Biophysical Modeling of Excitable Cells - a new Approach to Undergraduate Computational Biology Curriculum Development

Sorinel A. Oprisan[1] [0000−0001−6585−3985]

Department of Physics and Astronomy, College of Charleston, Charleston, SC, USA
oprisans@cofc.edu
http://oprisans.people.cofc.edu/bmec.html/

Abstract. As part of a broader effort of developing a comprehensive neuroscience curriculum, we implemented an interdisciplinary, one-semester, upper-level course called Biophysical Modeling of Excitable Cells (BMEC). The course exposes undergraduate students to broad areas of computational biology. It focuses on computational neuroscience (CNS), develops scientific literacy, promotes teamwork between biology, psychology, physics, and mathematics-oriented undergraduate students. This course also provides pedagogical experience for senior Ph.D. students from the Neuroscience Department at the Medical University of South Carolina (MUSC). BMEC is a three contact hours per week lecture-based course that includes a set of computer-based activities designed to gradually increase the undergraduates' ability to apply mathematics and computational concepts to solving biologically-relevant problems. The class brings together two different groups of students with very dissimilar and complementary backgrounds, i.e., biology or psychology and physics or mathematics oriented. The teamwork allows students with more substantial biology or psychology background to explain to physics or mathematics students the biological implications and instill realism into the computer modeling project they completed for this class. Simultaneously, students with substantial physics and mathematics backgrounds can apply techniques learned in specialized mathematics, physics, or computer science classes to generate mathematical hypotheses and implement them in computer codes.

Keywords: computational neuroscience · undergraduate education · interdisciplinary curricula.

1 Introductionn

Neuroscience is an interdisciplinary endeavor that requires biology and psychology knowledge and challenges undergraduates to cross the boundaries of their primary major [21]. Computational neuroscience (CNS) requires a further fundamental understanding of physics, mathematics, and computer science [2]. Nowadays, neuroscience graduate programs require at least a basic knowledge

ICCS Camera Ready Version 2021
To cite this paper please use the final published version:
DOI: 10.1007/978-3-030-77980-1_46

of computer algorithms used in a wide range of experimental techniques, from electrophysiological measurements, such as data acquisition, storage, spike sorting, and pattern recognition, to elaborate and computationally-intensive data analysis in functional brain imaging [7]. The students who attend a primarily undergraduate institution (PUI) and aspire to a spot in a neuroscience graduate program are often at a disadvantage regarding the depth of their experience when competing against those coming from research universities with dedicated state-of-the-art facilities and established neuroscience programs. Of all sub-fields of neuroscience research, CNS is the only one that requires the least infrastructure and investment into specialized equipment. Luckily, CNS only requires readily available computers, e.g., a fully functional Linux-powered Raspberry Pi costs only $35, and freely available software packages, such as NEURON, Genesis, or XPP [13].

Eric L. Schwartz coined the computational neuroscience (CNS) name in the mid-1980s to characterize vastly disparate computational research approaches to understanding how neurons process information and how the brain functions. [10].

In addition to contributing to students' personal and professional development [8], undergraduate research opportunities in CNS enhance their chances of successful and more productive completion of a graduate degree [16]. However, gaining research experience in CNS may be especially difficult due to (1) the lack of CNS-trained faculty at PUIs and (2) the breadth of knowledge required from undergraduates. National Institute of Health's (NIH) Blueprint initiative supports five large and well-established graduate programs in neuroscience that include some undergraduate CNS components [26]. Early and engaging neuroscience education is critical in recruiting and retaining undergraduate students to CNS [9]. While some undergraduates will pursue graduate studies, their first exposure to neuroscience will still occur in undergraduate classes. Moreover, every neuroscience graduate program has a computational component, and, therefore, there is a great need for bottom-up funding and growth of CNS starting at PUIs.

At the College of Charleston (CofC), we developed and implemented an innovative interdisciplinary curriculum in CNS consisting of an introductory research rotation class offered to incoming first-year students as a First-Year Experience (see http://fye.cofc.edu/) followed by an upper-level Biophysical Modeling of Excitable Cells (BMEC) class [19, 20]. The BMEC course is an enriching interdisciplinary learning experience that seemingly fits into the existing Neuroscience Minor and Biomedical Physics Minor at the CofC.

The primary goal of the BMEC course is to provide CofC undergraduates with an overview of the potential applications of CNS, offer a glimpse at the mathematical and computational techniques used in CNS, and analyze in-depth a few computational implementations of single-cell conductance-based models (see http://oprisans.people.cofc.edu/bmec.html/ for a complete list of computational models developed for this class). Another goal of the course is to foster the collaboration between our undergraduate institution (CofC) and the Neuroscience Department at Medical University of South Carolina (MUSC) through

ICCS Camera Ready Version 2021
To cite this paper please use the final published version:
DOI: 10.1007/978-3-030-77980-1_46

the direct involvement of graduate students in teaching undergraduate classes. We aim to contribute to both undergraduate and graduate students learning.

2 Our Curriculum Deployment Approach

1. Identify your Target Audience. In our case, with a successful and fast-growing Neuroscience Minor (developed and staffed by Biology and Psychology Departments) and a Biomedical Physics Minor (developed and staffed by Department of Physics and Astronomy), it became apparent that one crucial learning experience was missing, i.e., a computationally-oriented component of these two programs. After running our CNS class for a few years as a special topic course (2006-2010) and and analyzing the enrollment data, we concluded that our CNS course's target audience is the biology, psychology, physics, and mathematics undergraduates with a strong interest in computational biology.

2. Secure Administrative Support. With the administrative support of the two chairpersons (Biology and Physics), the Director of Neuroscience Minor, and the coordinators of Biomedical Physics Minor, we adjusted the prerequisites and the content of the course to serve both biology or psychology majors, presumably exploring a Neuroscience Minor option, and physics or mathematics majors, likely interested in Biomedical Physics. The BMEC course is maximizing the use of faculty who serves both Biology and Physics majors and two interdisciplinary minors (Neuroscience and Biomedical Physics).

3. Effective Academic Advising. One mechanism we used is the inclusion of two faculty members from the Physics and Astronomy Department in the Neuroscience Steering Committee. This ensures that biology and psychology students were aware of the BMEC course offered by the Physics and Astronomy Department. Simultaneously, physics instructors who were members of the Neuroscience Steering Committee make sure that physics majors are aware of biology and psychology prerequisites for the BMEC course and encourage them to consider a Neuroscience Minor pathway. The goal is to create the mindset, very early on, that mathematically-oriented physics students who would like to consider a career in life sciences need to enroll in biology and psychology classes. The earlier and more pervasive the academic advising is, the more effective it will be in breaking down the natural compartmentalization along discipline and department lines. In addition to academic advising, we use posters and short 10-minute talks delivered during the open enrollment period in targeted biology, physics, and neuroscience classes. The talks were pitched to the appropriate courses and majors to inform the students about the new curriculum.

4. Course Cross-Listing. The BMEC course is cross-listed with the Department of Physics and Astronomy as PHYS 396 and the Department of Biology as BIOL 396. This course serves as one of the mandatory electives for the Neuroscience Minor at the CofC. It is also a core required class for the Biomedical Physics Minor.

ICCS Camera Ready Version 2021
To cite this paper please use the final published version:
DOI: 10.1007/978-3-030-77980-1_46

3 Designing the Computational Neuroscience Curriculum for Undergraduates

3.1 Aims

BMEC curriculum was developed and implemented with three aims: 1) to provide an interdisciplinary undergraduate experience in CNS, 2) to promote interdisciplinary and computational thinking, and 3) create an environment that fosters pedagogical awareness in Ph.D. students from the MUSC early in their careers.

The main goal of the BMEC course is to provide a learning environment where undergraduates can apply their specialized major-related knowledge to solving problems outside their disciplines. For example, physics majors are well-versed in manipulating analytically and numerically differential equations for diffusion, thermal conduction, etc. Still, they rarely find themselves in an undergraduate class that requires solving diffusion equations across the cell membrane, using electrostatic interactions among different ionic species to determine the spatial distribution of charges in a living cell, or using finite difference schemes to solve action potential propagation along an axon. The same is true for biology students who know all the details of biochemical mechanisms involved in transmembrane transport but rarely make the connection with the mathematical description of such processes as they learn it in a traditional physics class [18].

3.2 Prerequisites

The current prerequisites for our BMEC course are unique, and this course introduced a new interdisciplinary curriculum design model. We adopted the model of a single course with two cross-listed sections and prerequisites both in Biology and Physics.

The Physics/Mathematics/Computer Science section of the BMEC course. i.e., PHYS 396, requires calculus-based physics classes through electricity (Physics 111 and 112) and introductory-level biology classes (BIOL 111 Introduction to Cell and Molecular Biology and BIOL 112 Evolution, Form, and Function of Organisms).

The Biology/Psychology/Neuroscience Minor section of the BMEC course, i.e., BIOL 396, requires algebra-based physics classes through electricity (PHYS 101 and PHYS 102) and advanced biology classes (BIOL 211 Biodiversity, Ecology, and Conservation Biology and BIOL 212 Genetics).

There is no formal computer literacy requirement for the BMEC course since the focus is on using dedicated computational tools to model biological processes and not the implementation of computer codes *per se*. Furthermore, to reduce the apprehension related to computer modeling, the course starts with a very user-friendly set of computer activities from the Neuron in Action package [25]. After the students are comfortable manipulating modeling parameters (cell radius, the density of ionic channels, half-activation potentials, etc.), the course gradually

ICCS Camera Ready Version 2021
To cite this paper please use the final published version:
DOI: 10.1007/978-3-030-77980-1_46

introduces them to the actual computer code that runs user-friendly interfaces Neuron in Action package. [13].

3.3 Class Resources

Like any computational biology course, BMEC requires extra resources.
Computers. Our CNS laboratory has 20 dedicated laptops which can be loaned by students enrolled in BMEC at the beginning of the semester. The Department of Physics and Astronomy also offers free access to all students to 20 desktop computers with all the necessary software.
Undergraduate Teaching Assistant. One teaching assistant (TA) is recruited from amongst the students who completed the BMEC class. The TA's primary duties are to help the instructor during the hands-on computational activities so that the computational questions and issues raised by students are promptly solved. The TA holds office hours to help students with homework assignments and computer codes, and grade assignments. The TA also ensures that all hardware and software issues related to BMEC class are solved expeditiously, maintain updated software for all laptops serving the class, and coordinate with Information Technology Department regarding required updates for all computational packages used in class and installed on departmental computers.
Teaching Training Fellowships for Ph.D. Students from MUSC. The ongoing collaboration between the CofC and MUSC extends beyond the research and co-mentoring undergraduates students. We involve senior Ph.D. students from MUSC as Teaching Training Fellows (TTFs) in our undergraduate classes. Although teaching is not required of Ph.D. graduate students at MUSC, studies showed that teaching experience has beneficial effects on enhancing oral and written communication skills and improving research performance [6]. The TTF program between the CofC and MUSC was designed to avoid usual pitfalls, i.e., unstructured pedagogical approach to teaching [1] and lack of precise and quantifiable learning goals and objectives [14].

We selected for the BMEC course only highly-motivated senior Ph.D. graduate students, usually from the labs of the instructor's collaborators, based on first-hand interaction during our collaborative research projects with MUSC. Opportunities are created for increasing pedagogical awareness of TTFs through discussions with other instructors and feedback from undergraduate students and the course instructor about the effectiveness of the teaching methods used in their guest lectures.

The purpose of TTF is to set aside protected time for Ph.D. students interested in pursuing a teaching career such that they can focus on pedagogy, develop teaching competencies, and help graduate students decide their career path beyond the Ph.D. The prospective TTF's research adviser agrees to release the senior Ph.D. student, who is in the final stages of the thesis preparation, from some of the research duties and consign a contract with a CofC instructor with whom the TTF will work. Although the TTF does not directly receive a stipend for teaching at the CofC, the research adviser's lab at MUSC receives

ICCS Camera Ready Version 2021
To cite this paper please use the final published version:
DOI: 10.1007/978-3-030-77980-1_46

compensatory funds from a CofC grant to help substitute the Ph.D. student with other undergraduate or graduate students.

The TTF conducts review sessions with undergraduates, prepares and presents two-three guest lectures, and attends the graduate-level Teaching Techniques class at MUSC. Many office hours go beyond the class topics and sometimes cross into personal advice from TTF to undergraduate students regarding effective learning strategies, what it takes to get admitted into a graduate program, what it takes to be a successful graduate student, etc. The undergraduates do not feel intimidated by the TTF and tend to ask questions more openly. At the same time, the undergraduates know from the research lab visits at MUSC, which are conducted by the TTF, and from the lectures taught by the TTF towards the end of the semester in our BMEC class that the TTF masters the neuroscience research techniques and respect him/her as a looked-up professional and potential role model.

4 Biophysical Modeling of Excitable Cells Course Logistics.

Teaching computational biology at the undergraduate level is challenging primarily because of the required breadth of knowledge. BMEC is a one-semester, upper-level, undergraduate course for students interested in exploring computational approaches to biologically-relevant questions. The course is a three contact hour per week class.

Gaining hands-on experience is crucial in computational biology [23], and we opted for a mix of lectures and hands-on computational activities during a three contact-hour class. Depending on the week's topic, at least one out of the three one-hour class periods is allocated to hands-on computational activities. The three-credit/three contact hours BMEC course is offered every fall semester.

BMEC is a single-instructor course and consists of standard two-hour lectures per week and one-hour hands-on computer activities weekly. Computational activities are selected from the Neuron in Action package during the first half of the semester and implemented in XPP during the second half of the semester. Class discussions focus on primary literature and database models. The students' workload consists of weekly reading and homework assignments, one term paper, and one end-of-semester computational project.

4.1 Delivering BMEC Content

Lectures and Hands-on Computational Activities. The course content is delivered primarily through lectures focused on the major points of the assigned readings. To increase class participation and get a feeling of the students' grasp on some tricky concepts, we use a classroom response system (iClickers) for anonymous polling. The small class size (10-16 students) helps students feel more comfortable speaking up, although iClickers is the preferred method to scale-up and involve larger classes [24].

ICCS Camera Ready Version 2021
To cite this paper please use the final published version:
DOI: 10.1007/978-3-030-77980-1_46

The purpose of computational activities is to familiarize undergraduate students with the user-friendly interface provided by Neurons in Action software [17] and guide them through a series of tutorials modeling different aspects of electric activity of excitable cells, e.g., passive properties of membrane bilayers, effect of voltage-gated ionic channels on electric activity of excitable cells, action potential propagation, synaptic coupling, etc.

During the second part of the semester, the undergraduate students are introduced to the computer programming behind the friendly graphic user interface. Since computer programming experience is neither required nor the main focus of the BMEC course, we decided to use a simple, straightforward, yet powerful scripting language called XPP developed at Pittsburg University by B. Ermentrout (see http://www.math.pitt.edu/˜bard/xpp/xpp.html). Extensive tutorials also support this cross-platform software package [5].

After the first half of the semester, the students become comfortable linking biological concepts, such as transmembrane ionic currents induced by protein conformation changes, with the corresponding mathematical representation. For example, all students in BMEC are familiar with the mathematical description of the leak current, which has the general form of Ohm's law $I_L = g_L \times (V - E_L)$, where g_L is the leak current conductance, V is the membrane potential, and E_L is the reversal potential of the leak current. In XPP, the implementation of the above current is straightforward:

$$\text{par } gl = 0.1, el = -50$$
$$il = gl * (v - el)$$
$$\ldots$$

The reserved word **par** in the above computer code signals that what follows is a list of parameters. Understanding XPP scripts is straightforward and gives undergraduate students the necessary confidence that CNS is not (only) about computer programming. After practicing with XPP during the second half of the semester, the students become confident that they can implement any conductance-based mathematical model.

Guest Lecturers and Lab Visits. The close ties with the MUSC and TTF Ph.D. graduate students' involvement offer CofC undergraduates the opportunity of class visits to observe wet electrophysiological or behavior experiments carried out at MUSC. We also monitor all steps of *in vitro* experiments using mice prefrontal slices from glass electrode and slice preparation, cell identification, to spike sorting. In a different lab visit at MUSC, we observed *in vivo* multielectrode recordings from mice performing a maze task. After completing the BMEC course, our undergraduates have the opportunity of gaining additional first-hand research experience and apply what they learned in the classroom by working in MUSC labs through the Summer Undergraduate Research Program (SURP) initiative.

To further strengthen the ties between the CofC and MUSC departments, experts from different fields are invited to give guest lectures. We usually do not have more than one guest speaker per academic year. In some particular

ICCS Camera Ready Version 2021
To cite this paper please use the final published version:
DOI: 10.1007/978-3-030-77980-1_46

academic years, we incorporated more electrophysiology background information by asking a faculty member from the Biology Department at the CofC to present this specific neuroscience-related topic. In other years we had MUSC guest speakers from Biomedical Imaging Center at MUSC and focused more on brain networks and behavioral-level neuroscience with connectomics emphasis. To secure a guest speaker, we usually send the invitation to targeted faculty at least three-four months before the beginning of the semester.

4.2 Online Course Management System

Class materials are organized and distributed via a secure wiki page. A screened wiki webpage summarizing materials from our CNS course is available at http://oprisans.people.cofc.edu/bmec.html/. The instructor edits and maintains a few webpages linked to the main wiki, e.g., the syllabus, the list of recommended computational projects, the list of recommended essays, the criteria for evaluating the presentations, the office hour schedule, the end-of-semester student presentation schedule, etc.

Couse's wiki webpage contains pages created and managed by each student or group of students. Each student must store all files related to his/her wiki webpage in an individual folder to avoid mixing and overwriting files from other users. A typical student webpage contains a detailed description of the end-of-semester computational project. It is organized as a research paper, i.e., it must have a title, abstract, introduction, method, and materials, results, conclusions, acknowledgments, references. The PowerPoint presentation and the final written report for the end-of-semester computational project are also linked to the student's wiki page. All references used during the project are stored as pdf files in the related student's folder to allow every student enrolled in the BMEC course quick access to the particular project's primary literature.

4.3 Course Topics

Course topics include (1) exploration of physics basis of (bio)electrical signals, such as electric potential, electric current, Ohm's law, Kirchhoff rules, an RC time constant, (2) search for experimental data and computational models in open databases, such as CRCNS - Collaborative Research in Computational Neuroscience (https://crcns.org/), ModelDB (https://senselab.med.yale.edu/modeldb/), and BioModels (https://www.ebi.ac.uk/biomodels/), (3) fit experimental data to analytic functions and calibrate ionic currents based on empirical data, (4) use freely available (NEURON, XPP, etc.) and proprietary (Matlab, Mathematica, etc.) computational tools to integrate model equations, and (5) relate computational predictions and results to behavioral and clinical data.

In BMEC, we cover four main topics: (1) electrical properties of excitable cells, e.g., capacitance, time constant, axial and trans-membrane electric resistances, length constant, and leak currents, (2) ionic currents, e.g., Ohmic and voltage-gated ionic channels, Kirchhoff rules, and Hodgkin-Huxley equations, (3) synaptic coupling, e.g., neurotransmitter release, calcium-sensing, GABA-

ICCS Camera Ready Version 2021
To cite this paper please use the final published version:
DOI: 10.1007/978-3-030-77980-1_46

and NMDA-gated ionic channels and long-term potentiation, and (4) multi-compartment models and neural networks (see http://oprisans.people.cofc.edu/bmec.html/ for weekly topics, objectives, assignments, etc.).

4.4 Textbooks

Due to the heterogeneity of students' backgrounds and the breadth of required knowledge, no single textbook can cover both the biological foundations and the mathematical/computational topics for an undergraduate-level CNS class. We used a combination of textbooks (available at CofC library) and review papers to cover the foundations of CNS:

1. Principles of Neural Science, E.R. Kandel, J.H. Schwartz, T.M. Jessell, 2005.
2. Computational Cell Biology: An Introduction to Computer Modeling in Molecular Cell Biology. Chris Fall, Eric Marland, John Tyson, and John Wagner (editors). Springer-Verlag. New York, NY. 2002.
3. Ionic Channels of Excitable Membranes, Third Edition. Bertil Hille. Sinauer Associates. Sunderland, MA. 2001.

Additional assigned readings are listed on our BMEC website.

4.5 Assignments

Reading Assignments. Primary literature is employed in three ways: (1) inclusion of experiments and models in all lectures, (2) individual written essays focused on a literature review of a specific computational model, and (3) end-of-semester computational projects. Through active reading assignments from the CNS field's primary literature, we reinforce concepts presented in class and guide students on integrating real data into computational models of excitable cells. The reading assignment also expose students to current research and teach them the importance of staying abreast of new developments in the rapidly changing field of CNS [22].

Literature Review Essay. All students enrolled in BMEC are required to summarize assigned primary literature articles in a short review paper, targeting non-science peers, called essay assignment. Through these assignments, the students became aware of the difficulties of conveying technical information to a broad audience and gaining experience in science writing and communication. As opposed to the regular class reading assignments, the literature review essay is a comprehensive overview focused on the novelty and uniqueness of a particular computer model applied to a biologically-relevant question. Each literature review essay must provide a historical overview emphasizing a broader understanding of the interdisciplinary and often sinuous track towards the "right" answer. In addition to introducing the specific subject of the essay, the literature review essay details the design, results, and interpretation of computer simulations and their relevance to biology.

Computational Project. Further student engagement in CNS comes in the form of an end-of-semester computational project. A list of projects, together

ICCS Camera Ready Version 2021
To cite this paper please use the final published version:
DOI: 10.1007/978-3-030-77980-1_46

with minimal bibliography and computer codes, is provided at the beginning of the semester. However, the students are free to select any other CNS-related topics (see http://oprisans.people.cofc.edu/bmec.html/).

At the end of the first month of the semester-long course, every group of (maximum three) students must select a computational topic and submit a brief one-page proposal detailing the title, abstract, and references for their intended computational project.

The project groups must have (at least) one biology/psychology/neuroscience minor member from the BIOL 396 section of the class and one from the mathematics/physics/computer science PHYS 396 section of the course. Course evaluations showed that students with stronger biology/psychology backgrounds and weaker physics/mathematical backgrounds benefit from the mixed teams' arrangement to explore quantitative and computational solutions. Simultaneously, students with stronger physics/mathematics backgrounds had the opportunity to understand better the hypothesis and assumptions made in tackling biological problems using mathematical models and computer models.

The midterm checkpoint of the computational project provides feedback to students regarding the consistency of their numerical simulations, the content, and the style of their presentation. For the end-of-semester computational project, the midterm requirement is a working computer code and a strategy for conducting numerical simulations for the rest of the term, e.g., computational resource allocation, time management, etc.

During the second part of the semester, the students summarize their numerical simulations, design a 10-15 minute PowerPoint presentation and an accompanying, more detailed paper summarizing their findings. The emphasis of the end-of-semester accompanying paper is on the clarity of writing, the relationship between a biologically-relevant question and the computational model they developed and tested, judicious selection of simulation parameters and their biological relevance, creativity regarding data mining and visualization of results, and the critical overview of shortcomings and possible improvement of the project.

At least a week before the end-of-semester presentation, each student is required to meet with the instructor to assess both the content and the format of the intended 10-minute class presentation. This meeting also allows the instructor to evaluate student fluency with the material presented and individual contribution to the team project. Many students reported that this was the first, or one of the only few, presentations required in any of their classes. Thus, BMEC also helps develop oral communication skills, which is a crucial feature of a liberal arts education.

While both the essay assignments and the end-of-semester computational projects develop and sharpen students' critical evaluation of the primary literature, teach students how to identify strengths and weaknesses, and present the results logically, they serve different purposes. The literature review essay's primary focus is to engage undergraduates in scientific thinking, critique what they have read, and understand what questions have been left unanswered or what

ICCS Camera Ready Version 2021
To cite this paper please use the final published version:
DOI: 10.1007/978-3-030-77980-1_46

new problems have emerged from the primary literature they covered. Critical evaluation of the primary literature during essay writing reflects their assessment of results' reliability, replicability, methods, and conclusions reached by the study's authors. The end-of-semester computational project also requires a literature review. Still, it focuses on a single computational model and, more importantly, requires a working computer implementation of the model under investigation to (1) replicate the data published in the literature and (2) suggest new implementations and new parameter ranges explored.

4.6 Learning Objectives Assessment

Reading Quizzes. The reading quizzes consist of multiple-choice questions that require 5-10 minutes of class time. One purpose of the reading quizzes is to check that the students read the assigned material and are familiar with the new vocabulary before starting the lecture. An equally important purpose is to signal to the instructor where the most misconceptions are so that the lecture's emphasis can be tuned to the student's actual needs. There is at least one reading quiz per chapter with the option of delivering them electronically via the college-wide course management system.

Homework. There is usually one homework assignment per week (see http://oprisans.people.cofc.edu/ bmec.html/ for a detailed list of tasks). The homework assignments are primarily quantitative and require computational proficiency in preparing charts, data visualizations, and statistical analysis.

Literature Review Essays and End-of-Semester Projects. Assessing course outcomes is crucial to determine what areas need improvements. We adopted and modified a rubric model of assessment to help students with the essay preparation and the end-of-semester computational project. For the essay rubric, the emphasis is on understanding the literature's scientific background and tune writing and communication skills to technical aspects of the paper. The rubric also makes several explicit aspects of scientific content and methodologies, such as identifying each experiment's aim in the assigned literature, stating and justifying the hypothesis, discussing the results, and identifying obvious shortcomings and possible suggestions for improvement. Critical evaluation of the primary literature is also required. Students must identify strengths and weaknesses and suggest experiments that would logically follow from the paper's results or fill in the article's gaps.

For the literature review essay, the students were required to organize multiple sources, emphasize the flow and progression from one experiment to the next, and identify open questions. Throughout the entire BMEC course, we caution our students that "all models are wrong, but some are useful" (George E. P. Box) and encourage students to consider both the limited scope of a given study and the totality of the evidence presented.

For the end-of-semester class presentations of the computational project, the project's team will cover the background literature and their numerical simulation results. Other students are randomly called upon to discuss or critique

ICCS Camera Ready Version 2021
To cite this paper please use the final published version:
DOI: 10.1007/978-3-030-77980-1_46

the hypothesis, assumptions, and limitations of the work presented by their colleagues.

Assessment of Teaching Training Fellows. In our experience, the TTF program benefits both our undergraduates, a fact that we attributed to the beneficial role of peer coaching [11], and the Ph.D. students. TTF students are encouraged to focus on multiple aspects of pedagogy, from general teaching style to specific teaching strategies. The lecture's roster faculty serves as a teaching mentor for the TTF and helps him/her develop lecture plans and assignments appropriate for undergraduates.

By observing how various instructional methods engage undergraduates in the course, TTF students can incorporate effective teaching strategies into their lectures. Of particular importance is the early exposure and adoption of modern classroom technology by TTFs. In our BMEC classroom, we use as many modern teaching technology tools as possible, from the Peer Instruction [15] with classroom response systems (iClickers) [3] to dynamic PowerPoint presentations that integrate multimedia content [4].

Our goal is to guide TTF students towards identifying effective teaching strategies that match both their personality and the intended audience, help them design the assignments given to undergraduates at the appropriate level of difficulty, design qualitative questions and computational problems that require synthesis and manipulation of the material to make sure students understood the key concepts, and convey the message that the instructor must always have a much deeper understanding of the topic than he/she may be teaching. To evaluate improved pedagogical skills of the TTF students, we rely on undergraduates' ratings on the clarity of learning objectives, the material presented, and qualitative feedback on the most and least effective components of the lecture from both students and course directors.

5 Discussion

We implemented at the CofC a computational neuroscience (CNS) program that fuses neuroscience with more math-oriented topics. It afforded new courses to be developed which have served a multitude of purposes, i.e., growth of both Neuroscience and Biomedical Physics Minors, introduced freshmen students to computational biology through our first-year experience, empower biology students to search for computational solutions of biologically-relevant questions, and open a new realm of discovery for mathematically-oriented and computer science savvy student.

The Biophysical Modeling of Excitable Cells course is unique at the CofC for several reasons. It bridges (1) multiple disciplines (physics, mathematics, computer science, psychology, and biology), (2) numerous programs on campus (Neuroscience Minor, Biomedical Physics Minor, and DATA Science), and (3) the neuroscience research at MUSC with undergraduate teaching at the CofC.

I the absence of a TA and TTF, this class would be challenging to implement with an enrollment greater than 15-20 students. One of the limitations is the

ICCS Camera Ready Version 2021
To cite this paper please use the final published version:
DOI: 10.1007/978-3-030-77980-1_46

number of end-of-semester presentations, which could be reduced by creating larger teams. It is more challenging to coordinate students' schedules to run numerical simulations for larger groups. Suppose a TA or TTF is not available during hands-on sessions. In that case, the instructor must adopt a synchronous, step-by-step approach such that any computation roadblock is removed for all students before moving forward.

This course promotes pedagogical awareness through its TA and TTF programs and helps prepare the next generation of neuroscience instructors. Through the strong ties we have with research labs at MUSC and the constant interaction among our students and the TTF, we created steady steam of students who successfully pursue Ph.D. degrees in (computational) neuroscience. Among other approaches, this is one of the most effective ways of preparing the next generation of computational biologists. [12].

6 Acknowledgments

This work was supported by a Research & Development grant form the CofC and an award from the South Carolina Space Grant Consortium.

References

1. Austin, A.: Preparing the next generation of faculty: graduate school as socialization to the academic career. J Higher Educ **73**, 94–122 (2002)
2. Bialek, W., Botstein, D.: Introductory science and mathematics education for 21st-century biologists. Science **303**, 788–790 (2004)
3. Caldwell, J.E.: Clickers in the large classroom: current research and best-practice tips. CBE life sciences education **6**(1), 9–12 (2007). https://doi.org/10.1187/cbe.06-12-0205
4. Chien, Y., Smith, M.L.: Powerpoint: is it an answer to interactive classrooms? International Journal of Instructional Media **35**(3), 271 (2008)
5. Ermentrout, B.: Simulating, Analyzing, and Animating Dynamical Systems: A Guide to XPPAUT for Researchers and Students. SIAM (2002)
6. Feldon, D., Peugh, J., Timmerman, B., Maher, M., Hurst, M., Strickland, D., Gilmore, J., Stiegelmeyer, C.: Graduate students' teaching experiences improve their methodological research skills. Science **333**, 1037–1039 (2011)
7. Holley, K.A.: The longitudinal career experiences of interdisciplinary neuroscience phd recipients. J Higher Educ **89**(1), 106–127 (2018)
8. Hunter, A.B., Laursen, S., Seymour, E.: Becoming a scientist: the role of undergraduate research in students? cognitive, personal, and professional development. Science Education **91**, 36–74 (2006)
9. Hurd, M., Vincent, D.: Functional magnetic resonance imaging (fmri): a brief exercise for an undergraduate laboratory course. J Undergrad Neurosci Educ **5**, A22–A27 (2006)
10. Kaplan, D.: Explanation and description in computational neuroscience. Synthese **183**(3), 339–373 (2011)
11. Knight, J.: A primer on instructional coaching. Principal Leadership **5**, 17–20 (2005)

ICCS Camera Ready Version 2021
To cite this paper please use the final published version:
DOI: 10.1007/978-3-030-77980-1_46

12. Kozeracki, C., Carey, M., Colicelli, J., Levis-Fitzgerald, M.: An intensive primary-literature-based teaching program directly benefits undergraduate science majors and facilitates their transition to doctoral programs. Life Sciences Education **5**, 340–347 (2006)
13. Latimer, B., Bergin, D., Guntu, V., Schulz, D., Nair, S.: Open source software tools for teaching neuroscience. J Undergrad Neurosci Educ **16**(3), A197–A202 (2018)
14. Luft, J., Kurdziel, J., Roehrig, G., Turner, J.: Growing a garden without water: graduate teaching assistants in introductory science laboratories at a doctoral/research university. Journal of Research in Science Teaching **41**, 211–233 (2004)
15. Mazur, E.: Peer Instruction: A User's Manual. Series in Educational Innovation, Prentice Hall (1997)
16. Miller, J., Martineau, L., Clark, R.: Technology infusion and higher education: Changing teaching and learning. Innovative Higher Education **24**, 227–241 (2000)
17. Moore, J., Stuart, A.: Neurons in Action Version 2: Tutorials and Simulations Using NEURON. Sinauer Associates, Sunderland, MA, USA (2007)
18. Muir, G.: Mission-driven, manageable and meaningful assessment of an undergraduate neuroscience program. J Undergrad Neurosci Educ **13**(3), A198–A2015 (2015)
19. Oprisan, S.: Teaching computational neuroscience at a liberal arts and sciences undergraduate college. Society for Neuroscience, Washington, DC (2011)
20. Oprisan, S.: Introducing computational neuroscience concepts and research projects to undergraduates. Society for Neuroscience, New Orleans, LA (2012)
21. Ramirez, J.J.: Undergraduate neuroscience education: Meeting the challenges of the 21st century. Neuroscience Letters **739**, 135418 (2020)
22. Salomon, D., Martin-Harris, L., Mullen, B., Odegaard, B., Zvinyatskovskiy, A., Chandler, S.: rain literate: making neuroscience accessible to a wider audience of undergraduatesy. J Undergrad Neurosci Educ **13**(3), A64–A73 (2015)
23. Schultheiss, S.: Ten simple rules for providing a scientific web resource. PLoS Computational Biology **7**(5), e1001126 (2011)
24. Stanley, D.: Can technology improve large class learning? the case of an upper-division business core class. Journal of Education for Business **88**, 265–270 (01 2013). https://doi.org/10.1080/08832323.2012.692735
25. Stuart, A.: Teaching neurophysiology to undergraduates using neurons in action. J Undergrad Neurosci Educ **8**(1), A32–A36 (2009)
26. Wiertelak, E., Hardwick, J., Kerchner, M., Parfitt, K., Ramirez, J.: The new blueprints: Undergraduate neuroscience education in the twenty-first century. J Undergrad Neurosci Educ **16**(3), A244–A251 (2018)

ICCS Camera Ready Version 2021
To cite this paper please use the final published version:
DOI: 10.1007/978-3-030-77980-1_46