

ARTICLE

The Design, Implementation, and Assessment of an Undergraduate Neurobiology Course using a Project-Based Approach

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Project-based learning (PBL) is a student-centered approach that allows students to build on prior knowledge and address relevant problems while working on challenging projects. PBL is well-suited to undergraduate neuroscience courses because students are often interested in learning about diseased states of the nervous system, but can be discouraged by having to learn the chemical and cellular mechanisms underlying pathologies in a lecture-based learning environment. PBL provides students with a significant learning experience that excites them and can help them learn challenging content. Drawing from the recommendations of multiple STEM education reform efforts, I examined the effectiveness of using PBL in an undergraduate neurobiology course to provide students with significant and engaging learning experiences. Students were grouped into teams using a

guild system and completed three substantial projects consisting of team-authored research papers and poster presentations. Each project was designed to address fundamental neuroscience concepts using a real-world problem. By the end of the course, students were more confident in their understanding of neuroscience and had greater understanding of neuroscience concepts. Student attitudes toward working on projects or working as a member of team did not change but remained positive throughout course. Taken together, these results suggest that PBL can be an effective way to actively engage students while allowing them to learn, integrate and communicate core neuroscience concepts.

Key words: project-based learning (PBL); undergraduate; neuroscience; neurobiology; self-efficacy; content knowledge; attitude; confidence; team

Many recent STEM education initiatives have described the need for changes in undergraduate science curricula to address the complex, contemporary issues facing our society (National Research Council (US) 2009; Labov et al., 2010; AAAS, 2011). The need to thoughtfully prepare future neuroscientists at the undergraduate and graduate level has also been highlighted (Hardwick et al., 2006; Akil et al., 2016). The modern neuroscience student must learn to think critically and integrate information from across disciplines in a meaningful way (AAAS, 2011). To meet these goals, undergraduate neuroscience courses need to be designed, not only to impart content knowledge, but also foster independent thinking, scientific inquiry and communication skills (Kerchner et al., 2012).

One way to address this need is to move away from traditional lecture-based teaching and move toward student-centered teaching (Knight and Wood, 2005; Regassa and Morrison-Shetlar, 2007; Armbruster et al., 2009). Student-centered teaching enables instructors to design courses that actively engage students by considering their prior knowledge and interests (Handelsman et al., 2007; Slavich and Zimbardo, 2012; Freeman et al., 2014). Engaging students in an active learning environment provides opportunities for students to develop skills necessary to make sense of a rapidly growing body of literature, collaborate with others and communicate effectively.

An example of a student-centered learning that takes both an active and collaborative approach is project-based learning (PBL). PBL draws from the constructivist approach of adding new knowledge to a framework of prior knowledge through research, conversations, activities, and

investigation (Piaget, 1959; Vygotsky, 1978; Perkins, 1991). This method centers on the learner and requires students to focus their learning around challenging, complex, meaningful questions or projects (Thomas, 2000; Helle et al., 2006; Markham, 2012). Well-designed projects allow students to use critical thinking, problem-solving, and investigative skills in a self-directed manner (Jones et al., 1997). Students are expected to produce projects that are high-caliber and relevant to real-world outcomes in the subject field with the instructor acting as an advisor (Wright and Boggs, 2002; Brunetti et al., 2003; Martinich et al., 2006).

PBL has five essential elements: 1) the project (a relevant problem or question that needs a solution), 2) student-centered activities (well-designed learning opportunities that allow students to take initiative and ownership of the project and their learning) 3) substantial time (enough time to allow for meaningful work to occur), 4) product (paper, poster, computer model, etc.) and 5) the instructor acting as an advisor and guide throughout the entire process (Thomas, 2000; Helle et al., 2006; Markham, 2012).

PBL can be done by individual students but is more commonly carried out by teams of students which fosters collaborative and cooperative learning (Dillenbourg, 1999). The teamwork aspect of PBL allows students to augment their learning through interactions with teammates, classmates and instructors (Vygotsky, 1978; Dillenbourg, 1999; Helle et al., 2006). During project work, team members can distribute tasks (cooperative learning) and work together on combining individual pieces into the final product (collaborative learning). The instructor interacts

with the student as an advisor and/or facilitator rather than delivering content in a lecture-based format. Students also interact with their classmates when presenting their final projects.

The project-based approach has been used extensively in engineering undergraduate classrooms (Dutson et al., 1997; Frank et al., 2003; Dym et al., 2005; Schaffer et al., 2012) but has not been as widely implemented in undergraduate life science courses. The biology courses that have implemented a PBL approach have shown increased critical thinking and analysis, course engagement, and interest in basic research (Wright and Boggs, 2002; Treacy et al., 2011). Furthermore, students reported greater course enjoyment and demonstrated an enhanced ability to navigate resources and the ability to communicate complex ideas (Wright and Boggs, 2002; Treacy et al., 2011). In addition, the PBL approach has been shown to be effective in providing practical field experience for career preparation (Martinich et al., 2006).

Integrating project-based learning into more biology and life sciences courses including neurobiology and neuroscience could be one way to effectively teach content while keeping students engaged. Undergraduate neuroscience courses are inherently interdisciplinary and can cover a wide-range of topics including development, cellular mechanisms, sensory and motor systems and diseases. Students are often interested in learning about the behaviors associated with the diseased states of the nervous system, but are frequently turned-off by having to learn the biological and cellular mechanisms underlying various pathologies. It can, therefore, be a challenge to provide students with significant learning experiences that they are excited about. Various methods have been used to teach neuroscience to undergraduates including: problem-based learning (Barrows and Mitchell, 1975; Roesch and Frenzel, 2016), case studies (Meil, 2007), computer simulations (Av-Ron et al., 2006), active learning (Lom, 2012), and the use of scientific and non-scientific literature (Lynd-Balta, 2006; Hoskins, 2008; Willard and Brasier, 2014).

Here, I describe the design and implementation of a project-based undergraduate neurobiology course. The entire course revolved around three main projects, each designed to engage and excite students. Using a backward design approach, I planned projects that would allow students to learn fundamental neuroscience concepts (Kerchner et al., 2012), integrate information from other disciplines, collaborate with teammates, and develop their writing and presentation skills. I hypothesized that employing PBL in an undergraduate neuroscience course would 1) promote learning of neuroscience concepts/knowledge, 2) build confidence in understanding neuroscience concepts as well as promote positive attitudes towards neuroscience; and 3) show that higher confidence and positive attitudes of students would correlate with higher neuroscience knowledge.

COURSE DESCRIPTION AND DESIGN

Neurobiology (BIOL 3360) is a four-credit, upper-level elective for undergraduate biology majors at Stockton

University in NJ, USA. The course described below met twice-a-week during a 15-week semester and each class meeting was 110 minutes long. The course was taught by one instructor and did not have a laboratory component.

Course Learning Goals

Neurobiology learning outcomes:

- Explain how cells, tissues and subdivisions of the nervous system are organized and associated with specific functions.
- Describe specific features of neurons that give their membranes the potential to be excited.
- Understand how ion gradients work together to generate and modulate action potentials.
- Describe synaptic transmission, including electrical and chemical synapses and the vesicular component of synaptic transmission.
- Relate how membrane, cytoskeletal and protein synthesis components are used to support neuronal function.
- Know how different neurotransmitter systems work including gated channels and g-protein coupled receptors and how they are linked to second messengers.
- Describe the somatic sensory system and how it transduces and transmits external stimuli.
- Understand spinal and brain control of movement.
- Understand the molecular basis for learning and memory.

Foundational learning outcomes:

- Develop the ability to effectively communicate scientific ideas, in writing, orally and using visual aids (graphs, diagrams, flowcharts, etc.).
- Develop the ability to manage one's time, work independently and in a team, take initiative, and collaborate.
- Develop the ability to think critically, analyze, synthesize, and use information to solve problems.
- Take greater responsibility for your own learning by identifying challenging concepts and asking meaningful questions and taking appropriate action to enhance your understanding of these concepts.

Teams and Team Formation

There are many different methods available to create teams. I chose a method that emphasizes the importance of functional teams and acknowledges that every student brings both strengths and weaknesses to their team (Wright and Boggs, 2002). Teams were created with the intent of incorporating a diversity of personality types that would be complementary. To identify the different personalities, an activity adapted from Wright and Boggs (2002) allowed students to determine their strength working within a team. Based on their own perceptions, students self-sorted into one of the following categories: administrator, artist, communicator, and expeditor. I grouped students into six-member teams, with each team having at least one member from all four categories. In

addition, attention was paid to avoid grouping good friends, siblings, or romantic couples together in a team. Teams were permanent for the duration of the semester.

Following each project, I utilized activities to address any negative team dynamics. For example, one activity had students identify a constructive or destructive team behavior that they exhibited during the first project (Brunt, 1993). Students shared these behaviors with their teammates and worked together to identify ways to promote constructive team behavior and ways to minimized destructive team behavior.

Buy-In

In my experience, students do not always embrace novel approaches to classroom instruction. To address this potential hurdle, the first week of class was devoted to philosophical buy-in to the project-based approach. Current research highlighting the effectiveness of project-based learning and its prevalence in higher education was discussed with students (Barak and Dori, 2005; Treacy et al., 2011).

To further gain student trust in this approach, a detailed description or “roadmap” of the entire semester was covered at the beginning of the course. This roadmap illustrated the multiple assignments that would contribute to the overall grade. For example, 20% of each team paper is graded as a team assignment, the entire team receives the same grade. However, the remaining 80% of each student’s grade is based on their individual contribution to the paper.

Project Descriptions

Coursework was divided into three main project themes: 1) neurotoxins; 2) spinal cord injury; and 3) cellular mechanisms of learning and memory (Table 1). Within each project theme, each team chose a specific topic for their project. For example, one team chose to research botulinum toxin for the neurotoxin theme. These project themes were chosen, in part, based on an article from Cleland (2002) suggesting that many of the principles theme, molecular mechanisms of learning and memory, was chosen because it aligned with components of basic

Project Topic	Project Description	Basic Neuroscience Knowledge Component
Project 1: Neurotoxins	<ul style="list-style-type: none"> • Choose a neurotoxin and describe relevant background information, including biochemistry, method of entry, extracellular/intracellular mechanisms of activity and deleterious effects/pathologies. • Describe previous research on treatments available, addressing side effects, and other relevant information. • Design a novel treatment against the toxin utilizing a unique method of action at the cellular level. Describe how to measure if the treatment is working, quantify treatment results and any potential risks or side effects associated with the new treatment. 	<ul style="list-style-type: none"> • Understanding the cellular and molecular function of neurons, including how neurons communicate. • Understanding of basic neuroanatomy.
Project 2: Spinal Cord Injury	<ul style="list-style-type: none"> • Describe spinal cord injury (SCI), at the anatomical level (primary spinal cord injury: trauma to the spinal cord and neuronal damage) and at the cellular and physiological level (immune response, excitotoxicity, apoptosis, etc.). • Choose an experimental treatment for SCI other than methylprednisolone. Describe how the treatment works at the cellular level. Describe the current research, the positive and negative aspects and how and why you would modify this treatment to make it more effective. • Describe a quality of life issue associated with SCI (neuropathic pain, sexual function, autonomic dysreflexia, bowel/bladder function, mobility, respiration, etc.). Describe the neuroanatomical pathways associated with normal functioning of the quality of life aspect. Describe how the pathway is altered during SCI and what dysfunction it results in. Describe any treatment options that exist and how and why would you modify this treatment to improve it. 	<ul style="list-style-type: none"> • Understanding the cellular and molecular function of neurons, including how they communicate. • Understanding of basic neuroanatomy. • Understanding of sensory and motor systems. • Understanding development and plasticity of the nervous system.
Project 3: Learning and Memory	<ul style="list-style-type: none"> • Choose a paper on learning and memory, focusing on invertebrate or avian research. • Provide relevant background information on learning and memory, explaining relevant neuroanatomy, pathways, mechanisms, etc. Describe previous experiments and what questions remained that led to subsequent hypothesis addressed in the paper. • Choose three questions or key areas from the paper that need to be investigated further. Describe how these areas might be investigated further and what experiments your team would design to answer these questions. 	<ul style="list-style-type: none"> • Understanding the cellular and molecular function of neurons, including how they communicate. • Understanding of basic neuroanatomy. • Understanding of sensory and motor systems, as they relate to neuroscience. • Understanding development and plasticity of the nervous system. • Understanding of behavior and cognition.

Table 1. Description of the three main projects and what basic neuroscience knowledge component each project aligned with. Basic neuroscience knowledge components were defined by the Faculty for Undergraduate Neuroscience (Kerchner et al., 2012).

neuroscience knowledge (Table 1) outlined by the Faculty for Undergraduate Neuroscience (Kerchner et al., 2012) that were not covered in the first two projects. Projects were also designed to meet the essential components of project-based learning. Each project required a description of relevant background information to the project topic focusing on neuroscience concepts, a review of previous research on the topic, and an attempt at solving a real-world problem associated with the topic (Table 1). Course concepts were taught using mini lectures (~30 minutes) and student-centered activities that allowed students to apply neuroscience concepts to their project topics. Students were given significant class time to work as a team on their projects. The instructor acted as a guide during class and outside of class. Some roles of the instructor included: clarifying concepts, assisting with locating and accessing primary research literature, interpreting primary literature, and focusing project goals.

Class Time

The class met on Tuesdays and Thursdays with each class meeting lasting 110 minutes. The classroom had moveable seats to allow students to group into teams and work face-to-face. To facilitate project completion, most classes began with a mini-lecture by the instructor and an activity that focused on a component of the current project. These mini-lectures were intended to deliver essential information and focus student work on important aspects of their project. For example, in the neurotoxin project, a mini-lecture was delivered on the role of ion channels in the action potential. Students were then asked to work on the following questions with their teams: “How does your neurotoxin affect the action potential? Does it affect an ion channel? How? What effects does this have on the neuron? The animal? Explain.” Students worked with their teams, using laptops, to find this information in the primary literature. Teams were also required to report or present their findings to the class. This was either done at the end of class, at the beginning of the next class, or in a written document that students turned into the instructor. Requiring students to report their findings was necessary to keep students on task during class time. Furthermore, having activities that were directly related to their projects helped students focus their efforts rather than spend time trying to figure out where to begin.

Primary Literature

To obtain information for the projects, students needed to successfully locate, access and interpret appropriate scientific literature. Because this course is an upper-level elective most students had experience in this area through prior coursework or from a required scientific literacy course. Therefore, explicit instruction was not provided; rather, the instructor built upon their prior knowledge and worked with teams and individual students as needed. Some students were less proficient in searching and accessing scientific literature, so the instructor modeled search techniques and strategies for them. Access to primary journal articles can be a challenge for smaller schools that do not have large library budgets. In

instances where students could not readily access a paper, they were encouraged to find them using Google Scholar or request them through interlibrary loan.

The ability to read and interpret primary literature varied among students. To address this, the instructor worked with teams during and outside of class to help them develop these skills and identify key information utilizing evidence-based methods (Hartman et al., 2017). Handouts on how to paraphrase and cite scientific literature were also provided. Finally, instructor comments on written assignments helped students identify areas that needed improvement.

Weekly Check-In

Each team was required to complete a weekly online check-in, to keep the instructor abreast of the team's progress and any problems teams were experiencing. Two members of each team were selected as team leaders for each project. This responsibility rotated among students within teams between each project ensuring each student had an opportunity to be a leader. The primary responsibility of team leaders was to update a weekly check-in discussion thread in an online course management system. Each weekly check-in contained: 1) project log – details of each team meeting, who was in attendance and what was accomplished; 2) team health summary – a description of general progress on the project and how well the team is interacting and functioning; 3) team update - any concerns that the instructor should be aware of (Wright and Boggs, 2002). A small percentage of points were awarded for completing the weekly check-in assignment.

Homework Assignments

To ensure that students began each project with a general understanding of each project topic, they were given a homework assignment. Homework assignments required students to read a review paper in the area of the project and answer five questions about the paper. The homework questions asked students to summarize key content in their own words and identify terms or ideas they were previously unfamiliar with. Questions were similar for all three projects and increased the likelihood that students would closely read the review article and promoted meaningful in-class work.

Papers

Each project culminated in a paper co-authored by all team members. There were no word count or page number requirements. However, students needed to write enough to demonstrate their understanding of the concepts. Each student was required to make meaningful contributions to the paper and to write their name above sections that they specifically authored. Individual students could report authorship of specific paragraphs or sections, multiple students could report co-authorship of a paragraph or section, or the entire team could report authorship of a paragraph or section. Students engaged in peer-editing of their team members writing, even though editing a section did not count as authorship. Even though each paper was

authored by multiple students, it was required that the paper read as if it had been written by a single author. This was achieved by encouraging students to avoid redundancy and incorporate smooth transitions between sections authored by different team members. Papers were graded using two rubrics (see Supplementary Material). The team rubric focused on cohesiveness, sources and citations, and overall paper preparation and counted toward 20% of the grade. The individual rubric (80% of the grade) was used to grade all sections authored by a single student (Anon, 2012). The individual rubric focused on the student's ability to articulate their understanding of key concepts which required them to thoroughly research the topic, integrate information, and write efficiently. To calculate a student's paper grade, their score on the individual rubric was combined with the score from the team rubric.

A draft of the paper was due approximately 10 days prior to the final due date. This allowed the instructor to make comments on content, depth, ideas, paraphrasing, citations, etc., and for students to see if there were any glaring errors, weaknesses, or problems. Papers were submitted to the online course management system and all team members could see all comments. Following draft comments, class time was used for teams to read their papers together, make comments and discuss strategies to improve the paper. This allowed students to hear their words read aloud, look for topic sentences and to see if they had provided enough information to support their statements. During these sessions, the instructor moved around the classroom working with each team. Writing is an iterative process. Receiving feedback on drafts from peers and the instructor encouraged students to reflect on their writing and improve it.

Poster Presentations

Teams were required to create and present a poster for each project. Quality and attention to detail was expected to be on par with posters presented at a scientific research meeting. Poster sessions were made as professional as possible and faculty from the natural and social sciences attended. Prior to the first poster session, an entire class session was devoted to discussing poster design, printing and presentation. Students were given a rubric and asked to evaluate three posters of their choice displayed in the science building at Stockton University. These posters were presented by students at regional and national conferences and contain both positive and negative poster design elements. The poster rubric (see Supplementary Material) was modified from the rubric used to judge the 2013 National Science Foundation (NSF) Integrative Graduate Education and Research Traineeship (IGERT) video and poster competition (www.igert.org). A discussion of the positive and negative attributes of the posters evaluated led to a list of items (content, font size, images, flow charts, references, etc.) for the students to address when creating a poster.

Teams presented each one of their projects at three separate poster sessions. All students were required to present at every poster session. Each team member was

required to be prepared to discuss all parts of the poster. This was done to prevent students from dividing up the content and "mastering" a specific section. To encourage students to have meaningful interactions with their classmates, they were required to evaluate other team's posters during the poster session using the poster rubric.

ASSESSMENT

Students enrolled in Neurobiology (BIOL 3360) during the fall 2013 semester were invited to participate in this study. The class consisted of 31 seniors and 6 juniors. The majority of students were biology majors (97%) and only 4 students were also enrolled in the behavioral neuroscience minor. For most of the students this was their first neuroscience course. Thirty-four out of 37 students (92%) completed both pre and postsurvey/posttests. All human subject research was approved by the Stockton University Institutional Review Board.

Content Knowledge Assessment

Pre and post tests were administered to students to measure changes in neuroscience content knowledge. To the best of my knowledge, at the time of the study there was no published neuroscience inventory used to measure student mastery of neuroscience concepts. Therefore, I chose 19 multiple-choice and true/false questions from the test bank of *Neuroscience: Exploring the Brain* (Bear et al., 2007), an undergraduate neuroscience textbook, that addresses major concepts in neuroscience. Questions from four categories: neuroanatomy (4 questions), synaptic transmission (3 questions), resting membrane potential/action potential (9 questions), and second messengers (3 questions) were included (see Supplementary Material).

Confidence and Attitude Assessment

Students completed pre and post surveys during the first and last week of classes, to measure changes in 1) confidence in neuroscience knowledge, 2) attitudes toward neuroscience, 3) attitudes toward working with a team, and 4) attitudes toward working on projects. Survey statements that addressed confidence in neuroscience knowledge and attitudes toward neuroscience were modified from the Student Assessment of Learning Gains (SALG) (Frantz et al., 2006). Statements that addressed working in teams were modified from a preexisting questionnaire (Parmelee et al., 2009). Statements that addressed attitudes toward working on projects were of the instructor's own design. Students rated their level of agreement on a Likert scale ranging from 4 (Strongly Agree) to 0 (Strongly Disagree) for 28 statements (Table 2).

Analysis

Wilcoxon signed-ranked tests were used to measure learning gains on pre and post neuroscience content knowledge tests. Effect size was estimated by calculating Cohen's r (Cohen, 1988; Pallant, 2007; Fritz et al., 2012). For pre and post course neuroscience content knowledge tests, the total number of questions answered correctly by each student in each category (neuroanatomy [4

questions], synaptic transmission [3 questions], resting membrane potential/action potential [9 questions], and second messengers [3 questions]) was determined. The overall content test score was determined by taking the sum of all correctly answered questions in all categories (Figure 1).

Internal consistency within the attitude and confidence surveys was calculated using Cronbach's alpha. To compare pre course and post course responses to attitude and confidence statements, Wilcoxon signed-rank tests were used. First, the degree of change for each individual question was calculated, then changes for each category of questions were calculated. The mean response (combined total) for each student in each category of questions (confidence in neuroscience knowledge [7 questions] attitudes toward neuroscience [4 questions], attitudes toward working in teams [13 questions], and attitudes toward working on projects [4 questions]) was also calculated (Table 2, Figure 2).

Correlations between responses to attitude and confidence statements and the neuroscience content test were identified using a Spearman correlation analysis (Figure 3).

RESULTS

Hypothesis 1: Utilizing PBL promotes learning of core neuroscience content.

Students answered 19 multiple choice and true-false questions on both the pretest and posttest. Across all questions, students answered more questions correctly on the posttest (mean score 10.265 ± 0.459) than the pretest (mean score 9.177 ± 0.404 , $z = -2.097$, $p = 0.036$, Wilcoxon signed-rank test, $r = 0.254$, Cohen's r). Questions were subdivided based on content assessed: neuroanatomy (4 questions), synaptic transmission (3 questions), resting membrane potential/action potential (9 questions) and second messengers (3 questions). Performance significantly increased on neuroanatomy questions (pretest mean score 1.588 ± 0.127 , posttest mean score 2.00 ± 0.169 , $z = -2.200$, $p = 0.028$, $r = 0.266$). There were no significant changes in synaptic transmission (pretest mean score 1.765 ± 0.174 , posttest mean score 1.841 ± 0.146 , $z = -0.969$, $p = 0.333$, $r = 0.117$), resting membrane potential/action potential (pretest mean score 4.177 ± 0.272 , posttest mean score 4.647 ± 0.301 , $z = -1.146$, $p = 0.252$, $r = 0.138$), or second messengers (pretest mean score 1.647 ± 0.146 , posttest mean score 1.677 ± 0.125 , $z = -0.183$, $p = 0.855$, $r = 0.022$, Figure 1).

Hypothesis 2: The PBL approach to teaching neuroscience helps students build confidence in their understanding of neuroscience as well as promote positive attitudes towards neuroscience.

Confidence and attitude surveys displayed high internal consistency across all items. Confidence in neuroscience knowledge consisted of 7 items (pretest, $\alpha = 0.868$; posttest $\alpha = 0.937$), attitudes towards neuroscience consisted of 4 items (pretest, $\alpha = 0.824$; posttest $\alpha = 0.937$), attitudes towards working in a team consisted of 13

items (pretest, $\alpha = 0.926$; posttest, $\alpha = 0.946$) and attitudes towards projects consisted of 4 items (pretest, $\alpha = 0.753$; posttest $\alpha = 0.910$).

During the first week of class, students reported a neutral opinion on 7 questions designed to measure confidence in their understanding of neuroscience and how it relates to other science classes (mean Likert score across 7 questions = 2.033 ± 0.110 , Table 2, Figure 2). The strongest agreement was with attitudes towards learning neuroscience (mean Likert score across 4 questions = 2.919 ± 0.145); however, students did not

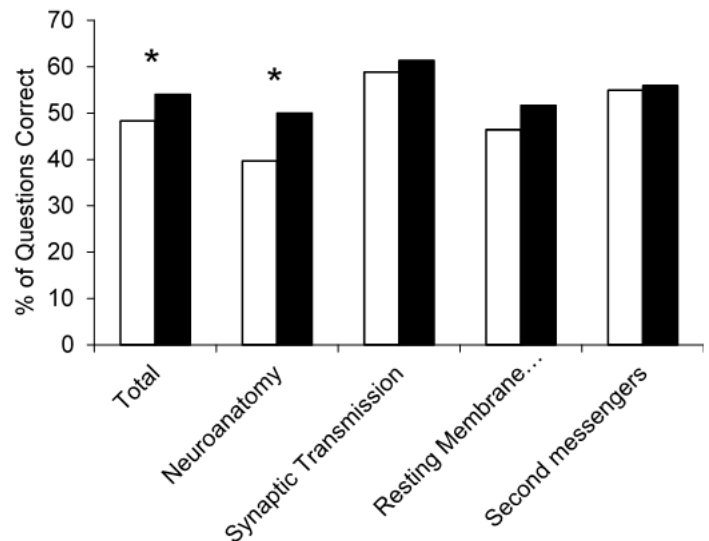


Figure 1. Percentage of correct responses students gave to neuroscience content questions. Total questions (19) were divided into four categories: neuroanatomy (4), synaptic transmission (3), resting membrane potential/action potential (9) and second messengers (3). Student responses on pretests (white bars) vs. posttests (black bars) were compared. $N = 34$, * $p < 0.05$, Wilcoxon signed-rank test.

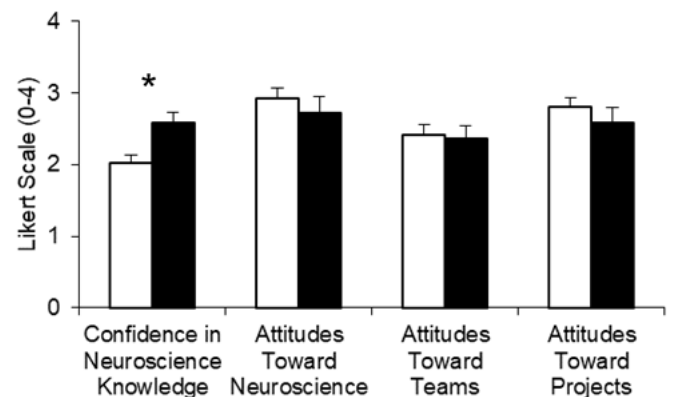


Figure 2. Student-reported confidence and attitudes toward aspects of neuroscience content and project-based learning. Comparison of students' pretests (white bars for mean \pm SEM) vs. posttests (black bars for mean \pm SEM). $N = 34$, * $p < 0.05$, Wilcoxon signed-rank test.

Question	Pretest		Posttest		p
	Mean	SEM	Mean	SEM	
Confidence in Neuroscience Knowledge					
I understand the main concepts of neuroscience.	2.706	0.182	2.765	0.189	0.009*
I understand the relationship between concepts in the field of neuroscience	1.912	0.191	2.706	0.187	0.014*
I understand how concepts in neuroscience relate to ideas in other science classes.	2.206	0.202	2.941	0.239	0.049*
I am confident in my understanding of cellular neuroscience.	1.677	0.145	2.324	0.162	0.002*
I can think through a problem or argument in neuroscience.	2.029	0.161	2.647	0.183	0.012*
I am confident in my ability to do neuroscience.	2.088	0.199	2.441	0.165	0.132
I feel comfortable with the complex ideas in neuroscience.	1.618	0.207	2.235	0.174	0.007*
Combined Total	2.033	0.110	2.580	0.159	0.004*

Attitudes Toward Neuroscience					
I am interested in learning more about the cellular aspect of neuroscience.	3.265	0.186	2.706	0.259	0.144
I appreciate neuroscience.	3.206	0.178	3.029	0.255	0.669
I am enthusiastic about studying neuroscience.	3.412	0.175	2.853	0.239	0.052
I enjoy teaching neuroscience to others.	1.794	0.183	2.324	0.234	0.075
Combined Total	2.919	0.145	2.728	0.226	0.658

Attitudes Toward Working with a Team					
I have found working as part of a team in my classes to be a valuable experience.	2.147	0.169	2.353	0.249	0.506
In most of the teams I have been on, the other team members have generally contributed as much as I have.	1.912	0.213	2.441	0.243	0.130
In most of the teams I have been on, the team has worked well together.	2.294	0.200	2.412	0.207	0.551
In most of the teams I have been on, I felt the other team members respected me.	2.823	0.166	2.735	0.212	0.720
I have found teamwork to be a productive use of course time.	2.118	0.188	2.235	0.231	0.704
I have found that teams help me learn course material more than if I just studied alone.	2.412	0.224	2.118	0.242	0.541
I have learned more in courses where I have been a member of a team.	1.970	0.191	2.000	0.189	0.618
I have found being part of a team improves my course grades.	1.971	0.177	1.824	0.255	0.610
I have found that being on a team has helped me become better at problem solving.	2.176	0.171	2.529	0.232	0.216
I have found that teams make good decisions.	2.147	0.159	2.235	0.203	0.747
Being part of a team discussion has improved my ability to think through a problem.	2.618	0.169	2.618	0.231	0.972
I have found that working with a team helps me develop skills in working with others.	3.118	0.162	2.677	0.252	0.185
I have found that working with a team has helped me develop cooperative leadership skills.	2.971	0.166	2.647	0.249	0.377
Combined Total	2.424	0.141	2.371	0.180	0.739

Attitudes Toward Working on Projects					
I prefer working on projects in class when compared to a traditional lecture class format.	2.265	0.176	2.324	0.245	0.919
I enjoy working on class projects with real world applications.	2.882	0.183	2.735	0.247	0.739
I prefer to learn science from practical experiments or projects.	2.882	0.173	2.324	0.252	0.135
Working on "real world" problems will be beneficial to my future career.	2.971	0.177	2.941	0.256	0.837
Combined Total	2.800	0.138	2.581	0.222	0.885

Table 2. Wilcoxon Signed-Rank Test of Significance for Confidence and Attitudes. 4 = Strongly Agree, 3 = Agree, 2 = Neither Agree nor Disagree, 1 = Disagree, 0 = Strongly Disagree. N = 34, * significant at 0.05 level.

seem confident in their ability to teach neuroscience to others (Likert score 1.794 ± 0.183). Students weakly endorsed statements that addressed the effectiveness of working in teams (mean Likert score across 13 questions = 2.424 ± 0.141) and work on course projects (mean Likert score across 4 questions = 2.800 ± 0.138 , Table 2, Figure 2).

By the end of the course, students reported significantly higher confidence in neuroscience knowledge (mean Likert score across 7 questions = 2.588 ± 0.110 , $z = -2.849$, $p = 0.004$, Wilcoxon signed-rank test, $r = 0.345$, Cohen's r).

Responses to the statement "I am confident in my ability to do neuroscience" was the only one that did not show a significant increase ($p = 0.132$). There was no change in attitudes toward neuroscience ($z = -0.442$, $p = 0.658$, $r = 0.053$), toward working in a team ($z = -0.333$, $p = 0.739$, $r = 0.040$) or working on projects ($z = -0.145$, $p = 0.885$, $r = 0.017$, Table 2, Figure 2).

Hypothesis 3: Increased confidence and attitudes toward neuroscience are correlated with higher neuroscience knowledge.

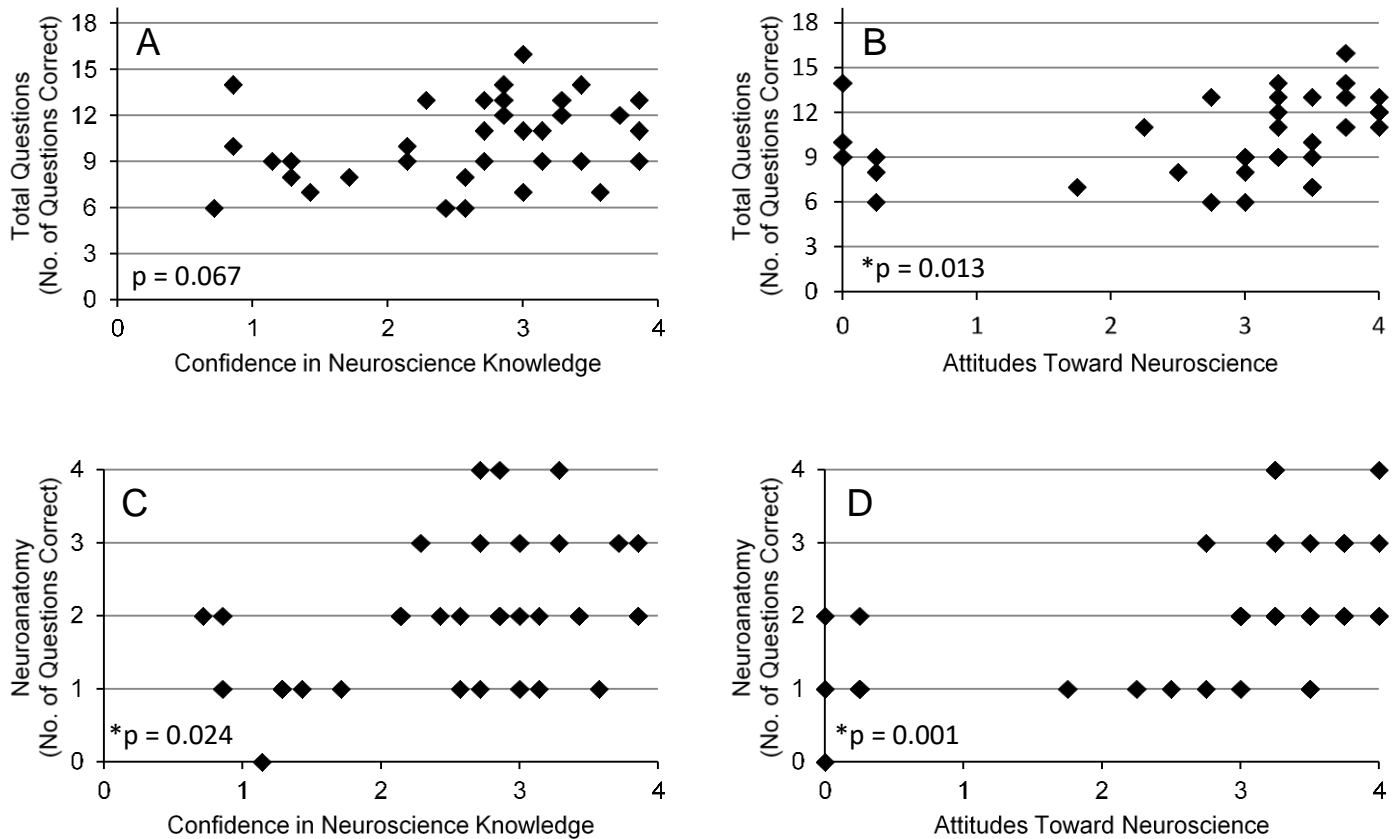


Figure 3. The relationship between neuroscience content knowledge and confidence and attitudes towards neuroscience. p-values were generated using a Spearman correlation analysis.

Student confidence in their neuroscience knowledge did not significantly correlate with ability to correctly answer neuroscience content questions ($r = 0.318$, $p = 0.067$, Spearman correlation analysis, Figure 3A). Conversely, as student attitudes toward neuroscience increased so did their ability to correctly answer neuroscience content questions ($r = 0.421$, $p = 0.013$, Spearman correlation analysis, Figure 3B). Student confidence in knowledge of neuroscience positively correlated with the ability to correctly answer the subset of questions specific to neuroanatomy ($r = 0.387$, $p = 0.024$, Spearman correlation analysis, Figure 3C). In addition, as student attitudes toward neuroscience increased so did their ability to correctly answer neuroanatomy questions ($r = 0.551$, $p = 0.001$, Spearman correlation analysis, Figure 3D). There were no significant correlations between attitudes toward teamwork and projects when compared to total neuroscience questions or the four subcategories (p values ranged from 0.140 to 0.946, Spearman correlation analysis).

DISCUSSION

Using Problem Based Learning (PBL) allowed students to learn, connect and integrate concepts across neuroscience disciplines while working with teammates on three challenging and relevant neuroscience projects. The primary motivation behind designing a project-based

course was to actively engage students to learn and communicate complex ideas in neurobiology while maintaining their enthusiasm for the subject matter. PBL was effective at promoting learning of core neuroscience concepts as well as increasing confidence in neuroscience knowledge and maintaining interest in neuroscience among students throughout the duration of the course. This is an alternative to traditional lecture-based approaches that depend on a unidirectional flow of information from the instructor to students. This paper provides instructors with an effective framework to incorporate project-based learning in their classes, either using the projects presented here or projects of their own design.

Course Framework

To facilitate team learning, significant class time was allotted for teams to work on their projects. The instructor acted as a guide and moved between teams throughout class. Additionally, students worked outside of class time to complete their projects. When designing the course, the instructor anticipated that much of the work occurring outside of class would be face-to-face; however, most students successfully utilized file sharing technology such as Dropbox (www.dropbox.com) and Google Docs (<https://docs.google.com/>) and group text messaging to communicate and work on their projects virtually. Teams

were able to edit documents and see real-time changes to their papers and posters. Additionally, commuter students or students who did not have the ability to meet face-to-face on a regular basis always had the ability to participate on the projects. Students organized this effort on their own without the assistance of the instructor. Because of the ability to communicate and work together at any time of the day from any location, collaborating virtually seemed to enhance a team's ability to complete papers and prepare posters. Future iterations of the course might include a single platform for all students to use so that the instructor can monitor or assess progress of individual students and teams.

I anticipated that most students would have experience working with a lab partner, but few would have experience working in a true academic team. I used a guild system to build the teams and make students aware of their contribution to team functionality. Students were also asked to identify what constructive and destructive behaviors they often exhibit while working in a team. Examples of constructive team behaviors include cooperating, inspiring other team members to participate, and keeping the team on task. Some destructive team behaviors include withdrawing from team discussions or activities, dominating other team members, and minimizing team member ideas (Brunt, 1993). At the end of each project, an entire class period was spent evaluating team dynamics and determining what improvements could be made moving forward to improve or maintain functional team behavior. This was an effective way for students to recognize healthy team behavior and their role in it. The weekly check-in allowed me to monitor the well-being of each team and intervene with formal team meetings, when necessary. Common unhealthy team behavior included team members not completing their work by a deadline or a single team member dominating the project. It has not been shown whether the guild-system results in better functioning teams when compared to random assembled teams and other methods that identify predetermined skills and abilities or learning styles to form teams (Huxham and Land, 2000; Potosky and Duck, 2014). Overall, students embraced their teams and were successful at overcoming issues that arose during the course.

Another essential element of each project was student access to primary literature. Despite the general increase in access to online journals and the increased speed of interlibrary loan, limited budget allocations to these resources at some institutions could present hurdles to implementation. Instructors considering this approach should evaluate their institutions resources and the ease and speed of access to primary literature when designing projects. In the present study, the instructor needed to work with teams to locate and access papers, but students became adept at navigating the different ways to find the literature they needed.

This paper presents a course framework for project-based implementation, the design of three projects to meet core undergraduate neuroscience learning outcomes and the assessment of content knowledge, confidence and attitudes. Due to the comprehensive nature of the project-

based approach it can address many different learning outcomes, in addition to content knowledge. Instructors could design projects that address critical thinking, scientific literacy, career choice, and quantitative reasoning among many others. Furthermore, each team has some autonomy to steer their project in a direction that interests them. Therefore, PBL courses can vary in their learning outcomes between courses and within a course. This inherent variability is what makes a PBL course engaging for both the instructor and the students, but also makes quantitative assessment difficult.

Content Knowledge Assessment

The three projects were intentionally planned with sufficient breadth and depth to impart essential neuroscience concepts which might typically be covered in an undergraduate neuroscience course (Table 1). The assessment was designed to capture knowledge of four areas most relevant to a neurobiology course and I anticipated that these four areas would be encompassed by the three projects. By the end of the course, students demonstrated modest but significant gains in overall neuroscience content knowledge. The effect sizes observed for these learning gains were near-moderate which provides suggestive evidence that this is an important achievement especially if it can be applied to all students and has cumulative effects over time (Glass et al., 1981, Cohen, 1988). This trend was more carefully evaluated by considering each individual section of the neuroscience assessment. The increase in the number of correct responses was primarily driven by a significant increase in knowledge of neuroanatomy. This could be due to all three projects requiring students to develop a basic understanding of neuroanatomy, while the other three content areas were not as systematically represented in each of the three projects. It is also possible that students came to the course with prior knowledge of neuroscience content from previous coursework.

The inherent variability among and within individual team projects can make it difficult to determine the level of breadth and depth an individual student might learn a concept. For example, one team of students might spend a great deal of time researching the role of sodium channels during an action potential to understand how their chosen neurotoxin works. Another team of students might need to research how acetylcholine antagonists work to understand how their neurotoxin works. Both teams of students learn essential neuroscience content, but it is likely that they learn different concepts at different levels.

Future courses could utilize an assessment that measures a broader set of learning outcomes at different levels of mastery. This might provide a better estimate of the different content learned across students in a course, but it might still be challenging to document learning gains unless there is a great deal of topical overlap between the projects completed by students. While gains in neuroscience content knowledge were challenging to assess in the present study, other response variables such as confidence and attitudes are less dependent on the content addressed within different projects.

Even though PBL significantly promoted learning it did not result in high learning gains. It might be that PBL courses inherently result in differences in learned content among students. Even though learning outcomes were clearly defined, and the projects were designed to meet them, the instructor has considerably less control over content delivery than in a traditional lecture-based course. This difference could have led to the moderate learning gains observed using the content knowledge assessment instrument. Instructors could potentially tighten the alignment of team projects to force more overlap in content knowledge across students, but this could limit student autonomy. As instructors increase their influence on team projects the benefits of PBL can become diluted. Instructors should consider this compromise when choosing to utilize the PBL approach.

Confidence in Neuroscience Knowledge

Confidence in neuroscience knowledge significantly increased in six out of the seven statements over the duration of the course. These results are consistent with a study that used a collaborative learning model to engage undergraduate students in neuroscience research (Frantz et al., 2006) and with a project-based undergraduate engineering course (Schaffer et al., 2012). The increase in confidence in neuroscience knowledge may be due to the project-based nature of the course. Because students were responsible for directing their own learning and solving real-world problem by critically evaluating peer-reviewed literature in the field, they were empowered to make meaning of the material in a self-directed manner. The only statement where there was not a significant increase in confidence was, "I am confident in my ability to do neuroscience." This statement specifically addressed carrying out neuroscience research, so the non-significant result was not surprising because the course did not include a laboratory component. Increases in confidence in content knowledge across classroom and laboratory contexts within neuroscience and across different fields strongly suggests that project and team-based approaches to learning can be applied in a wide range of courses and fields.

Attitudes Towards Neuroscience, PBL, and Teams

Students began the course with high enthusiasm and interest toward neuroscience and this interest was maintained throughout the semester. As a result, student attitudes toward neuroscience did not change markedly over the semester. In addition, attitude scores toward neuroscience were the highest across all questions on the presurvey. Students began the course with high interest in neuroscience and ended with high interest. This suggests that the PBL approach was successful at maintaining student interest in neuroscience throughout the duration of the course.

Although there were no significant differences between presurvey and postsurvey scores on neuroscience attitude questions, an interesting finding emerged. In response to the statement "I am enthusiastic about studying neuroscience" there was a marginally significant decrease

in attitude ($p = 0.052$, Wilcoxon signed-rank). One possible explanation for this result is that students began to appreciate the challenges associated with developing a thorough understanding of neuroscience content and may have initially overestimated their abilities. This finding is in direct contrast to a research intensive undergraduate neuroscience summer program designed to attract students to research careers. Franz et al. (2006) showed that attitudes towards neuroscience among students immersed in a summer research program, significantly increased at the end of the research experience. Again, this difference may be a result of students gaining more confidence when exposed to the hypothesis-driven research laboratory environment.

Student attitudes toward working in teams or on projects did not significantly increase or decrease over the course of the semester. Student attitudes toward working on projects were weakly positive at the beginning of the course and did not change. Working on significant projects as the primary learning tool is not a common approach to instruction in biology at Stockton University. For most students, this was the first time they were in course that did use a traditional lecture-based approach. A similar pattern emerged when looking at students' attitudes toward teamwork. Students began the course with an overall median (weakly positive) attitude toward working on teams and ended with the same level of attitude.

This was consistent across all subcategories of team-related statements such as: satisfaction with the team experience, team impact on quality of learning, team impact on reasoning ability, and professional development. Students may be reluctant to acknowledge or unable to assess the impact of the team on their performance. First- and second-year medical students exhibited similar perspectives on teamwork (Parmelee et al., 2009). These medical students did not show any change in mean attitudes toward satisfaction with the team experience, team impact on quality of learning, and team impact on reasoning during a team-based course.

Self-Efficacy

Self-efficacy or student's perceptions of their performance capabilities has been shown to be an important component of student achievement (McMillan and Forsyth, 1991; Bandura et al., 1996; Zimmerman, 2000). Students self-reported confidence levels may influence their motivation to persevere on a challenging task (Lent et al., 1986). Results from this study indicate that students with high attitudes towards neuroscience correlated with higher neuroscience content knowledge. There was also a positive trend for a relationship between confidence and content knowledge, but this trend was only significant when considering confidence and knowledge of neuroanatomy specifically. These results are similar to findings of self-efficacy scores in undergraduate engineering and foreign language courses (Mills, 2009; Schaffer et al., 2012).

The role of self-efficacy, confidence and attitudes triggered by using a project-based approach may be an important motivator that contributes to student learning. Not only does this approach focus on students learning in a

constructivist manner, but it also engages students in exciting real-world problems. The convergence of these two important educational theories: constructivism and self-efficacy may be what drives learning gains, promotes positive attitudes, and enhances confidence in the project-based learning environment.

Conclusion

Carefully designed PBL courses can be an engaging and effective way to teach undergraduate neuroscience. They transform student educational experiences from passive lecture-based settings to active, real-world, team-driven learning environments. By utilizing this approach in neuroscience courses, instructors act as guides assisting and motivating students to build and connect core neuroscience concepts to real-world applications. Students also gain practice accessing, understanding and making connections with scientific content across disciplines that contribute to neuroscience. In addition, PBL allows students to work with a team and disseminate their ideas in papers and presentations, all necessary skills for the modern scientist. This study provides support that PBL can help neuroscience instructors achieve goals outlined by STEM initiatives and other essential education venues and make progress towards transforming undergraduate neuroscience education.

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