.3389/fphar.2022.850586

[15] M. Miah, M. S. Hossain, Md. S. Ali, S. B. Shahid, S. Sharmin, S. Zakir, and H. M. Shaila, "Textile effluent treatment in a pilot-scale UASB bioreactor followed by biofilter and aerobic processes," *Case Studies in Chemical and Environmental Engineering*, vol. 11, art. no. 10175, Jun. 2025. https://doi.org/10.1016/j.cscee.2024.101075

[16] J. H. Chin, R. Fowler, and C. Brooks, "Analyzing Patterns of Pre-Semester Concerns in First-Year Engineering Students," in *Proceedings of the 2024 ASEE Annual Conference & Exposition*, Portland, OR, Jun. 2024. https://doi.org/10.18260/1-2--46577

[17] M. Orr, Z. Hazari, P. Sadler, and G. Sonnert, "Career Motivations of Freshman Engineering and Non-Engineering Students: A Gender Study," in *Proceedings of the 2009 Annual Conference & Exposition*, Austin, TX, Jun. 2009. https://doi.org/10.18260/1-2--4872

[18] A. Godwin, "The Development of a Measure of Engineering Identity," in *Proceedings of the 2016 ASEE Annual Conference & Exposition*, New Orleans, LA, Jun. 2016. https://doi.org/10.18260/p.26122

[19] Layton, R. A., Loughry, M. L., Ohland, M. W., & Ricco, G. D. (2010). Design and validation of a web-based system for assigning members to teams using instructor-specified criteria. *Advances in Engineering Education*, 2 (1), 1-28.

[20] Ohland, M. W., Loughry, M. L., Woehr, D. J., Bullard, L. G., Felder, R. M., Finelli, C. J., Layton, R. A., Pomeranz, H. R., & Schmucker, D. G. (2012). The comprehensive assessment of team member effectiveness: Development of a behaviorally anchored rating scale for self and peer evaluation. *Academy of Management Learning & Education*, 11 (4), 609-630.

[21] Loughry, M. L., Ohland, M. W., & Moore, D. D. (2007). Development of a theory-based assessment of team member effectiveness. *Educational and Psychological Measurement*, 67, 505-524.

[22] Y. Kong, "The Role of Experiential Learning on Students' Motivation and Classroom Engagement," *Front. Psychol*., vol. 12, 2021. doi: doi.org/10.3389/fpsyg.2021.771272.

[23] G. F. Burch, R. Giambatista, J. H. Batchelor, J. J. Burch, J. D. Hoover, and N. A. Heller, "Meta-Analysis of the Relationship Between Experiential Learning and Learning Outcomes," *Decision Sciences Journal of Innovative Education*, vol. 17, no. 3, pp. 239-273, July 2019. doi: 10.1111/dsji.12188.

[24] D. Miller, J. Deshler, T. McEldowney, J. Stewart, E. Fuller, M. Pascal, and L. Michaluk, "Supporting Student Success and Persistence in STEM With Active Learning Approaches in Emerging Scholars Classrooms," *Frontiers in Education*, vol. 2021, 2021.

[25] Z. Hazari, G. Sonnert, P. M. Sadler, and M.-C. Shanahan, "Connecting high school physics experiences, outcome expectations, physics identity, and physics career choice: A gender study," *J. Res. Sci. Teach.*, vol. 47, no. 8, pp. 978–1003, Oct. 2010. https://doi.org/10.1002/tea.20363

Appendix

Soil Experiment – Student Version: Flow-Through Experiments & Planting Seeds

Transport of materials and fluid dynamics are important considerations in the field of bioengineering research. Porous materials (bone, tissue engineered scaffolds, etc.) can help transfer of molecules, substrates, drugs, other therapeutics, and more. Moreover, fluid flow is critical to many physiological systems in our bodies, including the circulatory system (blood flow), lymphatic system, and more. In this experiment, you will investigate the properties of two types of soils, which can emulate other porous materials relevant to bioengineering.

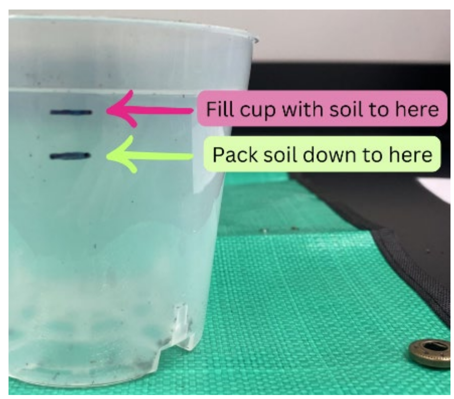
Materials

- ☐ 2 pots with 2 white labels
- ☐ 2 saucers
- ☐ 1 absorbent mat (this will be your workspace to catch dirt)
- ☐ 2 measuring cups (labeled as 1 and 2)
- ☐ Gloves
- ☐ Plastic spoons
- ☐ Sharpie (for labeling)
- ☐ Ruler (for measuring)
- ☐ Shared as a class: 2 types of soil (indoor mix and potting soil)
- ☐ 12 seeds (6 for each pot)

Protocol

Preparation

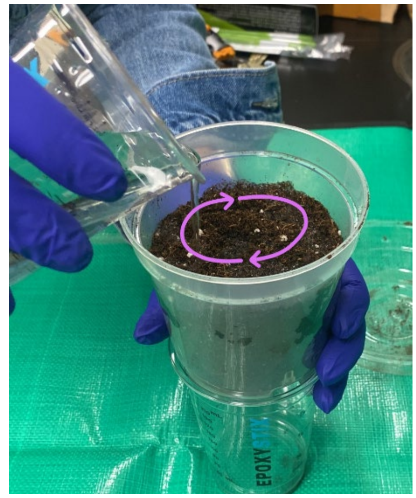
1. Make sure your station is set up with the materials above. Put on gloves.
2. GETTING SOIL: Keeping the saucer underneath the pot, measure out the soil into respective pots, adding it to the top marked line (7 cm from the bottom).
    - Use the *provided cup* for the *indoor* soil, and *gloved hands* for the *potting* soil.
    - Make sure to keep the pot in the saucer in case some of the soil spills through. If soil falls through the drainage holes, pour it back on the top of the pot.
    - *Gently* pack down the soil to the bottom marked line (6 cm from the bottom) with a spoon, hands, or base of a measuring cup.
    - Leave the pots at your station on the absorbent mat.
3. Use the white labels to indicate soil type and group number and place the labels in the soil.



Flow-Through Experiments

4. Use the sink to add 200 mL of water into Measuring Cup 1. Take this back to your station.
5. Stack one soil pot onto a dry Measuring Cup 2, so that the pot will drain into the cup and catch the water.
    - One group member will need to hold the pot steady on top of the measuring cup.
6. In preparation, have a second group member open the stopwatch app on their phone, and have a third group member ready to mark water levels on Measuring Cup 2 with a Sharpie.

7. *Slowly* pour the water into the pot, making sure to saturate the top layer of soil (pour evenly in circles to coat the top). Use the stopwatch app to mark the water level over time on Measuring Cup 2:
    - Mark/measure the water levels at 10s, 20s, 30s, 40s, 50s, and 60s with a Sharpie.
    - At the top of all of your markings, label which soil type was measured. (You will be using the same cup for the next soil type – don't mix them up!)



8. When you are finished:
    - Place the pot back into its saucer.
    - Pour the dirty water from Measuring Cup 2 into the waste jar in the sink. Then, wipe it completely dry with a paper towel.
9. Repeat steps 3-7 with the second pot of soil and Measuring Cups 1 and 2 (now clean). Make sure you are pouring the water into the pot at approximately the same rate as you did for the first pot.
10. Record your water level volume markings for both soil types in a spreadsheet.
    - If the level is below the first mark on the cup, you can approximate the volume.

Planting Seeds

11. Take a wooden stick and use a Sharpie to mark it at 1 cm. Use the marked stick to make six different holes, evenly spaced apart, each ~1 cm deep below the top surface of soil.
12. Acquire 12 seeds from your TA.
13. Add 6 seeds to each pot, putting one seed in each hole.
    - *Gently* cover the holes with surrounding soil and press down very lightly.

Clean Up Checklist

- ☐ Pour all dirty water into the waste beaker in the sink.
- ☐ Dispose of your plastic measuring cups (but make sure you've recorded the data first!).
- ☐ Dispose of your absorbent mat, gloves, and spoon, being careful not to spill soil on the floor.
- ☐ Leave the Sharpie and ruler on your bench. Bring the pots to the TA.
- ☐ Clean off the benchtop and floor using a wet or dry paper towel.

Question Set 1

1. How much water was absorbed by the soils overall?
2. We measured the two soils by volume, but they have different densities.
    - Density = mass/volume. Without a scale, how could you find this value?
    - If you measured the soil by weight, what changes would you expect, if any?
3. How much water flowed through at each time interval? Make a graph of water volume (milliliters) vs time (seconds) and find the average flow rate through each soil type.
4. What are the sources of potential error from your work today? What potential differences should be considered when comparing your data to another group, at each step of the experiment?
5. How can you envision that this experiment is related to bioengineering, in addition to the ways described on the protocol?
6. Why did the protocol ask you to pour the water slowly into the soil? Why is this preferred over watering quickly?

Question Set 2

1. What differences did you observe in the flow rates between the two soil types? How do these differences relate to the properties of the soils (e.g., texture, porosity)? *{Note: in the protocol, you can find a link to the soil products we used.}*
2. How might the results change if we used a different liquid, such as an oil-based substance instead of water? How could this relate to bioengineering applications, like drug delivery?
3. Discuss some examples of fluid flow in biology and bioengineering. How do you think the flow-through properties of soil in this experiment relate to the movement of fluids through biological tissues?
4. If you had repeated the experiment under different environmental conditions, how might that have affected the water absorption rates? What are other variables that could be considered or could contribute to differences in your results?
5. In what ways can the experiment's results be applied to real-world problems, such as irrigation or improving biomedical devices? What did you observe with the moisture sensors in your pots? What are advantages, drawbacks, and considerations for different types of sensors?
6. Plot as much of your data as you can. (For example, plant height or number of sprouts over time, for each group.) What else could you compare between your groups? Include graphs as well as a table of your data. Think about how to best represent these data.

Soil Experiment – Staff Version

Plan for 18 groups with 4 students per group.

Protocol

Preparation

1. Prepare each station with the necessary materials:
    - Absorbent mat, 2 pots, 2 saucers, 2 measuring cups, 1 Sharpie, 1 ruler, paper towels.
2. Prepare a station for shared materials, including gloves, plastic spoons, and soil.
3. Label each pot with a group number (1-18) and soil type (indoor mix or potting soil).
    - There should be 2 pots and saucers per group.
4. ON EACH POT: draw two lines to mark the soil levels
    - Top line: 7 cm
    - Bottom line: 6 cm
5. Label each group's measuring cups as 1 and 2.
6. Prepare a waste jar in the sink for the dirty water.

During Experiment

- 1 person at soil containers
- 1 person monitoring sink/waste/trash
- 1-2+ people walking around to help groups

Clean Up Checklist

- ☐ Dispose of dirty water properly. (Dirt does not go down the drain!)
- ☐ Dispose of any extra or dirty materials.
- ☐ Clean off any dirt on the benchtop or floor using a wet or dry paper towel.
- ☐ If applicable, set up stations for the next set of groups.
- ☐ Return (cleaned) tables to their original locations.
- ☐ Bring pots to windowsill on 3rd floor.