ARTICLE
Assessment of *Mapping the Brain*, a Novel Research and Neurotechnology Based Approach for the Modern Neuroscience Classroom

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Neuroscience research is changing at an incredible pace due to technological innovation and recent national and global initiatives such as the BRAIN initiative. Given the wealth of data supporting the value of course-based undergraduate research experiences (CUREs) for students, we developed and assessed a neurotechnology CURE, *Mapping the Brain*. The goal of the course is to immerse undergraduate and graduate students in research and to explore technological advances in neuroscience. In the laboratory portion of the course, students pursued a hypothesis-driven, collaborative National Institutes of Health (NIH) research project. Using chemogenetic technology (Designer Receptors Exclusively Activated by Designer Drugs-DREADDs) and a recombinase-based intersectional genetic strategy, students mapped norepinephrine neurons, and their projections and explored the effects of activating these neurons *in vivo*. In lecture, students compared traditional and cutting-edge neuroscience methodologies, analyzed primary literature, designed hypothesis-based experiments, and discussed technological limitations of studying the brain. Over two consecutive years in the Program at North Carolina State University, we assessed student learning and perceptions of learning based on Society for Neuroscience's (SfN) core concepts and essential principles of neuroscience. Using analysis of student assignments and pre/post content and perception-based course surveys, we also assessed whether the course improved student research article analysis and neurotechnology assessment. Our analyses reveal new insights and pedagogical approaches for engaging students in research and improving their critical analysis of research articles and neurotechnologies. Our data also show that our multifaceted approach increased student confidence and promoted a data focused mentality when tackling research literature. Through the integration of authentic research and a neurotechnology focus, *Mapping the Brain* provides a unique model as a modern neuroscience laboratory course.

Key words: laboratory education; technology; CURE (course based undergraduate research experience); graduate education; primary literature; FIGURE FACTS; collaborative research; BRAIN Initiative

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The brain is the body's most complex organ. Unraveling this complexity requires interdisciplinary collaboration and researchers with capacity for technological ingenuity (Jorgenson, 2015; Bargmann and Newsome). The Brain Research through Advancing Innovative Neurotechnologies (BRAIN) Initiative was introduced by the Obama Administration in 2013 and outlines priority research areas to spur innovation and coordination of efforts across disciplines. With established goals through 2025, The BRAIN initiative should also spur educators to provide undergraduate and graduate students with direct engagement and experience with modern neurotechnologies (Shaefer, 2016). CUREs (course-based undergraduate research experiences) offer novel yet foundational neuroscience education opportunities by giving students early exposure to new technological approaches, research methods, scientific process, and critical analytical skills (Auchincloss, 2014; Lemons, 2016; Olimpo, 2016; Kowalski, 2016.

Many neuroscience-oriented CUREs have emerged as models for fostering students' critical thinking and reasoning skills in research (Kreitzer et al., 2013; D'Arcy et al., 2019; Fromherz et al., 2018; Nahmani et al., 2019). Most recently, a brain mapping and connectomics CURE allowed students to take autonomous approaches to their research, resulting in increased engagement, creativity, and responsibility for their projects (D'Arcy et al., 2019). Other neuroscience CUREs have demonstrated high levels of success using a variety of approaches including publicly available datasets (Nahmani, 2019), experimental methods courses (Hall & Harrington, 2003), collaborative research (Kowalski et. al, 2016), and optogenetics (Roberts et al., 2016). The benefits of CUREs, such as enhanced student interest in research, content retention, quantitative reasoning, development of 'expert-like' thinking, and retention in STEM, are not confined to neuroscience and have been well documented across a variety of STEM disciplines (Metz, 2008 American Association for the Advancement of Science, 2011; Brownell et al., 2012; Remsburg et al., 2014; Ward et al., 2014; Jeffery et al., 2016; Rodenbusch et al., 2016.; Lipchock et al., 2017; Reeves et al., 2018).

Inspired by this evidence, we created *Mapping the Brain*, a neuroscience laboratory course designed to develop crucial science processes and technical lab skills

through hypothesis-driven research. *Mapping the Brain* enables students to design and execute experiments which address the core tenets of the BRAIN initiative, beginning at the cellular level and ending at the behavioral. To do this, *Mapping the Brain* utilized an on-going collaborative NIH research project, led by authors S.R. and P.J. Following the CURE model, students were asked to "think like a scientist" at each stage of the course. Collaboratively as a class, we identified a research question, developed hypotheses, performed experiments, and drew conclusions based on our results. We also engaged students from diverse academic backgrounds (Table 1), many with little to no neuroscience exposure, creating an interdisciplinary environment based on the principles of the BRAIN initiative.

This report describes the design, assessment, and impact of our neurotechnology focused CURE on students. Our data shows that *Mapping the Brain* benefits student learning as the majority of students achieved the course learning outcomes, reported gains in transferable technical and intellectual skills as well as acceptance of core concepts and essential principles of neuroscience determined by SfN. We also validate existing pedagogical tools and offer new approaches for engaging students in research literature and neurotechnology evaluation. Collectively, our data illustrates that *Mapping the Brain* benefits students and is an adaptable model for integrating modern neuroscience technology and research into undergraduate curricula.

Table 1. Participant Demographics

	2015 (n=12)	2016 (n=12-13)
Female	58% (7)	54% (7)
Male	42% (5)	46% (6)
PhD Student	17% (2)	—
MS Student	25% (3)	31% (4)
Undergraduate	58% (7)	69% (9)
Degree Program		
Biochemistry BS	—	8% (1)
Biological Sciences BS	—	31% (4)
Chemical Engineering BS	58% (7)	8% (1)
Chemistry PhD	8% (1)	—
Food Science/Nutrition MS	—	8% (1)
Genetics BS	—	8% (1)
Materials Science BS	—	15% (2)
Physiology MS	25% (3)	23% (3)
Physiology PhD	8% (1)	—
*Neuroscience focused PhD	17% (2)*	—
First Neuroscience Course	83% (10)	67% (8)
Intent to pursue a career in Neuroscience	17% (2)	33% (4)

*Students with neuroscience focused PhD research theses

Table 1. Mapping the Brain Student Academic Demographics. Student enrollment in the course was capped at 12 or 13 students as a result of laboratory space limitations.

COURSE DESIGN

Institutional Context

Mapping the Brain is an 8-week course offered through the North Carolina State University (NCSU) Biotechnology (BIT) program. BIT is an interdisciplinary program that enrolls roughly 500 different students each year from a variety of colleges and over 80 academic programs. Three undergraduates, including the first author (Z.J.), and one graduate teaching assistant worked with the instructor (S.R.) over two years to offer and assess *Mapping the Brain*.

Student Participants

This article includes data from 24-25 upper level undergraduate and graduate students from a variety of disciplines and two sections offered in the fall of 2015 and 2016 (Table 1). Participation in the research study was solicited on the first day of class. All 25 students consented and completed the survey after a brief description of the study. Students were not offered incentives to participate in the research. Participation in the post-course survey was solicited 7 months after the course. Of the 25 students invited to participate, 24 fully completed the Qualtrics pre- and post-course surveys while one student only completed the pre-survey. The NCSU Institutional Review Board approved the research described here as an exempt protocol on August 4, 2015 (Protocol number 6093).

Course Structure

Mapping the Brain consisted of weekly laboratory (5 hours) and class (non-laboratory, lecture/active learning; 110 minutes) sessions for 8 weeks (Figure 1). The course was structured using a backwards design approach (Wiggins and McTighe, 1998; Cooper et al., 2017) and based upon three overarching course goals to support student achievement of learning outcomes (Appendix 1). Course goals: After completing the course, students will:

1) Appreciate the fundamental challenges inherent in studying the brain.
2) Understand the applications and limitations of traditional and emerging methodology in modern neuroscience.
3) Have applied a combination of laboratory approaches to investigate a collaborative neuroscience research project.

In class, students compared traditional and cutting-edge neuroscience methodology, analyzed primary literature in journal clubs, reflected on our experimental design, and discussed ethical and technological limitations of studying the brain. The theme for each session and a sample of technologies covered are shown in Figure 1.

In the laboratory, students first explored basic neuronal signaling properties using cockroaches and the classroom-friendly "bioamplifier" from Backyard Brains©, the SpikerBox™ (Marzullo and Gage, 2012). For the remainder of the course students pursued a hypothesis-driven,

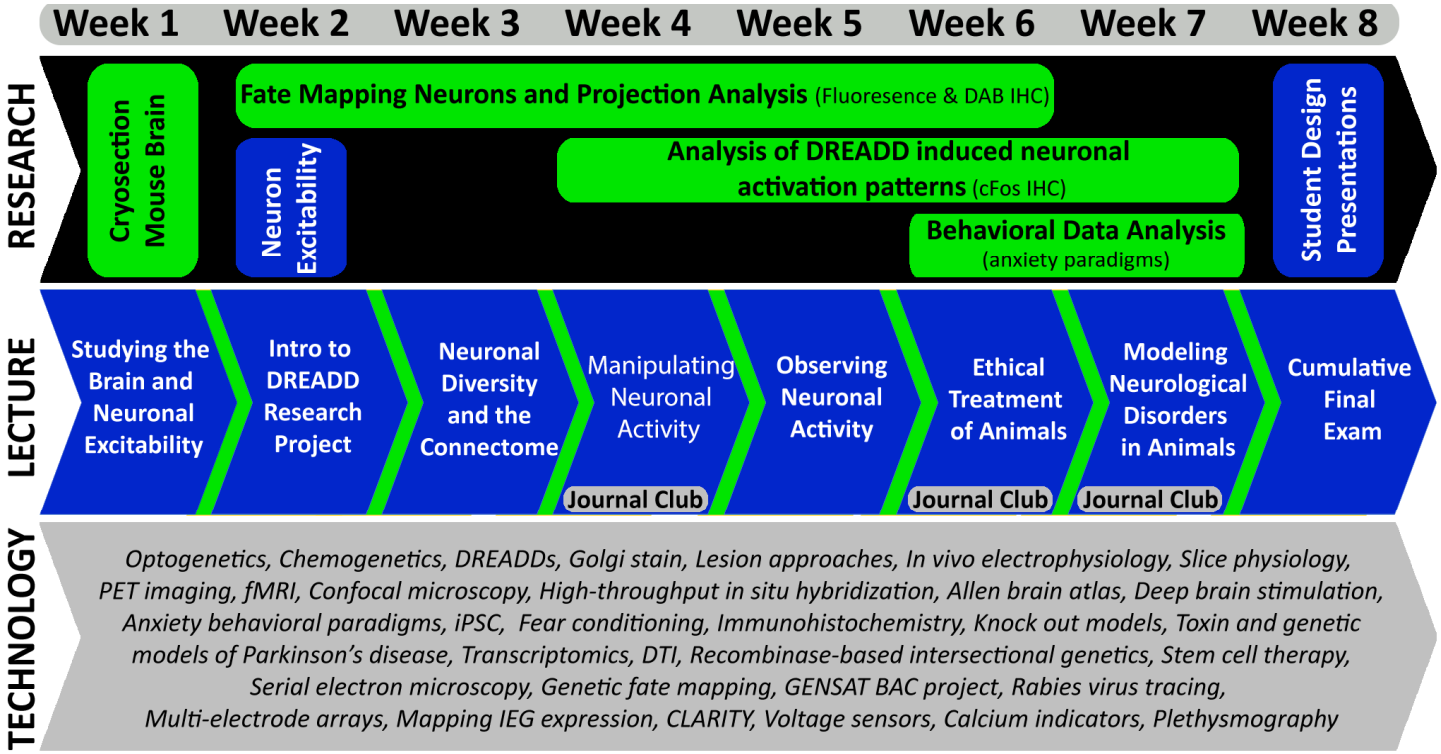

Figure 1. Laboratory and lesson structure of *Mapping the Brain*. Weekly 5-hour laboratory sessions focused on a collaborative NIH research project (green). Students worked with brain tissue and behavioral data from transgenic mice to map a subset of norepinephrine neurons, analyze their projections, and explore the effects of activating these neurons *in vivo*. Students performed fluorescent and 3,3-diaminobenzidine (DAB) horseradish peroxidase (HRP) immunohistochemistry experiments and analyzed behavioral data collected from their animals in the light/dark box, elevated plus maze and open field paradigms. Two additional laboratory sessions provided hands on review of fundamental neuronal excitability principals utilizing Spiker boxes from Backyard Brains® and student presentations of team research design projects (blue weeks 2, 8). Weekly 110 min class sessions focused on a variety of neuroscience topics and technologies (blue arrows-lesson topics; grey box-neurotechnologies discussed). Three journal club sessions (grey ovals) enabled students to explore four research papers and their associated methodology.

collaborative NIH-NCSU research project. Using chemogenetic technology (DREADDs) (Armbruster et al., 2007) and a recombinase-based intersectional genetic strategy (Dymecki et al., 2010), students mapped norepinephrine neurons, their projections, and explored the effects of their activation *in vivo*.

Student grades were based on pre-labs, lab notebooks two research reports, research article analysis worksheets, journal club participation, a team-based research design presentation, attendance and a final exam. A detailed course schedule is provided at the end of the syllabus (Appendix 1). The course structure was nearly identical in 2015 and 2016. Educators interested in using course materials may reference the appendices and supplemental materials or contact the corresponding author.

Neurotechnology Focus

The scale of the BRAIN initiative ($4.5 billion 12-year budget) promises new tools to interrogate brain structure and function and an evolution of modern neuroscience. To match this momentum in the field, *Mapping the Brain* focused on the practice of neuroscience research and the neurotechnologies that enable it. Three broad approaches to studying the brain were identified to provide a conceptual framework for students:

1) Manipulating neuronal activity and observing behavior.
2) Stimulating the brain and/or behavior and observing neuronal activity.
3) Assessing brain structure to understand function.

Every class was structured around the "3-approaches to studying the brain" scaffold, and we covered content from a researcher's perspective, assessing available methodology to investigate varied research questions. Fundamental techniques as well as cutting edge methods (Figure 1) were explored using a variety of active learning pedagogy (think-write-pair-share (Lyman, 1981), five-minute paper breakdowns, one-minute papers (Cross and Angelo, 1988; Davis et al., 1983), etc. Students compared the strengths and limitations of each technology, and for the research design project each team chose their own neurotechnologies to present, refreshing the range of methodologies covered.

NIH-NCSU Collaborative Course Research Project

Utilizing an ongoing research collaboration between the authors P.J. and S.R. was key to our success. While we discuss the specifics of our project, educators could easily adapt our neurotechnology focused CURE structure around

any collaborative neuroscience research project. The broad goal of our research is to understand the role of genetically defined subpopulations of norepinephrine neurons in shaping brain structure and function. *Mapping the Brain* integrated student lab work with the research goals of the collaboration to engage students in authentic research and provide experience working with cutting-edge genetic technology (Sciolino et al., 2016).

Project Description

Norepinephrine neurons, which are defined by their ability to synthesize and release norepinephrine, are spread widely across the brainstem and modulate a range of physiological and behavioral processes from stress to food intake to drug abuse (Berridge and Waterhouse, 2003; Rinaman 2011; Chandler et al., 2019; Sara and Bouret, 2012; Sciolino et al., 2016. How the cellular and molecular organization of norepinephrine neurons relates to this functional diversity remains unclear. Many studies have focused on the largest subpopulation of norepinephrine neurons, the locus coeruleus, and relied solely on long-standing anatomical subdivisions of the system. Taking an alternative approach, we redefined norepinephrine neuron identity based on developmental gene expression (Robertson et al., 2013), to understand the role of unique subpopulations of norepinephrine neurons in shaping brain function (Robertson et al., 2016; Sciolino et al., 2016; Plummer et al., 2017).

Mapping the Brain students joined our efforts and applied a dual recombinase based intersectional genetic approach (Awatramani et al., 2003; Farago et al., 2006; Jensen et al., 2008; Robertson et al., 2013) to selectively manipulate, *in vivo*, a subpopulation of norepinephrine neurons defined by their expression of the transcription factor gene engrailed-1 (En1-NE neurons). Selective expression of mCherry-DREADD in the En1-NE neuron subpopulation enables activation of these neurons through the injection of the compound clozapine n-oxide (CNO), which activates the DREADD receptor and simulates action potential firing (Sciolino et al., 2016). All other norepinephrine neurons (non-En1-NE neurons) express GFP. At the time, this brand new transgenic DREADD mouse model had not been fully characterized (Sciolino et al., 2016). Students worked on four overarching research project goals that complemented ongoing work at the NIH:

1) Validation of the new triple transgenic DREADD model.
2) Assessment of the projection pattern of norepinephrine neurons without a history of En1 expression (GFP-expressing norepinephrine neurons).
3) Evaluation of whole brain neuronal activation patterns in response to En1-NE neuron stimulation.
4) Analysis of the behavioral effects of stimulating En1-NE neurons (mCherry-DREADD) in vivo.

Student Research Activities

At the NIH, a cohort of DREADD mice and their littermate controls went through anxiety-related behavioral paradigm testing (light/dark box, elevated plus maze, and open-field testing). Several weeks later, the same cohort was dosed with CNO (5 mg/kg) or vehicle for 2 hours. After 2 hours the mice were sacrificed, fixed by transcardial perfusion, and cryopreserved for subsequent student sectioning. Teams of two students cryosectioned tissue. Over the first three weeks, students assessed the validity of the new transgenic model using immunohistochemistry. Adapting a traditional staining protocol to a lab that met only weekly was a challenge. The summer before the course we piloted and optimized staining and microscopy protocols. We share the detailed procedure (Supplemental Materials 1-2) for instructors implementing immunohistochemistry and/or microscopy in their lab. GFP and mCherry-DREADD receptor staining confirmed restricted expression to the appropriate subpopulations of norepinephrine neurons. mCherry-DREADD expression was limited to norepinephrine neurons with a history of En1 expression and GFP was expressed in all other norepinephrine neurons. Students took advantage of this GFP expression in non-En1-NE neurons. This unprecedented labeling of axonal projections meant students had the potential to discover brain regions receiving inputs from En1-NE neurons (Robertson et al., 2013).

Next, students compared neuronal activation patterns in CNO versus vehicle treated DREADD animals using expression of the immediate early gene c-fos (Sagar et al., 1988; Bullitt, 1990). Again, students had the potential for novel discovery and were able to test their predictions regarding which areas of the brain may be activated in response to En1-NE neuron stimulation. Finally, students analyzed behavioral data collected at the NIH from the class's cohort of animals.

Research Article Analysis

Given our neurotechnology and research focus, primary literature analysis was a key component of the course. Numerous activities and assignments, described below, required students to read and analyze research articles. We discuss each pedagogical tool in detail and describe how they could be adapted to other neuroscience classrooms. We also provide the guidelines and rubrics (Appendices 2-5) for easy adoption by instructors.

Research Article Worksheets

To prepare for our journal club sessions, students completed research article analysis worksheets, with step-by-step instructions on how to read research articles and the FIGURE FACTS template (Round and Campbell 2013) (Appendix 2). The worksheets also required three additional student writing components: (1) a short overview of the article, (2) a personal reflection with article specific reflection questions and comparisons to the course research project, and (3) a lay audience abstract where students articulated the key scientific findings in terms understandable by non-scientists. Related popular science stories were also assigned to model science communication with the general public. The worksheets require significant student writing time and instructor grading time for feedback, yet they are a powerful tool. Instructors can directly adopt or adapt this

tool in any course that engages students with primary literature. For example, the step-by-step "how to" instructions could be posted with the first research article assignment in a course or the lay audience abstract could be used as a mechanism for students to communicate scientific findings with a broader audience. We used the latter approach in a different course, where lay abstracts on neurotechnological advances in Parkinson's Disease were posted on a student created website for the general public.

Journal Clubs

Journal clubs (Glazer, 2000; Edwards et al., 2001; Kozeracki et al., 2006) covered the literature students analyzed in their research article worksheets. We used a rubric to assess journal club participation (Appendix 3). Students participated in a team to present figures and asked questions following figure presentations from other groups. Papers reflected current research related to the neurotech topic and students compared their project with each article. The general journal club format of assigning groups to present specific figures, which can be applied to any article, facilitates collaboration, in-depth analysis, and discussion. We explored a similar DREADD-based intersectional genetic approach in the serotonin system (Brust et al., 2014), two articles using optogenetics or DREADDs for generating synthetic memories (Garner et al., 2012 and Liu et al., 2012), and use of optogenetics to elucidate how stem cells alleviate Parkinsonian symptoms (Steinbeck et al., 2015).

Research Design Presentations

For the research design presentation (Appendix 4) teams of two picked a recent neuroscience article. Students explored popular science stories and the research behind them, as inspiration for designing a research study. For the presentations, students summarized relevant background research and proposed a cutting-edge experimental design to expand on the published work. This assignment is a particularly powerful pedagogical tool that fully engages students' creativity and showcases their research related skills. The guidelines and rubric are quite generic so students can pursue their own research interests, which also enables easy adoption of the project into any upper-level neuroscience classroom.

Comprehensive DREADD Research Report

Students wrote a comprehensive research report in a journal article format that covered all work related to the DREADD project (weeks 2-8). The report's introduction was due mid semester to provide a feedback opportunity as students articulated their scientific question, research goals, genetic approach, etc. Reports also included a discussion of how their research compared to contemporary studies of norepinephrine neurons with citations of relevant scientific literature (Appendix 5).

ASSESSMENT METHODS

Learning Outcome Assessment

Learning outcomes for the course (Appendix 1) included both intellectual and technical outcomes. Some outcomes were neuroscience specific while others address skills broadly applicable across the life sciences. Two central outcomes dictated course organization: (1) Evaluate the limitations and potential of traditional and modern neuroscience tools, and (2) Analyze and interpret data from primary research articles that employ novel methodology.

Student achievement of the stated outcomes was directly analyzed with a variety of assessments (final exams, research design presentations, and the research reports). After the completion of both semesters, assignments were analyzed from the 2015 and 2016 cohorts simultaneously for each outcome, only on fully completed work (n=23-25). Points allocated to each outcome were identified from the assignments, and student scores represent the percentage earned relative to the total number of points.

Assessment of Student Attitudes and Perceived Learning Gains

The pre- and post-course surveys (Appendix 6) were used to collect qualitative and quantitative data to assess student perception of learning gains and attitudes about analyzing research articles, course structure, and the SfN core concepts and essential principles of neuroscience. Students were assigned a unique code so responses pre- and post-course could be matched. Student codes were assigned by a BIT instructor who had access to the codes but not to the data collected. The authors had access to the data but not the student codes to protect the anonymity of student responses. In 2015 all 12 students completed both surveys, and in 2016 12 of 13 students completed both surveys, one student did not complete the post survey.

The post-course survey used a Likert scale to assess student perception of their achievement of the learning outcomes. The pre- and post-course surveys also assessed student attitudes (feelings of stress and frustration) when reading research articles as well as student acceptance of SfN's core concepts, essential principles of neuroscience, and a common neuroscience myth. In a multiple-choice format, students were also asked to choose any combination of the listed options (see Figure 4A) reflecting their primary focus while reading research articles. To evaluate student attitudes about the course structure (neurotechnology focus, NIH-NCSU collaborative course research project, and research article analysis), free response questions included in the post-course survey were qualitatively and quantitatively analyzed. Students responded to questions asking for identification of their favorite and least favorite components of the course and ideas for improvement of the course. Responses that addressed one of the three themes of course structure were tallied, and the percent of student responses related to that theme relative to the total number of student responses was calculated.

Statistics

One-way ANOVAs with Tukey's HSD tests were used to test for differences between learning objectives in student assignment scores. McNemar chi-square tests were used To assess pre-course to post-course differences in primary reading strategies. Wilcoxon signed-rank tests were used

to assess pretest-posttest student self-report Likert scale items.

RESULTS

Evidence of Student Achievement of Course Goals

Mapping the Brain was designed around three overarching course goals (see Course Structure section). We began by assessing students' application of a combination of laboratory approaches to investigate a collaborative research project. Students successfully designed, implemented, and analyzed experiments and were able to validate collaborative project results while also generating novel data (Figure 2). First, students assessed GFP and mCherry-DREADD expression in the predicted norepinephrine neuron subpopulations and confirmed results seen at the NIH (Figure 2 top left panels; Sciolino et al., 2016). This repeated observation of expression patterns by multiple student groups helped establish confidence in the new mouse model. Students also had the potential to reveal previously unidentified projection targets but we did not uncover projections in any unanticipated locations and only confirmed existing descriptions of the norepinephrine system (Fritschy and Grzanna 1990; Robertson et al., 2013). Student comparison of c-fos based neuronal activation patterns (CNO versus vehicle treated DREADD animals), did yield novel results and enabled students to test their predictions about which areas of the brain may be activated in response to En1-NE neuron stimulation (Figure 2 bottom panel). In summary, while the data generated by students was preliminary, students met one of our overarching goals—to use a combination of approaches to investigate a collaborative research project and generate novel results.

Assessment of *Mapping the Brain* Learning Outcomes

We next focused on the remaining two course goals: After participation in *Mapping the Brain,* students will:

1) Appreciate the fundamental challenges inherent in studying the brain.
2) Understand the applications and limitations of traditional and emerging methodology in modern neuroscience.

Using a backwards design approach (Wiggins and McTighe, 1998; Cooper et al., 2017) we created specific and measurable student learning outcomes (LO) (Figure 3A). Our LOs were designed to support attainment of our course goals and the development of essential neuroscience technical and intellectual skills. Given their broad applicability, these LOs could be adopted or adapted to support a variety of neuroscience classrooms.

Student achievement of the learning outcomes was first assessed using an assignment analysis based on an outcome-specific combination of questions from the final exam, the comprehensive DREADD research report and/or the research design presentations (Figure 3B). For every learning outcome, the average student score from the assignment analysis was greater than 75%. Within the research design presentation (Figure 3B right bars), student scores were significantly higher for LO (learning objective)-9 (evaluate modern neuroscience tools) relative to LO-10 (analyze primary research articles). Within assignment comparison of the remaining learning outcomes did not reveal any other significant differences.

To support the neurotechnology and research-based

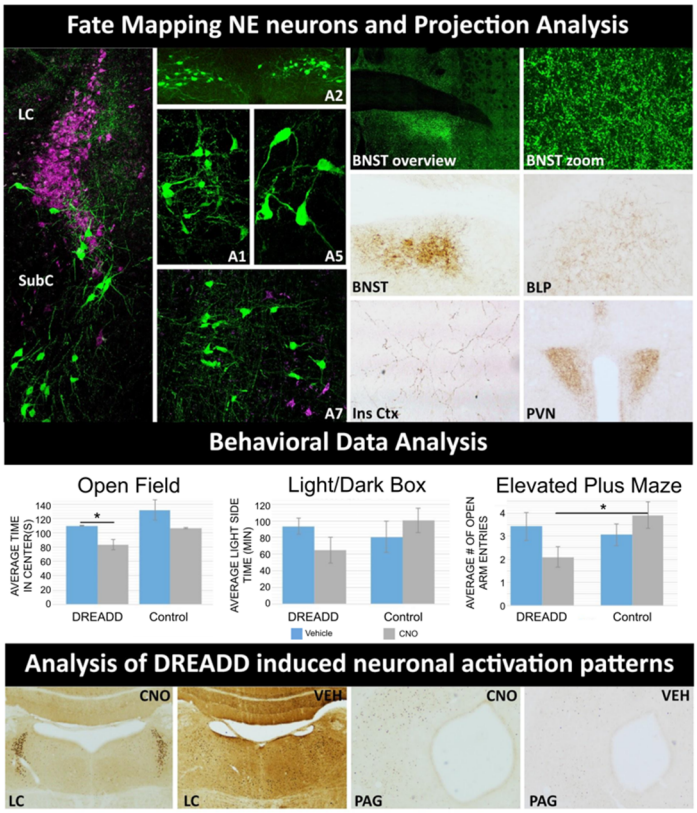

Figure 2. Examples of student data from *Mapping the Brain*. Students performed fluorescent immunohistochemistry to assess if the new intersectional genetic approach worked and resulted in GFP (green) and hM3Dq-mCherry (violet) expression in the expected norepinephrine subgroups *(top left)*. Students also searched their 40µm sections across the brain for ectopic GFP and hM3Dq-mCherry expression. Projections from the non-En1 NE subpopulation (GFP expressing) were also assessed using both fluorescent and DAB anti-GFP immunostaining *(top right)*. Students identified known targets of NE projections (bed nucleus of the stria terminalis-BNST, basolateral amygdala posterior part-BLP, insular cortex-Ins Ctx, and paraventricular hypothalamus-PVN). *(Middle Panel)* Sample student analysis of behavioral data from the DREADD mice and their littermate controls (n=18-20). DREADD (left bars) and control mice (right bars) were treated with vehicle (blue) or CNO (grey) in the open field (left), light-dark box (middle) or elevated plus maze (right). Data are mean ± s.e.m. *(*p* <.05; unpaired t-test). Some student groups also performed an ANOVA. *(Bottom Panel)* Students assessed the efficacy of CNO in activating mCherry-DREADD En1-NE neurons using immunohistochemistry staining for c-fos relative to vehicle (VEH) treated DREADD mice (left two panels). Students also used c-fos to map neuronal activation patterns in response to En1-NE neuron stimulation with CNO compared to vehicle (VEH) treated DREADD mice. Students identified several areas with enhanced activation in CNO-treated compared to vehicle treated animals, an example in the periaqueductal gray (PAG) region is shown (right two panels).

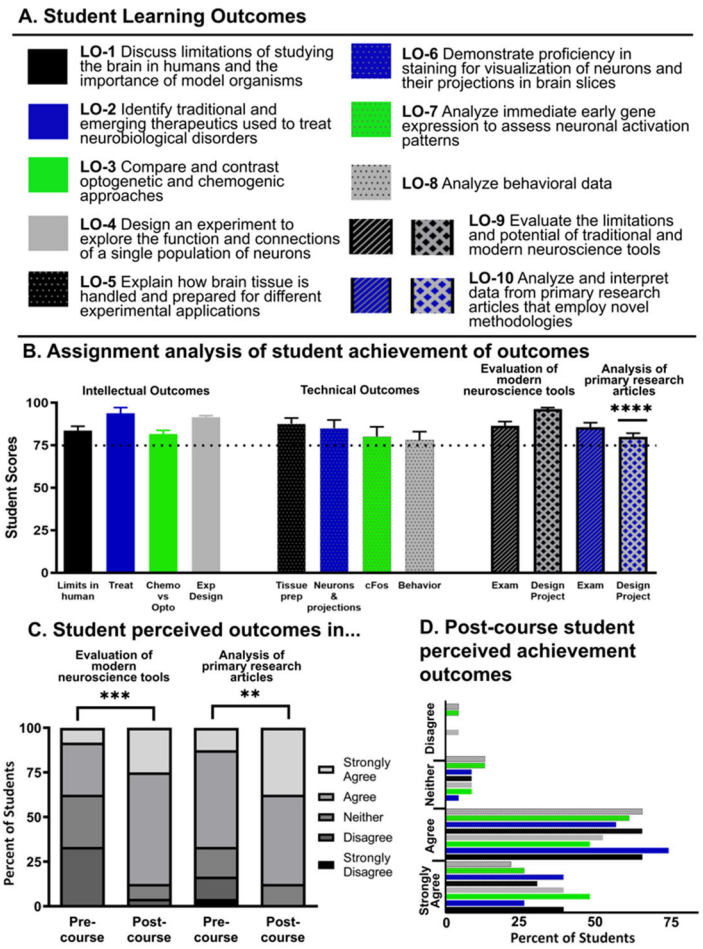

Figure 3. Student achievement and perceptions of gains related to course learning outcomes *(A)* Intellectual and technical course learning outcomes (LO). *(B)* Analysis of student assignments to determine if students achieve the LOs. Student achievement of intellectual LOs was assessed based on the percent correct of related questions in the cumulative final exam (left bars). Student achievement of technical LOs was assessed based on research report analysis (middle bars). Student achievement of LO-9 and LO-10 from the cumulative final exam (striped bars) or research design project (checkered bars). A one-way ANOVA followed by a Tukey's HSD test was used to compare levels of student achievement across outcomes. Student scores were only compared for outcomes assessed with the same assignment(s) (****p<.0001). *(C)* Pre- and post-course student perception of their ability to evaluate the limitations and potential of modern neuroscience tools (Wilcoxon*** p < .001) and analyze and interpret data from primary research articles that employ novel methodology (Wilcoxon **p < .01). *(D)* Post course, students indicated their perception of the impact of the course on their ability to do each LO. For each LO, students answered the question "By participating in this course, I gained the ability to…" using a Likert scale (strongly agree, agree, neither agree nor disagree, disagree, or strongly disagree). The percent of students is reported, and the color key shown in A indicates the LO in the bar graph. Strongly disagree is not shown because it was not selected by students for any LO.

assignments, etc. were focused on these outcomes to reach a critical point where students could evaluate and analyze any new neurotechnology and neuroscience research article with confidence. Analysis of the Likert scale data revealed a significant impact of *Mapping the Brain* on reported student confidence (Figure 3C). Collectively, these results provide evidence that the course accomplishes a major goal and leaves students feeling confident in their ability to analyze novel methodology and research articles. For the remaining course LOs, students were only asked post-course to report
the impact of *Mapping the Brain* on their ability to perform LO 1-8. Students reported gains in their ability to perform each LO (Figure 3D). A minimum of 83% of students strongly agreed/agreed that course participation enabled their ability to perform the outcome.

Impact of Course Focus on Research Article Analysis

Understanding and analyzing primary research literature is an essential skill to develop as a scientist (Hoskins et al., 2007, 2011; Snow, 2010; Choe and Drennan, 2001; Gottesman and Hoskins, 2013; Krontiris-Litowitz, 2013; Round and Campbell, 2013; Segura-Totten and Dalman, 2013; Abdullah et al., 2015). Analysis of research literature requires critical thinking, enables sound hypothesis development and experimental design, and reveals to students the structure of scientific writing and the application of the scientific process. Despite its importance, research article analysis is a challenging skill to teach students. *Mapping the Brain*'s central focus on research article analysis increased student confidence in their ability to analyze articles (Figure 3C).

We also hypothesized that our approach would (1) encourage students to take a "data-centered" method of analysis, and (2) reduce negative student perceptions commonly associated with the challenge of primary literature analysis (Round and Campbell 2013; Hoskins et al., 2011; McBride and Sweeney 2019). Previous research indicates that structured reading assignments, like FIGURE FACTS, can teach students to focus on data rather than text while also reducing the stress and frustration associated with article analysis (Round and Campbell 2013). We employed a variety of easily adoptable approaches to build literature analysis skills, including research article analysis worksheets with FIGURE FACTS (Round and Campbell 2013), reflection questions and lay audience abstracts, journal clubs (Glazer, 2000; Edwards et al., 2001; Kozeracki et al., 2006), 5-minute paper breakdowns, etc. Our goal was to encourage students to take a "data-centered approach" (Round and Campbell 2013; Massimelli et al., 2019) and to scaffold article analysis practice throughout the course to reduce the stress and frustration commonly encountered by novices. We asked students to select their primary focus when reading an article pre- and post- course (Figure 4A). Prior to the course only 33.3% of students reported a primary focus on the data while post-course the percentage significantly increased to 66.7%. No other categories of student focus changed significantly post-course.

Student Reported Stress and Frustration

While the FIGURE FACTS approach significantly reduced student reports of stress and frustration in other settings (Round and Campbell 2013), we did not observe the same effect. Prior to the course, 16.7% and 29.2% of *Mapping the*

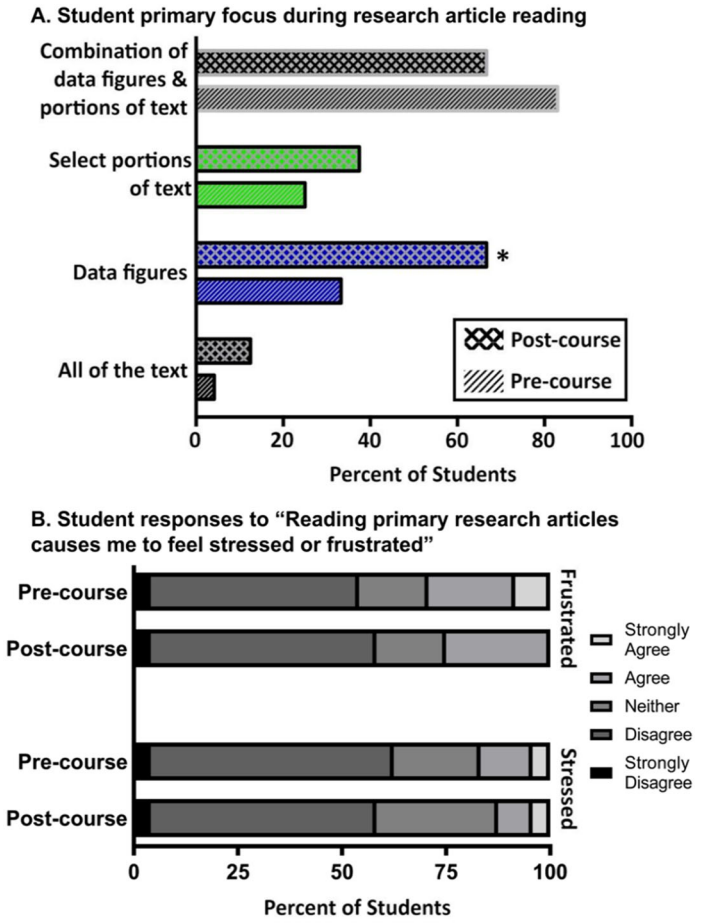

Figure 4. Impact of *Mapping the Brain* on student stress, frustration and primary focus while reading research articles. (A) Pre- and post- course students selected their primary focus while reading a research article (one-tailed McNemar chi-square *p<.05). (B) Pre- and post-course students answered the questions "Reading primary research articles causes me to feel stressed (bottom bar), or frustrated (top bars) using a Likert scale, (Wilcoxon ps > .05).

Brain students reported feeling stressed and frustrated, respectively by reading research articles (Figure 4B). Post course 12.5% and 25% of students felt the same way. Interestingly, before the course, the majority of *Mapping the Brain* students report feeling little stress or frustration when reading an article. Only 16.7% and 29.2% strongly agreed/agreed pre-course that article analysis caused them stress or frustration. This is in stark contrast to 47% and 58% of students reporting stress and frustration pre-FIGURE FACTS implementation in Round and Campbell 2013. *Mapping the Brain* student reports of stress and frustration pre-course are more similar to the post-FIGURE FACTS results—12% and 19% of students reported feeling stressed or frustrated, respectively. Student comments from the post survey also reveal insights into how students felt about the course's focus on research article analysis (Appendix 6). The bulk of comments were positive with only three negative comments tallied. Even in one comment where the student expressed dislike for the research article analysis worksheets the student still attributed learning gains to the activity:

"Although my least favorite component was the Primary literature reviews, this is where I found my weakness in comprehension of neuroscience research articles reduce significantly."

Student Perceptions of SfN's Core Concepts and Essential Principles of Neuroscience

As part of its educational mission, SfN identified a set of core concepts and essential principles of neuroscience that align with U.S. National Science Education Standards. While designated for K-12 education, these concepts and principles represent essential knowledge that students should acquire, if they have not already, after participation in a college neuroscience course. We assessed the impact of *Mapping the Brain* on student perceptions of SfN's core concepts and essential principles of neuroscience.

Students answered questions or rated a series of statements on a Likert scale to determine how course participation influenced their knowledge and perception of key neuroscience principles (Figure 5). Student responses were compressed into two categories: Agree (Strongly agree/Agree) and Other (neither agree nor disagree, disagree or strongly disagree), and the percentage of student responses in the "Agree" category were reported. For six of the ten principles, the percentage of students who correctly identified or recognized those principles increased post-course. Individual changes in the frequency of student responses were not significant (*Figure 5)*.

Interestingly, four concepts were identified with low pre-course student agreement (<75% of the students agreed/strongly agreed):

1) Genetically determined circuits are the foundation of the nervous system.
2) Circuits of neurons underlie complex cognitive processes and emotions.
3) Neuroscience research is limited by the technologies available to study the human brain.
4) Neuroscience research is limited by the complexity of the human brain.

For each of these concepts, the percentage of students who agreed/strongly agreed increased post course. The first two concepts require an understanding of the role of neuronal circuitry in mediating complex physiological and behavioral processes and relate to the essential principle "The brain is the foundation of the mind". Post-course percentages for these two concepts increased by 13% (Concept 1) and 17% (Concept 2) (Figure 5). Gains in this realm could be attributed to our course research project and associated article analysis, which focused on revealing the link between neuronal genetic identity, circuit function and subsequent impacts on behavior. Students also analyzed research that emphasized the significance of neuronal circuit control of key functions including respiration (Brust et al., 2014), fear, aggression, and mating (Lin et al., 2011; Anderson 2012). Student acceptance of concepts 3 and 4, which are related to the two essential principles, "The brain is the body's most complex organ" and "Research leads to essential understanding for Therapies", also increased.

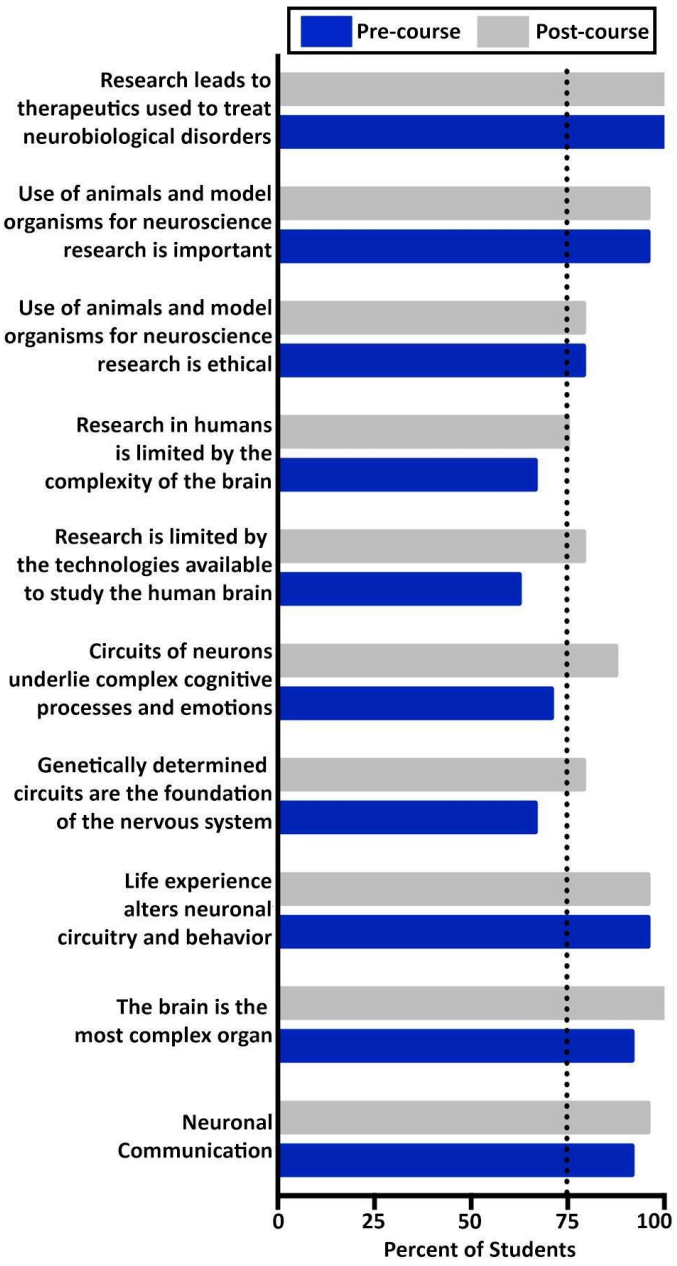

Figure 5. Student perception of the SfN's essential principles and core concepts of neuroscience. Students answered questions related to the essential principles and core concepts on a Likert scale (strongly agree, agree, neither agree nor disagree, disagree, or strongly disagree) with the exception of a question on neuronal communication. See Appendix 6 for the list of questions. The percent of students who strongly agree/agree is graphed pre-course (blue bars) and post-course (grey bars). Wilcoxon signed-rank tests to detect significant changes in frequencies of strongly agree/agree responses pre- and post-course were all non-significant (*p*s > .05).

Course content, linked to LO-1, addressed these concepts through the first article analysis worksheet on a review of the BRAIN initiative and through in class comparisons of available tools for research in model organisms (optogenetics, DREADDS, etc.) with those available in humans (fMRI, etc.). Both activities illustrated the technical and ethical limitations associated with human studies and the importance of investing in model organisms and new innovative technologies for studying the brain.

Prior to the course, most (92%) students answered correctly that neurons communicate via electrical and chemical signals and 96% of students answered correctly post-course. The bulk of students also strongly agreed/agreed that "the brain is the body's most complex organ" prior to the course, and 100% agreed post-course. Since *Mapping the Brain* is not a required course and students "opt-in", they all are likely interested in neuroscience research and believe (100%) pre- and post-course that "neuroscience research leads to essential understanding for the development of therapeutics used to treat neurobiological disorders". In class, we specifically discuss Parkinson's disease, the history of the MPTP animal model and its role in the discovery of L-DOPA treatment and new stem cell and deep brain stimulation-based therapies.

Interestingly, when asked about animal research and ethics student opinions do not change pre- and post-course (Figure 5). Research ethics is discussed openly using a case study format that emphasizes the importance of institutional regulation to ensure ethical practices. This discussion does not impact student opinions as the same percentage of students strongly agreed/agreed that the use of animals and model organisms is ethical (79%) and important (96%) pre- and post-course. Only one student moved between strongly agreed and agreed for both questions. There is also a divergence in student opinion regarding the importance versus ethical nature of animal research.

The final component of the SfN core concept and essential principles of neuroscience survey focused on a neuroscience myth. The pre- and post-course survey included a question to assess student attitudes regarding the neuroscience myth that humans only use 10% of brain capacity. Pre-course, only 75% of students strongly disagreed/disagreed with the myth and post-course still only 83% disagreed. It was surprising to see the myth persist after directly addressing the topic in class with follow up clicker and exam questions.

Analysis of Course Structure and Core Themes

Finally, we evaluated student attitudes regarding *Mapping the Brain*'s technology and research focus through qualitative and quantitative analysis of student post-course responses. Our goal was to determine if courses with a neurotechnology and research emphasis are well received by students and could serve as a core foundation for other unique CUREs or neuroscience courses. Student data were analyzed according to the three-course themes: (1) Neurotechnology, (2) Research article analysis, and (3) the Collaborative NIH-NCSU Course Research Project (Table 2). Reflections from students indicated students enjoyed the course neurotechnology focus. When asked to reflect on their favorite component of the course, 41% of students cited coverage of specific neurotechnologies (Table 2). No students cited specific neurotechnologies as their least favorite component or as part of suggestions for course improvement. A smaller percentage (14%) cites some aspect of research article analysis as their favorite class

Theme: Research Article Analysis	**Percent of student responses related to theme:** Favorite lecture- 14%; Least favorite component- 18%; Improve- 5%
In general, I really enjoyed all the "journal club" lectures. While normal lectures are always interesting, it's nice to really go in depth on a topic through a paper.	
My favorite lecture session was the journal club where we discussed the two papers, one of which used an optogenetic approach and the other one used a chemogenetic approach.	
Although my least favorite component was the Primary literature reviews, this is where I found my weakness in comprehension of neuroscience research articles reduce significantly.	
Theme: Neurotechnology	**Percent of student responses related to theme:** Favorite lecture- 41%; Least favorite component- 0%; Improve- 0%
It is difficult to choose my favorite lecture session because each one was incredibly useful to me. However, I do specifically recall the lecture which reviewed the different levels and methods by which to perform connectomics being of particular interest to me. Learning about rabies viral tracing and CLARITY was very interesting and I plan to perform these techniques in my own research.	
I really enjoyed the optogenetics portion of the course. I loved all lectures though.	
Favorite Topics: Genetic fate mapping, using viruses to express modifications to brain cells, DREADS, using the combo of fate mapping and DREADS. I liked the Optics for mapping projections, but it appeared complicated.	
Theme: Collaborative NIH Course Research Project	**Percent of student responses related to theme:** Favorite lecture- 18%; Least favorite component- 0%; Improve- 5%
Dr. Robertson's dual recombinase-based intersectional genetic approach, which we learned about over the entire course, is extremely clever science and I was inspired by that approach to investigate how I could apply something similar to study the dopaminergic system.	
Favorite Topics: Genetic fate mapping, using viruses to express modifications to brain cells, DREADS, using the combo of fate mapping and DREADS. I liked the Optics for mapping projections, but it appeared complicated.	
This was an excellent module. If you had explained more about the DREADD project in the first lecture I believe I would have understood what we were trying to accomplish in lab better. Eventually the pieces all fell into place but a broad/ general overview at the beginning before diving into the details would have been helpful. I know class time is limited so maybe even a written overview to read before the first lab would have helped.	

Table 2. Excerpts of student responses to end-of-course survey questions asking for their most and least favorite lessons. Percentages were calculated out of all students enrolled in *Mapping the Brain.*

component. On the other hand, 18% of students described some aspect of research article analysis as their least favorite component. Interestingly, even when reported as a least favorite component, many still report learning gains from article analysis:

> *"Even though the primary literature assignments were time consuming, I think that they were valuable. I think my ability to read and comprehend scientific literature improved as a result of the primary literature assignments."*

Students also proposed new, supportive pedagogical activities for article analysis, such as a "how to read and analyze primary literature" breakout session.

Finally, 18% of students cite the collaborative course research project as their favorite aspect while zero students indicate this as their least favorite. In these comments, students shared their excitement for research:

> *"I enjoyed the first lecture about DREADD mice because it is an interesting technology that was exciting to get to use"*

Students also discussed how the research project inspired them to consider research and similar approaches:

> *"I was inspired by that approach to investigate how I could apply something similar to study the dopaminergic system"*

These comments support well-documented (Metz, 2008; Brewer and Smith, 2011; Brownell et al., 2012; Remsburg et al., 2014; Ward et al., 2014; Jeffery et al., 2016; Rodenbusch

et al., 2016.; Lipchock et al., 2017; Reeves et al., 2018) evidence that CUREs increase student enthusiasm, science literacy skills and identity in science. These results also reveal that a neurotechnology focus is met with enthusiasm from students and can provide an innovative way to design new or modernize existing neuroscience courses.

DISCUSSION

We created a novel 8-week neuroscience CURE structured around (1) the BRAIN initiative and its supporting neurotechnologies and (2) a collaborative NIH research project. *Mapping the Brain* meets the defining criteria of a CURE by incorporating collaboration, neuroscientific practices, iteration, broad relevance, and discovery (Auchincloss et al., 2014). Student immersion in research article analysis is also a cornerstone of the course with journal clubs, research article worksheets and research design presentations as key pedagogical tools. In class (110 min/week) students compared fundamental and cutting-edge neuroscience methodology while in lab (5 hours/week) students developed their technical and science process skills. Research focused on the broadly relevant norepinephrine neurotransmitter system, and students used a cutting-edge combination of chemogenetics and intersectional genetics to map norepinephrine neurons, map their projections, and explore the effects of activating these neurons *in vivo*. Students validated our animal model, and ultimately generated novel results to investigate their own proposed hypotheses. Students also critically evaluated neurotechnologies (optogenetics, chemogenetics, stem cell therapies, transcriptomics, etc.) highlighting strengths, limitations, and comparisons with their own research. Here we will discuss insights from our assessment of this unique CURE and how it can be adapted to fit other curricula.

Our multifaceted assessment explored student achievement of generally applicable, neuroscience related LOs, the impact of easily adaptable pedagogical tools on student research article analysis, and the change in student perceptions of SfN's Core concepts and essential principles of neuroscience. We also used qualitative data to assess student satisfaction with *Mapping the Brain*'s technology and research focus to reveal the broader utility of designing neuroscience courses around these cornerstones. Students were highly confident in their ability to perform all 10 LOs and direct assessment of a variety of student work also supports their achievement of LOs. Pre- and post-course comparisons showed a significant increase in students' confidence in their ability to analyze novel methodology and research articles, two central course LOs and broadly applicable skills across the life sciences.

To facilitate deep reading and analysis of research articles, we used a variety of adoptable pedagogical tools (research analysis worksheets, journal clubs, research design presentations, comprehensive research reports, strength and limitation activities, etc.). We hypothesized that our multi-pronged approach would encourage students to take a "data-centered" mentality and reduce feelings of stress and frustration with primary literature reading. Our results did reveal a significant increase in students' focus on data, but student reports of stress and frustration did not change significantly. Few of our students agreed pre-course that article analysis caused them stress or frustration in contrast to other reports (Round and Campbell 2013) which could be related to academic experience (400/500 versus 200 level courses) or curriculum design differences. For example, the BIT program emphasizes research integration into its curriculum, especially in pre-requisite courses for *Mapping the Brain* (Garcia et al., 2021). BIT students' research experience may lead to their reduced stress and frustration levels. Future research exploring student experiences with research articles prior to our course and across curricula in general could help identify and validate pedagogical approaches and experiences that reduce negative perceptions commonly affiliated with reading primary literature.

We also assessed, pre- and post-course student perceptions of SfN's core concepts and essential principles of neuroscience. While intended for K-12 education, at the time of our course offerings no other concepts or competencies had been outlined for neuroscience undergraduate education. Only four concepts had low student agreement (<75%) prior to our course, and student acceptance of these four principles increased post course. Gains in acceptance of these principles likely reflect our course focus on the link between genetically distinct groups of neurons and their control over certain circuits and specific physiological processes and behaviors (Brust et al., 2014). We also routinely discussed the power of new neurotechnology for answering longstanding questions (Lin et al., 2011) and the need for new tech to address the incredible complexity of the human brain. In our SfN principles assessment, we were also surprised by some disagreement with the ethics of animal research (21%) and persistent belief in the neuroscience myth that humans only use 10% of brain capacity (17%). 96% of students agree that animal research is important yet, students' opinions regarding the ethics of animal research do not change at all pre- and post-course. This is despite targeted discussions and activities on governmental and institutional rules that support ethical animal research. We also explicitly dispelled the neuroscience myth in class. In the future, asking students open-ended questions or creating focus groups may help us better understand why a neuroscience myth and the discordance between the importance and ethics of animal research persists for some students. Since the design of this study, SfN shared core competencies for neuroscience undergraduates, and efforts are ongoing (FUN meeting 2020) to identify, review, revise and share core concepts for undergraduate neuroscience education. Assessing future courses and curricula with these tools will help instructors and programs identify gaps in their undergraduate training or individual course designs.

To assess the broader value and adaptability of our course design around (1) neurotechnologies, (2) research article analyses, and (3) collaborative research, we also assessed students' attitudes regarding the course. Students enjoy the neurotechnology focus and collaborative research project as many students listed these as their favorite parts and no student mentioned them as their least. Research article analysis was met with more mixed emotions from

students. Our results support the notion that students are interested in neurotechnologies and excited to explore them in depth. In our experience, this excitement for neurotech was amplified when students choose their own technologies to explore in their research design presentations. Incorporation of the design presentation or the redesign or creation of new courses around cutting-edge neurotech is likely to be well-received by undergraduates and is a simple way to modernize existing neuroscience curricula. Our data also supports existing research that engagement in broadly relevant, novel research in a CURE increases student enthusiasm and engagement. Yet, our data also highlights a significant challenge in delivering a CURE. How do we help students critically analyze research articles *but also* help them to enjoy and embrace the struggle of this skill development? Several studies propose specific pedagogical tools or interventions to help students tackle primary literature, but in their assessment of such tools little attention is typically paid to how students feel about the process (Glazer, 2000; Edwards et al., 2001; Gillen et al., 2004; Wu, 2009). Future work to identify and assess the emotional impact of essential yet easily adaptable tools for primary literature analysis is necessary. We should also consider assessing student's confidence and emotions at different points in our curricula to identify useful interventions and the critical windows for those approaches.

Our assessment of *Mapping the Brain* indicates it could be adopted directly or adapted to benefit students and engage them in research and learning about the potential of neurotechnology and the BRAIN initiative. We offered the 8-week course in an interdisciplinary biotechnology program where both undergraduate and graduate students participated from 10 different degree programs. For the majority of students *Mapping the Brain* was their first neuroscience course, yet despite the disparities in their neuroscience backgrounds, students met the learning outcomes of the course and reported enjoyment of their experience. Thus, this short, neurotech focused CURE, or components of it (LOs, research article analysis pedagogical tools, etc.) could be added easily to a variety of curricula and programs. For example, the condensed structure may make it an ideal module that institutions could use for new summer courses, part of an existing lab course, expansion into a full semester CURE, formal lab training to accompany a summer REU program, etc. Individuals could also adapt our framework, using neurotechnology and the BRAIN initiative, to create new courses that integrate their own research collaborations. Versions of the course, with the neurotechnology and research article analysis focus but no wet lab research component may also be a good fit for those interested in developing research related skills. Incorporation of "dry" research methods using freely available, yet not fully mined datasets (e.g., Allen Brain Resources) for bioinformatic analyses may be an especially important alternative for our current remote learning world.

In conclusion, *Mapping the Brain* offers an adaptable CURE model with a unique neurotechnology and collaborative research project focus that from our assessment clearly benefits students in a variety of ways. Our course design also offers a variety of easy to implement pedagogical approaches for engaging students in research article analysis and to help them take a data centered approach and "think like a neuroscientist." Our assessment also highlighted important STEM education research areas that warrant further investigation. What experiences and pedagogical approaches reduce negative perceptions associated with reading primary literature? Why do some neuroscience myths persist despite intervention in our well-educated students? How do we help students to enjoy and embrace their struggle with research article analysis? We hope to address some of these questions and more in future iterations and adaptations of *Mapping the Brain*. In the meantime, we assert that *Mapping the Brain* provides a framework for faculty to meet the essential need of integrating modern neuroscience approaches and technology into our curricula. To obtain any materials related to the class, see appendices and supplemental materials, you may also contact corresponding author S.R.

APPENDICES AND SUPPLEMENTAL MATERIALS

A1. *Mapping the Brain* Syllabus
A2. Research Article Worksheets
A3. Journal Club Participation Rubric
A4. Research Design Presentation Guidelines and Rubric
A5. Research Report Expectations
A6. Pre and Post Course Survey Questions
S1. Lab 2 Protocol Mapping Neurons
S2. Lab 3 Protocol Mapping Neuronal projections/activation
S3. Lab 4 Protocol Behavioral Data Analysis

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APPENDIX 1:
SYLLABUS

BIT478/578: Mapping the Brain

You ***MUST*** be registered for lecture (section 001) and lab (section 201) to receive credit for this course.

Office hours:)

Course Meetings: August 16th-October 10th

Laboratory	Tuesday	12:50-5:50 pm	6109 Jordan Hall
Lectures	Thursday	3:00-4:50 pm	6117 Jordan Hall

Course Description: Mapping the Brain is designed to provide students with an inquiry-based authentic neuroscience research experience. In lecture, students will gain an appreciation for the fundamental challenges inherent in studying the brain and explore the theory, applications, and limitations of new and traditional technologies employed in modern neuroscience. In the lab, students will use a novel transgenic mouse model to analyze the connections of a single population of neurons and the effects of stimulating their activity *in vivo*. This hands-on laboratory research experience will expose students to a combination of universal laboratory approaches (histology, microscopy, etc.) as well as to new genetic approaches that are becoming common staples in every neuroscientist's toolkit.

Prerequisite: BIT410/510 Manipulation of Recombinant DNA/Core Technologies in Molecular Biology

Course goals:

After completing the course, students will:

1. Appreciate the fundamental challenges inherent in studying the brain
2. Understand the applications and limitations of traditional and emerging methodology in modern neuroscience
3. Have applied a combination of laboratory approaches to investigate a collaborative neuroscience research project

Student Learning Outcomes:

Upon completion of the course, students will be able to:

Intellectual Skills

1. Design an experiment to explore the function and connections of a single population of neurons
2. Evaluate the limitations and potential of traditional and modern neuroscience tools
3. Analyze and interpret data from primary research articles that employ novel methodology
4. Discuss the limitations of studying the brain in humans and the importance of model organisms
5. Identify traditional and emerging therapeutics used to treat neurobiological disorders
6. Compare and contrast optogenetic and chemogenetic approaches

Technical Skills

1. Explain how brain tissue is handled and prepared for different experimental applications
2. Demonstrate proficiency in immunostaining for visualization of neurons and their projections in brain slices
3. Employ microscopy to quantify the density of neuronal projections
4. Analyze immediate early gene expression to assess neuronal activation patterns
5. Analyze behavioral data

Course Materials:

- No textbook is required for this course. We will be using scientific literature (primary research articles and reviews).
- You will use an **electronic lab notebook (ELN)** to document your progress in the lab. LabArchives will email you a link to the lab notebook prior to the first lab; use this link to create an account and gain access to the lab notebook.
- The **course laboratory manual** (including background information, experimental goals, and lab protocols) is included in the ELN. We will work on four labs that are spread across the laboratory periods of the semester. Use the ELN posted protocols and the course schedule to identify each lab period's experimental goals and corresponding lab protocols. *You are required to begin creation of your lab entry **BEFORE** each laboratory period*. Experiments for the course will take the full five hours so having the lab protocols copied into your lab entry prior to each lab period will ensure you are able to finish on time.
- USB Flash Drive (~15$)

Grading:

Item	Weight (%)
Pre Labs	**10**
Pre Lab Electronic Outline	**5**
Lab notebook	**5**
Lab report 1 (Neuronal excitability)	**10**
Lab report 2 Introduction (DREADD project)	**5**
Lab report 2 (DREADD project)	**15**
Primary literature analysis worksheets	**15**
Journal club participation	**10**
Design Presentation	**15**
Final Exam	**10**
Attendance	***-10%***

See Attendance policy for more details. Since this is a laboratory-based course, attendance is mandatory

This Course uses Standard NCSU Letter Grading and Numerical grade cut-offs are as follows:

97	≤	**A+**	≤	100
93	≤	**A**	<	97
90	≤	**A-**	<	93
87	≤	**B+**	<	90
83	≤	**B**	<	87
80	≤	**B-**	<	83
77	≤	**C+**	<	80
73	≤	**C**	<	77
70	≤	**C-**	<	73

67	≤	**D+**	<	70
63	≤	**D**	<	67
60	≤	**D-**	<	63
0	≤	**F**	<	60

Course Schedule is a guideline. Dates may be adjusted for experimental timing or to accommodate student interests. **Pre-Labs are due at the start of each lab period on Tuesday. ELN entry outlines are due 11:59pm the day before lab.**

Week	Laboratory	Lecture
1	Tuesday August 15th No Laboratory	Thursday August 17th **Lecture1: Neuron excitability** ● Course overview, syllabus & expectations ● Qualtrics Survey ● Studying the brain & Neuron Excitability ● **Sign up for Day 1 of Mapping Lab**
2	Tuesday August 22nd **Lab1:** ● Lab Safety ● **Exploring neuron excitability in insects (1)**	Thursday August 24th **Lecture2: Introduction to course DREADD research project** ● **Interim lab: Day 2 of Mapping Lab**
3	Tuesday August 29th **Lab2**: ● **Day 3 of mapping lab** ● Dissections of mouse tissue ● Mini Lecture: Allen brain atlas activity and Introduction to DREADD project part II	Thursday August 31st **Lecture3: Studying neuronal diversity** ● **Primary Lit Assignment 1: "The BRAIN initiative: developing technology to catalyze neuroscience discovery" Jorgenson et al. 2015**
4	Tuesday September 5th **Lab3**: ● **Insect lab report due (1)!** ● **Day 4 of Mapping Lab (image, pictures & analysis)** ● **Day 1 of cFos & Projection Lab**	Thursday September 7th **Lecture4**: **Manipulating neuronal activity** ● Stimulating behavior via activation of specific neuronal circuits ● DREADDS ● Channelrhodopsin ● **Primary Lit Assignment 2 & JOURNAL CLUB: "Functional and Developmental Identification of a Molecular Subtype of Brain Serotonergic Neuron Specialized to Regulate Breathing Dynamics" *Cell Reports* Brust et al. 2014**
5	Tuesday September 12th **Lab4**: ● **Day 2 of cFos & projection lab**	Thursday September 14th **Lecture5: Connectome, observing neuronal activity &behavior** ● Calcium imaging, cFos and fMRI ● **DREADD project lab report introduction due**
6	Tuesday September 19th **Lab5**: ● **Design presentation outline due** ● **Behavioral data analysis** **OR** ● **Day 3 of cFos & projection lab (image, pictures & analysis)**	Thursday September 21st **Lecture6: Ethical treatment of laboratory animals** ● Institutional animal care and use ● **Primary Lit Assignment 3 & JOURNAL CLUB: "Generation of a synthetic memory trace." *Science* Garner et al. 2012** **"Optogenetic stimulation of a hippocampal engram activates fear memory recall" *Nature* Liu et al. 2012**
7	Tuesday September 26th **Lab6**: ● **Behavioral data analysis**	Thursday September 28th **Lecture7: Modeling neurobiological disorders in animals & current therapeutics**

	OR ● **Day 3 of cFos & projection lab (image, pictures & analysis)**	● Parkinson's Disease **Primary Lit Assignment 4 & JOURNAL CLUB: "Optogenetics enables functional analysis of human embryonic stem cell-derived grafts in a Parkinson's disease model" *Nature Biotech* Steinbeck et al. 2015**
8	Tuesday October 3rd **Design presentations** (use a new tool to explore the function of your favorite neuronal population)	Thursday October 5th **FALL BREAK!!! No Class**
9	Tuesday October 10th **Cumulative FINAL 12:50 -5:50pm**	**DREADD project lab report due Thursday Oct 12th by 5:00pm**

Pre-Labs: All lab protocols must be read before coming to lab. Corresponding pre-labs will be posted on Moodle and printed copies are due at the start of class for each lab session.

Pre-Lab Electronic Outline. Students are required to develop a lab entry outline for every lab period including interim labs. The outline is to be entered on the Lab Entry page for the week and is due by 11:59 PM the day prior to lab. The outline must include, in the student's own words, a statement describing the goals, purpose, and expected results of experiments to be conducted in the corresponding lab period. The outline must also include all protocols to be used during that lab period. The protocols can be found in the "Protocols" folder of the ELN. Students should include only the steps of the protocol and not the introduction to the protocol. All calculations necessary for performing the protocol(s) should be carried out or the appropriate formula to determine correct volumes, concentrations, etc. should be written into the methods section.

Lab notebooks: Each entry must be dated and must include a reference to the protocol, as well as all results, conclusions, and answers to discussion questions. You must complete your notebook entry before leaving the lab, and your TA must sign your notebook before you leave the lab. Your lab notebook will be collected and graded at the end of the semester. For notebook grading guidelines, refer to the Moodle website.

Lab reports: Lab reports must be typed and submitted either as a pdf or a word document in **journal article format**. This will be good practice for entering the research world so choose your favorite journal and make your lab report look like articles published in that journal. All lab reports should contain the following sections: title, purpose/introduction, materials and methods, results (data and text), and discussion. You may discuss results with your lab partner, but reports are to be *written independently and in your own words*. Under NO circumstance should you share your lab report with another individual besides the instructor, doing so constitutes and academic integrity violation! Lab reports will be submitted on-line and are due by **12:50 pm at the start of lab**. **No late lab reports will be accepted; any lab report that is not turned in on time will receive a zero.**

Primary literature analysis worksheets: Primary lit analysis worksheets are due at the start of the lecture period when the article will be discussed. These worksheets are designed to help you read primary scientific literature and serve as an aid for you during journal club discussion, so be sure to print a copy for the in class discussion.

Journal club participation: Students will be graded on their participation in three journal club discussions in class. Students are expected to read the entire paper and come prepared to discuss or present ***any figure*** in the paper. See the posted journal club participation rubric for more details.

Design Presentation: Students will work in pairs to design a research strategy, using a cutting edge neuroscience technique, to explore the function or projection pattern of your favorite neuronal population. You will use a published research article as your foundation for developing a scientific question and your growing knowledge of neuroscience methodology to design a future research strategy to answer that question. Students will then present their strategy to the class in a 15-minute presentation with an opportunity for questions from their peers at the end.

Final Exam: Exam will be a mixture of multiple choice, short answer and essay. *NOTE BIT578 students will be expected to complete an additional open book portion of the final exam*

Attendance Policy: Attendance is mandatory. You will be working in groups of two for the duration of the semester. It is your responsibility to read the laboratory protocol *before* class and to *attend each session*. Failure to do so will place an undue burden on your lab partner. Attendance at **ALL** laboratories is mandatory. Examples of excused absences are scientific conferences pre-approved by the instructor, religious observance, death in the family, or serious illness/injury accompanied by a doctor's note. Review the NCSU policy on excused absences: http://policies.ncsu.edu/regulation/reg-02-20-03. **To be considered for an excused absence, you must present the instructor with a written excuse for your absence no later than the next class period. The burden to remember this written notice is on the student. Any planned absence should be requested for approval prior to the absence. Illnesses must be documented with a doctor's note.**

One unexcused absence from lab will result in a reduction of a full letter grade in the course (10 percentage points off the final grade). Two unexcused absences will result in failure of the course. Missing a lecture period during which lab exercises/activities are performed decrease your final grade by 5 percentage points. If both partners miss a lecture period during which lab exercises are performed, it is possible that you will be unable to complete that week's lab. If you have more than two **excused lab** absences, you will receive an incomplete for the semester. Unexcused absences to lecture will affect your journal club grade.

Lates to lab are counted as follows: two unexcused lates of 15 minutes or more count the same as an unexcused absence. Students **may not leave a lab that is still in session** without prior approval from the instructor and appropriate documentation. Leaving the laboratory while in session for any period of time greater than 15 min without prior approval from the instructor will be counted as an **unexcused lab absence** (see above for penalty).

Any assignment or work missed during an excused absence is required to be made up by the student. Assignments due on the date of an excused absence need to be turned in before their absence if the absence is arranged with the Instructor prior to the due date of the assignment. For an excused absence without advanced notification, students must schedule a time with the instructor to make up the assignment as soon as possible. **No make-up work will be offered for unexcused absences.** A grade of **Incomplete (IN)** will be given only if there is an excused significant and verifiable disruption in the student's work.

Late Assignments and Assignment Submission: No late assignments will be accepted unless the Instructor receives proper documentation (i.e., Doctor's note that is submitted to the Instructor). Any assignments turned in after the due date without proper documentation will receive a ***zero***.

Lecture notes: The lecture slides will be posted on Moodle prior to lecture. http://wolfware.ncsu.edu/. These slides outline the day's lecture, but they do not cover every detail we cover in class. You are responsible for coming to class and taking appropriate notes. You must also bring your lab notebook to lecture each week.

Academic Integrity: No course materials from previous semesters may be used for any assignment in this course. No old exams, papers, lab reports, assignments, or notes, etc. may be used.
Guidelines set forth in the NCSU Policy on Academic Integrity will be strictly followed. These can be viewed at http://policies.ncsu.edu/policy/pol-11-35-01.

In particular, sections 7-12 should be reviewed if there is any doubt as to what constitutes plagiarism or cheating. It should also be noted that helping others is a violation if independent work is requested. You will be working with a partner for each of the laboratory exercises. It is expected that you will work together, or in groups, for data analysis and presentation. However, each lab report must contain original data from your experiments and the written part must be in your own words and represent your understanding of the conclusions to be drawn from the experiment. **You also must not copy directly from the lab protocols.** Any evidence of plagiarism will be dealt with according to section 9.

Students with disabilities: Reasonable accommodations will be made for students with verifiable disabilities. In order to take advantage of available accommodations, students must register with Disability Services for Students at 1900 Student Health Center, Campus Box 7509, 515-7653. For more information on NC State's policy on students with disabilities, please

see the Academic Accommodations for Students with Disabilities Regulation (http://dso.dasa.ncsu.edu/). Please also meet with me as soon as possible to discuss special accommodations.

Behavior is also addressed under the Code of Student Conduct: Inappropriate behavior of any kind will not be tolerated and includes behavior that is directed toward a particular person (or persons), is unwelcome and severe or pervasive, and violates criminal law, civil rights law, the NCSU Administrative Regulation on harassment, or that unreasonably interferes with the target person's employment, academic pursuits, or participation in University-sponsored activities.

Online course evaluations will be available for students to complete during the last two weeks of class. Students will receive an email message directing them to a website where they can login using their Unity ID and complete evaluations. All evaluations are confidential; instructors will never know how any one student responded to any question, and students will never know the ratings for any particular instructors.
Evaluation website: https://classeval.ncsu.edu Student help desk: classeval@ncsu.edu
More information about ClassEval: http://www2.acs.ncsu.edu/UPA/classeval/index.htm

Audits: Students auditing the course must discuss assignment requirements with the instructor the first week of class. Attendance is required of auditors.

Supporting Fellow Students in Distress: As members of the NC State Wolfpack community, we each share a personal responsibility to express concern for one another and to ensure that this classroom and the campus as a whole remains a healthy and safe environment for learning. Occasionally, you may come across a fellow classmate whose personal behavior concerns or worries you, either for the classmate's well-being or yours. When this is the case, I would encourage you to report this behavior to the NC State's Students of Concern website: http://go.ncsu.edu/NCSUcares. Although you can report anonymously, it is preferred that you share your contact information so they can follow-up with you personally.

APPENDIX 2

Review Article Summary

"The BRAIN Initiative: developing technology to catalyze neuroscience discovery"

A **one-page summary** of the article is due Thursday at the start of class. Summaries will be used to cultivate your writing and critical thinking skills, and ensure you understand the paper. ***This is your opportunity to take notes and think about the future of neuroscience research and then spend some time thinking and writing about your impressions.***

Evaluation Method (20 points total)

2 points – Overview
7 points – Analysis of 7 priority research areas
7 points – Personal reflection
4 points – Lay-audience abstract

Overview

- Include article title, authors and journal reference
- Include a short statement describing the purpose of the article and how it contributes to knowledge in the field.

Analysis of 7 priority research areas

- Provide 2-4 sentences to describe in your own words the priority research area and how it is important for contributing knowledge to the field of neuroscience. Think about these research areas with a critical eye. Is this an important problem to consider? Is there another point of view to consider?

Personal reflection

- Overall, what knowledge did you acquire from reading the review?
- What are the complexities of the situation?
- What questions remain to be answered?
- Did you like the article? Why or why not?

Lay-audience abstract

- Write a lay-audience abstract. Write a paragraph to summarize the article in your own words at a level that any non-scientist could understand. You will have to work to make the complex scientific concepts/techniques clear but remain accurate.

Learning Outcomes

After completion of this assignment and the accompanying lecture and discussion, you will be able to:

- Describe key areas of neuroscience research in need of new innovation and technology
- Reflect on priority research needs in the neuroscience field
- List the three spatial scales of structural analysis of the connectome
- Identify some limitations of current neuroscience tools
- Discuss the limitations of studying the brain in humans
- Communicate complex scientific concepts in understandable but accurate terms

Primary Research Article Worksheet

"Functional and Developmental Identification of a Molecular Subtype of Brain Serotonergic Neuron Specialized to Regulate Breathing Dynamics" *Cell Reports* 2014

A **1-2 page analysis** of the article is due September 3rd at the start of class. This analysis will be used to cultivate your writing and critical thinking skills, ensure you understand the paper, and aid you in the journal club discussion (you may want to print 2 copies one to hand in and one for yourself during journal club). ***This paper applies an approach in the serotonin system that is very similar to the approach we are using to study the norepinephrine system. Take this opportunity to think about the similarities and differences between this study and our experimental design.***

Primary research articles can be frustrating for novice readers. Here is a sequence of steps to help you approach reading primary scientific literature:

(1) Focus on the DATA!
(2) You do not need to read a scientific article from start to finish straight through. Give yourself an idea of the big picture before you delve into the details.
    a. Read the abstract
    b. Skim the figures. Look at the figure legend titles, axes, techniques, etc.
    c. Read the introduction
(3) Work to understand each figure and fill out your FACTS table as you progress.
    a. Use the written results portion to supplement your understanding of the figures
    b. If you do not understand a technique or require clarification use the methods section
    c. Always check for supplemental figures or data
(4) Read the discussion with a critical eye. Do the data support the authors' claims?

Evaluation Method (20 points total)

2 points – Overview
8 points – Analysis of two figures with the figure FACTS table
6 points – Personal reflection (2 points for each question)
4 points – Lay-audience abstract

Please write each of these as a separate section (total 1-2 pages). ***See the next page for a breakdown of these sections!!!***

Overview

- Include article title, authors and journal reference
- Include a short statement describing the purpose of the article and how it contributes to knowledge in the field.

Figure Analysis

- Fill out the figure FACTS table for **at least two figures**. You may do more figures if you find the table helpful but this is not required and will not factor into your grade for the assignment. Only the first two will be graded.

Figure	Panel	Technique:	These data show:
Figure #	A B C D	Transfected neurons w/GFP Immunostain for PSD95 Counted stable vs. transient puncta Stained for AMPA receptors	Transfection was successful Synapses were formed 80% of synapses were transient Stable synapses are AMPAR+
Figure 1			
Figure 2			

Personal reflection

- **How is this study similar to our class project?**
- **How is this study different from our class project?**
- Did you like the article? Why or why not?

Lay-audience abstract

- Write a lay-audience abstract. Write a paragraph to summarize the article in your own words at a level that any non-scientist could understand. You will have to work to make the complex scientific concepts/techniques clear but remain accurate.

Learning Outcomes

After completion of this assignment and the accompanying lecture and discussion, you will be able to:

- Describe how DREADDs are used to manipulate neuronal activity
- Compare the advantages and disadvantages of the chemogenetic approach
- Describe the respiratory chemoreflex
- Analyze and interpret data from a research article that uses DREADDS and a recombinase based intersectional genetic approach to manipulate serotonin neurons *in vivo*
- Communicate complex scientific concepts in understandable but accurate terms

Primary Research Article Worksheet 3

"Generation of a Synthetic Memory Trace" *Science* 2012
&
"Optogenetic stimulation of a hippocampal engram activates fear memory recall" *Nature* 2012

A **1-2 page analysis** of the two articles is due **online** September 17th at the start of class. This analysis will be used to cultivate your writing and critical thinking skills, ensure you understand the paper, and aid you in the journal club discussion. ***Both papers take advantage of the c-fos promoter to drive expression of either a DREADD receptor (chemogenetic approach) or channelrhodopsin-2 (optogentic approach). Remember c-fos is turned on in highly activated neurons (i.e. firing many action potentials). Take this opportunity to think about the strengths and weakness of each approach.*** *Also the link below will take you to a popular media article about the research articles. I suggest you read it first! It will help you conceptualize the methods and significance of the articles.*

Popular article
http://blogs.discovermagazine.com/notrocketscience/2012/03/23/scientists-create-mice-that-automatically-label-new-memories-for-easy-reactivation/#.VfLaVGTBzGd

Primary research articles can be frustrating for novice readers. Here is a sequence of steps to help you approach reading primary scientific literature:

(5) Focus on the DATA!
(6) You do not need to read a scientific article from start to finish straight through. Give yourself an idea of the big picture before you delve into the details.
    a. Read the abstract
    b. Skim the figures. Look at the figure legend titles, axes, techniques, etc.
    c. Read the introduction
(7) Work to understand each figure and fill out your FACTS table as you progress.
    a. Use the written results portion to supplement your understanding of the figures
    b. If you do not understand a technique or require clarification use the methods section
    c. Always check for supplemental figures or data
(8) Read the discussion with a critical eye. Do the data support the authors' claims?

Evaluation Method (20 points total)

2 points – Overview
8 points – Analysis of the two **assigned** figures with the figure FACTS table
6 points – Personal reflection
4 points – Lay-audience abstract

Please write each of these as a separate section (total 1-2 pages). ***See the next page for a breakdown of these sections!!!***

Overview

- Include article title, authors and journal reference
- Include a short statement describing the purpose of the articles and how they contribute to knowledge in the field.

Figure Analysis

- Fill out the figure FACTS table for **the two assigned figures**. You may do more figures if you find the table helpful but this is not required and will not factor into your grade for the assignment.
-

Figure	Panel	Technique:	These data show:
Figure #	A B C D	Transfected neurons w/GFP Immunostain for PSD95 Counted stable vs. transient puncta Stained for AMPA receptors	Transfection was successful Synapses were formed 80% of synapses were transient Stable synapses are AMPAR+
Figure 1			
Figure 2			

Personal reflection

- **How do the studies take advantage of *c-fos* and how does this compare with our experiment?**
- **Describe 1 advantage and disadvantage of hM3Dq and channelrhodopsin-2**
- Overall, what knowledge did you acquire from reading the article?
- **Which article did you like better? Why?**

Lay-audience abstract

- Write a lay-audience abstract. Write a paragraph to summarize the article in your own words at a level that any non-scientist could understand. You will have to work to make the complex scientific concepts/techniques clear but remain accurate.

Learning Outcomes

After completion of this assignment and the accompanying lecture and discussion, you will be able to:

- Compare the advantages and disadvantages of the chemogenetic approach
- Describe how *cfos* is used in a genetic strategy to activate specific neurons associated with a memory
- Analyze and compare data from 2 primary research articles that employ novel methodology
- Communicate complex scientific concepts in understandable but accurate terms

Primary Research Article Worksheet 4

"Optogenetics enables functional analysis of human embryonic stem cell-derived grafts in a Parkinson's disease model"
&
News and Views "Illuminating Parkinson's therapy with optogenetics" *Nature Biotechnology* 2015

A **1-2 page analysis** of the article is due **online** before the start of class. This analysis will be used to cultivate your writing and critical thinking skills, ensure you understand the paper, and aid you in the journal club discussion. ***Take this opportunity to think about the strength of the optogenetic approach. Would a chemogenetic approach have been better?*** *Also posted is a news and views commentary about the research article. I suggest you read it first! It will help you conceptualize the methods and significance of the research article.*

Primary research articles can be frustrating for novice readers. Here is a sequence of steps to help you approach reading primary scientific literature:

(9) Focus on the DATA!
(10) You do not need to read a scientific article from start to finish straight through. Give yourself an idea of the big picture before you delve into the details.
    a. Read the abstract
    b. Skim the figures. Look at the figure legend titles, axes, techniques, etc.
    c. Read the introduction
(11) Work to understand each figure and fill out your FACTS table as you progress.
    a. Use the written results portion to supplement your understanding of the figures
    b. If you do not understand a technique or require clarification use the methods section
    c. Always check for supplemental figures or data
(12) Read the discussion with a critical eye. Do the data support the authors' claims?

Evaluation Method (20 points total)

2 points – Overview
8 points – Analysis of the two figures **of your choice** with the figure FACTS table
6 points – Personal reflection
4 points – Lay-audience abstract

Please write each of these as a separate section (total 1-2 pages). ***See the next page for a breakdown of these sections!!!***

Overview

- Include article title, authors and journal reference
- Include a short statement describing the purpose of the article and how it contributes to knowledge in the field.

Figure Analysis

- Fill out the figure FACTS table for **two figures of your choice**. You may do more figures if you find the table helpful but this is not required and will not factor into your grade for the assignment.

Figure	Panel	Technique:	These data show:
Figure #	A B C D	Transfected neurons w/GFP Immunostain for PSD95 Counted stable vs. transient puncta Stained for AMPA receptors	Transfection was successful Synapses were formed 80% of synapses were transient Stable synapses are AMPAR+
Figure 1			
Figure 2			

Personal reflection

- Overall, what knowledge did you acquire from reading the article?
- **How do you feel about the therapeutic potential of the optogenetic approach versus the chemogenetic approach?**
- **What kind of scientific hurdles have to be cleared for this to be a realistic therapeutic? And should the scientific community even work to clear the hurdles?**
- Did you like the article? Why or why not?

Lay-audience abstract

- Write a lay-audience abstract. Write a paragraph to summarize the article in your own words at a level that any non-scientist could understand. You will have to work to make the complex scientific concepts/techniques clear but remain accurate.

Learning Outcomes

After completion of this assignment and the accompanying lecture and discussion, you will be able to:

- Compare the advantages and disadvantages of the chemogenetic and optogenetic approach
- Describe one example of how Parkinson's disease is modeled in animals
- Analyze and interpret data from a primary research article that employs novel methodology

Communicate complex scientific concepts in understandable but accurate terms

APPENDIX 3

Journal Club Participation Rubric

Criteria	Needs Improvement (≤C)	Satisfactory (B)	Excellent (A)
Preparedness	● Student has not read the paper fully	● Student has read and analyzed the paper	● Student has read and analyzed the paper ● Student has a clear grasp of the paper's purpose and experimental details
Presentation of Figure	● Figure is not explained adequately ● Figure is explained inaccurately	● Figure is adequately and accurately explained ● Experimental details may require clarification	● Figure is adequately and accurately explained ● Experimental details are clearly portrayed and understood ● Student conveys the relevance of the figure to the paper and author's purpose
Critical analysis	● Failure to actively participate in class discussion ● Failure to ask questions of their peers	● Participates in the class discussion ● Asks questions of their peers	● Frequently makes helpful, relevant contributions to the class discussion ● Offers observations that challenge others to think about material in a new light ● Asks questions of their peers

Remember to THINK! (NC STATE Intellectual Standards)

CLARITY- Can you illustrate what you mean?
ACCURACY- How could we verify or test that?
PRECISION-Can you give me more details?
LOGIC- Does evidence support the conclusions?
FAIRNESS- Do I have any vested interest in this issue?

SIGNIFICANCE-Is this an important problem to consider?
RELEVANCE- How does that relate to the problem/scientific question?
DEPTH- What factors make this a difficult problem?
BREADTH- Do we need to consider another point of view?

APPENDIX 4

Research Design Presentation

GOAL: Design a research strategy, using a cutting edge neuroscience technique, to explore the function or projection pattern of your favorite neuronal population.

(1) **Pick a recent neuroscience research article that captures your interest from a good journal**. You can look for interesting neuroscience stories released in the popular media and track down the primary research article behind the story (ex: NPR's Science Friday) or explore recent table of contents from your favorite journals.
A few neuroscience research journals: *Neuron*, *Cell*, *Science, Nature, Nature Neuroscience, Journal of Neuroscience, eLife, Nature Biotechnology, New England Journal of Medicine*

(2) **Choose a cutting edge neuroscience technique.** Consider methods that we have discussed in class or pick a new technology.
A few examples: CRISPR/CAS genome editing, light sheet microscopy, CaMPARI, Recombinanse-based intersectional genetic strategies, DREADDS, optogenetics, CLARITY, rabies virus, etc.

(3) **Design a future study that expands on the authors' published work and incorporates your chosen neuroscience tool.** *Your research strategy should be designed to explore the function or projection pattern of a specific neuronal population*. Use the published article as your foundation for developing a scientific question and your growing knowledge of neuroscience methodology to design a future research strategy to answer that question.

PRESENTATION OUTLINE:
1. **Title.** Create a title that captures your proposed research project
2. **Introduction and Background.** Why is your scientific question interesting or important? What is the current state of the field? Summarize the findings of the article you chose but remember this is not a journal club but an opportunity to introduce your proposed research. Use only the most pertinent and important items/figures from the article and incorporate other necessary background information.
3. **Hypothesis.** Clearly indicate your hypothesis and the rationale behind it. How did your article and your research lead you to this specific hypothesis? What larger scientific question are you addressing?
4. **Research Design.** Clearly outline your research design. Describe fully the methodology you will employ. How will you target a specific neuronal population? Be creative! Provide figures, drawings, cartoons, diagrams, flow chart, concept maps, etc. to help your audience understand your research design.
5. **Potential and Limitations.** What kind of data and information will the proposed experiments provide you with? Will this data be able to support or refute your hypothesis? Analyze the potential and limitations of the methodology you chose.
6. **References.** Include citation of all documents and resources used throughout and at the end.

PRESENTATION GUIDELINES:
Prepare a presentation ~15 minutes in length and be prepared to answer questions from your peers for 5 minutes following your presentation (total 20 min). Design your slides to cover each of the topics indicated in the outline above. Practice your presentation to gauge how much time it will take.

LEARNING OUTCOMES:
Through the course of this research project and presentation, students will:
(1) Design an experiment to explore the function and/or connections of a single population of neurons
(2) Evaluate the limitations and potential of traditional and/or modern neuroscience tools
(3) Analyze and interpret data from primary research articles that employ novel methodology

PRESENTATION GRADING RUBRIC:

Criteria	Outstanding	Developing	Inadequate
Title	3- Clearly, succinctly describes the research project. Students' names are listed. *How can I summarize my project in one sentence or phrase?*	2-Too wordy. Does not accurately describe the research design proposal.	>2 No title slide
Introduction and Background	10-Introduction to the scientific field of interest. *Why is your scientific question interesting or important? What is the BIG picture?*	5-Insufficient introduction to the field. Broader scientific picture is unclear	>5 Significant background missing.
	15-Summary of the related article. Clearly describes important figures/items from the related article and incorporates any other significant background information *What is the current state of the field?*	7.5-Too few or too many figures of the related paper are discussed. Additional papers or background information would help describe the current state of the field	>7.5 Failure to discuss the current state of the field and a related research article
Hypothesis	5-Clearly describes the rationale that influenced the development of the hypothesis. Hypothesis is specific and testable. Hypothesis is creative and unique.	3-Hypothesis is specific and testable but may not be very creative or unique	>3 Hypothesis is not specific or testable
Research Design	15-Clear description of the cutting edge neuroscience technique used	7.5-Methodology details are unclear	>7.5 Technique is described inaccurately
	15-Clearly outlines how a specific neuronal subpopulation will be targeted	7.5-Targeting strategy details are unclear	>7.5 A specific neuronal subpopulation is not targeted
	10-Creative illustration of research design (figure, drawing, cartoon, or diagram etc.)	5- Figure is included but is not creative or does not fully illustrate strategy	>5 Illustration of research strategy is missing
Potential and Limitations	10-Balanced analysis of the potential and limitations of the neuroscience tool	5- Analysis is not balanced or pros and cons are overlooked	>5 No analysis of the limitations and potential
	5-Brief description of the kind of data or information that the proposed experiments will provide	3- Discussion of the type of data is not complete or a bit inaccurate	>3 No mention of the type of data that will be generated
	5-Commentary on the ability of this technique to address your specific hypothesis. *Would you need to do more? (Almost always the answer is yes!)*	3-Not clear if the data would be sufficient or if more studies need to be done	>3 No discussion
References	5-Includes citation of all documents and resources used throughout the presentation and in a slide at the end of the presentation	3-citation slide at the end but no citations throughout the presentation	>3 citations missing
Printed slides for instructor	2-Provided a printed copy of the presentation slides to your instructor on the day of your presentation (2 slides per page)		0-Not done

APPENDIX 5

DREADD Research Report Expectations & Rubric

Again, this lab report should be formatted like a primary research article and it will be graded based on the posted lab report rubric. **This lab report will challenge you to think about all of the DREADD related experiments we have performed this semester and incorporate them into one cohesive report that addresses each goal of our DREADD project (reviewed throughout the semester and outlined explicitly in Lab 3 Intro slides).** The goal for the course has been to help you think like a neuroscientist and by compiling, analyzing, and sharing your data you will move one step closer to this goal! Provided here are a few explicit expectations, however you are free to present your data however you see fit. How can you best present your data to "tell a story" and fairly represent your findings?

Introduction: This introduction should be more thorough than lab report 1. We have discussed norepinephrine (NE) neurons at length this semester. Use the lectures on our project and the introductions to each lab protocol to help you with this section. Also **use outside scientific literature to put our project in context**. Be sure to cover the following:

Why are NE neurons important?
What kind of behaviors and physiological processes are they involved in?
How are we going to study NE neurons?

Describe each goal of our study.

Why is this a unique approach? Don't forget the bigger picture!

How does our approach compare to other contemporary studies of NE neurons (i.e. cite scientific literature)?

Methods: Here, you need to strike the right balance of sufficient detail but not too much detail. Do not write your methods like a lab protocol! Use primary research articles as your guide. Also, remember we are working on an actual collaborative research project, and at times you were tasked to try different variations of the protocol. It is essential that we can glean these details from your methods and determine if any deviations from the provided protocol were performed so your results are reproducible!

Results data to include, but remember to organize this data how you see fit to best address our project goals:

(1) Schematic of the genetic approach
(2) eGFP and mCherry-hM3Dq expression patterns (one confocal picture must be included!)
(3) *c-fos* expression in the locus coeruleus
(4) Projection pattern data
(5) Neuronal activation pattern data across the brain
(6) Behavioral data

Discussion: Here are questions you **must** address when writing your discussion. What did your data reveal? Is there a particular piece of interesting data from your results that we should follow up on? What were the limitations of our approaches and data? What should we do next? Use your discussion questions to help guide these answers as well.

References: To fairly represent your findings and present "a nice story", you will have to look at other research articles. *Since you are writing your introduction in advance, you have plenty of time to place your work in context of the scientific literature.* Be sure to adequately cite these references **in the text** and at the end of the report.

One last suggestion…
In general, when writing a scientific manuscript I approach it much like I do reading a primary research article. I start with the methods and results section (i.e. the data) first! This allows me to organize the data and reflect on it before I begin to think about introducing my results or discussing the big picture. This assignment

requires that you write about your goals (i.e. the intro first) so that you better understand all of the data we are collecting, however as you go to complete the assignment and write the rest of the report, I highly suggest starting with your data first.

Student's name:						**Points**
TITLE	**0 point** Missing	**1 point** Inaccurate or too lengthy of description	**2 points** Concise accurate title representative of the work completed			**/2**
PURPOSE & INTRODUCTION	**0 point** Missing	**1-2 points** Lacks clarity and is missing multiple primary elements (ex: no description of goal, inadequate mention or no mention of methods); too short	**3-5 points** Lacks clarity; missing a primary element (goal or method); methods are only listed without purpose recognized	**6-8 points** Lacks full clarity or too lengthy of a description of the goals and methods	**9-10 points** Clearly and concisely explains and introduces the goal of the experiment and primary methods used.	**/10**
METHODS	**0-3 points** Missing or copied from the lab manual	**4-7 points** Several methods are omitted; others are presented in a piecemeal, vague form.	**8-10 points** Methods are listed as tables or figures, and/or bullet points rather than text; Some methods are omitted. The purpose of the method steps is omitted.	**11-13 points** Some methods are presented so briefly and/or vaguely that it is unclear how or why they were done. Written as a protocol rather than a description.	**14-15 points** Gives the reader a clear picture of the methods and materials used and their purpose. Does not use prescriptive language. Uses specific, not general, terminology. Detailed, step-by-step procedures are clearly referenced. Avoids long, redundant descriptions.	**/15**
RESULTS - DATA	**0-4 points** Missing many pieces of data (figures, tables, etc.)	**5-8 points** Data is included but legends are not present. Irrelevant data may be included, and relevant data left out.	**9-12 points** Data is presented haphazardly. It is sometimes not possible to tell what material or procedure was used to obtain the data.	**13-16 points** All or most of the data is present. Legends may be too brief, vague or uninformative. Controls or borrowed data not clearly indicated.	**17-20 points** All figures and tables have titles and legends with all items labeled. All results are clearly presented, with a logical sequence. Controls are clearly indicated. Borrowed data is referenced.	**/20**
RESULTS-TEXT	**0-4 points** Missing textual description of the results (text other than figure legends/table headings)	**5-8 points** Text lacks full description of each item in each figure, table, etc. No logical connection between methods and data	**9-12 points** Text presents most data but haphazardly and is difficult to follow.	**13-16 points** Text clearly presents almost all data. Comparisons of experimental to control results are stated.	**17-20 points** Clear, Full description in the text of each item in each figure, table, etc. Comparisons of experimental to control results are stated	**/20**

APPENDIX 6:
PRE- AND POST-COURSE SURVEY QUESTIONS

Mapping the Brain

Pre-course questions only:

Q1 - I have read and understand the above information and agree to participate in this
Q2 - Please enter your student code
Q3 - Are you a graduate or undergraduate student?
Q4 - Have you taken a neuroscience course before?
Q5 - If yes, please list the title(s) and briefly describe the course(s).
Q6 - Briefly describe the reason(s) you chose to enroll in this course.

Pre and post-course survey questions:

Q7 - How interested are you in learning more about neuroscience?
Q8 - How likely are you to pursue a career in neuroscience?
Q9 - How do neurons communicate with each other?

Likert-scale questions (strongly disagree, disagree, neutral, slightly agree, agree):

Q10 - The brain is the body's most complex organ.
Q11 - Life experiences can alter neuronal circuitry and behavior
Q12 - Genetically determined circuits are the foundation of the nervous system.
Q13 - Circuits of neurons in the human brain are the foundation of complex cognitive
Q14 - We mostly use only 10% of our brain
Q15 - Neuroscience research in humans is limited by the current technologies available to study the human brain.
Q16 - Neuroscience research in humans is limited by the complexity of the human brain
Q17 - The use of animals and model organisms for neuroscience research is ethical.
Q18 - The use of animals and model organisms for neuroscience research is important.
Q19 - Neuroscience research leads to essential understanding for the development of therapeutics used to treat neurobiological disorders

Q20 - I feel confident in my ability to evaluate the limitations and potential of traditional and modern neuroscience tools
Q21 - I feel confident in my ability to analyze and interpret data from primary research articles that employ novel methodology.
Q22 - Reading primary research articles causes me to feel stressed.
Q23 - Reading primary research articles causes me to feel frustrated.

Q24 - When reading scientific research articles what is your primary focus
Combination of data figures & portions of text

Select portions of text
Data figures
All of the text

Post-course only questions:

Q25 - By participating in this course (Mapping the Brain), I gained the ability to....(Likert scale)

a. ...design an experiment to explore the function and connections of a single population of neurons.
b. ...evaluate the limitations and potential of traditional and modern neuroscience tools.
c. ... analyze and interpret data from primary research articles that employ novel methodology.
d. ...discuss the limitations of studying the brain in humans and the importance of model organisms.
e. ...identify traditional and emerging therapeutics used to treat neurobiological disorders.
f. ...compare and contrast optogenetic and chemogenetic approaches for the norepinephrine system.
g. ...explain how brain tissue is handled and prepared for different experimental applications.
h. ...demonstrate proficiency in immunostaining for visualization of neurons and their projections in brain slices.
i. ...employ microscopy to quantify the density of neuronal projections.
j. ...analyze immediate early gene expression to assess neuronal activation patterns.
k. ...analyze behavioral data.

Q26 - What was your favorite lecture session in Mapping the Brain and why?
Q27 - What was your favorite laboratory session in Mapping the Brain and why?
Q28 - What was your least favorite component, activity or lecture etc. in Mapping the Brain and why?
Q29 - As your instructor, what could I have done to improve your experience in Mapping the Brain?
Q30 - If you have any additional comments or suggestions please include them here.