ARTICLE
A Versatile Psychoneuroimmunology Course-based Undergraduate Research Experience

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The Psychoneuroimmunology Course-based Undergraduate Research Experience (PNI CURE) was designed with the purpose of engaging undergraduate students in research and discovery. As part of this experience, students were assigned to a team based on their personal interests. Each team selected a psychosocial variable of interest (e.g., sleep, belongingness, stress, or happiness) and identified two well-validated questionnaires to assess it. Then, student volunteers donated blood samples and completed student-selected questionnaires via Qualtrics. The blood samples were assayed by the course instructor for proinflammatory cytokines. With the collected data, students 1) evaluated the association between peripheral inflammation and their psychosocial variable of interest and 2) created hypotheses regarding inflammation in the brain. Students' experimental results were reported in the form of a research manuscript and scientific poster, both of which comprised 15 percent of their course grade. Further, to evaluate the effectiveness of the PNI CURE, students were asked to complete assessment surveys before and after project implementation. Assessment results demonstrate that participating in the PNI CURE increased self-efficacy and research identity among students. Besides exposing undergraduates at UNC-CH to a comprehensive research experience, we hope to inspire neuroscience educators to adopt and adapt the PNI CURE as a mechanism to broaden undergraduate research opportunities in neuroscience.

Key words: psychoneuroimmunology (PNI); neuroimmunology; course-based undergraduate research experience (CURE); psychosocial variables; proinflammatory cytokines; assessment

A primary goal of neuroscience educators is to enhance the educational experiences of undergraduate students (Ramirez, 2020). A way to do this is to design and implement course-based undergraduate research experiences (CUREs). These learning experiences engage students in scientific research and discovery via active learning (Bangera and Brownell, 2014). They also present an inclusive teaching practice that contributes to diversifying the scientific community, because students simply need to enroll in a course to participate in scientific research (Brownell et al., 2015; Ott et al., 2020). Indeed, by engaging in a CURE, students will develop a deeper understanding of content knowledge and gain confidence in their research abilities, among other benefits (Petrella and Jung, 2008; Olson & Riordan, 2012; Brownell, 2015; Dolan, 2016; National Academies of Sciences, Engineering, and Medicine, 2017; Cooper et al., 2020).

CUREs have been featured in several STEM courses (Kowalski et al, 2016; Villa-Cuesta and Hobbie, 2016; Olimpo et al., 2016; Kerr and Yan, 2016):and neuroscience CUREs are becoming more common at the university level (D'Arcy et al., 2019; Ryan and Casimo, 2021). This is in-part because research experience can help students have a more solidified plan for post-graduation, especially in STEM fields wherein graduate school and research associate positions are plentiful. With this in mind, we designed the Psychoneuroimmunology Course-Bbased Undergraduate Research Experience (PNI CURE) and implemented it in an upper-level neuroscience course on Neuroimmunology.

Psychoneuroimmunology (PNI) is an interdisciplinary field that examines how the nervous and immune systems interact to influence behavior (Maier et al., 1994; Kiecolt-Glaser et al., 2002). To explore research questions in this field, scientists integrate methods that explore biology (i.e., physiology) and psychology. Biological assessment can include the quantification of biomarkers in blood or saliva, whereas psychological assessment can include completion of questionnaires or behavioral tasks. In this way, PNI research exposes individuals to both biological and psychological research methods. To date, the topic of PNI is commonly addressed in neuroscience courses focusing on mind-body interactions, stress, and neuroimmunology. Still, no CURE on this topic has been shared with the broader neuroscience education community.

To address this gap, we designed and implemented the PNI CURE. As part of this novel CURE, undergraduate students 1) generated and tested hypotheses regarding the association between peripheral inflammation and their psychosocial variable of interest and 2) utilized the collected data to make predictions about the brain microenvironment. Additionally, the students reported their research findings in the form of a research manuscript and poster. These group assignments, together with individual self-reports, were utilized to assess the effectiveness of the CURE.

As neuroscientist educators working towards the goal of enhancing educational experiences of undergraduate

neuroscience majors, we want to highlight the versatility of the PNI CURE. While the described project involves the collection of blood samples and the assessment of proinflammatory cytokines, another instructor can modify the CURE in accordance with their specific course, interests, and institutional resources. If your adaptation retains components of scientific discovery, iteration, collaboration, and research practices (Auchincloss et al., 2014; Dolan 2016), you will be implementing a CURE in your class.

Knowledge Objectives	Method Objectives
Define neuroimmunology and psychoneuroimmunology.	Write a viewpoint article evaluating a neuroimmunology-related concept or published article.
Explain the interactions between the nervous, endocrine, and immune systems.	Formulate a research question that would help fill a gap in the neuroimmunology field.
Describe the role of cytokines, neurotransmitters, and other chemical substances in the neuroinflammatory response.	Generate and test a hypothesis regarding how a psychosocial variable of interest associates with inflammation.
Summarize the mechanisms by which inflammation is regulated within the nervous system.	Analyze, interpret, and report experimental results collected in class.
Integrate neuroimmunology with neurological conditions (e.g., aging and stress) and diseases (e.g., multiple sclerosis, Alzheimer's, and traumatic injury).	

Table 1. List of knowledge and method learning objectives used to guide the Neuroimmunology course content and the PNI CURE.

COURSE DESIGN

Institutional Context

The University of North Carolina at Chapel Hill is a 4-year public university, home to approximately 30,000 students. At this institution, the Neuroscience major established in 2018 has demonstrated exponential growth. To date, we support 500 neuroscience minors and 865 majors, and are among the most popular majors in the institution.

Student Participants

In the Psychology & Neuroscience Department at UNC-CH, upper-level courses are capped at 32 students and restricted to our majors and minors. During Fall 2021, Professor Gaudier-Diaz offered an upper-level Neuroscience course on Neuroimmunology, where the PNI CURE was first implemented. Thirty-two (32) students enrolled in the class: 100% were seniors and 97% completed the course. From those who completed the course, 58% were Neuroscience majors, 39% were Psychology majors, and 3% Biology majors. Further, data available through My Course Analytics Dashboard (N=21):demonstrate that there were 16 students who identified as female, 5 students who identified as first-generation college students, 4 students who identified as belonging to an underrepresented minority group, and 8 students who identified as part of a non-white racial group.

Course Structure

The Neuroimmunology course met twice per week for 75 minutes to 1) cover how the nervous and immune systems function together to serve homeostasis, behavior, and disease, and 2) engage in scientific research. Accordingly, the course objectives were inclusive of content knowledge and methods (Table 1). To promote higher-order learning and facilitate the CURE, the course instructor implemented a series of in-class workshops that scaffolded the research process.

CURE Description and Student Research Activities

During Fall 2021 we implemented the PNI CURE in an upper-level Neuroscience class on Neuroimmunology, in which students 1) generated and tested hypotheses regarding the association between peripheral inflammation and their psychosocial variable of interest, and 2) utilized student-collected data to make predictions about inflammation within the brain. To scaffold the research process, in-class workshops on designing a research study, conducting a research study, analyzing data, and reporting research findings were offered throughout the semester (Table 2).

Prior to the "Designing a Research Study" workshop, there was a class period devoted to the study of psychoneuroimmunology, where seminal studies assessing the relationship between the social environment and inflammation were discussed (Maier et al., 1994; Ader, 2000). Following lecture, students were prompted to identify a topic (i.e., psychological variable) that they would have liked to see included in the lesson. Responses to this question, which included sleep, belongingness, stress, and

happiness, allowed the course instructor to assign students

In-class Workshops	Objectives	Activities	Assignments
Designing a Research Study	Summarize the steps and assessments associated with the PNI CURE. Describe the research process. Identify the steps and criteria for generating a novel research question.	Identify teams for the PNI CURE. Blood collection with traditional blood spots.	Each team identifies and submits 2 questionnaires that can be used to assess their chosen psychosocial variable of interest.
Conducting a Research Study	Compare and contrast primary and secondary literature. Define the role of the Institutional Review Board (IRB.)	Generate a research question for an outlined study and predict the results.	Teams submit a research proposal containing their background research, hypothesis, and predicted results.
Data Analysis	Explain how immunoassays (i.e., Ella) work. Describe statistical analysis methods and how to choose the best fit for a data set.	Organize experimental data, run statistical analyses, and generate graphs on SPSS.	
Reporting Research Findings	Explain what poster sessions are and what they are used for in science. Develop strategies for designing posters that enhance scientific communication and understanding.	Practice creating a poster based on research on neuroinflammation and COVID-19 (Liu et al., 2020).	Each team generates a scientific poster and manuscript explaining their results. Students present their posters to small groups of students and instructors.

into small teams (4-6 students). Then, during the workshop,

Table 2. Representation of the in-class workshops offered throughout the semester, including the learning objectives, activities, and assignments that were provided to students.

the FINER criteria (Farrugia, 2010) were used to explain what constitutes a good research question, and student teams were prompted to identify a psychosocial variable of interest and two well-validated questionnaires to assess it. On this day, additional in-class time was devoted to collecting blood samples from student-volunteers who consented to participate in the research study. For the blood collection, we presented students with an instructional video and an in-person demonstration on how to collect their own blood samples using traditional blood spots (Freeman et al., 2018):a process which they later followed. Specifically, we collected blood samples from 24 students. Outside of class, teams worked together to identify two well-established questionnaires to assess their variable of interest, which they later shared with us for creation of the student-selected questionnaires Qualtrics survey.

The topic for the second in-class workshop was “Conducting a Research Study.” On this day, the course instructor discussed the role of the Institutional Review Board (IRB) and the process of submitting a proposal. Then, the PNI CURE was described for students to generate a representative experimental timeline. Altogether, these activities enabled students to become familiarized with the process associated with designing a research study and the detailed steps to be conducted as they continued working on the PNI CURE project throughout the semester.

During the third workshop, “Data Analysis,” students were introduced to immunoassays using the Ella platform (Yeung et al., 2016) and provided an overview on SPSS statistics software. Specifically, the course instructor described how to organize experimental data on SPSS software and introduced students to basic forms of statistical analysis (e.g., correlations, regressions, t-test and ANOVA) that they could use to analyze their data. Then, class time was allotted for student teams to begin working on their analyses. In this way, students were able to receive immediate feedback regarding their plan for analyzing and visualizing their experimental results. Outside of class, teams worked together to finalize data analysis and figures, which they later used to generate their manuscript and poster.

In the fourth and final in-class workshop, “Reporting Research Findings,” the process of designing a research poster was described. Then, students spent time putting content knowledge to practice by designing a research poster representative of the research article (Liu et al., 2020)

they had to read as a pre-class assignment. Indeed, the goal of this workshop was to equip students with the skills

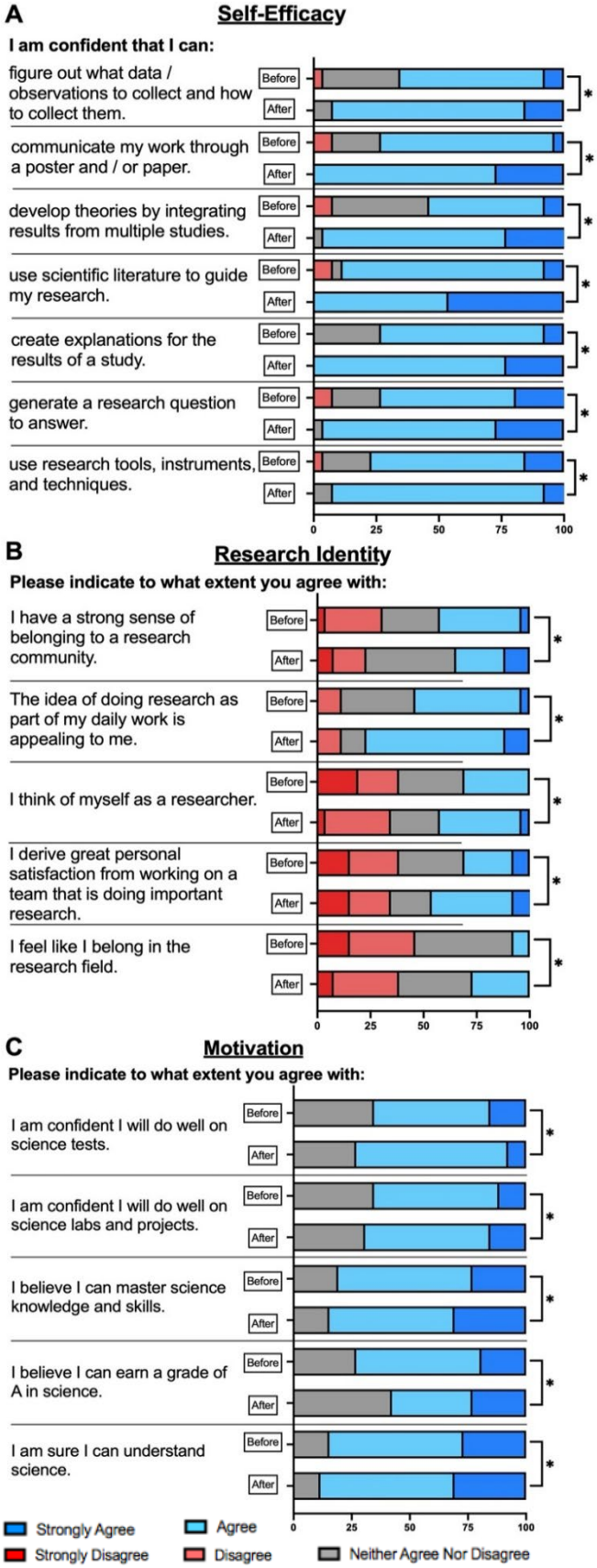

Figure 1. Benefits of the PNI CURE on self-efficacy *(A)*: research identity *(B)*: and science motivation *(C)* *p>0.05.

and content necessary for them to be able to generate a scientific poster to summarize their PNI CURE project.

To conclude the PNI CURE, student teams were required to write a research manuscript and to present their analyzed data in the form of a scientific research poster. Instructional guidance was provided to students in the form of grading rubrics (Supplemental Materials), which were also used to evaluate the attainment of a broader course objective: Analyze, interpret, and report experimental results collected in class. To provide students with structure, rubrics and additional requirements (e.g., minimum page number and presentation time) were made accessible to students prior to assignment deadlines. On this note, we encourage instructors to modify our rubrics and requirements according to their specific course objectives and instructional preferences.

ASSESSMENT METHODS

Student perceptions and course assignments allowed for the evaluation of the PNI CURE, an assessment protocol that received exemption status from the Institutional Review Board at UNC-CH (IRB #21-1588). To assess student perceptions, we administered surveys before and after implementing the PNI CURE. This analysis includes data from the 24 students that completed both surveys. Additionally, student performance on course assignments was used to evaluate the achievement of learning objectives. This analysis includes data from the 31 students that completed the course.

Assessment of Student Perceptions

To determine the effectiveness of the PNI CURE, we assessed self-efficacy (Hanauer et al., 2016):research identity (Syed et al., 2018):and science motivation (Glynn et al., 2011):before and after implementing the CURE. In addition to these, open-ended questions regarding student reflections were included in the post-CURE survey. These surveys were administered via Qualtrics and completed by24 students.

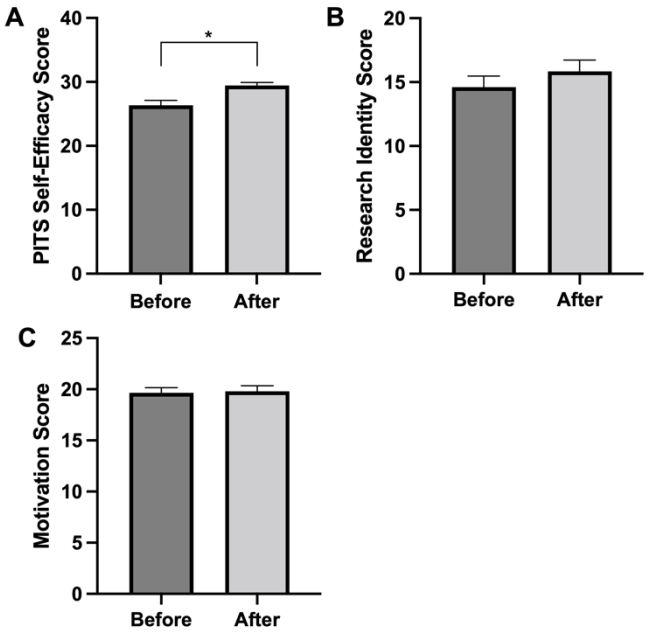

Figure 2. PNI CURE participation significantly increased overall scores on the PITS self-efficacy scale *(A)* :but not the research identity *(B)* and motivation in science *(C)* scales. *p<0.05.

Assessment of Student Performance

Student teams submitted a research proposal, manuscript, and poster. The grades on these CURE-related assignments were evaluated to determine the achievement of learning objectives. These assignments were graded with carefully constructed rubrics (Supplemental Materials).

Statistical Analysis

Wilcoxon-ranked t-tests were conducted to compare before and after measures, as well as to compare responses to each item in the self-efficacy, research identity, and science motivation questionnaires. Descriptive statistics were also conducted for all measures.

RESULTS

Impact of the PNI CURE on Student Perceptions

We assessed student's sense of self-efficacy, research identity, and science motivation before and after implementing the PNI CURE, for which all items were analyzed independently. Specifically, students were asked to describe their level of agreement for each statement in the form of a 5-point Likert scale. When comparing before and after responses with the Wilcoxon-ranked t-tests, all were found to be statistically significant ($p \leq 0.05$).

In terms of self-efficacy (Figure 1A):only 73% of students responded that they agreed or strongly agreed that they had confidence in communicating work through a poster and/or paper before completing the PNI CURE. However, after writing a manuscript and presenting a research poster, 100% of students either agreed or strongly agreed that they were confident in their ability to communicate their research in these forms. Under this category of assessment, before completing the CURE, only 73% of students agreed or strongly agreed that they were able to create explanations for the results of a study. Afterwards, 100% of students agreed or strongly agreed that they were confident in explaining research study results. Also, prior to the PNI CURE, only 72% of students agreed or strongly agreed that they felt as if they could generate a research question to answer, which increased to 96% of students following CURE implementation.

With regards to students' perceptions of research identity (Figure 1B) we evaluated interest and pride in participating in scientific research. Before completing the CURE only 54% of students agreed or strongly agreed that the idea of doing research as part of their daily life was appealing to them, but this number increased to 77% after CURE implementation. Further, in the before survey, 31% of students agreed or strongly agreed that they derived great personal satisfaction from working on a team that is conducting important research. Forty-six percent agreed or strongly agreed with the same statement after completing their research projects.

Assignment	Mean ± SEM
Research Proposal	93.0 ± 0.59
Manuscript	93.9 ± 0.39
Poster Presentation	97.5 ± 0.94

Table 3. Students' mean grade for each PNI CURE assignment. These were completed as group work and grades were determined based on the rubrics provided in supplemental materials 1-3.

In the before and after PNI CURE surveys, students were also asked questions designed to measure their motivation towards science (Figure 1C). In response to "I believe I can master science knowledge and skills," 58% of students responded that they agreed with the statement, and 23% strongly agreed before finishing the CURE. Afterwards,54% agreed and 31% strongly agreed that they had the ability to thoroughly learn science content. In terms of understanding science, 85% agreed or strongly agreed that they could accomplish this before taking the course, and 89% agreed or strongly agreed by the end of the semester.

To assess the overall scores for the for the self-efficacy, research identity, and motivation surveys, we summed the score for all individual items. When assessing the overall scores, only self-efficacy increased from before to after the PNI CURE implementation (Figure 2A; Wilcoxon, $p \leq 0.05$). There was a non-significant 1.23-point increase when comparing the before and after research identity score (Figure 2B; Wilcoxon, $p=0.39$) and no overall difference in motivation (Figure 2C; Wilcoxon, $p=0.71$).

Impact of the PNI CURE on Student Performance

As part of the PNI CURE, student teams completed a research proposal, manuscript, and scientific poster. Student grades on these assignments (Table 3) were used to assess student performance and the achievement of learning objectives. The mean grades for the research proposal, manuscript and poster were 93/100, 93.9/100 and 97.5/100, respectively.

Student Reflections

As part of the after PNI CURE survey, students were asked which portion of the PNI CURE (i.e., manuscript, blood data collection, poster presentations, in-class workshops, or data analysis) they enjoyed the most. Sixty-one percent of students selected the blood collection as their favorite activity, and 18% selected poster presentations as the most enjoyable. The remaining 21% were evenly split between the manuscript, in-class workshop, and data analysis activities.

When elaborating on the blood collection, one student commented that "[I]t was cool that our research wasn't just based on surveys. It made the research feel different from other classes," which highlights a novel component to the PNI CURE. Other students' response about the blood collection process noted that, "[I]t was fun to have hands-on experience," and "[I]t made me feel like I was actually doing research!"

When commenting on the poster presentations, most students responded that they were proud and happy to share their findings with their classmates. One student notably remarked that, "[T]he poster presentations felt very much like a celebration of the hard work that we did throughout the CURE project." Indeed, having students find pride in the work designed to improve their confidence in conducting research was invaluable to us as an instructional team.

DISCUSSION

Over the course of the Fall 2021 semester, students enrolled in the Neuroimmunology course at UNC-CH participated in the PNI CURE, wherein they generated and tested hypotheses focused on a psychosocial variable and its relation to peripheral inflammation. Then, they presented their research findings in the forms of a poster and manuscript. The effectiveness of the PNI CURE was assessed with student self-reports and completed assignments.

Of the variables assessed by self-report surveys, increases in self-efficacy and research identity after completing the PNI CURE were evident. These results align with previous CURE findings reporting that students possess a higher level of self-confidence after completing a CURE (Dolan, 2016). Previous findings, together with our ability to detect a significant positive impact among high-performing senior students whose baseline (i.e., before) scores for all self-efficacy, research identity, and science motivation items were high, suggest that CUREs can benefit all students, even those that come into a course with strong competencies and motivation.

Because engaging with written and oral forms of scientific research encourages active learning practices (Coticone and Bailey Van Houten, 2020): we built into the PNI CURE assessment writing assignments and an oral presentation. Assignment grades on these course assignments were evaluated to assess student performance and the achievement of learning objectives. Specifically, the research proposal aimed to assess the ability of students to perform background literature reviews and generate a sensible hypothesis from the information collected. On the other hand, the research manuscript and poster grades indicate students' ability to decipher their scientific results and communicate their knowledge in written and oral formats. Since most student teams received a grade above a 90 on these assignments, it can be concluded that students were able to effectively execute all the aforementioned skills.

In terms of increasing inclusivity in the scientific community (Bangera and Brownell, 2014):the PNI CURE was successful in providing students in different majors (e.g., neuroscience, psychology, and biology) and with varying demographic characteristics (e.g., gender, generation in college, and race/ethnicity) an opportunity to engage in scientific research. These successes all point towards the implementation of an effective CURE in the integrative field of psychoneuroimmunology.

A goal of implementing the PNI CURE was to assess the effectiveness of creating a research experience for students in an interdisciplinary field that can be easily modified by instructors to fit their own curriculum. The increases in self-

efficacy and research identity, coupled with the fact that student reflections indicated enjoyment of the project, demonstrate that the PNI CURE was useful and engaging for students. When it comes to the versatility of the PNI CURE, it can be adjusted to fit most research-oriented STEM courses. To accomplish this, instructors can alter the workshops (Table 2): mode of student-collected data, and grading rubrics (Supplemental Materials) to best fit their course requirements.

CONCLUSION

Conducting research is a vital educational component in all science fields, and it represents a valuable skill set for students to further develop their learning. Despite limitations to the present study regarding our sample (e.g., small sample size and only senior students):our work describes an effective novel teaching tool that can easily be adapted for neuroscience, psychology, biology, and other science courses, to guide students through the research process. In terms of the versatility of the PNI CURE, future iterations can be easily adapted to use student-centered data, such as saliva samples and field-relevant student questionnaires. Together with exposing undergraduate students to an authentic research experience, we aim that the PNI CURE will inspire other instructors to incorporate and create novel student-centered CUREs, where students can collect data among themselves.

SUPPLEMENTAL MATERIALS

S1. Grading rubric for the research proposal
S2. Grading rubric for the scientific poster presentation
S3. Grading rubric for the research manuscript

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