WIP: An Undergraduate Neural Tissue Engineering Lab Course

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Introduction

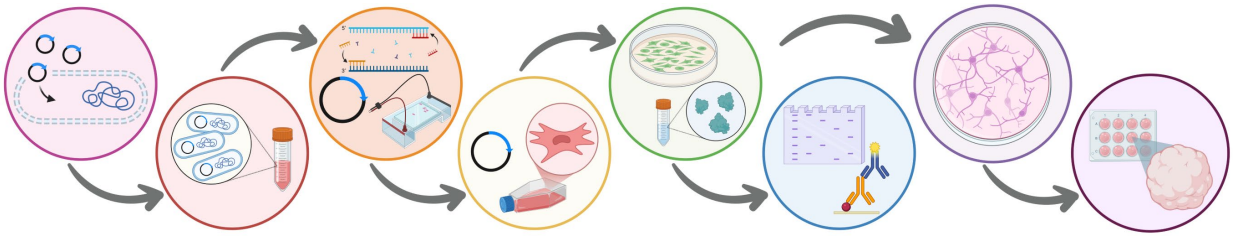
As the interdisciplinary field of neural engineering has rapidly expanded, its growth has created a strong demand for engineers who are not only conceptually grounded in neuroscience but also trained in hands-on techniques [1]. Laboratory experiments in neural engineering are complex, resource-intensive, and often require specialized facilities and expertise. These challenges are further amplified when designing courses for undergraduates with diverse prior wet lab experiences. Practical constraints also include equipment cost, biosafety considerations, and the difficulty of adapting multi-day protocols into a typical four-hour laboratory session. Nevertheless, authentic laboratory experiences are widely recognized as essential for enabling students to meaningfully engage with the principles and practices of bioengineering [2,3].

Most formal instruction in neural engineering has been offered primarily at the graduate level, but a growing number of programs have recently introduced coursework for undergraduates. The University of Illinois Urbana-Champaign launched a degreed B.S. in Neural Engineering [4] in 2023. In this Work in Progress paper, we describe the first offering of Neural Cell and Tissue Engineering Laboratory (NE 431) as a research-proximal laboratory experience designed to translate complex neural engineering practices into a feasible undergraduate instructional context for upper-level students in the Neural Engineering program. The course was designed to build students' competence in core neural cell and tissue engineering techniques while also strengthening experimental skills, quantitative data analysis, and scientific communication. Here, we present preliminary observations and areas of improvement for this lab course.

Methods

Course Context. NE 431 is an upper-level undergraduate lab course that was instructed by a teaching faculty member with neural tissue engineering research experience and supported by a graduate teaching assistant and an undergraduate lab assistant in Bioengineering. It was designed to provide hands-on training in experimental techniques that are central to neural tissue engineering. Course objectives included training students in foundational laboratory practice and safety, molecular biology, mammalian stem cell culture, neural differentiation, the engineering and characterization of three-dimensional (3D) neural spheroids [5], data analysis, and technical communication skills. In Fall 2025, eight students enrolled in the first offering of NE 431 (see course and student details in **Table A1**). Performance was evaluated through biweekly low-stakes quizzes (**Table A2**) and worksheets that assessed understanding of concepts aligned with each module, a cell culture practical exam, a journal club, and cumulative lab reports.

Experimental Design. NE 431 met twice per week for three-hour sessions that allowed for consistent scaffolding of material while working within the constraints of course scheduling, experimentation with live cells needing frequent care, and breadth of topics covered in a 4-credit hour lab course. The semester was organized around a continuous experimental workflow (**Figure 1**) that progressed from foundational laboratory skills to advanced tissue engineering applications. An introductory lecture embedded in the lab session provided just-in-time theoretical background and contextualized the day's experimental tasks within the broader workflow. The remainder of the session was devoted to hands-on laboratory work, during which students implemented experimental protocols with partners.



Early lab modules focused on ***foundational lab skills*** in molecular biology: biosafety, pipetting, dilutions, bacterial transformation, plasmid preparation, DNA amplification, and agarose gel electrophoresis.

Mid-semester modules trained students in ***mammalian stem cell culture***. Human iPSCs were differentiated into neurons using a doxycycline-inducible system [5]. Students monitored morphological changes through live fluorescence imaging.

Later modules focused on ***protein analysis and 3D models***. iPSCs were transfected using fluorescent reporters and assessed via microscopy and flow cytometry. Protein analyses included SDS-PAGE and Western Blot. 3D neuronal "spheres" were engineered using microwell plates [8].

Figure 1: Experimental Workflow of the Course. (Image made with BioRender.)

Data Collection and Analysis. Assignments evaluated students' ability to implement key molecular and cellular workflows. Skill development was compared between weeks 1-15 using a 2-tailed paired t-test. To confirm retention of core concepts, earlier quizzes were reassessed at week 15 to examine trends across major topic areas. Surveys captured open-ended student feedback throughout the semester. At the conclusion, a focus group was conducted externally for course improvement. This study was deemed Non-Human Subject Research (IRB26-0178).

Results and Discussion

Experimental Outcomes. The course centered on the differentiation of human induced pluripotent stem cells (iPSCs) into iNeurons via Ngn2 induction [6,7] and the subsequent generation of neural organoids, or self-assembling three-dimensional cell culture models that recapitulate key features of neural tissue [4,8,9]. Students successfully differentiated stem cells into neural spheres and then performed additional molecular techniques and cellular assays to analyze transfection efficiency, fluorescent imaging, protein expression, neurite outgrowth, and 3D viability (**Figure 2**). A guest speaker introduced current research on organoid transplantation and disease-relevant applications in neural regenerative medicine [10,11]. Additionally, NE 431 included a neural engineering research lab tour and presentations by prominent researchers in the field, allowing students to connect course protocols to real-world applications.

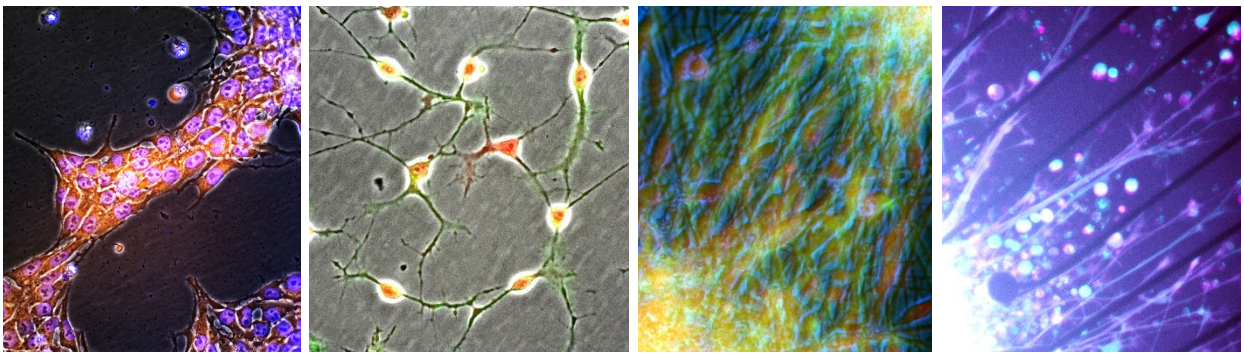


Figure 2: Differentiation of iPSCs. *From left to right:* human induced pluripotent stem cells (iPSCs) in 2D culture; day 3 iNeurons plated on Matrigel; neurite extension from 3D neuronal organoids; 4 days after attaching onto a multielectrode array (MEA).

Skill Development and Content Retention. To examine how instructional scaffolding supported students' engagement with laboratory techniques that were introduced with increasing difficulty, we analyzed material retention through average quiz scores, which markedly improved throughout the semester (**Table A2**). Moreover, when students were asked to self-report their familiarity with key technical skills, we observed significant increases in Likert scores (**Table 1**). Rather than necessarily indicating mastery, these subjective longitudinal trends reflect students' increasing functional familiarity with progressively introduced techniques.

Table 1: Skill development measured at weeks 1 and 15. Percent increase and p-values (measured using a 2-tailed paired t-test) are noted. Color scale indicates increasing percent change from lowest (yellow) to highest (dark green). All skills significantly increased in measure over the course of the semester (* = $p \leq 0.05$; ** = $p \leq 0.01$; *** = $p \leq 0.001$).

Week(s)	How familiar are you with the following topics? *(1 = not at all … 7 = completely)*	Week 1	Week 15	Increase	p-value
Experimental					
1	Laboratory safety & fundamentals	5.6	6.6	18%	0.05*
2	Bacterial culture techniques & transformation	4.0	6.5	65%	0.0004***
2-3	Plasmid preparation, gel electrophoresis	3.5	6.4	83%	0.00008***
3-4	Aseptic technique & stem cell culture	3.5	6.8	91%	0.001***
4	Mammalian cell culture	3.7	6.9	88%	0.00005***
5	Quantitative immunofluorescence microscopy	3.1	6.1	101%	0.002**
5	Analysis of neural differentiation	1.8	6.4	254%	0.0002***
6	Transfection of human iPS cells	2.4	6.4	171%	0.00005***
7-8	Protein extraction, quantification, & detection	3.1	5.9	93%	0.005**
9-10	Engineering of 3D neuronal spheroids	1.7	6.1	266%	0.0002***
Technical Analysis and Communication					
6-16	Quantitative data analysis, assessment of outcomes	4.3	6.0	40%	0.01**
6-16	Scientific writing	4.6	5.8	26%	0.009***
10-16	Oral presentation of scientific results	4.6	5.9	28%	0.01**

Course Feedback. Students provided feedback directed towards course improvement (**Table 2**). Overall, they agreed that the expectations were clear and that the lectures helped to introduce and reinforce the content and protocols. In particular, they appreciated understanding the overall "big picture" of the workflow (**Figure 1**). However, they reported difficulties with the class structure during experiments with long wait times, which sometimes increased with protocol difficulty. Students suggested incorporating more pre-lab course work and posting the protocols further in advance for pre-lab review. Additional ideas included asynchronous introductory lectures and demonstration of expected outcomes if the in-class lab results were inconclusive or unforeseen.

Table 2: Representative Course Feedback.

Successful Course Aspects	Room for Improvement
• "Having a flow chart of the experiments to see how they relate to each other" • "Being able to do something multiple times like cell culture" • "Being able to do something ourselves even if we mess it up" • "The lectures feel goal-oriented and with a purpose that translates to the benchwork during lab." • "Hands-on [activities help] me connect concepts [to] real procedures in lab [and] understand how and why they are used." • "Talking to people actively working in the field was insightful."	• "I believe that maybe adding short pre-labs might be helpful." • "Having the lab protocols posted in advance" • "Would like [a] more clearly defined structure, especially in the second half of class…Maybe have some kind of connection to theory during a long wait time to keep the students engaged?"

Conclusion and Future Directions

NE 431 offers an exclusive insight into an instructional lab course relevant to the modern neural engineering field. The format and scheduling allowed students to understand the conceptual foundations behind the experimental procedures by directly and immediately observing and analyzing the results of their work. Preliminary assessment demonstrated strong growth in key technical and communication skills to meet stated objectives (i.e., foundational laboratory practice, stem cell culture and differentiation, and engineering spheroids). Though the small cohort size does not make this evaluation of the course generalizable, we believe that it is a worthwhile endeavor to improve the student experience by further refining the course structure, experimental scope, and assessment strategies [4].

Though NE 431 was fortunate to benefit from appropriate biosafety facilities and sufficient budget, both challenges must be considered when translating neural tissue engineering into an instructional lab. Scaling the course beyond this small pilot group may present some difficulties, especially for students with limited cellular or wet lab experience; the suggestions to provide more background information and preparation outside of class could reduce these barriers to entry. Subsequent iterations that address these major challenges should consider optimization of experimental timeline and pacing, procedural clarification, team workload and delegation, and scaling of experiments and materials to larger class sizes. In the future, we will also assess the use of organoid-based experiments in establishing experimentally accessible platforms for modeling neurological systems within the constraints of an undergraduate lab environment.

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Appendix

Table A1: Course information from enrollment and course syllabus.

	Neural Cell and Tissue Engineering Laboratory (NE 431)

Enrollment	• 8 students
	  ○ 7 undergraduate seniors studying Bioengineering, Neural Engineering, and Chemistry
	  ○ 1 graduate student studying Biomedical Engineering
	  ○ Most students had some introductory prior experience in neural engineering or cell culture, though some had not previously worked in a wet lab environment.

Topics	• Laboratory safety and fundamentals • Bacterial culture techniques and transformation • Plasmid preparation and gel electrophoresis • Aseptic technique and stem cell culture • Transfection of human pluripotent stem cells • Quantitative immunofluorescence microscopy • Analysis of directed neural differentiation • Engineering of 3D neuronal spheroids • Protein extraction, quantification, and detection • Quantitative data analysis and assessment of outcomes
Grading	• Participation: 5% • Quizzes: 10% • Worksheets: 20% *(assess understanding of procedures, calculations, and core concepts aligned with each module)* • Cell Culture Practical: 10% *(present and discuss primary research articles closely aligned with course content)* • Journal Club Presentation: 10% • Lab Reports: 45% *(help to develop students' analytical and scientific writing skills)* ○ Report 1: 10%; Report 2: 15%; Report 3: 20%

Table A2. Students' retention of neural engineering topics. Retention was assessed throughout the course and at the end of the semester using quiz questions covering laboratory safety, cell culture, and molecular biology techniques. All questions increased in average score except question 1; "Gloves no matter what" was frequently incorrectly selected and may have been unclear (gloves should not be worn when touching devices, etc). * *indicates the correct answer(s) for each question.*

Question	Initial Score	Final Score	Percent Increase
Q1. Which of the following are required in a Biosafety Level 2 (BSL2) lab? • Long pants* • Lab coat* • Closed-toe shoes* • Long hair tied back* • Safety (or regular) glasses* • Gloves no matter what • Mask	79%	79%	0%
Q2. What are the layers of protection provided by a biosafety cabinet (BSC)? • A. They protect the lab. • B. They protect your sample. • C. They protect you. • A & B are true. • A & C are true. • B & C are true. • A, B, & C are true.*	75%	100%	33%
Q3. Which precautions should be taken when working with cells? • Gloves, lab coat, and closed toe shoes should be worn.* • Any time you pull your hands out of the biosafety cabinet, spray them again with 70% IPA or EtOH before putting them back.* • Assume anything coming from the water bath is not sterile* • Spray *everything* that enters into the BSC. • Spray *everything* that leaves the BSC. • Work as far forward to the front of the BSC as possible. • You can carefully pass your hand or arm over an open bottle, plate, or dish if you are wearing gloves and have disinfected your sleeve.	70%	94%	34%
Q4. What type of proteins can be extracted using a RIPA buffer? • cytoplasmic* • nuclear* • membrane* • extracellular	84%	87%	5%
Q5. Which samples would serve as appropriate positive controls for MAP2 Western blotting for iPSC-derived day 7 neurons? (Check all that apply.) • Purified recombinant MAP2 protein* • Cells engineered to overexpress MAP2* • Primary neurons* • iPSCs • iPSC-derived day 7 neurons	81%	90%	11%
Q6. Which samples would serve as appropriate negative controls for MAP2 Western blotting for iPSC-derived day 7 neurons? (Check all that apply.) • iPSCs* • A knockout neuronal line* • Glial cells such as astrocytes and oligodendrocytes* • Cells engineered to overexpress MAP2 • Primary neurons • iPSC-derived day 7 neurons	79%	96%	22%