Building a New Translational Research Program with Undergraduates: A Student-driven Research Class

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Abstract
Course-based undergraduate research is an effective active, inquiry-based pedagogical tool. In many cases, these research experiences build on established research programs. This project report describes a research course designed to establish a new translational research program in epilepsy and to test the feasibility of engaging students early on in the research process. The outcomes of this class, including research deliverables and student learning gains assessments, indicate that engaging students in research at a very early stage in project development is a meaningful and productive pedagogical framework for student and faculty development. This high-risk model for course and research development is a novel and exciting method for engaging students in mentored research at the undergraduate level.

Introduction
Mentored research at the undergraduate level is considered a high-impact pedagogical practice (Kuh, O'Donnell, & Reed, 2013), and many STEM courses incorporate students into established research programs and projects. The benefits of course-based research are not limited to students, as faculty research progress can be boosted by the concentrated student collaboration found in these

courses. Moreover, students can bring fresh perspectives and make important contributions to research at the point of new project development. Involving students in "early" research (e.g. establishing research aims, refining protocols and procedures, and collecting and analyzing background data) can be a context for simultaneously robust student learning and faculty professional development. However, the risks of failure associated with early research may make faculty reluctant to consider building a research course specifically centered on developing a new and untested project. The course described below provides evidence in favor of building a course around a new research program, using the example of a successful pilot of course-based translational neuroscience research at the undergraduate level. The work of this course, offered at a small liberal arts college, set the stage for a robust, student-centered translational research program that also advanced the instructor's research agenda.

Translational research: from basic science to disease intervention

The confirmation in humans of the results of basic science research using cell and animal models is a critical step in developing patient-centered interventions to improve human health (US Department of Health and Human Services [USD HHS], 2015). Translational research, which bridges basic science and clinical research, is a major focus of NIH funding and support through the National Center for Advancing Translational Sciences. However, it can be challenging to implement translational research at small colleges and universities, as many of these institutions are not in a position to conduct clinical and patient-centered translational research. These shortcomings may be circumvented through the use of publicly available online databases that provide students and faculty with the opportunity to work directly with human data collected under IRB approval from large research institutions. As funding for basic science research decreases, engaging undergraduate students in the process of translational research is critical to the enhancement of their understanding and appreciation of the fundamental role of basic science in improving the health and well-being of the broader population (Hobin et al., 2012).

Epilepsy and EEG

Approximately two percent (+/- 0.11) of Americans suffer from epilepsy (US DHHS, 2017), a family of disorders in which a person who has previously had a seizure is likely to experience another unprovoked seizure (Fisher et al., 2014). The etiologies of epilepsy are varied and, in many cases, still unknown (Shorvon, 2011). Thus much of the effort in the clinic is aimed at seizure management and prevention.

The monitoring of the epileptic brain via electroencephalography, or the recording and analysis of the electrical signals of the brain, is critical to the management of epilepsy. In particular, many patients with intractable epilepsy, i.e. epilepsy that is resistant to management by medication, undergo long-term intracranial electroencephalography in the inpatient hospital setting to collect electroencephalogram (EEG) signals from up to hundreds of locations across the cortex of the brain over the course of several days. The signals are analyzed to determine whether surgical resection of the epileptic locus, or the portion of the brain implicated in the start of seizure activity, is a possible epilepsy management strategy. Yet EEG analysis is time-consuming and subject to low inter-observer reliability, especially regarding the precise timing and location of seizure onset in the brain (Abend et al., 2011; Benbadis et al., 2009; Tatum, 2013). Therefore, research on the development and use of automated, standardized, and quantitative EEG analysis through computer is an expanding field of inquiry (Acharya et al., 2013; Halford et al., 2011).

Course structure and implementation

Translational research towards understanding how EEG analysis is similar or different among rodent models of epilepsy and human epilepsy in the clinical setting serves as the foundation for the research course described in this report. An advanced topics course (BIOL 373, Advanced Neuroscience Research) was developed and implemented in spring 2017 to model a translational EEG research laboratory environment for eleven undergraduate students. The three goals for this course were to: (1) engage multiple students in a semester-long mentored research experience, (2) determine whether student learning gains through engagement with an early research project are similar to those of students in established research projects, and (3) determine the feasibility of conducting and developing the background work for translational epilepsy research at Beloit College, a small liberal arts college with no clinical research affiliation. In this model, students were full partners with the instructor in the research process to determine the goals and direction of the project. Students gained experience with the research process and its challenges, became familiar with the procedures and outcomes of a basic science investigation of seizure detection in mice (Bergstrom et al., 2013), identified and mined a publicly available human intracranial EEG database, revised and tested a MATLAB-based algorithm—originally developed for seizure identification in mice—on human EEG signal, and established and validated a procedure for quantitative analysis of human intracranial EEG signal.

The course began with a review of research in the analysis of rodent EEG (Bergstrom et al., 2013) and a discussion of the function of translational research. The students and instructor collaboratively identified a strategy for goal-setting and reflection-based assessment that would be completed every two weeks throughout the 15-week semester, with one single-week goal-setting and reflection cycle before the mid-term break. Major assessments for the class were: (1) a public works-in-progress seminar at the Beloit College Student Research Symposium and (2) smaller weekly student-driven lecture/discussion presentations on timely research-related questions of neuroscience and epilepsy in the literature, e.g. neuron and brain anatomy, the action potential, the contribution of interictal spiking brain activity to epileptogenesis, and automated EEG analysis tools. Additional assessments included (1) pre- and post-course Course Undergraduate Research Experience (CURE) survey (Denofrio et al., 2007; Lopatto et al., 2008), (2) Student Assessment of Learning Gains, or SALG survey (Carroll, 2010), (3) and completion of the standard Beloit College end-of-semester course evaluations. Data collection and reporting procedures were approved by the Beloit College Institutional Review Board, and students provided informed consent for their participation in this study.

Students self-identified interests within the project and formed small groups to develop and accomplish sub-goals for the research project. Groups of two to six students were fixed for each two-week goal-setting/reflection period in the first half of the term and worked on goals within the broader research aims, such as identifying data sources, learning basic seizure analysis in EEG, and annotating and implementing MATLAB code. At the midterm, students re-organized into stable groups for the remainder of the semester. These groups were focused on preparing a literature review (four students), establishing a strategy for manual scoring of EEG signals (three students), and revising and analyzing MATLAB algorithm code (three students). One student served as an official liaison between the manual scoring and code revision groups (eleven students total). The two-week reflection cycle was maintained through the second half of the course. Class time (twice a week for 110 minutes per meeting) was used primarily for weekly lab group meetings, student presentations of relevant neuroscience topics, and individual and group work interactions with the instructor. Students were expected to be largely self-directed and to allot additional time outside of class, though logs of work were not required.

Preliminary observations and outcomes

Seven of the eleven course participants completed both the pre- and post-course surveys. Their responses indicate that students in this course made similar learning gains in relevant research skills to those of the CURE survey comparison groups (Denofrio et al., 2007; Lopatto et al., 2008) ($n \leq 9603$, Figures 1 and 2, two-sample t test, $p > 0.05$ for all comparisons). This indicates that engaging students in a course-based project at a very early stage is a meaningful mechanism for research at the undergraduate level and also performs an important role for faculty interested in establishing a new research project or trajectory.

Student responses from the SALG survey and Beloit College course evaluation seem to indicate that students, even while doing translational research, did not make significant connections between the concepts of basic science and translational research. For example, they did not mention translational research in any of their long-form comments. However, students did report in the course evaluations and the SALG that they made clear gains in self-directed learning (Box 1). It is important to note that, while most students had little or no prior experience with neuroscience, epilepsy, EEG, or the MATLAB programming environment, they were junior- or senior-level students who had already had extensive experience with

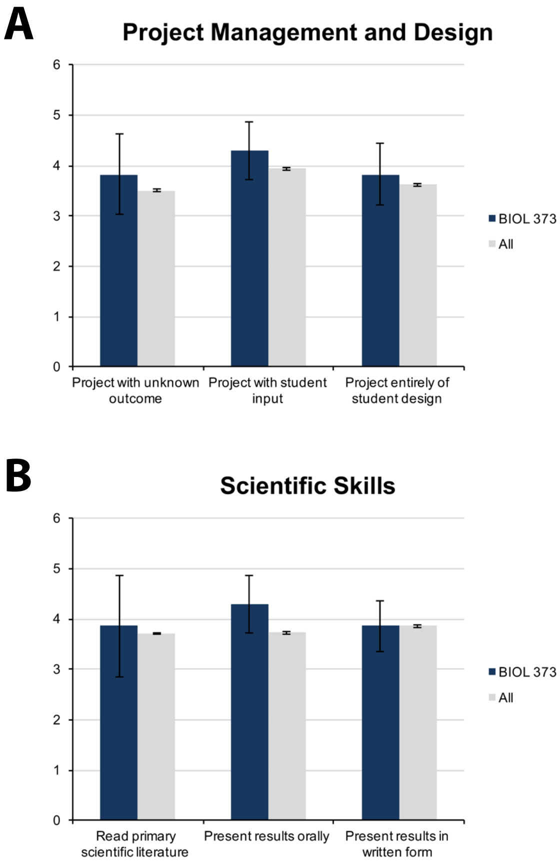

FIGURE 1:

Students reported learning gains in skills associated with research.

In this class, students were responsible for starting and defining a new research project that would continue beyond the course. Because starting a new project is, in many ways, different from continuing an established project, learning gains were assessed in areas similar to those made by students engaging in established research programs through course-based research activities. Students in BIOL 373 Advanced Neuroscience Research (blue bars) made learning gains similar to national averages (gray bars) in skills related to project management and design (A) and scientific research (B), indicating that engaging students in the research process early in a new project is a meaningful way to involve students in faculty research and development (two-sample t test, $p > 0.05$ for all comparisons). Though there was no statistically significant difference between this course and national averages for these assessment categories, gains associated with project management and design (A) were slightly higher than national averages, perhaps because the students were deeply involved in determining the progress and trajectory of the research plan. A larger gain was also noted in skills related to oral presentation of results (B) because one of the main assessments for the course was a public works-in-progress presentation as a part of our institutional student research symposium. 1 = little gain, 5 = great gain. Error bars represent 95% CI.

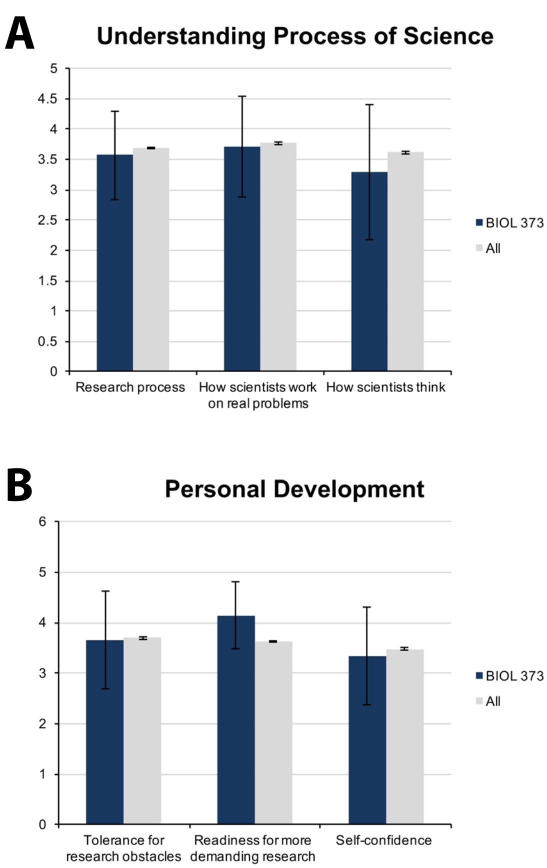

FIGURE 2:

Course benefits.

The benefits of mentored research extend far beyond learning basic scientific content. These CURE survey results indicate that students make valuable learning gains related to scientific research, even at a very early stage in the research project. Students in BIOL 373 Advanced Neuroscience Research (blue bars) made learning gains in personal development (A) and understanding the process of science (B) similar to national averages, indicating that engaging students early in the research process can be an impactful research experience (CURE survey). Together, these results suggest that undergraduate educators should consider engaging students at all stages of the research project, especially including the evaluation of project feasibility and the gathering of background data and information. 1 = little gain, 5 = great gain. Error bars represent 95% CI.

student-driven learning and research design through the broader Beloit College curriculum. Thus it is possible that students at an earlier level of academic development might not have made similar learning gains (Kirschner, Sweller, & Clark, 2006).

Establishing a new research project: engaging students in faculty development

In many course-based research projects, students are inserted into an already-established research project and are given a single task or experiment to complete by the end of the class. This course was different, in that the students were involved in establishing a new research program from the ground up and therefore were required to consider not only their role in the project but also how the project fit into a much broader context of sustained research. This challenging authentic research experience provided students with many opportunities to develop cognitive skills and resilience around the challenges of research and learning, especially self-directed learning and identifying research and educational resources. Assessment of the learning outcomes of this project indicate that involving students in research at a very early point in the process, even before research aims and procedures are fully developed, can be a powerful learning tool for students.

Involving students early in the development of a new research project can also be an efficient mechanism for increasing faculty research output. The translational research outcomes of this course were significant; the deliverables completed in the class which are relevant to starting a new research project are summarized in Box 2. Further, this preliminary work set the stage for three of the eleven students in the course to continue work with the faculty member on this project after the course, including serving as mentors for two new student researchers. Additional students will be recruited to this project in the future and will eventually see it through to completion and publication.

Together, the research deliverables and learning outcomes analyses suggest that situating early research project activities and goals as the context for a structured undergraduate course is an effective mechanism for faculty to test-drive or establish a new research

Box 1: Student Comments

SALG:

Please comment on how THE WAY THIS CLASS WAS TAUGHT helps you REMEMBER key ideas.

- Because we mostly worked autonomously and spent a lot of time learning how to teach ourselves the things we needed to learn in order to move on with the project, the knowledge gained was a lot more active and integrated in the discovery process.
- I don't think there was much "teaching" involved per se. We had a lot of guidance and mentorship, but I learned a lot on my own. I also don't think we had many key ideas. Shared goals of course, but I think in terms of class content and understanding, we each walked away with different things.

College Course Evaluation:

Please reflect on both the strengths of the course and areas for improvement.

- I think taking a course like this is invaluable. It certainly was for me. Working doing research on a brand new subject for me and doing so outside of a wet lab was very interesting and formative. And structuring it as a work environment helped the students to become a good team.
- This course challenged me to find sources and information that I needed in order to understand this neuroscience and effectively try to apply it to our research work and to the general public.
- [I] wish there was more structure and guidance. We are not a big research lab, we aren't even just an undergraduate lab, we are a class, in a classroom, with class times, grades and all the class stuff. Sometimes I felt like cheap labor because I wasn't getting much out of it, but ambivalently was also getting lots of experience.

College Course Evaluation:

Would you recommend this course to others? Why or why not? (n = 11, all responded "Yes")

- Yes. It is a good stepping stone into what the real world team work is like. The professor will challenge but help you move along with the student's individual ideas. Class and professor also provide a great deal of practice and opportunities to better our presentation skills, and effective ways of presenting our knowledge to the general public.
- Yes, 300-level biol course, good to take for independence, synthesis, and "upper level" skills and independence.

program that extends beyond the course and, at the same time, engage more students in mentored research.

Challenges and Recommendations

The overt link to the unique niche of translational research within the biomedical community did not come through in the analysis of student responses, even though students were actively engaged with the process. The concept of translational research is new to most students, and so more careful attention to highlighting the important role of this type of work is needed in models like this. Because this was a laboratory course designed to focus on analysis of EEG signal, the student presentations were primarily focused on the neurological concepts relevant to the project. However, more attention could have been directed to the impact and structure of the bench-to-bedside research model.

A future course is planned around this research project, but it will be situated at a different point in the research process than the course described here. This new course could provide additional opportunities for students to engage with the research process and to gain a broader understanding of the clinical aspects of epilepsy. Three potential additions to the course could include (1) inviting a physician to meet with the class to discuss epilepsy and EEG in the clinical context, (2) including a conference call or in-person meeting with an epilepsy researcher at a large research institution to provide additional input to the project and to model effective research collaboration, and (3) assigning students to prepare patient-centered documents or presentations to explain epilepsy, EEG, and the analysis tools that they are developing.

Finally, it is important to note that this model requires significant buy-in and trust from the students, as it is a high-risk project for both the students and the faculty member, and many students expressed uncertainty regarding their progress at some point in the course. For instance, one student commented on a lack of typical "classroom-like" learning (Box 1) while also noting clear gains in experience. While a neuroscience "crash course" or more regular lectures and activities centered on the concepts of neuroscience might have been useful for content acquisition, it is important to help students recognize that these may be common feelings as they transition from a more typical undergraduate lecture-discussion course format to a student-centered project in which students themselves are responsible for identifying and structuring their learning content. It was useful to have regular check-ins with students to help to normalize feelings of frustration and uncertainty as they encountered research roadblocks and conflicting information from published reports. Still, it is possible that recognizing the emotional investment inherent in research can help students at this stage of their academic career build resilience for future challenges. This hypothesis must be tested as we build new models for engaging students in research at the undergraduate level and in preparation for broader participation within the STEM fields.

Box 2: Research Deliverables

The students completed the following research tasks by the end of the semester, building a strong background core for continued work on the research project.

- A literature review, summarizing the current state of wavelet-based EEG analysis, a core element of the neuroscience research component of the course.
- A library guide as an introduction to the project for student and faculty use at http://guides.beloit.edu/BIOL373.
- Identification of and interface with a public database of human intracranial EEG at ieeg.org.
- Analysis and annotation of murine EEG analysis code with special emphasis on identification of relevant parameters for testing in human EEG.
- Development of a quantitative manual EEG scoring strategy and description for novice evaluators that results in high reproducibility and inter-observer reliability.

Conclusion

Mentored research is a high-impact undergraduate education practice (Kuh, O'Donnell, & Reed, 2013), and STEM educators in particular must therefore be creative and develop more opportunities for students to be involved with and learn from the process. Students can and do make important learning gains through the process of investigating the feasibility of a translational research project and gathering background data and material in support of a larger project. The dual purpose of this course, to engage students in research and to develop a new avenue for a faculty member's research, situates it as a model through which instructors can recognize and harness the power of students at this stage of the research project. These results should encourage faculty to consider course-based research as a powerful tool that they may wish to use to develop new lines of inquiry, and student contributions to faculty work at all other stages of a research project should be considered an essential component of research at undergraduate institutions.

About the Author

Rachel A. Bergstrom is an assistant professor of biology at Beloit College in Beloit, WI. She is a SENCER Leadership Fellow with two major arms to her research agenda: 1) identification and quantification of ictal and interictal events in EEG, with a focus on seizure diagnosis and prediction, and 2) the intersection of identity and education in STEM, specifically how group work impacts the student experience in the classroom and is related to persistence in STEM.

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