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The NEURON Program: Utilizing Low-Cost Neuroscience for Remote Education Outreach

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The NEURON initiative (Neuroscience Education in Undergraduate Research, Outreach, and Networking) is a free program engaging first year students, including underrepresented minority (URM) students in Neuroscience and Cognitive Science (NSCS) at the University of Arizona (UA).

The NEURON program builds on former Grass Foundation-sponsored workshops run by Dr. Ricoy (2010-2019) implementing hands-on and culturally responsive active learning curriculum with low-cost equipment from Backyard Brains to increase student retention of URM students in the sciences at Hispanic Serving Institutions (HSI). We present the implementation of the NEURON program at the onset of the COVID pandemic. Combining best practices of distance learning and peer mentoring, we conducted three-week projects exploring principles of neuroscience and neurophysiology.

Enrollment and demographic data from NSCS at the UA demonstrate historical disenfranchisement and program attrition primarily impacting URM students. As an extension on previous URM peer mentorship programs in Neuroscience (Ricoy, presentation at Northern New Mexico College Research Symposium, 2010, 2011; presentation at Society for Advancement of Chicanos/Hispanics and Native Americas in Science, 2012), we leveraged low-cost equipment and remote sessions to advance the community of undergraduate mentors and pair with high school mentees on hands-on curriculum. Throughout the program, undergraduate mentors received guidance while crafting and delivering four laboratory lessons to mentees. By coordinating with a Title I school, we better connected with historically underserved students. Critical to this program was providing hands-on opportunities to students who were undergoing distance-based learning during the pandemic. Distribution of equipment allowed high school students to experiment remotely, guided by undergraduate mentors. The NEURON program met its objectives of fostering both mentors and mentees as burgeoning scientists.

Key words: Electrophysiology; Backyard Brains; Madagascar Hissing Cockroaches; Mentorship; Peer mentoring; Distance Learning; Low cost; Undergraduate Education; Retention; high school; program evaluation

The Neuroscience and Cognitive Science undergraduate program (NSCS) at the University of Arizona struggles with retaining and supporting diverse students. Of the students who changed academic programs after Fall 2018, 43.75% were Hispanic and 55.81% of students who left the University from the NSCS program were Hispanic, yet only 23.9% of the University population is Hispanic or Latino (NSCS program data; NSCS 2020 Annual Report Presentation). This suggests a massive disparity between Hispanic and non-Hispanic students in the success they find within NSCS, in accord with national trends of higher attrition among communities of color (National Center for Education Statistics, 2019). For the purposes of promoting neuroscience education for all, it is critical to undercut such disparities and bring forward every student, including those engaged with distance learning.

Of the many lessons shown through historical NSCS retention data, a pattern emerges which can be leveraged to support students. Statistics demonstrate a trend in which less engaged students are less likely to persist with their neuroscience education. For example, of the students who left the University and the students who switched majors in 2019, 0.0% and 9.3% were involved in research, respectively. In the same year, there was an overall 31.91% enrollment in research (NSCS program data; NSCS 2020 Annual Report Presentation). More broadly, student engagement has been shown to promote successful student outcomes (Manyanga, 2017; Truta et al., 2018). The application of research has been implemented into learning in many ways (e.g., course-based undergraduate research experiences, lab courses). One way in which this course-based research has been shown to be pedagogically effective is project-based learning. Data show course- and project-based learning approaches provide greater engagement and connection with material for students who work to investigate a question (Barron, 1998; Ricoy, presentation at Northern New Mexico College Research Symposium, 2010, 2011; presentation at Society for Advancement of Chicanos/Hispanics and Native Americas in Science, 2012). This relationship of research involvement and program retention is critical to engaging diverse students. While consistent involvement of students in a research lab may create a burden on student scheduling, shorter duration opportunities for students to engage in exploring questions may provide an opportunity for similar benefits (Hanzlick-Burton et al., 2020). Critical support for diverse students can be provided through small-scale research opportunities. Creating accessible, remote, project learning opportunities is expected to improve student outcomes.

Beyond treatments, it is important to identify how these trends in attrition may begin. Notably, literature highlights the relationship of earlier pipeline programs for underrepresented minorities in science, technology, engineering, and mathematics (STEM) and choices and outcomes related to higher education (Miller et al., 2018). The COVID-19 pandemic has furthered the disparities in attrition. Parolin and Lee (2020) identified K-12 schools with lower test scores and higher proportions of racial minority students who remained online throughout the pandemic. Overall, all, students have been affected during the pandemic creating a greater disparity in education (Casciano et al., 2023).

To address program disparities, there were four objectives in the NEURON program design and implementation. First, due to the challenges of the pandemic, all programming was conducted remotely. This first aspect continues to be relevant to other programs, even as we step out of the pandemic (see discussion).

The second requirement was the use of peer mentor programming. In both URM and non-URM contexts, peer mentorship has shown improvements in participant self-efficacy and self-confidence. Delivery through a peer mentor model has been shown to have a transformative effect on students, especially those from minoritized groups (Ricoy, presentation at Northern New Mexico College Research Symposium, 2010, 2011; Chavez, 2019). Beyond efficacy, by leveraging the peer mentor model there is a further opportunity to engage two key groups: our undergraduate students and high school students, both of which have large attrition.

While considering the historical attrition and decreased engagement from URM students in NSCS, the NEURON program was developed to serve and engage URM students. As described in David Asai (2020) "Race Matters", educational models for minoritized communities are often based in "deficit thinking", in which programs are "assuming students lack interest or preparation". In contrast, in peer mentor models the discussion is led by members of minoritized communities. There is a synergy in the composition of this program being focused on promoting minoritized communities in a peer mentor context.

The final structural requirement was to keep materials accessible via low-cost equipment and supplies. Low-cost programming offers the opportunity to serve more students, the potential that each student will have their own equipment for experiments (important for remote access), while maximizing program feasibility. Collectively, a remote, low-cost, URM peer-mentor program focused on neuroscience education offers ample opportunity for engagement and advancement of undergraduate neuroscience education.

To meet these four objectives, we paired first-year undergraduate NSCS student mentors with student mentees from a local Arizona high school. The high school mentees are from a low-income, historically underserved Title I school, meaning that 40% of its family population fall below the United States Federal Poverty Line.

The development of community relationships for our program preceded the workshop by nearly 8 months, during the beginning of the pandemic. The prolonged nature of developing a program, like NEURON, requires a multifaceted commitment to outreach and building a support infrastructure. The final requirement for conducting a remote workshop series like NEURON is providing accessible materials for remote learning.

MATERIALS AND METHODS

Materials

Because of the number of students and the importance that each student had their own accessible "lab," it was critical to leverage low-cost equipment, which allows for more project-based investigations in neuroscience for under-supported populations. To provide sustaining access each year, the NEURON program established a low-cost equipment library which will be maintained from year to year. For this workshop, the equipment library consisted of 120 individual kits to be used by 60 high school students, and 35-40 Neuroscience undergraduate mentors. Materials were organized and divided into containers which included Backyard Brains equipment that records electrical activity from nerve, muscle, heart, and/or brain.

The Backyard Brains (BYB) Company works to provide easy-use, low-cost equipment based on principles of electrophysiology in insects and humans. This project's equipment included four primary amplifiers (Muscle Spiker Box, Neuron Spiker Box, Heart-Brain Spiker Box, Human-Human Interface) as well as two supplemental experiments (Plant Spiker Box and Reaction Timer). These amplifiers corresponded with four unique lesson plans "Record Electricity from Your Muscles!" (REFYM), "Referencing your Spikes" (RYS), "Heart Action Potentials" (HAP), and "Advanced NeuroProsthetics: Take Someone's Free Will" (ANP). Three different amplifiers were given to each student and one to each mentor (See Methods). BYB experiments were also used as baseline material for guiding mentor instruction. Three different amplifiers were given to each student and one to each mentor. BYB experiments were also used as baseline guidance for mentor instruction.

Animal Model and Storage

Madagascar Hissing Cockroaches (*Gromphadorhina portentosa*) were distributed to self-selected participants. Cockroaches were generously provided to students from the stock of Dr. Kathleen Walker (UArizona Entomology) or provided by T-Rex Ranch. The cockroaches were stored in small "Critter Crates" which were stocked with pathway bark, had edges coated with petroleum jelly (to secure the cockroaches), and secured with 3M fiber tape. All

IN PERSON WEEKLY CYCLE:

	Monday	Tuesday	Wednesday	Thursday	Friday
6th	Online Experiment	Return Demo during class			Pick up kit
7th	Pickup Kit	Online Experiment		Return Demo during class	

WEEKLY GROUPS BY TASK

6th Period		Week 1	Week 2	Week 3	Not performed
9	Muscle	A	C	B	
9	Neuron	B	A	C	
8	Heart-Brain	C	B	A	
	Human-Human	No-Roach People			A, B, C
7th Period		**Week 1**	**Week 2**	**Week 3**	**Not performed**
5	Muscle	A	D	C	B
4	Neuron	B	A	D	C
5	Heart-Brain	C	B	A	D
5	Human-Human	D	C	B	A

Figure 1. NEURON Program images. *Top:* Equipment pickup for mentors following COVID guidelines and safe practices. *Middle:* Rotating schedule for three weeks of content from four kits, across to classrooms. *Bottom:* Students working with the human-human interface kit (ANP). The use was modified to allow a single student to control their own arm.

cockroaches were fed romaine lettuce once to twice a week.

METHODS:

Recruitment

Recruitment of mentees was performed in collaboration with Tucson Magnet High School local schoolteachers. Mentor recruitment information was shared by advisors and faculty within the NSCS program. All mentors and mentees had the option to participate in the associated study, which was approved by an Institutional Review Board at the University of Arizona.

Mentor Equipment Distribution

Equipment was distributed in an outdoor environment, consistent with COVID guidelines at the time; face masks were always worn. The mentors selected times and a pickup site, and then quickly obtained their kits. Cockroaches were distributed to mentors later due to supply chain issues (Figure 1, top panel).

Mentee Equipment Distribution

Due to the hybrid structure for high school students at the time, there was limited opportunity for students to collect kits. To minimize complications for entirely remote students, kits were prepackaged into three kit combinations and collected at the beginning of the program. In-person students followed the prescribed schedule ("In person weekly cycle"). Because one of the experiments involved keeping a living cockroach, students were surveyed beforehand for parental permission to keep a cockroach in the home. Those students who were not able to keep a cockroach, or self-selected out, were assigned to a rotation where they would instead perform the ANP experiment (Figure 1, middle panel). See Scheduling for more discussion.

Mentor Instruction/Guidelines

Mentors were sent a survey where they could select multiple training times and then were grouped based off their assigned piece of equipment. A total of nine virtual training sessions were offered at an hour each. Mentors were instructed in how to use the equipment, could ask questions, and were encouraged to "allow for the natural error of science" and "be comfortable making mistakes" with mentees. It was noted to everyone that coordinators (Bassil Ramadan or Ulises Ricoy) would be available throughout each session for support. Video recordings were taken of each training session for the four pieces of equipment for later reference by the mentors. Mentors were provided with links to their experimental procedure and provided with an optional mentorship session prior to the program start.

Scheduling

We set up a schedule to optimize the distribution of resources for small groups across different sections where mentees would work on one assigned experiment per week (Figure 1 middle panels). Creating small groups in each class allowed for materials to be shared efficiently (i.e., students in group A could pick up materials from group B for the second week, and group B could pick up materials from group C, and so on). Each mentee group had its own complexity: 1) not all students were able to keep live cockroaches, and 2) some students were hybrid (engaging in mixed in-person and online) while others were exclusively online. The rotation system we developed allowed us to have 4 experiments cycling across 3 weeks, (i.e., keeping the students unable to work with cockroaches in a group that would complete the other three cockroach-free experiments). Hybrid students were asked on NEURON course days (once a week) to attend the online section.

	Before	After	Change
How important do you think writing skills will be to your career?	4.1875	4.375	0.1
How would you rate your confidence to communicate scientific findings?	3.875	4.125	0.25
I am interested in pursuing science as a career.	4.5625	4.625	0.0625
I feel confident doing/conducting science.	4.1875	4.4375	0.25
I look forward to science classes in school.	4.3125	4.5	0.1875
Science intimidates me.	2.5625	2.5	-0.0625
Science is boring.	1.25	1.5625	0.3125

Figure 2. Quantitative opinions using a five-point scale with 0 being "strong disagreement"/ "very low" and 5 being "Strongly Agree"/ "Very High". Note there were only 16 respondents from the Arizona NEURON program, leading to high variance. Some sampled questions are highlighted in orange to indicate they are framed negatively (i.e., student benefit will see a negative value shift).

Weekly Workshop Format

Each week mentees would join Zoom rooms with mentors where mentors did a short introduction of how to perform the experiment of the week, then as the experiment was performed, mentees were able to ask the mentors questions about the procedures, troubleshooting, or aberrant results. After the basic principles were highlighted, mentors would ask prompting questions such as "what would happen if you carried additional weight while flexing the measured muscle?" or "what happens if someone were to lift your arm, would there still be a signal?" Finally, if mentors determined that a productive session was finished on the planned experiment, mentees were able to ask questions related to the college experiences of the mentors.

Experiment Learning Objectives

All experiments are designed to teach components of physiology and are appropriate for high school age groups. Specific learning objectives are laid out in the material for each Backyard Brains experiment. REFYM uses an amplifier to perform electromyogram recordings on human subjects. RYS uses a cockroach leg to demonstrate multi-neuron signal recording by stimulating sensing organs of the cockroach. HAP presented an opportunity to quantify heart rate for the individual. ANP was modified to allow for an individual to control one muscle with another (e.g., using a bicep to control the contralateral side), demonstrating the function of prosthetics and how electrical signaling manages muscle contraction (Figure 1, bottom panel). Experiments were modified to varying degrees and mentors were given the flexibility to extend lesson plans freely and include the associated "Spike Recorder app" in the data visualization process. These sets of experiments were developed to serve the diverse needs and learning of the mentees. Successful completion of learning objectives was evaluated by the mentors though successful experiments and qualitative evaluation of engagement; no quantified evaluation of learning outcomes was performed.

Weekly Check-Ins

At the end of each session, after mentees left, each virtual room of mentors was asked a series of questions about what worked well and what needed improvement for the next week. This provided additional support and feedback for the mentors. Similarly, mentees were asked at the beginning of each session (after mentors were put into their breakout rooms) if they had any additional needs or thoughts on the program.

Questionnaire

A questionnaire was compiled and distributed using REDCap software as part of an Institutional Review Board (IRB) approved study. No students were excluded from the program if they refused participation in the study. The surveys consisted of a series of quantified discrete rating scale questions, as well as qualitative free answer opportunities and word association paradigms. The questionnaire was provided before and after the 3 weeks of programming for paired analysis. Analysis consisted of both holistic analysis and paired T-Test of pre- and post- surveys for statement agreement ranking and chi-squared analysis for word association. These questions have since been used in other Grass Foundation workshops.

RESULTS

This work helped bring to light several challenges and disparities, which shape the conditions and successful deployment of the virtual workshops. First, by virtue of working with an underserved mentee group, students often had outside employment obligations during scheduled meeting times. Second, many mentees, despite living in urban areas, had issues with internet access which caused recurring disconnection from the session. Third, the complexity of homelife and the discomfort of sharing video led to approximately 1/3 of mentees not turning on cameras throughout a given session which may have limited engagement. Beyond this, technical barriers persisted within the course content such as the "Spike Recorder App" software not being universally compatible, with Android and Windows computers failing to detect the connected device driver.

Our questionnaire analysis suggests an overall positive shift in science attitudes in the Arizona-based NEURON program for our mentors (Figure 2). This trend matches the aggregate data inclusive of the previous workshops (New Mexico 2011-2022). Because of the lower survey participation in Arizona, there is a high degree of variability. So while the data is not statistically significant, it follows closely the trend of our previous findings. The use of an inclusive mentoring model, rather than a deficit model, has brought forth a clear effect on students' attitudes toward science. Reviewing current and past programs, we have

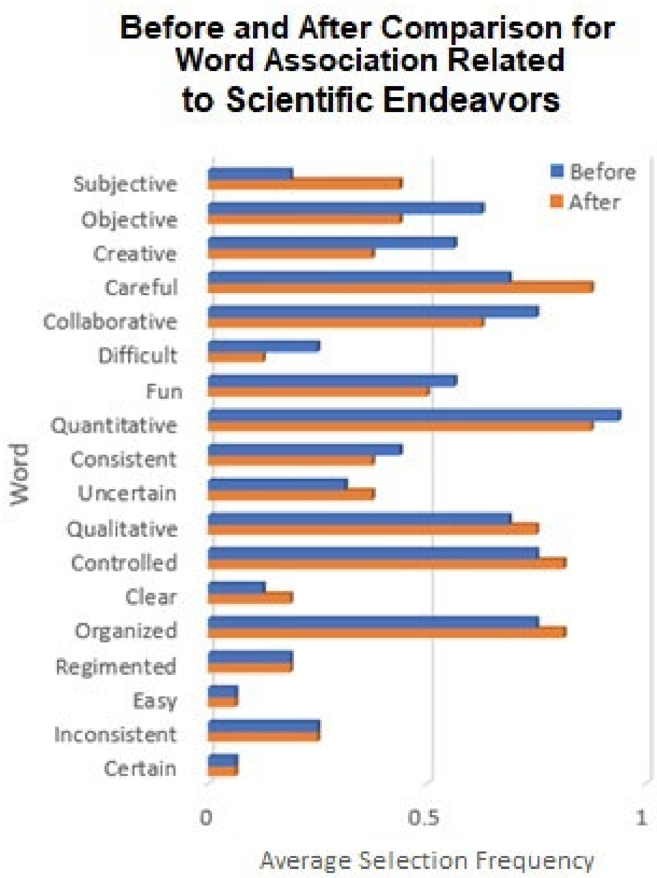

Figure 3. Peer Mentoring program data. Word association results based on average number of selections before and after the program (ordered by degree of change).

examined attitudes toward science in over 100 students (i.e., survey participants). We have served over 300 students in Arizona and New Mexico. Overall, more than 90% of the participants surveyed are URM (underrepresented minority) students and these results suggest a strong positive shift in science identity as the result of low-cost neuroscience mentoring experiences.

Despite the presented challenges, there was remarkably positive feedback in the open-ended answer section of the questionnaire. The opportunity for mentors to have hands-on experience teaching and exploring neuroscience was repeatedly noted as being highly valuable and enjoyable in qualitative feedback. Informal post-session mentor discussions included generally positive feedback, including the desire to continue the workshop into the future. Mentees similarly noted a desire for more time and more ways to engage with the material. Across both groups, "would you participate again in something like this in the future," and, "did you enjoy last week's lessons," were met with positive feedback. With respect to undergraduate neuroscience education, this represents a model to engage undergraduates in tangible ways which transcend barriers of remote learning.

Data analysis from the NEURON program mentor and mentee participants shows that, in a word association question asking, "Which terms likely apply to a scientific endeavor?" more students selected "subjective" and "careful" after participating in the program (Figure 3). Notably, fewer students selected "difficult" and "objective." While it is a challenge to rule out the number of effectors that students underwent over the course of the program and throughout COVID, it is positive to see that minoritized students are learning that the process of science can bear uncertainty which requires inquiry and should foster intellectual debate. Simultaneously, the trend for "difficult" being associated less with science similarly suggests an increased comfort with the topic and the process of science. It is important to acknowledge that, due to the limited sampling data, this difference in word association is not statistically significant.

DISCUSSION

The current workshop provides a baseline and a point for further examination of diversity and accessibility in neuroscience education as well as a potential mechanism for undergraduate retention in neuroscience. In line with previous work (Asai, 2020; Chavez, 2019; unpublished Grass Foundation NEURON program data), models in which students are empowered to think of their in-group as capable can improve outlook and self-efficacy (e.g., an improvement in perceived ability to communicate and perform scientific tasks). Due to limited sample, data and conclusions are limited, though qualitative responses and historical trends for similar programs (other Grass Foundation workshops) show a promising development. This program stands alongside other Grass Foundation programs engaging university faculty as well as K-12 and community college teachers on the disciplines of neuroscience and neurophysiology. In designing programs, however, it is important to acknowledge that each of these groups requires different teaching methodologies. As an extension of the prior workshops supported by the Grass Foundation, the NEURON program is designed to leverage peer-mentor intervention on student persistence as well as attitudes towards science. Ultimately the responses from NEURON align with other similar programming which demonstrated an improvement in the relation to the sciences, though insufficient sample size failed to deliver statistical significance from this program.

While more work is required to create a well-defined baseline and metrics, NEURON brings forward a critical tool in the process of serving and engaging all students in neuroscience during both in-person and remote courses. The use of these survey structures, the challenges and lessons from the programs, and the qualitative feedback are all critical for future programmatic successes. Both G.A. Garcia (2020) and T.J. Yosso (2005) discuss the importance of community cultural wealth as an array of knowledge, skills, abilities, and contacts possessed and utilized by Communities of Color to survive and resist macro and microforms of oppression. We are still uncovering the effects of the pandemic and its impact on how Communities of Color learn. Educational programs at all levels can engage diverse students by providing the opportunity to support and grow as learners and teachers. This workshop, like the previous ones supported by the Grass foundation, is participant-driven rather than faculty-driven, a crucial as the experiments were chosen to *serve* these students and their institutional learning outcomes.

There remain significant questions for the neuroscience educator community regarding remote education. Many agree that standard teaching models are less expensive and more available than remote models (DeBoer et al., 2017, Bernard et al., 2009). Still, many also understand the critical need to develop remote learning tools and techniques (Allen and Seaman, 2013). NEURON is designed to employ and engage traditionally marginalized undergraduate students and empower them to serve students earlier in the pipeline, building a path for everyone to thrive.

Future Directions

The NEURON program is the first documented remote, low-cost, peer-learning model for neurophysiology education in Arizona. While the program focused on a live session model, as highlighted in the results section, several challenges of prolonged attendance emerged. Better understanding of the efficacy of asynchronous mentoring may inform content organization and production. In addition, a larger network of supplementary tools should be compiled to provide mentors with additional resources and directions. Mentors sited an interest in having a variety of resources at their disposal beyond the BYB material (e.g., a lesson plan library). For rural and transit-limited learners, strong consideration should also be given to shipping options to increase accessibility.

We plan to track future student cohorts (undergraduate mentors), as we are extremely interested in the longitudinal effects of this program on student retention and program performance in marginalized populations. While there remains the need to evaluate more metrics for retention and success, this work serves as a promising pathway for engaging and retaining traditionally marginalized students and sets the IRB-approved baseline study for evaluation and consideration of future programs.

Student-centered mentor programs which use inclusive pedagogies show deep promise (Dewsbury and Brame, 2019); still, work conducted by one of the authors (BAR) in the College of Science's Committee on Diversity, Equity, and Inclusion has shown that it is critical to take a multi-programmatic approach to inclusion, restructuring systems toward a model of inclusive excellence. Engaging diverse students across science, technology, engineering, and mathematics (STEM) research is highly beneficial to student outcomes. Even at research-active campuses, however, there are not enough labs to accommodate the large number of STEM majors (Gentile, 2017). One of the authors (UR) is reforming existing and developing new curriculum as the direct result of this NEURON workshop including advancing culturally centered and responsive mentoring via low-cost approaches in neuroscience to directly increase retention by exposing more students. The University of Arizona is both a major research-intensive university and a Hispanic Serving Institution (HSI). In 2018, a University of Arizona HSI STEM group defined what it means to be an HSI; to be centered in *servingness*. To be centered on *servingness,* means that we are intentionally strengthening the conditions needed to responsively support the needs of students with diverse backgrounds, particularly our Hispanic/Latinx students (Garcia, 2020). There is value in promoting culturally enhancing, equitable approaches that offer transformative experiences leading to both academic and non-academic outcomes. In this regard, there is evidence that greater student retention stems from promoting interest and persistence in science especially in URM students. (Dewsbury and Brame, 2019).

Concluding Notes

The NEURON program stems from previously successful peer-mentoring training programs led by Ricoy in Northern New Mexico as early as 2010 and in South Tucson to bilingual (English and Spanish speaking) communities since 2019. Mentorship has been well established in the literature as fostering scientific identity and career pathways for URM students in STEM fields (see examples Freedman M, 1992 and Chavez 2019). Peer mentoring has a historical basis in education but is often only utilized for excellent students (Freedman, 1992). Programs that aim to increase diversity and support future leadership in STEM fields prioritize mentorship, but in-depth understandings of mentorship to URM students and remote/urban contexts remain limited. As the pandemic comes to a close, it is important to remember the staunch inequities revealed. The peer-mentor (not deficit-based) model of the NEURON program serves as one tool in structuring hybrid and remote learning that aims to benefit all students.

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