ARTICLE

"Thinking like a Neuroscientist": Using Scaffolded Grant Proposals to Foster Scientific Thinking in a Freshman Neuroscience Course

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Learning and practicing scientific inquiry is an essential component of a STEM education, but it is often difficult to teach to novices or those outside of a laboratory setting. To promote scientific thinking in a freshmen introductory neuroscience course without a lab component, we developed a series of learning activities and assignments designed to foster scientific thinking through the use of scientific grant proposals. Students wrote three short grant proposals on topics ranging from molecular to cognitive neuroscience during a 10-week class (one quarter). We made this challenging and advanced task feasible for novice learners through extensive instructional scaffolding, opportunity for practice, and frequent peer and instructor feedback. Student and instructor reports indicate that the assignments were highly intellectually engaging and that they promoted critical thinking, a deeper understanding of neuroscience material, and effective written communication skills. Here we outline the mechanics of the assignment, student and instructor impressions of learning outcomes, and the advantages and disadvantages of implementing this approach.

Key words: grant proposal; scientific thinking; novice learners; scaffolding; inquiry; STEM education.

Inquiry is recommended as a core teaching strategy in STEM courses (Handelsman et al., 2004). According to national recommendations on STEM education, "science should be learned and taught as science is done in the real world" (Quitadomo et al., 2008, citing the American Association for the Advancement of Science [AAAS] 1989 and National Research Council [NRC] 1996 and 2000 reports). The most direct way to achieve this goal at the undergraduate level would be to offer students authentic research experiences, particularly early in their academic careers. Previous work has shown that involving freshmen in research improves critical thinking skills and significantly enhances retention in science disciplines, particularly for students from disadvantaged backgrounds (Russell et al., 2007). However, most universities and colleges do not have the capacity to involve all of their freshmen in research experiences. In light of this, we sought to develop a set of learning activities focused around grant proposal writing that would replicate at least some of the benefits of doing authentic research for a large freshmen introductory neuroscience class.

Authentic research experiences allow students to develop questions, plan experiments, and collect, analyze, and interpret data. For scientists in the real world, a major part of this process occurs during the experiment-planning phase, in which scientists develop a specific and testable experimental question, select the most appropriate approach out of many, predict and interpret the data that might be collected, and anticipate potential pitfalls or problems. Often, this plan is formally written up in a grant proposal. Grant proposals require critical thinking, logic, and reasoning and also represent one of the major intellectual things that scientists "do." Therefore, it would seem that requiring students to write grant proposals would reap many of the benefits of authentic research without requiring the use of a lab or materials.

Despite the potential benefits of using grant proposals as a pedagogical tool, only very few cases have been described in literature: Itagaki (2013) and Oh (2005) used grant proposals as a capstone assignment in upper-level undergraduate biology and biomedical sciences courses, while Vaidean et al. (2013) and Evans (1991) outlined their use in graduate-level courses. However, to date, there appear to be no described cases of assigning grant proposals in freshman- or introductory-level courses. Presumably, this is because writing a successful professional-level grant proposal requires content and conceptual knowledge that is beyond what an introductory student could be expected to know. However, given the push for inquiry-based learning at all stages, it is important to examine whether grant proposal assignments can be adapted for an introductory course.

In this article, we describe a series of learning activities and assignments to help students write short grant proposals in a large introductory neuroscience course for freshmen at Stanford University in the Winter quarter of 2014. These activities build a conceptual framework or scaffold that allows students to practice using scientific inquiry to address a problem in neuroscience with little or no prior neuroscience knowledge. In the process, they learn to formulate their own questions, think analytically about experiments, and write clearly and concisely. As students progress through the course and become more familiar with the grant writing process, the scaffolding is gradually reduced. We found that by the end of the quarter, freshmen with little to no prior neuroscience or biology experience were able to write short grant proposals on a wide variety of neuroscience topics. The vast majority of students reported gains in their ability to wrestle with complex scientific questions and experimental approaches and to concisely and effectively communicate their ideas. Overall, we feel that although the grant proposal assignments increased the workload for both instructors and students, they were a worthwhile and rewarding introduction for freshmen into the process of scientific inquiry at the university level.

COURSE DESCRIPTION

The course *How Does Your Brain Work?* is part of the *Thinking Matters* program, a collection of freshmen courses that teach critical thinking, reasoning, and writing across a wide range of disciplines within the humanities and sciences at Stanford. The overarching learning goal of all *Thinking Matters* courses is to help students develop the ability to tackle relevant, real-life problems by asking rigorous questions and developing strategies for their solutions. These courses also emphasize analytical and critical reasoning and effective communication. All incoming freshmen at Stanford must enroll in at least one *Thinking Matters* course during their first year, and in the Winter quarter of 2014, *How Does Your Brain Work*? was one of the most popular classes, drawing 109 students. The course was open to all freshmen and had no prerequisites, but in general it attracted students with more STEM-focused primary interests, including biology, psychology, economics, computer science and engineering. Because Stanford students do not typically declare a major until sophomore year, almost none of the students had formally declared a major.

How Does Your Brain Work? met weekly for two 50-minute lectures and two 50-minute sections. The course material was originally conceived of and designed by Dr. Russell Fernald, a professor in the Biology Department at Stanford, who delivered the lectures on topics ranging from cellular and molecular neuroscience to behavioral psychology. The content was organized into three “units” focused on understanding brain action at three different levels of brain organization: cellular/molecular, systems, and behavioral/cognitive. The lectures included frequent live demonstrations of neuroscientific phenomena, and special emphasis was placed on posing “thought questions” to the students during each lecture. Students were encouraged to collaborate and discuss solutions with their neighbors before volunteering answers to the entire class. Thought questions challenged students to think deeply about the lecture content and, together with section activities, reinforced their sense of scientific inquiry and intuition.

In addition to lecture, all students attended two additional mandatory 50-minute sections of no more than 15 students twice a week, led by one of four postdoctoral lecturers (the authors). The role of sections is to reinforce the lecture material and to help students become rigorous scientific thinkers. We chose to use scientific grant proposal assignments as a way of developing a core set of scientific competencies. Thus, we structured section time around a variety of activities designed to appropriately scaffold the grant-writing process and thereby introduce students to the ways in which neuroscientists approach real problems. We four postdoctoral lecturers designed and led the section activities and assignments, provided feedback on all student work, and evaluated student performance. Additionally, students were required to attend three “tutorial” meetings throughout the quarter, where they met either individually or in small groups with their postdoctoral lecturer.

How Does Your Brain Work? was first taught in Winter 2013, the first year of the *Thinking Matters* program. Winter 2014 was therefore the second time the course was run. However, there had been substantial turnover of the teaching team, and for 2014 we extensively overhauled several aspects of the course, including the readings, section activities, exams, and written assignments. In particular, while the previous iteration of the course focused on evaluating the quality of scientific studies, informal observations suggested that it was difficult for the students to do that if they did not have repeated practice recognizing and creating good scientific studies. Our “Thinking like a Neuroscientist” activities grew out of a desire to develop these scientific thinking and experimental design skills.

MECHANICS OF THE ASSIGNMENTS

To make writing a neuroscience grant proposal feasible for novices with little to no prior neuroscience knowledge, we scaffolded the process in two ways: 1) by providing a structured progression of learning activities and feedback that preceded each grant proposal (termed “Thinking Like a Neuroscientist” activities) and 2) by building constrained experimental environments that provided students with the necessary background information to write a grant proposal while still leaving room for creative problem-solving. Over the course of the quarter, students completed three ‘grant-proposal cycles.’ With each cycle, the scaffolding was progressively removed to allow students increasing ownership and creative freedom.

Figure 1 provides a timeline of the major milestones for each grant proposal cycle within the context of the 10-week course. Each 3-week grant proposal cycle was thematically aligned with lecture content, which was organized into three units: ‘cellular/molecular neuroscience,’ ‘systems neuroscience’ and ‘behavioral and cognitive neuroscience.’ The Thinking Like a Neuroscientist activities consisted of four components applied sequentially over the course of each grant proposal cycle.

Previous research has shown that prefacing instruction with activities in which students invent original solutions to novel problems helps students build a mental organizational framework that prepares them for future learning, even if their proposed solutions are initially suboptimal (Schwartz and Martin, 2004; Day et al., 2010). We therefore began each grant proposal cycle with a **brainstorming activity** in which students brainstormed neuroscience experiments relating to lecture material. Students were presented with a thought question designed to provoke them to evaluate what information they had been given in lecture and what information they still needed in order to answer the question. Then, in small groups and for homework, students brainstormed neuroscience experiments to address their outstanding questions (see Appendix I for brainstorming worksheet). This initial exercise engaged students to assess their own knowledge and to think creatively in preparation for the next activities in our series.

Following the brainstorming activity, the section leader presented a **case study** of an actual neuroscience experiment, using variations of the interrupted case-study method described by Herreid (2005). In this method, the instructor leads students through a published experiment by progressively disclosing components of the experiment in a piece-meal fashion, allowing students to discuss at each stage what they would do next, what results they would predict, or how they would interpret the results. The case study gave students the opportunity to discuss and critique an actual experiment and also provided them with examples of possible questions, experimental approaches, methods and techniques that they could use in their own grant proposals.

Next, students were given the grant proposal prompt, which presented them with a **constrained experimental environment** within which to write their grant proposal. Each prompt was thematically related to the lecture material and specified the lab environment, the experimental context, and the methods that students had at their disposal. Importantly, the prompt also provided students with all the necessary background information to evaluate what questions remained unanswered (see Appendices III-V for grant proposal prompts). The constrained environment was key in making the grant proposal feasible for novice learners, since it eliminated the need for students to be familiar with the scientific literature or conduct their own literature searches.

Students then received **instructor and peer feedback** on their proposal ideas. Students met in small groups and presented their research question and experimental

Unit	**Wk**	**Progression of activities and assignments**			
Cellular/ Molecular Neuroscience	1				
		Brainstorming activity #1			
	2		Case study #1		
				Tutorial #1 (instructor and peer feedback)	
	3				
					Mini grant proposal due
Systems Neuroscience	4				
		Brainstorming activity #2			
	5		Case study #2	Tutorial #2 (instructor feedback, self-reflection)	
	6				Mini grant proposal due
	7				
Behavioral/ Cognitive Neuroscience					
	8	Brainstorming activity #3			
			Case study #3		
	9			Tutorial #3 (instructor and peer feedback)	
	10				Mini grant proposal due

Figure 1. Timeline of the major milestones for each grant proposal cycle within the context of the 10-week course.

approach to their postdoctoral instructor and two of their peers. We called these tutorials "pitch meetings" (see Appendix II for preparatory instruction sheet). In addition to giving students the opportunity to present and receive individualized feedback on their ideas, the tutorial also allowed them to constructively critique each other's plans and compare experimental approaches. Previous research has emphasized the efficacy of targeted and individualized feedback as a means developing expertise (Ericsson, 2006; Lepper and Woolverton, 2002).

Following the tutorial, students wrote a short grant proposal (<1500 words). We chose to structure the assignment with four major sections that compose most common grant proposals: Question & Hypothesis, Experimental Design, Predicted Results and Interpretations & Discussion.

GRADING

Grant proposals were evaluated by the postdoctoral lecturer using a rubric specifically designed for this assignment (see Appendix VI for rubric). The rubric equally weighed both content (such as whether the experimental question was specific and testable, the experiment included the necessary controls, and the student discussed alternate interpretations of results) and the quality of writing (such as whether the proposal was structured well and the wording was concise and specific). Students received comments on specific items from the rubric, as well as a written summary of the main strengths and weaknesses of the proposal. For the first grant proposal, in addition to receiving written comments, students also met individually with their postdoctoral lecturer in a tutorial for oral feedback. Self-reflection on the most difficult aspects of the process, as well as the feedback from the instructor, prepared them for the next grant proposal cycle.

When filling out the rubric, subsections, such as "Experimental Design" or "Wording," were evaluated holistically, paying special attention to the bullet points highlighted in the rubric. Each subsection was assigned a score of +, √ or –. After all the proposals were scored, all the postdoctoral lecturers met to make sure grading was consistent and to assign a number of points to take off per √ or – from 100, generally 2 or 3 points.

To direct the students' attention to and to prioritize our learning goals, we weighted the grant proposal assignment heavily. About 60% of students' final course grade came from the grant proposals and other Thinking Like a Neuroscientist assignments, whereas 40% of the final grade came from three take-home exams that tested their understanding of factual information. Without this emphasis, we feel that students may not have recognized the significance of this assignment, and we emphasized to them that learning to use the tools necessary to write a successful grant proposal can be valuable for all students, regardless of intended major.

STUDENT OUTCOMES

From watching students grapple with how to pose their own scientific questions and plan corresponding experiments, it was evident that the assignments were both intellectually engaging and productively challenging for the majority of students. When asked to self-reflect on the most difficult parts of the process and the areas of greatest improvement, student responses indicated a strong correspondence to the *Thinking Matters* learning goals of formulating good questions, developing systematic approaches to questions, and practicing analytic reasoning and effective communication (Figure 2). Several student comments also highlight their active engagement and sense of ownership over their own learning; multiple students commented that although it was challenging, they enjoyed the process and took pride in their ideas and completed assignments. In addition, several students commented that the grant proposals also contributed to their understanding of factual neuroscience information, suggesting that developing these scientific skill sets may support the learning of factual information.

STUDENT PERCEPTIONS OF THE THINKING LIKE A NEUROSCIENTIST ACTIVITIES

In addition to collecting the self-reflection comments, we gauged student reactions to the Thinking Like a Neuroscientist activities using a brief 15-min survey to determine whether the students believed various elements of the course improved their learning. Although student evaluations do not necessarily correlate with learning, student resistance can cause reduced motivation and engagement (Crouch and Mazur, 2001; Seidel and Tanner, 2013). We believe that when students perceive the gains in their own learning, it causes them to have greater engagement with course material and more overall motivation to succeed in the course.

The survey questions were mostly multiple-choice, although we also included some free-response questions to gather free-form comments and suggestions. The survey was administered anonymously in the last section of the term by an assistant not associated with the course, and none of the instructors were present while students completed it. Although the survey was optional and no reward was offered for completing it, 93 of the 109 students enrolled chose to respond. It should be noted, however, that despite precautions taken to prevent students from feeling pressured in any way, the request for participation in the research study originated from the postdoctoral lecturers, who students knew would determine their final course grades.

In the multiple-choice section of the survey, the students overwhelmingly believed that the Thinking Like a Neuroscientist activities increased their learning. We asked students to what extent the Thinking Like a Neuroscientist activities increased specific scientific competencies such as comprehending complex subjects in neuroscience, formulating good scientific questions, developing experimental design, interpreting the results of an experiment, evaluating the effectiveness of an experimental design, communicating scientific ideas in writing, and making connections across different lecture topics. The results, shown in Figure 3, show that for all of these competencies, an absolute majority of students believed that the activities increased their ability either "very much" or "extremely." In all cases, the number of students who thought that the activities did not increase their ability "at all" was very small, 2% or less. While it is not surprising that the students believed that the Thinking Like a Neuroscientist activities increased their abilities in areas specifically related to grant-proposal writing, such as how to formulate good scientific questions and develop experimental designs, they also believed that these activities increased their abilities in areas that we did not specifically target, such as discriminating between misconceptions and scientific knowledge and comprehending complex subjects in neuroscience. These findings suggest that teaching competencies related to writing grant proposals may also increase competencies in other domains.

When we examined more specifically how much students felt the grant proposals contributed to their learning about factual neuroscience information versus their learning to "think like a neuroscientist" (Figure 4), more students felt that the grant proposals contributed to learning to "think like a neuroscientist" compared to learning factual neuroscience information (X^2 test, $P<0.001$). Interestingly, however, a majority of students

Formulating good questions:
"The most difficult part of this proposal was coming up with a question that was interesting, specific and testable. Many of my original questions were interesting but did not lend themselves to an experiment"
"The most difficult part was coming up with a specific, testable question. I had to choose something that would give unequivocal results that could be interpreted conclusively"
"My question simplicity and testability improved the most since our first proposal exercise. Whereas I began with very convoluted and complicated experimental designs, they are now rational and easy to test"
"The most difficult part of the proposal was deciding exactly what question I wanted to test. There were several possible ways to approach the project, so choosing a specific, interesting, testable question was somewhat hard"
Developing systematic approaches to questions:
"Designing the experiment [was the most difficult part]. Normally in Chem Lab, the experiment is given to us and we follow directions, but in this assignment, I was the creator. It took a bit more thinking, which I think is why this is a Thinking Matters class, and it was really challenging but it made me think like a scientist, so I enjoyed it."
"The most difficult part of writing this proposal was summing up my thoughts to come up with a concise but comprehensive experimental design. I had several ideas for the possible experiment I could design, but none of them offered conclusive evidence. I tried using several [experiments] that could build a case."
"I feel that I improved the most in coming up with controls and being really specific when describing them. My controls are what I am most proud of."
Analytic reasoning:
"[I most improved in terms of] analyzing the relationship between causation and correlation in an experiment: I feel as though I have gotten better at seeing how correlation between two variables can be caused by outside factors"
"The most difficult part of writing the proposal was the interpretation and discussion section. This component required the most thinking because it got me to consider other potential outcomes and interpretations. It was very useful for me […] to talk through my ideas and get feedback regarding this component of the process"
"The most difficult part was anticipating different possible interpretations of the data and designing experiments to ensure your hypothesis was one of the only/the only interpretation of the data."
[I improved the most in terms of] looking conclusively at my experiment to see where it may have pitfalls, and thinking of variables that we can control to ensure the experiment is valid and can prove a cause and effect.
"This project taught me to think critically about a scientific experiment – how to isolate the variables that I was testing using the tools I had access to.
"I'm thinking more carefully about my hypothesis and trying to capture the data that can directly/indirectly prove it"
Effective communication:
"The most difficult part of writing the proposal was ensuring I explained all of my reasoning and methods clearly throughout the work. I have a tendency to not relay all the ideas of reasoning from my head to the paper, so making sure everything that was necessary for the experiment was on paper took the most time. I solved this with lots of revisions"
"The most difficult part for me was keeping my proposal under 1000 words. As I was writing, I found I had a lot to say and really had to work to keep my thoughts concise"
"I thought the most difficult aspect of writing the proposal was how to articulate my experimental design concisely and clearly."
"My ability to describe an experiment thoroughly yet concisely vastly improved"
Factual neuroscience information:
"My knowledge of neurons in general improved so much while writing this proposal. Not only learning these things but actually having to apply them really helped me understand the material".
"The biggest improvement I noticed was that I started thinking more deeply about all the different mechanisms [of synaptic transmission] and how they each affect many things."
"[The biggest area of improvement was] my knowledge of how the cell works at the molecular level"

Figure 2. Sample self-reflection comments from students in response to the questions "What was the most difficult part of writing the proposal?" and "In what area did you feel you improved the most while writing this proposal?"

To what extent did the Thinking Like a Neuroscientist activities increase your ability to do each of the following:					
Percentage of respondents answering:	Not at all	Slightly	Somewhat	Very much	Extremely
Comprehend complex subjects in neuroscience	1%	11%	34%	45%	9%
Formulate good scientific questions	1%	3%	25%	56%	14%
Develop experimental designs to test scientific questions	0%	2%	21%	52%	25%
Interpret whether the results of an experiment support a hypothesis	1%	7%	20%	61%	11%
Evaluate the effectiveness of an experimental design	1%	8%	21%	56%	14%
Discriminate between common misconceptions and scientific knowledge about how the brain works	1%	15%	24%	42%	18%
Communicate scientific ideas in writing	2%	7%	23%	48%	20%
Make connections across different lecture topics	1%	8%	29%	49%	13%

Figure 3. Self-reported student gains as a result of the Thinking Like a Neuroscientist activities. (n=93)

How much did [the graded grant proposals] contribute to your learning…					
Percentage of respondents answering:	Not at all	Slightly	Somewhat	Very much	Extremely
…about factual neuroscience information?	4%	14%	26%	46%	8%
…to “think like a neuroscientist”?	2%	10%	17%	47%	24%

Figure 4. Self-reported student gains in factual knowledge versus scientific thinking. (n=93)

To what extent did the “Thinking Like a Neuroscientist” activities increase your level of interest in each of the following:					
Percentage of respondents answering:	Not at all	Slightly	Somewhat	Very much	Extremely
The field of neuroscience	3%	9%	24%	30%	34%
Conducting neuroscience research	11%	16%	23%	31%	19%

Figure 5. Self-reported student increases in interest in neuroscience and neuroscience research. (n=93)

thought that the proposals also contributed to learning factual information, as 54% answered either “very much” or “extremely.” This result surprised us because we did not specifically test or target factual information in our activities. It suggests that our students felt that developing science-related skills did not come at the expense of learning factual information.

While it is too early to determine whether the students in our course will be more likely to declare science majors or stay in them, we wanted to gauge whether the Thinking Like a Neuroscientist activities increase their interest in neuroscience and neuroscience research. Figure 5 shows that a majority of students (64%) said that the activities increased their level of interest in the field of neuroscience either “very much” or “extremely”, and 50% said that they increased their interest in conducting neuroscience research by that much. It would be interesting to follow-up on our students three years from now to see if they do go on to major in neuroscience-related fields, conduct research, or submit student research grants.

AREAS OF POSSIBLE IMPROVEMENT

We identified a few areas of improvement for future iterations of this course that were echoed in student survey comments. The first area of improvement relates to the total course workload. In addition to the three short grant proposals, students completed three take-home exams based on lecture material, usually around the same time as the grant proposals were due. A minority of students suggested either spreading out the test and grant proposal due dates or reducing the total number of assignments for the course.

A second area of improvement involves the brainstorming activities. Some students felt that by the end of the course, the experimental design worksheets were getting repetitive. One student commented, “Although they are good practice at applying the scientific method, they get old quickly because the scientific method is not that difficult to apply.” While on the one hand these types of comments may suggest student mastery of intended competencies, it may also suggest that some more advanced students may be bored by the repetition. To address this concern, we may scale back the worksheets toward the second half of the course as students become more comfortable with the brainstorming phase of experimental design.

ADVANTAGES

A major advantage of the grant-proposal based Thinking Like a Neuroscientist activities is that students are exposed to the process of doing science at an early stage in their learning. Many traditional biology and neuroscience curricula first emphasize memorization of factual lecture or textbook material before exposing students to authentic research experiences, sometimes not until several years later (Russell et al., 2007). By exposing students to the elements of grant proposal writing in an introductory level course, students can immediately practice essential thinking skills such as selecting an appropriate research question, organizing their experimental approach, predicting and interpreting different outcomes, and identifying potential pitfalls. Additionally, grant proposals provide an excellent opportunity for creative problem-solving and self-directed learning, potentially engaging and inspiring many newcomers to science. As a result, students are armed with the tools they will need to succeed in higher-level classes and may be more motivated to pursue their own research in the future.

An advantage of our 10-week recurring assignment design is the opportunity for students to practice scientific thinking and writing three times throughout the instruction period. Although each grant proposal was rooted in a different subfield of neuroscience (cellular/molecular, systems, behavioral/cognitive), students practiced using the same analytical tools to formulate experimental questions and critically evaluate an experiment within each of these disciplines. Unlike a final research paper or literature review where students may only revise their work once or never at all, smaller writing assignments encountered more frequently allow students to reflect on previous feedback and immediately implement changes for the next assignment. As a result, many students reported seeing significant improvements in their ability to explain complex ideas or experimental plans in a clear and concise manner. Additionally, many also commented on their improved ability to evaluate multiple interpretations of predicted data and a better understanding of whether an experiment could conclusively support their hypotheses.

Perhaps most importantly, creating constrained experimental environments within which students design their experiments does not require students to be familiar with the scientific literature or to conduct their own literature searches, which can often be a significant barrier for novice learners. Unlike previous upper-level courses that have used grant proposals as capstone assignments by requiring students to first do their own literature reviews (Itagaki, 2013; Oh et al., 2005), our activities are accessible and appropriate for a broader range of students, including those who have had little or no experience reading primary scientific papers. At the same time, students who have had previous research experience or who are more comfortable with scientific literature can also be accommodated within our assignment design. Since each proposal is somewhat self-directed, more advanced students can ask more ambitious questions or propose more complicated experiments.

DISADVANTAGES

Like other courses that have used grant proposals and peer review as a pedagogical tool (Itagaki, 2013), one of the major drawbacks to our assignment design is the amount of time and organization required from students and instructors. Since the quarter is only 10 weeks long, students must write and review three grant proposals in a relatively short time period. Providing students with timely and useful feedback on each proposal can be challenging, especially during the weeks when students are also coming in for tutorial meetings. Additionally, the tutorial meeting system and small section sizes were only possible in our setting because the 109 students were divided into eight sections with four instructors to share the work.

From an organizational standpoint, the instructors also needed to be highly organized to ensure that section time was spent explaining appropriate background material for each unit as well as scaffolding the activities that helped students write a successful grant proposal. The balance between reviewing lecture content and teaching or modeling scientific thinking was often difficult to practically implement with only two 50-minute sections per week, and we occasionally had to sacrifice lecture review for discussing a case study or teaching best practices in scientific writing. Institutions on the semester system or classes with longer class meetings may be able to devote more time to covering additional lecture review.

Organization of the tutorial meetings three times throughout the quarter was greatly facilitated by Stanford's CourseWork interface, an online course management system that includes a meeting sign up tool where students can self-sort into predetermined meeting times that fit their schedules. Without this online meeting scheduler, the amount of time devoted to soliciting 109 student's schedules and then planning group meetings outside of class would have been a significant obstacle. A reduced class size or use of an outside web-based scheduling system would be recommended for those without access to such scheduling tools.

A small minority of students voiced some resistance to the emphasis in sections on scientific thinking over more traditional factual content review. Even though the class was clearly marked as a *Thinking Matters* course, some students may have expected a more traditional curriculum centered on memorization of factual information (Seidel and Tanner, 2013). In this regard, a grant writing assignment in an introductory course may discourage students who do not see the value in learning to question or evaluate scientific evidence at this stage in their learning. Additionally, students who do not intend to advance in the sciences may not see the benefits of learning the mechanics of writing a convincing scientific argument clearly and concisely. To counter these objections, it may be necessary to specifically emphasize the utility of analytic thinking and persuasive writing irrespective of discipline or intended major.

ADDITIONAL CHALLENGES AND CONSIDERATIONS

One challenge to implementing this type of assignment is how to evaluate submissions that propose impossible or inappropriate experiments given the subject area. While students were prompted to consider questions that were testable and feasible, it was often difficult for students to be able to gauge whether their approach satisfied these criteria without prior knowledge of current experimental approaches. For example, one student's proposal asked a question about the effects of the popular acne drug Accutane on cortical development in mice and proposed using an *in vitro* culture system to incubate developing mouse embryos over several weeks to observe brain development at various time points. Since such a system does not exist, an *in vivo* approach would be more practical and appropriate in this case. However, since the class did not include detailed instruction on the experimental methods of developmental neuroscience, the student made an educated guess about how to carry out the experiment. Since one of the major learning goals was for students to invent an experimental approach to test a hypothesis, students were corrected but not penalized if their reasoning led them beyond the boundaries of what is technically possible. While some might argue that it is more important for students to learn the "correct" *in vivo* system to use in the example above, we believe that the process of creatively reasoning through the problem is more valuable at this stage of student's scientific development.

Given that our series of learning activities does not require any background knowledge, we believe that this assignment can be extended to other introductory science courses at other institutions. However, instructors may have to modify some aspects of the assignment structure to fit their students. One consideration for introducing grant proposal assignments to novices at other institutions may be the level of student engagement and preparation. Stanford freshmen arrive on campus as motivated, high-achieving students who may have already practiced some of the competencies involved in the Thinking Like a Neuroscientist activities; for example, some of our students had already conducted their own research. At other institutions, if there are fewer students who have practice in scientific thinking, it may be necessary to adjust the pace of the grant proposal cycles and the level of scaffolding for each assignment. On the other hand, it could be argued that these "Thinking Like a Neuroscience"-like activities are more important for students who have not yet been exposed to authentic research experiences. Another consideration may be the subject matter of the course. In neuroscience and biology, it is relatively easy for novices to propose novel, scientifically-unexplored questions, especially with appropriate scaffolding. That may be more difficult in other scientific disciplines. A third consideration may be the goals of the class. Since the grant proposal assignment was well-suited to the *Thinking Matters* learning goals, we were able to dedicate a significant portion of class time to reinforcing skills related to the Thinking Like a Neuroscientist activities. Traditional introductory science courses with a primary focus on delivering factual information may need to explicitly adjust their learning goals and overall student assessment to emphasize scientific thinking, and this kind of course transformation can be very difficult. Creating a balance between delivering factual content and practicing scientific thinking is the key to the success of the grant proposal assignment, and it is one of the more challenging aspects of the course design.

SUMMARY

We used a series of scaffolded activities to help students develop their own neuroscience questions, brainstorm experimental approaches, and predict and analyze various potential outcomes. In writing short grant proposals, novice students were exposed to the ways that "real" scientists tackle problems and design solutions. This approach is one solution to the problem of bringing authentic research experiences and thus active learning into introductory-level neuroscience classes. Indeed, challenging the students to think through the complexities of an experimental problem can help combat the common misconception that the process of doing science is formulaic, as presented in many biology textbooks, and that science itself is just a collection of facts to be memorized. We also believe that this approach engages students and motivates them to think more deeply about course content than they otherwise would with a more traditional curriculum, and we encourage other instructors to consider integrating this type of assignment into other introductory biology courses.

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APPENDIX I: Example brainstorming activity Name: ________________________

From Jan Purkinje's "experiment" (Hanzlik, 1925), it seems like foxglove extract (digoxin) is affecting neuronal signaling in some way. You would like to explore what digoxin is doing on a cellular / molecular level.

You have access to a solution of digoxin and an electrophysiology set-up, including electrodes, neurons in a petri dish, and other basic lab solutions and equipment. You also have the ability to artificially stimulate the neuron (using stimulating electrodes, neurotransmitters, etc.). Using these tools, come up with an experimental question that would shed light on the effects of digoxin on neuronal function.

There are many good questions you could ask using these tools. Pick one and explore it in detail.
Please write legibly (or type) using complete sentences.

Research question and rationale:
What is your question? Make sure it is specific and testable. Come up with an associated hypothesis.

In what ways is your question a "good" scientific question? Justify your answer.

Experimental Design:
Describe your experimental plan. Make sure that it directly reflects the research question and includes relevant controls. Be as specific as you can and use scientific terms to describe your procedure. You may accompany your written description with a diagram.

Predicted Results:
Draw a graph showing your hypothesized result. Make sure that axes are labeled with numbers and text. Explain how this graph supports your hypothesis.

Interpretations and Discussion:
How would you interpret your predicted results?

What if your results did not support your hypothesis? Why might this be?

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APPENDIX II: Tutorial prompt

Tutorial #1: Pitch Meeting

Purpose: This tutorial session will help you develop your ideas for your Unit 1 proposal. You will also practice the peer review process and give *constructive* feedback to each of your peers.
Assignment: For your first tutorial, you will prepare a **5 minute** oral presentation outlining your plan for how you will answer the Unit 1 proposal prompt. You will present to a group of one or two of your classmates and your section leader. Collectively, we will discuss your ideas and evaluate the strengths and weaknesses of your plan.
Your presentation should include each of the following elements:

1. A well-defined question.
2. Your hypothesis.
3. A clear and concise description of what experiments you will propose to test your hypothesis and what data you will collect. It will be helpful to sketch a graph of your predicted results.
4. A description of any potential pitfalls or sources of error associated with your experimental set-up.

Peer Review:
Before coming to your tutorial, you must read over the grading rubric carefully. For each of your fellow presenters, you will use the criteria on the grading rubric to provide feedback on at least one strength of the proposal and one area of improvement. You are also expected to ask questions and suggest ideas to help your peers.

APPENDIX III: Unit 1 proposal prompt
Unit 1 Project Proposal (10% of class grade)
Due date: 1/28/2014

Assignment Overview:
You are a staff scientist at the pharmaceutical company Pfizer, where a new antidepressant (called Fernaldia™) is in development. To obtain U.S. Food and Drug Administration approval, Pfizer needs to know Fernaldia™'s mechanism of action.

Preliminary data indicate that Fernaldia™ produces a decrease in the amount of neurotransmitter found in the synaptic cleft. You also know that Fernaldia™ does NOT act on the re-uptake transporter or enzymatic degradation in the synapse.

You have access to all of the molecular / cellular neuroscience tools that you have encountered in lecture or section so far. Using these tools, come up with ONE specific experimental question that would shed light on how Fernaldia™ affects neuronal function and propose an experiment to address your question.

Your proposal will be evaluated on content, structure, and writing style, and it should include all of the elements listed below. It should also demonstrate your knowledge of cellular / molecular processes discussed in class so far as well as your understanding of the scientific process. For more detailed guidelines on how you will be evaluated, please refer to the grading rubric.

Your proposal should be typed, double-spaced, and *no more than 1000 words long*. All figures should be appropriately labeled with captions of no more than 75 words.

Structure:
I. Research question and rationale
This section delineates your experimental question and hypothesis along with an explanation of why this question is important and needs to be studied. It is essential that your question be testable and clearly defined. Here you should also provide relevant background information to support your question and give it appropriate context.
II. Experimental design
This section should clearly explain the experimental strategy that you will use. Identify the important variables in your experiment, including potential confounding factors. Clearly describe your experimental treatment(s) and controls. Using figures or diagrams to describe your strategy may be beneficial.
III. Predicted results
Imagine the data that would directly support your hypothesis. Describe your potential results using both words and properly labeled graphs with captions.
IV. Interpretations and discussion
In this section, describe how the predicted results will be interpreted and how they will answer the original hypothesis. Discuss alternative outcomes, potential problems, and any confounding factors as well as your strategies to realistically deal with these situations. Conclude with a few sentences summing up the proposal and reflecting on what impact the experimental outcomes will have on our scientific knowledge.

APPENDIX IV: Unit 2 proposal prompt
Unit 2 Project Proposal (10% of class grade)
Due date: 2/13/2014

Assignment Overview:
You are a doctor with an MD/PhD at Stanford. You both head a lab that studies the visual system in monkeys and treat patients at the university hospital. Knowing of your expertise, several patients with blindsight have come to see you within the past few years. Their deficits and abilities have intrigued you, and you are interested in further exploring visual system function in patients with this disorder.

The current literature suggests that in patients with blindsight the LGN acts as a key relay center for transmitting information from the eyes to the rest of the brain. However, it is not clear what further brain areas or connections after the LGN share responsibility for the residual visual functions in these patients.

You have access to all of the systems/circuits neuroscience tools that you have encountered in lecture or section so far. Using these tools, come up with ONE specific experimental question that would shed light on the systems/circuits basis of blindsight and propose an experiment to address your question.

Your proposal will be evaluated on content, structure, and writing style. It should include all of the elements listed below. It should also demonstrate your knowledge of systems/circuits processes discussed in class so far as well as your understanding of the scientific process. Above all, we are most interested in your experimental strategy and the thought process that led you to choose your strategy. For more detailed guidelines on how you will be evaluated, please refer to the grading rubric.

Your proposal should be typed, double-spaced, and *no more than 1000 words long*. All figures should be appropriately labeled with captions of no more than 75 words.

<u>Structure</u>:

I. Research question and rationale

This section delineates your experimental question and hypothesis along with an explanation of why this question is important and needs to be studied. It is essential that your question be testable and clearly defined. Here you should also provide relevant background information to support your question and give it appropriate context.

II. Experimental design

This section should clearly explain the experimental strategy that you will use, including WHY your experimental design addresses the question. As part of your explanation, clearly describe your variables, experimental treatment(s), controls and measurements. Using figures or diagrams to describe your strategy may be beneficial.

III. Predicted results

Imagine the data that would directly support your hypothesis. Describe your potential results using both words and properly labeled graphs with captions.

IV. Interpretations and discussion

In this section, describe how the predicted results will be interpreted and how they will answer the original hypothesis. Discuss alternative outcomes, potential problems, and any confounding factors as well as your strategies to realistically deal with these situations. Conclude with a few sentences summing up the proposal and reflecting on what impact the experimental outcomes will have on our scientific knowledge.

APPENDIX V: Unit 3 proposal prompt
Unit 3 Project Proposal (20% of class grade)
Due date: 3/14/2014

<u>Assignment Overview:</u>

You have just been accepted into Stanford University's Neuroscience PhD Program. Because your advisor has limited funding, you are applying for a National Science Foundation (NSF) grant for first-year graduate students pursuing research projects in neuroscience. You may pursue any question related to the material from lecture and section, and you have access to all of the techniques and model systems discussed in lecture and section.

The NSF, like nearly all funding agencies, evaluates proposals most favorably when the question is specific, testable, and plausible in light of what we already know. Be sure to address this last criterion by making a clear link from your question to the appropriate material from lecture or section. You may choose to revisit the Unit 1 or Unit 2 Proposal Assignment, but you must address a question that is substantially different from your original question for that assignment.

Your proposal should be typed, double-spaced, and *no more than **1000** words long*. All figures should be appropriately labeled with captions of no more than 75 words.

<u>Structure</u>:

I. Research question and rationale

This section delineates your experimental question and hypothesis along with an explanation of why this question is important and needs to be studied. It is essential that your question be specific, testable and clearly defined. Here you should also provide relevant background information from lecture or section to support your question and give it appropriate context.

II. Experimental design

This section should clearly explain the experimental strategy that you will use, including WHY your experimental design addresses the question. As part of your explanation, clearly describe your variables, experimental treatment(s), controls and measurements. Using figures or diagrams to describe your strategy may be beneficial.

III. Predicted results

Imagine the data that would directly support your hypothesis. Describe your potential results using both words and properly labeled graphs with captions.

IV. Interpretations and discussion

In this section, describe how the predicted results will be interpreted and how they will answer the original hypothesis. Discuss alternative outcomes, potential problems, and any confounding factors as well as your strategies to realistically deal with these situations. Conclude with a few sentences summing up the proposal and reflecting on what impact the experimental outcomes will have on our scientific knowledge.

APPENDIX VI: Grading Rubric

Weight	Item	Evaluation	Comments	Grade
CONTENT (50%)	Research question and rationale	• Is concise, specific and testable • Includes a clearly stated hypothesis • Briefly describes WHY the question is interesting, important or testable (rationale)		+ √ —
	Experimental design	• Is appropriate for and consistent with the research question • Includes necessary controls • Is concise but presented in sufficient detail to demonstrate conceptual understanding of methodological approach		
	Predicted results	• Include graphs of expected data as well as a written description • Are appropriate for the methods used and consistent with the initial question and hypothesis • Are clear, well-presented, and include labeled axes and legends		
	Interpretations and Discussion	• Discusses how and whether the predicted results conclusively support the original hypothesis. • Discusses alternative possible results and their interpretations. • Discusses the limitations of the proposed experimental strategy • Briefly summarizes and reflects on the impact of the proposed research on scientific knowledge		
	Internal consistency	• Logical relationship between question(s), experimental design, predicted results and interpretations / concerns		
	Factual accuracy	• All relevant concepts from lecture or section are accurately portrayed		
STRUCTURE (25%)	Overall	• Clear and coherent structure with section headings and paragraphs		+ √ —
	Paragraphs	• Thoughts are organized into coherent paragraphs with clear topic sentences and without irrelevant information		
	Transitions	• Logical flow between sections, paragraphs and sentences		
STYLE (25%)	Sentences	• Clear, concise, to the point. No long-winded, awkward or convoluted sentences		+ √ —
	Wording	• Precise and specific. No “fuzzy” or vague wording. No colloquial terms or narrative style.		
	Grammar	• No errors in grammar, punctuation, usage or spelling.		

Overall grade: __________