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# A critical systematic review assessing undergraduate neurology pipeline programs

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**Background:** Although current programs exist to encourage undergraduate interest in neuroscience and neurology, few students go on to pursue a career in neurology. Thus, there is a need for more neurologists in the US. To assess undergraduate pipeline programs and their goals of garnering interest and knowledge of neurology, we systematically reviewed available literature on existing undergraduate neurology pipeline programs.

**Methods:** A medical librarian conducted an electronic database search of PubMed, EMBASE, PsycINFO, Education Source, and ERIC based on a search strategy developed with a team of undergraduates and a neurologist. Of the 2,852 articles screened, 33 met the systematic review criteria and were evaluated based on the type and goal of the pipeline program, its delivery, and efficacy.

**Results:** The 33 programs were classified into subtypes of pipeline programs, with focuses ranging from student-led projects to early clinical research opportunities. All programs were found to be successful in attracting student interest in neurology, providing exposure to relevant opportunities, and classroom enrichment.

**Discussion:** The existing literature shows that neurology pipeline programs successfully inspire interest in a career in neurology among undergraduate students. These programs are valuable supplements to undergraduate neuroscience curricula and instrumental in introducing students to various fields.

#### KEYWORDS

undergraduate, education, neurology, neuroscience, pipeline programs

# Introduction

Over 7,208 students major in neuroscience in college (1), and nearly one-fifth of them express interest in going to medical school. However, under 3 % of pre-medical students matriculating into medical school indicate an interest in pursuing a career in neurology. Thus, a disconnect appears between this expressed interest in neuroscience among undergraduates and the long-term pursuit of the field (2). This dwindling interest among undergraduate students is oftentimes attributed to limited clinical experience, lack of guidance and support from mentors, and insufficient knowledge about neuroscience that motivates them to pursue such a field of study (3). Additionally, the COVID-19 pandemic has led to increased concern among neurology residents on the future of neurological patient management, care, and research, which

could translate to unease about the profession at the undergraduate level (4).

Early exposure to neuroscience-based training programs and research opportunities has been proven to bolster students' interest in learning about neuroscience (5). However, such programs for undergraduate students appear inaccessible to a wide student population, making integration into the classroom and related settings imperative to create a more adaptable way of learning (6). A pipeline program, described as a structured educational pathway that guides students from an early stage through various stages of education and training toward a specific career, plays a vital role in ensuring broader accessibility to certain career paths. Expanding neuroscience curricula with diverse programs or research opportunities may not only make neuroscience more interdisciplinary for students but also garner interest among underrepresented minority (URM) students and better inform them of related careers to pursue in neuroscience (7).

We conducted a systematic review of the literature on past and current undergraduate neurology pipeline programs to better understand their intent in garnering student interest in neuroscience. Our research question was: What neurology pipeline programs have been designed and implemented to attract undergraduate students into neurology? We also wanted to further analyze program designers, delivery methods, target audience (including any programs for URM students due to a shortage of URM neurologists), and success measurements.

# **Methods**

We conducted a systematic review to identify existing neurology pipeline programs using the Population, Intervention, Control, and Outcome (PICO) framework to strategize and develop our research question. We limited our population for this systematic review to undergraduate students; studies of programs that focused on populations of K-12 students were evaluated in a separate review. Interventions refer to the implementation of neurology pipeline programs intended to impart knowledge about neuroscience to students. We also measured the outcomes of the programs or the success with which they achieved such goals.

Under the guidance of a neurologist (MTM), a team of six undergraduate research assistants (AK, IY, JE, KO, NL, and RA) iteratively created a list of keywords related to neurology education and career pipelines, which a medical librarian (CP) then expanded and refined. The librarian searched PubMed, Embase, and PsycINFO via the Ovid platform and Education Source and ERIC via the EBSCO platform for articles describing neurology pipeline programs. For our study, this was defined as: any initiative that introduced, educated, or imparted students with the knowledge and an interest in neurology that may inspire them to explore these interests to potentially pursuing the field. Each search strategy included a combination of keywords and controlled vocabulary appropriate to each database. The complete search details can be found in Appendix A. The strategy was registered via the Open Science Framework (OSF) with the registration doi: 10.17605/OSF.IO/2G8CN.

The search was conducted on July 5, 2022, and was not limited by the language or year the article was published. The resulting citations and abstracts were put into Covidence software. As shown in the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) diagram (Figure 1), 278 duplicate studies were removed, and 2,574 studies were screened for inclusion by the six reviewers (AK, IY, JE, KO, NL, and RA) based on the following inclusion criteria: (1) The program must be related to neuroscience or neurology, (2) The population of participants was limited to students in either K-12 education or undergraduate college students, and (3) The program had to have been implemented and provided specified outcomes. Before the Covidence screening, the medical librarian (CP) met with the reviewers to review the screening process and to ensure fidelity. Two different reviewers independently screened and voted upon each citation, and disagreements were resolved through discussion, resulting in a final vote. 146 studies were selected for fulltext review, with 56 ultimately meeting the inclusion criteria after two rounds of in-depth independent screening. These 56 studies were then differentiated by targeted age groups: K-12 and undergraduate students. Of these, 20 were relevant to the K-12 age group, 28 were relevant to undergraduates, and 8 described programs that included participants in both target groups. In the mixed group, the reviewers determined which age groups benefited more directly. Ultimately 33 studies were included for this review, 28 exclusively targeted to undergraduate students, and 5 from the mixed group section of articles. A summary of the included programs is included in Table 1.

# Results

# **Publications analysis**

The articles were published between 1997 and 2022, with 25/33 (76%) published in the last ten years. Although the articles targeted an undergraduate student population, only about 5/33 (15.2%) explicitly mentioned including or targeting a URM student demographic. Programs targeted at URM students are marked with an asterisk (\*) in Tables 2–6. The most common journals for the articles to be published in were the *CBE – Life Sciences Education, Journal of Neuroscience Education (JUNE)*, *PLOS One, Neurology*, and *Advances in Physiology Education*.

# Programmatic content analysis

To better assess the different measures of success with each pipeline program, the 33 programs were classified into subtypes of pipeline programs implemented for undergraduate students.

Six programs (6, 14–18) emphasized student involvement in casestudy-based or collaborative-based projects (Table 2). Case-studycentered programs required students to analyze literature-based case studies on neurological illnesses. In project-based approaches, students presented their findings on neurological themes to peers, fostering teamwork and enhancing scientific literature analysis skills (16). Students provided feedback and assessed their knowledge through pre- and post-assessments and surveys.

Eight programs (19–26) involved learning tools and activities to help enrich the undergraduate classroom (Table 3). Interactive modules augmented students' current curriculum, introducing them to various neurological conditions and procedures, from Parkinson's disease to electroencephalograms (EEG). Progress was recorded frequently, and participation, engagement, knowledge reports, and



final exams determined grades. Both students and faculty evaluated overall effectiveness.

Five programs (8–10, 12, 13) were integrative courses, with neuroscience and other science and non-science-related subjects for a unique perspective on neurological concepts (Table 4). These interdisciplinary disciplines ranged from media to art to convey neurological concepts by catering to students' diversified interests through cross-disciplinary learning. One program, for example, taught students' neural mechanisms through yoga and other mindful habits (9). Other courses focused on broader methodological analyses, such as the intersection between neuroscience with technology or environmental issues. Toward the end of these programs, data for student progress was collected through open-ended questionnaires, writing reflections, or final examination scores.

Six programs (4, 7, 11, 27–29) were internships or REU (Research Experience for Undergraduates) programs, exposing students to firsthand clinical or field research opportunities to pique their interests in neurology (Table 5). Students were able to attain valuable technical skills, which they could utilize in future professional endeavors. Furthermore, students were informed of different career paths with

which they could specialize in neurology, which were not just healthcare-driven but also research-driven. One program, for instance, introduced students to experiences that can reinforce their confidence in research, such as attending weekly seminars and presenting their research in symposia at the end of the program (7). These programs were often implemented over the summer, allowing students to better immerse themselves in the experience compared to other short-term programs. Completion rates, qualitative feedback, and surveys measured program outcomes. Longitudinal assessments were conducted by some programs to gage how students augmented their experiences by measuring career progression into graduate studies. In one program, many students who originally expressed an interest in matriculating into medical school remained interested in this pursuit. In contrast, others who did not share this initial interest ended up enrolling in graduate programs, such as master's or doctoral programs (4). Programs also assessed student feedback and impressions to assess how well they enriched students' experiences.

Eight programs (5, 30-36) were extracurricular workshops or capstone projects for students to participate in and further their neuroscience knowledge. Some of these programs also involved the

## TABLE 1 Summary of included programs.

Title, First Author, Year, Journal	Program type	Program goals	Participants	Program duration	Program measures	Program outcomes
Neuroscience and Sustainability: An	Neuroscience concepts were	To enhance students'	Participants: 26 students	The module was conducted	Students' papers were given critiques for	Students mostly showed significant
Online Module on "Environmental	incorporated into a mid-level	understanding of		over the course of the	revisions, completed an anonymous	increase in knowledge and awareness
Neuroscience" (8) The Journal of	biopsychology course	neuroscience and how it can		semester, with an	evaluation of the module, and took a	of neuroscience and how it connects
Undergraduate Neuroscience	through an online	contribute to both		"Environmental Stewardship	knowledge test with results compared to a	to other disciplines of science, like
Education (JUNE)	"Environmental	sustainability efforts and		Portfolio" due at the end of the	control group (n = 27) of students who did	environmental issues, and also
Year Published: 2018	Neuroscience" module	other scientific disciplines		term. Students wrote	not take the online module but the same	scored higher than the control group
		(e.g.: environmental psych)		reflection papers based on five	course.	on the knowledge assessment
				articles of their choosing, each		(median score of 67.8, SD of 16.9).
				due every 2-3 weeks. Most of		
				the work was done outside of		
				class, meaning the module did		
				not take up class time.		
Integrating Brain Science into	Undergraduate health class	Engage a broader student	Participants: 80 students	Semester-long course that met	One cohort of 12 students was	Significant increase in scores on
Health Studies: An Interdisciplinary	combining contemplative	population in neuroscience	between fall 2012 and	for 1 h and 45 min once a week	administered a 10-item multiple choice	neuroscience knowledge posttest;
Course in Contemplative	neuroscience with yoga	learning, beyond those	spring 2015 in sections of	with ${\sim}50{-}55{\rm min}$ of lecture/	neuroscience pre/posttest; at the end of	average student course ratings
Neuroscience and Yoga (9) The	practice to introduce students	already interested in science,	10-16 students	discussion followed by yoga	the semester, students complete a course	indicated that students had more
Journal of Undergraduate	who might otherwise avoid	by relating neuroscience to		practice relevant to the	rating assessing their progress in course	positive feelings about the field of
Neuroscience Education (JUNE)	taking explicit neuroscience	health concepts through the		contemplative neuroscience	objectives on a Likert scale	neuroscience after taking the course
Year Published: 2011	classes to elements of	interdisciplinary field of		topics previously discussed;		
	neuroscience in an integrative	contemplative neuroscience		required readings were		
	and accessible manner			accessible to a lay audience;		
				students were required to		
				complete a weekly journal and		
				one final exam		
Reading the Brain: An	Interdisciplinary 1st-year	To highlight benefit of using	Participants: 32 students	Course was a part of first-year	- assessed the degree to which the	Students had positive view on course
Interdisciplinary First-Year Seminar	seminar that is taught on the	non-technical sources to	(for 2 years)	seminar program that is	student's writing has improved over the	content and course interdisciplinary
on the Intersection of Neuroscience,	intersection of neuroscience,	introduce students to		limited to small # of students.	semester (compared results on students'	writing improved over the course
Literature, and Popular Culture (10)	literature, films, plays and	scientific concepts and value		Course was taught in 2	1st analytical paper to performance on	and ability to make interdisciplinary
The Journal of Undergraduate	advertisement + ways that	of teaching collaboratively		subsequent academic years.	students' 2nd analytical paper),	connections in both class and written
Neuroscience Education (JUNE)	brain science can help people	across disciplinary		Class met weekly for two	- assessed analytical paper over 3 metrics:	assignments. 68% (11) of students
Year Published: 2021	understand why and how	boundaries. Engaging		75-min periods. Used	literary analysis, brain literacy and	went on to declare majors, 11% of
	we read	students in cross-disciplinary		discussion format	interdisciplinary to see impact	students declared minors in STEM
	taught by cognitive	thinking and helping		course was divided into 8	- administered mid-semester and end-of	disciplines
	neuroscientist and literary	neuroscience students grasp		segments	semester evaluation to assess degree of	
	scholar	difficult topics (achieve better			which the course was successfully	
		learning outcomes)			implemented according to students	

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Title, First Author, Year, Journal	Program type	Program goals	Participants	Program duration	Program measures	Program outcomes
Drugs, the brain, and behavior: a	2 semester upper-level course	expose students to	Participants: 240 students	run and taught by Ph.D.	students enrolled in fall semester filled out	in the fall semester, students showed
graduate student-run	that employs an	neuroscience + knowledge in	in their second/third year	students in the	a questionnaire after the midterm	significant improvement (21%) in
comprehensive course in	interdisciplinary approach to	neurological and		Interdisciplinary program in	(agreements with 9 statements of	raw scores between the midterm and
neuroscience (12) The Journal of	normal and altered nervous	neuropsychiatric illness;		Neuroscience at Georgetown	proficiency in topics taught) - asked to	final examinations, all students rated
Undergraduate Neuroscience	system function; aimed	promote scientific literacy in		University/24 students	estimate agreement prior to start of the	themselves at a higher level in their
Education (JUNE)	toward both undergraduates	undergraduates and provide			course and at the time of the midterm	proficiency of the topics taught
Year Published: 2021	and PhD students	pedagogical experience for			compared final and midterm exam scores	compared to the beginning of the
		PhD students				course
Social neuroscience at the college of	a new undergraduate level	to develop an effective team-	Participants: 15 students	traditional lecture-style course	students were given a anonymous	students reported gaining a better
saint rose: the art of team teaching	course for neuroscience that	taught course in social		with seminar-style course	questionnaire and demographic survey at	understanding of the material
in emerging areas of psychological	merges psychology and	neuroscience at the		combination, students were	the end of the course, two-tailed one	through team teaching vs. single
science (13) The Journal of	neuroscience	undergraduate level, provide		assigned readings from text	sample t-tests used to analyze data	teacher teaching, students reported
Undergraduate Neuroscience		undergraduate students with		and one student was deemed		enjoying taking the newly designed
Education (JUNE)		access to new, developing		discussion leader for that text,		course
Year Published: 2010		content merging social		three exams delivered		
		psychology and neuroscience		throughout the term, students		
				required to develop research		
				proposal and present it to the		
				class		
Using case studies as a semester-	Model-based program having	Implement basic and applied	Participants: 50	Students met three days a	Program was evaluated from quality of	85% of students reported positive
long tool to teach neuroanatomy	students work together with	neuroanatomy with the	undergraduates	week over the 14-week	student presentations, assessment of	feedback in using the case studies to
and structure-function relationships	case studies as a tool to teach	fundamentals of structural		semester and had seven days	knowledge, discussion questions and level	learn concepts, as well as more peer
to undergraduates (14) The Journal	brain structure-function	organization of the nervous		devoted to presentations and	of engagement, as well as peer feedback.	engagement. One criticism was
of Undergraduate Neuroscience	relationships.	system.		discussions of assigned case		feeling more time was needed to
Education (JUNE)				studies.		learn concepts, feeling some were too
Year Published: 2010						"condensed."
Professor Eric Cannot See: A	Case study incorporated in	Focuses on teaching to	N/A	Taught in a Neurobiology of	Tracked progress with in-class and	Overall class average from unit exam
Project-Based Learning Case for	an upper-level undergraduate	critically evaluate primary		Disease course, case had five	homework assignments, students were	was 83.9%, and some provided
Neurobiology Students (15) The	course	literature and analyze		scenes and an in-class	asked to thoughtfully identify learning	positive feedback in wide range of
Journal of Undergraduate		symptoms and treatment of		worksheet, unit was taught in	objectives and took a final exam.	material taught from the case-study.
Neuroscience Education (JUNE)		relevant case-study scenario.		six 75-min class periods.		
Year Published: 2016						
Using Case Studies to Promote	Lesson plan for incorporating	Increase student engagement	Participants: 29 students	Students worked in small	Assessed learning with take-home exams	Students appreciated clinical/real-
Student Engagement in Primary	literature-based neurology	with primary/basic		groups to discuss case studies	and gave individual pass/fail grades;	world applications; increased
Literature Data Analysis and	case studies into cellular and	neuroscience literature,		with Pretzel Syndrome and	qualitative student evaluation of lesson	confidence in understanding
Evaluation (16) <i>The Journal of</i>	molecular neuroscience	especially among students		ALS and answered questions;	(verbal feedback) and quantitative (Likert	neurodevelopment, cellular/
Undergraduate Neuroscience	course for upper-level	interested in clinical		whole class reviewed in larger	scale) before and after lessons.	molecular neuroscience, and diseases
Education (JUNE)	undergraduates.	healthcare careers		discussions throughout		and drugs used in treatments.
Year Published: 2017				course.		

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Title, First Author, Year, Journal	Program type	Program goals	Participants	Program duration	Program measures	Program outcomes
The Design, Implementation, and	Project-based approach	Better engage students in	Participants: 37 upper-	Students met 2x a week during	Pre- and post-tests given to students to	Greater performance on the post-test
Assessment of an Undergraduate	consisting of student-led	upper-level neurobiology	level undergraduate	15-week semester; each class	measure content knowledge, students	compared to the pretest, by end of
Neurobiology Course using a	work, team-authored research	course and promote positive	students	meeting was 110 min long and	completed pre- and post-surveys during	course students reported significantly
Project-Based Approach (6) The	papers, and poster	attitudes in confidence with		taught by 1 instructor. 3 main	first and last week of class to measure	higher confidence in neuroscience
Journal of Undergraduate	presentations to improve	material.		project themes (neurotoxins,	confidence in neuroscience and attitudes	knowledge.
Neuroscience Education (JUNE)	understanding of			spinal cord injury and	working in team projects.	
Year Published: 2018	neuroscience.			learning and memory).		
'Without A Key': A Classroom Case	Case study using a narrative	Allow students to work	Participants: 25 students	Students worked in small	students provided anonymous feedback	96% of participants agreed or
Study (17) The Journal of	focused on Locked-in	collaboratively to apply their		groups in upper-level	online about the case, 8 feedback	strongly agree that exercise was
Undergraduate Neuroscience	syndrome to engage upper-	analytical and course-related		Cognitive Neuroscience	questions assess the students' qualitative	"engaging and enjoyable," 83%
Education (JUNE)	level undergraduates with	skills in an open-ended space		course with both lecture and	experiences rating on a scale based on the	agreed it was more interactive than a
Year Published: 2019	neuroanatomy, clinical	to extended scientific skill		lab components. Case is	goals of the program (specific content	traditional lectures, and 96% agreed
	neuroscience and brain	development.		preceded by brief review	questions and general interest)	that the case studies increased their
	computer technology.			lecture and implementation		knowledge of the topic and
				takes 90 min. Class session		syndrome.
Effective Use of Student-Created	Students made case-studies	improving student	Participants: 24 students	Administered over zoom	Students used a Likert scale to self-report	Grades increased compared from
Case Studies as Assessment in an	used as an assessment tool for	performance and increasing		during weekly 3-h lab period	their knowledge of content learning	first exam to the final, supporting
Undergraduate Neuroscience	an online neurovirology	students' knowledge and		for 4 weeks (week 3-4 used for	objectives and confidence in skills learning	that interactive writing practices and
Course (18) The Journal of	module in a neuroanatomy	confidence in neuroscience		case study assignment)	objective after completion of the module	low-stakes exams can improve
Undergraduate Neuroscience	and physiology course			students used writing practice	and the case-study assignment	performance. Students reported that
Education (JUNE)				to write their case studies	compared students grades of 1st and final	writing, teaching and completing a
Year Published: 2021				(graded), students exchanged	draft of case study.	neurovirology case-study all
				case studies with their peers		increased knowledge - writing
				and taught/completed case		ranked higher than teaching or
				studies with their peers as a		completing.
				low-stakes assessment		
Learning Neuroscience: An	ICON, interactive case-based	Enhance students' approach	Participants: 12	Applied in Harvard Faculty of	letter grades for the tutorials were assigned	full participation in all modules;
Interactive Case-Based Online	online network, that is	to problems, solutions, and	undergraduates	Arts and Science curriculum	according to online participation,	thoughtful analysis of the each
Network (ICON) (19) Journal of	introduced to undergraduate	insights in neuroscience		as an honors elective (for 1	contributions to discussions, written case	other's scientific reasoning in the
Science Education & Technology	curriculum to bring a			semester), students met face to	summaries, and final examination - also	case studies, weekly face to face
Year Published: 2002	different focus on reshaping			face for 2 h 1x week in two	had students and faculty submit an	meetings were lively and
	their thinking in			tutorial groups of 6 students	evaluation of the program as a learning	conversation picked up from the
	neuroscience			each.	tool	previous meetings (ICON supported
						the active participation of the faculty
						and students' learning)

Title, First Author, Year,	Program type	Program goals	Participants	Program duration	Program measures	Program outcomes
Online Teaching Tool Simplifier	Developed Online	Developed to help increase	Student participants 221	Supplemented existing	Comparing outcomes for students who	OMTT used at USC during Fall
Eaculty Use of Multimedia and	Multimedia Teaching Tool	student knowledge and	Faculty 5	curricula in multiple courses	volunteered to participate in the program	Semester of 2009 showed registered
Improves Student Interest and	(OMTT) in Neuroscience for	interest in neuroscience +	Faculty = 5	-1st Beta phase released on	to a control group of students in that class	students did significantly better
Knowledge in Science (20) CPE	(OWITT) III Neuroscience for	simplify instructor		-Ist Beta phase released on Derkinson's disease and phase	who did not choose to register for OMTT	when instructor used OMTT in
Life Sciences Education	and in a resources in a similar	adaptation by giving a		released OMTT chapters on	for the course Conducted survey of user	lactures and when even covered
- Life Sciences Education	forme at used in their leatures	lasture based method of		Ion sharped Surranges 2nd	nor the course. Conducted survey of user	metarial in the OMTT OMTT in
Tear Published: 2011	format used in their fectures.	licital anni alam		ion channels, synapses. Sru	opinion on use of OM11. Also compared	material in the OM 11, OM 11 in
	Students had unlimited	digital curriculum		phase released Functional	whether students who used OM I I had	neuroscience viewed positively by
	online access for self-			Neuroanatomy and Biogenic	better performance on traditional in-class	students across all 4 courses, also felt
	exploration on the topic of			Amines – developed over	forms for assessment.	instructors' use of OMTT in class
	neuroscience			2 years which students and		helped them understand material
				faculty had access to, giving		better and made them want to self-
				instructional login at the		explore OMTT in their free time
				beginning of the semester and		
				results compared at the end of		
			-	the course		-
The Lateralizer: A Tool for Students	A tool that implements the	To help students explore the	Participants: 240 upper-	Program was introduced	Research reports, multiple-choice	significant improvement in scores
to Explore the Divided Brain (21)	divided visual field (DVF)	differences between the left	level undergraduates	during a 2-week module in a	questionnaires about the lateralization of	from pretest to posttest, students
Advances in Physiology Education	technique, introduced as a	and right cerebral		large research methods course	cognitive function, the anatomy of the	gained a new knowledge of brain
Year Published: 2012	problem-based learning	hemispheres		halfway into the semester,	brain, and the spatial frequency	anatomy and connectivity, project
	module in a research			large weekly lecture (50 min),	hypothesis to test student learning	added to students' research skills
	methods course, students			2 h laboratory classes a week	outcomes, pretest and posttest.	
	designed DVF experiments.					
The Open PicoAmp: an open-source	An open-source lipid bilayer	Hands-on approach to	N/A	It was about a 4-h laboratory	Program was studied by the adjuncts	In a typical four hours session, all
planar lipid bilayer amplifier for	amplifier was developed for	learning neuroscience to		session. Usually, one group of	instructors and older students which have	students were able to obtain the lipid
hands-on learning of	use in neuroscience	teach about different		two students is assigned per	been previously trained.	bilayer formation and study its
neuroscience (22) PLOS ONE	introductory courses.	electrical properties of the		bilayer setup. To allow the		electrical properties. Also, a majority
Year Published: 2014		cell membrane.		session to run smoothly and		of attendees could actually succeed
				maximize the interactions		to observe the single channel
				with the students, one		currents. This was a good
				instructor for two groups of		performance, as it is a rather delicate
				students is an optimal		experiment and for many students
				configuration. Lab sessions at		this was their first experience in such
				our institution are run with		a laboratory environment.
				ten bilayer setups working		
				simultaneously.		

(Continued)

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Title, First Author, Year, Journal	Program type	Program goals	Participants	Program duration	Program measures	Program outcomes
Neurogaming Technology Meets	A teaching lab with	Use cost-effective tools and	Participants: 268	EEG headsets and software	Students took in-class surveys with a	Students have shown that the EEG-
Neuroscience Education: A Cost-	equipment to incorporate	implement a teaching lab to	undergraduates, but only	were incorporated to students'	5-point Likert scale with responses	incorporated labs were enjoyable and
Effective, Scalable, and Highly	into an introductory	be able to expose students to	150 students fully	lab sessions over the course of	consolidated into three findings:	increased their knowledge in
Portable Undergraduate Teaching	neuroscience curriculum. The	laboratory/research	completed the evaluation	their semester, with each lab	enjoyment, usefulness, and improvement	neuroscience concepts and EEG, as
Laboratory for Neuroscience (23)	devices used to EEG	experience	survey	session about 1-h long	on understanding; and their completed	well as provided them firsthand
The Journal of Undergraduate	machines for the students to				labs were looked into	research experience.
Neuroscience Education (JUNE)	use as a research tool and					
Year Published: 2017	enhance student's'					
	introduction into					
	neuroscience					
Using A Contrast Illusion to Teach	an interactive laboratory	to understand the	Participants: 112 students.	Students conducted simple	in a pre and post survey, students'	students had significant
Principles of Neural Processing (24)	exercise to challenge	effectiveness of this active		psychophysical experiments to	confidence and practical understanding of	improvements in content knowledge
The Journal of Undergraduate	undergrads to use	learning exercise in		measure thresholds for	3 main concepts neural processing were	and increased confidence in ability to
Neuroscience Education (JUNE)	observational measurements	increasing student		detecting illusory spots under	evaluated on a Likert Scale.	demonstrate understanding after the
Year Published: 2018	of a visual contrast illusion to	understanding of how		various conditions and		lab. Students had overall positive
	study neural activity	perception is shaped by		described their results in a		attitudes toward the lab.
		neural circuits in the retina		laboratory assignment.		
Hands-on Undergraduate	Implementing EEG through	To determine whether or not	Participants: 26 upper-	Students utilized EEG in	Students reflected on their own EEG data	Students felt more motivated to work
Experiences Using Low-Cost	MUSE headbands.	EEG can help students learn	level undergraduate	classrooms to see how the	and filled out surveys to determine	on their current tasks and projects
Electroencephalography (EEG)		better about their brain	students	brain functioned while doing	whether or not the implementation of	due to the EEG. Many students
Devices (25) <i>The Journal of</i>				several different brain	EEG had an effect on understanding the	expressed enthusiasm and
Undergraduate Neuroscience				exercises. This consisted of	brain.	excitement for learning more.
Education (JUNE)				trying new tastes and		
Year Published: 2019				answering different questions.		
Signal: A Neurotransmission Board	use of a board game designed	game-based learning serves	Participants: 36 students	participants were	After completing the board game, students	80.5% (n = 24) agreed or strongly
Game (26) The Journal of	to test students'	an effective and engaging tool	(38 played the game but 2	undergraduate students	asked to complete survey on their	agree $(n=5)$ that the game helped
Undergraduate Neuroscience	understanding of core	to review fundamentals of	opted out)	enrolled in "Fundamentals of	impressions of the exercise (rated their	them assess their knowledge and
Education (JUNE)	concepts of core concepts	neurotransmission in science		Neuroscience" course;	agreement to statements)	understanding of action potential
Year Published: 2021	covered in introductory	courses - allowed students to		students played signal during		and 83.3% $(n=22) + (n=8)$ agreed
	neuroscience courses - action	develop skills and gained a		week 13 of semester an in-		that it helped their understanding of
	potentials and synaptic	greater understanding of		class activity in groups 4–5		synaptic transmission. 30 students
	transmission	neuroscience		players - carried out in 2		agreed that it allowed to develop
				sections of course in 1		communication skills as they talked
				semester		to their peers about scientific
						concepts

Title, First Author, Year, Journal	Program type	Program goals	Participants	Program duration	Program measures	Program outcomes
Evaluation of an undergraduate	neuroscience summer	*Expose undergraduate	Participants: 80 students	throughout the summer in 5	annual end of summer survey	participation in this program may
neuroscience research program at	research experience	students to various graduate		different components - 1.		have strengthened students'
the University of Kentucky (7) The		careers, inform them of		neuroscience course, 2.		applications to graduate schools,
Journal of Undergraduate		neuroscience opportunities,		independent research projects,		high satisfaction with the material
Neuroscience Education (JUNE)		increase URM students, give		3. lunchtime seminars, 4.		students were exposed to,
Year Published: 2003		them research project of their		summer symposium, 5. oral		successfully increased URM in
		own		presentations at the end of the		neuroscience research, participation
				summer		in program increases chances
						students will apply to graduate
						school
Partnerships in Neuroscience	Neuroscience internship	Goal is to provide students in	Participants: 35 total	An intern would then work	Program studied based on student	Many stayed consistent with where
Research Between Small Colleges	program for students (ideally	smaller colleges a program	interns have completed	8-12 h/week during the school	performance and completion of the	they wanted to go versus where they
and Large Institutions: A Case Study	2nd or 3rd years) at Stonehill	within a larger institution	this program and went	year, but then increase their	program. Survey was done comparing the	ended up, specifically with doctoral
(4) The Journal of Undergraduate	College to participate in	with resources to enrich their	onto graduate programs;	workload to full time for	interns' initial goals once leaving the	programs (i.e.: medical school) with
Neuroscience Education (JUNE)	either the Basic Research or	curricula and extracurricular	25 responded to a survey	10 weeks (35 h/week) during	program versus actual outcomes on where	~13. Many more students actually
Year Published: 2018	Clinical Research division of	experience; helps to give	done by the authors	the summer typically through	they are after college. Also largely studied	went into research with masters or
	the Laboratory of	students an experience they		the Stonehill Undergraduate	on student feedback and impressions	PhD, with not many having that as
	Neuroscience in the	can utilize when applying to		Research Experience		an initial goal (2–3 responded as a
	Department of Psychiatry, at	graduate programs				goal, 8–10 responded as an outcome)
	Harvard Medical School					
Integrating Research into the	This article expands upon the	To figure out different	N/A	Studied different articles and	Program was studied based on how	Found that it is beneficial to support
Undergraduate Curriculum: 1. Early	information presented in	benefits and challenges of		information from workshops	students from different backgrounds	students as they discover science,
Research Experiences and Training	workshop discussions,	implementing research in the		to sort out details of what is	(experienced or non-experienced) were	grow in confidence and competence,
(27) The Journal of Undergraduate	focusing on ways to promote	undergrad experience		beneficial or not for students.	able to perform in their research.	and move toward a future that will
Neuroscience Education (JUNE)	early research opportunities.					be well served by a diverse group of
Year Published: 2020						thoughtful, curious, well-prepared
						individuals as they are able to enter
			27/4			the workforce.
Integrating Research into the	This article expands upon the	To figure out different	N/A	Studied different articles and	Program was studied based on how	Found that it is beneficial to support
Undergraduate Curriculum: 3.	information presented in	benefits and challenges of		information from workshops	students from different backgrounds	students as they discover science,
Research Training in the Upper-	workshop discussions,	implementing research in the		to sort out details of what is	(experienced or non-experienced) were	grow in confidence and competence,
Ievel Neuroscience Curriculum (28)	tocusing on ways to promote	undergrad experience		beneficial or not for students.	able to perform in their research.	and move toward a future that will
The Journal of Undergraduate	early research opportunities.					be well served by a diverse group of
Neuroscience Education (JUNE)						thoughtful, curious, well-prepared
Year Published: 2020						individuals as they are able to enter
						the workforce.

(Continued)

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Title, First Author, Year, Journal	Program type	Program goals	Participants	Program duration	Program measures	Program outcomes
Building the Neurology Pipeline	Article studies different	This article discusses how	Participants: 50	Various different articles and	Various different articles and data	We incorporated undergraduate
with Undergraduate Students in	logistics, potential benefits	working with undergraduate		data collected from previous	collected from previous research was	student perspectives regarding the
Research and Clinical Practice (29)	and challenges on	students represents a unique		research was studied to	studied to determine the different	impact of their experiences on their
American Academy of Neurology	implementing undergrad	opportunity to expose		determine the different	implications of clinical neuroscience	personal and professional lives. In
Year Published: 2021	neuroscience clinical	students to neurology		implications of clinical		total, we received reflections $(n = 32)$ .
	research	through research and clinical		neuroscience		emails $(n = 4)$ , applications for
		care while also generating		incur obcionee.		opportunities $(n = 7)$ , and a program
		many beneficial experiences				feedback survey $(n = 1)$ . In a process
		for the student and the				considered exempt by the Wake
		neurologist. We outline				Forest Baptist Institutional Review
		notential benefits and				Board we qualitatively analyzed
		logistical considerations				these data into themes with
		involved in working with				representative examples to best
		undergraduates				understand each theme
Understanding How to Strengthen	Focused on input from	In order to seek how to	Participants: 1,085	study was comprised of 1,085	results from an anonymous cross-sectional	Qualitative results include student
the Neurology Pipeline With	undergrad students on their	implement more	undergraduate students	undergraduates in either	online survey were studied	perspectives from those who did and
Insights From Undergraduate	experiences with	neuroscience into classrooms	0	neuroscience courses or	,	did not work with a neurologist,
Neuroscience Students (11)	neuroscience. The survey	based on undergrad student		majoring/minoring in		describing how they were or were
American Academy of Neurology	quantitatively and	experience with science/		neuroscience from across the		not able to obtain such opportunities.
Year Published: 2022	qualitatively assessed	neuroscience.		United States to better		We discuss translating the survey
	students' clinical neurology			understand their clinical		findings into actionable results with
	exposure, research			neurology experiences and		opportunities to target the
	experiences, and career goals.			perspectives.		undergraduate neuroscience interest
				1 1		to improve the neurology pipeline
Everyday Neuroscience: A	service-learning course	engage interest in	Participants: 43-44	undergrad students assigned	undergraduates were asked to write 4	Compared to the beginning of the
Community Engagement Course	"Everyday Neuroscience" in	neuroscience in the high	undergraduate students	to 1 of 5 team, all teams	1-page reflections to link community	course (77%) at the end, 88% of
(30) The Journal of Undergraduate	which undergraduate	schoolers; undergraduates		charged with developing	engagement experiences with students'	students thought they had something
Neuroscience Education (JUNE)	students developed 10	increase their awareness of		lesson plans for 2 hands-on	personal growth + survey at the beginning	important to contribute to society.
Year Published: 2019	neuroscience-relevant for	social disparities; improve		activities; 10 visits to the high	and end of the about their impressions,	For psychological well-being, there
	under-resourced high school	communication skills in		school	what contributed to their learning, what	was no change in the frequency for
	students; students rand these	conveying neuroscience			was most interesting and what skills were	students feeling challenged to grow.
	lab activities with small	principles to a non-specialist			developed	Attitudes toward teaching and feeling
	groups of high-school	audience *				confident to expression their ideas
	students					were more positive at the end of the
						course (77% v 96% <i>p</i> < 0.05)

Title, First Author, Year, Journal	Program type	Program goals	Participants	Program duration	Program measures	Program outcomes
Strategies for the Introduction of	series of learning experiences	*To encourage URM	Participants: 12,893	Series of four activities - 1.	qualitatively and quantitatively: Likert-	students highly rated presentations
Neuroscience for Underrepresented	during Brain Awareness	students to specialize in the	registered for BAW, 250	Brain games, 2. Learning	scale survey, open-ended questionnaires,	on stroke rehabilitation and fMRI in
University Students (5) Journal of	Week to increase interest in	neuroscience field by	students counted in	activities, 3. Academic	Spanish-English bilingual questionnaire	neuroscience, 100% students who
College Science Teaching	the field of neuroscience	increasing their knowledge of	attendance at academic	conferences, 4. A research		responded to open ended questions
Year Published: 2011		the neuroscience field	conferences	poster session during Brain		thought the conference was
				Awareness Week		meaningful, increased knowledge
						about research techniques
A proposal for undergraduate	proposal for the Brain	use Brain Awareness Week	Participants: 300	BAW lasted for a week	questionnaire given to students to assess if	90% of physiology students said the
students' inclusion in brain	Awareness Week to be a	(BAW) to increase interest in	undergraduate and		involvement in BAW activities increased	BAW activities increased their
awareness week: promoting interest	neurophysiology teaching	neuroscience and physiology	graduate students		their interest in physiology/neuroscience	interest in physiology and
in curricular neuroscience	strategy to include					neuroscience
components (31) The Journal of	undergraduate physiology					
Undergraduate Neuroscience	students in the organization					
Education (JUNE)	and presentation of BAW					
Year Published: 2014	events					
Introducing high school students to	undergrads present	Developed by graduate	Participants: 240 students	Neurophysiology lab,	students gave comments on their	Quantitative analysis from student
neurophysiology (32) Advances in	physiology research projects	student volunteers and	in their second/third year	undergrads conduct an	experiences anecdotally	comments: high school students
Physiology Education	to high school seniors	physiology undergrads.		experiment over three weeks		claim to become very excited about
Year Published: 1997		Participants: ~100 high		and present to high school		physiology and leave the campus
		school students each year,		seniors at a 3-h event. All		with a greater feeling of confidence
		unspecified number of		students have the opportunity		in their ability to succeed in
		undergrads (>100 per year).		to both present and hear their		university science. Undergrad
				classmates present. High		presenters feel inspired and
				schoolers receive a basic pre-		appreciate the ability to showcase
				lab tutorial to learn basic		their work.
				physiology concept and then		
				ask questions during		
				presentations. The event takes		
				place over four presentation		
				days.		

Title, First Author, Year, Journal	Program type	Program goals	Participants	Program duration	Program measures	Program outcomes
Neuroscience Workshops for Fifth-	University-school	undergrads learn how to	Participants: 99	As part of a senior seminar	pre- and post-test developed by	Mixed ANOVA showed workshops
Grade School Children by	partnership: scientist-in-the-	conduct field research using	elementary school	course, undergrad psychology	undergrads delivered one week before and	improved the children's knowledge of
Undergraduate Students: A	classroom visits from	an inquiry-based approach	students, 8 undergraduate	students developed a research	after visit testing elementary student's	neuroscience concepts; qualitative
University-School Partnership (33)	undergrads to elementary	and elementary students	students	study to deliver workshops to	knowledge of neuroscience concepts.	analysis of open-ended questions by
CBE – Life Sciences Education	students on brain structure,	learn basic neuroscience		elementary students and	Undergrads evaluated their experience	undergraduates showed they also
Year Published: 2006	disorders, perception.	concepts		evaluate effectiveness of their	with Likert scale and open-ended	found their learning experience
	Undergrads develop and			teaching. Undergrads created	questions.	engaging and productive
	implement a fieldwork study.			and practiced lessons over the		
				course of 15 weeks, and		
				delivered a single 1-h		
				neuroscience lesson to		
				elementary school students.		
Teaching about the brain and	Called the Pipeline	This pipeline program	Participants: 8	Program was a semester long	Students provided informal feedback to	Overall feedback from the high
reaching the community:	Neuroscience Program, this	mutually serves benefit to the	undergraduates, around	on a weekly basis, with classes	their program coordinators; some were	schools, undergraduate TAs, medical
undergraduates in the pipeline	is an educational outreach	high school students who are	26 high school students*	about 90 min long. Upper and	selected to take videotaped exit interviews	students, and residents, have been
neuroscience program at the	and mentorship program	being taught neuroscience		lower-level medical students	recounting their experiences.	positive with the goals and outcomes
university of Pennsylvania (34) The	where undergraduate	concepts and career options		took turns in delivering the	Undergraduates were also tested on their	of the pipeline program. Many
Journal of Undergraduate	students teach neuroscience	by undergraduate students, as		lessons, and undergraduates	knowledge from their seniors from pre-	expressed the program increased
Neuroscience Education (JUNE)	concepts to high school	well as the undergrads who		were teaching assistants (TAs)	and post-program quizzes. 2007 also	knowledge of neuroscience, positive
Year Published: 2007	students	are taught and guided by		to the high school class and	introduced a longitudinal evaluation of	impacted on mastery of material, and
		medical students and		held small group activities.	the students' college matriculation into	influence on career goals or plans for
		neurology residents			neuroscience careers.	a medical subspecialty.
Bridge to neuroscience workshop:	full-day hands-on workshop	to identify promising	Participants: 200 high	*Targeted URM, one-full day	pre and post evaluations, feedback forms	participation in the workshop increases
An effective educational tool to	in neuroscience education	students for the Bridge to the	school students and 424	workshop, 4 sessions in the		understanding and enthusiasm for
introduce principles of neuroscience		PhD in Neuroscience	undergraduate students	workshop		neuroscience as a field, high schoolers
to Hispanics students (35) PLOS		Program, to increase				had more incorrect answers on the
ONE		awareness of neuroscience as				pretest than undergraduate students
Year Published: 2019		a discipline and a career				did, mean percentage of correctly
		option				answered questions increased for both
						high school and undergraduates in the
A Constant Course Million Stallarts		Transa la construction de star	Denticia en terrera di mar		TT. J	posttest
A Capstone Course where Students	neuroscience capstone course	For undergrads to apply their	Participants: over three	as part of a semester-long	Undergrads rated the capstone course in a	Over 5 years, course ratings averaged
Present Contemporary	where students choose and	neuroscience knowledge and	years, number of	senior course, undergrads	course evaluation quantitatively and	5.87, 4.45, and 4.61 with a positive
School Students (26) The Jacune 1 of	study contemporary	communication skills. High	undergrad students varied	developed a research project	quantatively with open ended questions	it a maaningful subministing
School Students (56) The Journal of	in double of the second articles	schoolers also benefit from	thick of a labor with	by reading through scientific	and 1–10 ratings. Figh schoolers were not	it a meaningful cummating
Education (UINE)	them to high ash as a students	presentations.	1 mgn school class each	merature. Undergrads adapted	evaluated.	experience of their undergraduate
Laucation (JUNE)	in chart wideos		year.	presentations for their high		neuroscience education
iear Publisned: 2020	in snort videos			school audience in the form of		
				posters or videos. Presentation		
				was an hour long.		

## TABLE 2 Case-study/project-based programs.

Title, First Author, Year, Journal	Program type	Program goals	Developers/ Participants	Program duration	Program Measures	Program Outcomes
Using case studies as a semester-long tool to teach neuroanatomy and structure-function relationships to undergraduates (14) <i>The Journal of</i> <i>Undergraduate</i> <i>Neuroscience</i> <i>Education (JUNE)</i>	Model-based program having students work together with case studies as a tool to teach brain structure–function relationships.	Implement basic and applied neuroanatomy with the fundamentals of structural organization of the nervous system.	Developed by faculty at Denison University Participants: 50 undergraduates in a Biological Psychology course.	Students met three days a week over the 14-week semester and had seven days devoted to presentations and discussions of assigned case studies.	Program was evaluated from quality of student presentations, assessment of knowledge, discussion questions and level of engagement, as well as peer feedback.	85% of students reported positive feedback in using the case studies to learn concepts, as well as more peer engagement. One criticism was feeling more time was needed to learn concepts, feeling some were too "condensed."
Professor Eric Cannot See: A Project-Based Learning Case for Neurobiology Students (15) The Journal of Undergraduate Neuroscience Education (JUNE)	Case study incorporated in an upper-level undergraduate course	Focuses on teaching to critically evaluate primary literature and analyze symptoms and treatment of relevant case-study scenario.	Case study developed by: Eric Ribbensy Participants: N/A	Taught in a Neurobiology of Disease course, case had five scenes and an in-class worksheet, unit was taught in six 75-min class periods.	Tracked progress with in-class and homework assignments, students were asked to thoughtfully identify learning objectives and took a final exam.	Overall class average from unit exam was 83.9%, and some provided positive feedback in wide range of material taught from the case-study.
Using Case Studies to Promote Student Engagement in Primary Literature Data Analysis and Evaluation (16) The Journal of Undergraduate Neuroscience Education (JUNE)	Lesson plan for incorporating literature-based neurology case studies into cellular and molecular neuroscience course for upper-level undergraduates.	Increase student engagement with primary/basic neuroscience literature, especially among students interested in clinical healthcare careers	Developed by: faculty in neuroscience program at Carthage Collegey Participants: 29 students	Students worked in small groups to discuss case studies with Pretzel Syndrome and ALS and answered questions; whole class reviewed in larger discussions throughout course.	Assessed learning with take-home exams and gave individual pass/fail grades; qualitative student evaluation of lesson (verbal feedback) and quantitative (Likert scale) before and after lessons.	Students appreciated clinical/real-world applications; increased confidence in understanding neurodevelopment, cellular/molecular neuroscience, and diseases and drugs used in treatments.
The Design, Implementation, and Assessment of an Undergraduate Neurobiology Course using a Project-Based Approach (6) The Journal of Undergraduate Neuroscience Education (JUNE)	Project-based approach consisting of student-led work, team-authored research papers, and poster presentations to improve understanding of neuroscience.	Better engage students in upper- level neurobiology course and promote positive attitudes in confidence with material.	Developed by: Professor Zwick at Stockton University Participants: 37 students (31 seniors and 6 juniors).	Students met 2x a week during 15-week semester; each class meeting was 110 min long and taught by 1 instructor. 3 main project themes (neurotoxins, spinal cord injury and learning and memory).	Pre- and post-tests given to students to measure content knowledge, students completed pre- and post- surveys during first and last week of class to measure confidence in neuroscience and attitudes working in team projects.	Greater performance on the post-test compared to the pretest, by end of course students reported significantly higher confidence in neuroscience knowledge.

Title, First Author, Year, Journal	Program type	Program goals	Developers/ Participants	Program duration	Program Measures	Program Outcomes
'Without A Key': A Classroom Case Study (17) The Journal of Undergraduate Neuroscience Education (JUNE)	Case study using a narrative focused on Locked-in syndrome to engage upper-level undergraduates with neuroanatomy, clinical neuroscience and brain computer technology.	Allow students to work collaboratively to apply their analytical and course-related skills in an open-ended space to extended scientific skill development.	Developed by: faculty in dept. of psychology at Lewis and Clark College Participants: 25 students	Students worked in small groups in upper-level Cognitive Neuroscience course with both lecture and lab components. Case is preceded by brief review lecture and implementation takes 90 min. Class session	students provided anonymous feedback online about the case, 8 feedback questions assess the students' qualitative experiences rating on a scale based on the goals of the program (specific content questions and general interest)	96% of participants agreed or strongly agree that exercise was "engaging and enjoyable," 83% agreed it was more interactive than a traditional lectures, and 96% agreed that the case studies increased their knowledge of the topic and syndrome.
Effective Use of Student-Created Case Studies as Assessment in an Undergraduate Neuroscience Course (18) The Journal of Undergraduate Neuroscience Education (JUNE)	Students made case- studies used as an assessment tool for an online neurovirology module in a neuroanatomy and physiology course	improving student performance and increasing students' knowledge and confidence in neuroscience	Developed by: Participants: 24 students	Administered over zoom during weekly 3-h lab period for 4 weeks (week 3-4 used for case study assignment) students used writing practice to write their case studies (graded), students exchanged case studies with their peers and taught/completed case studies with their peers as a low- stakes assessment compared students grades of 1st and final draft of case study.	Students used a Likert scale to self-report their knowledge of content learning objectives and confidence in skills learning objective after completion of the module and the case-study assignment	Grades increased compared from first exam to the final, supporting that interactive writing practices and low-stakes exams can improve performance. Students reported that writing, teaching and completing a neurovirology case- study all increased knowledge – writing ranked higher than teaching or completing.

direction of medical students or neurology residents, and undergraduates presented their applied knowledge to a younger audience, from K-12 students (Table 6). Through interactive field studies and presentations, undergraduates taught core concepts, such as brain structure, disorders, and physiology, in a comprehensible manner to children and adolescents. These programs benefited both high school students and undergraduates, with the latter gaining mentorship and encouragement by medical students and residents. Feedback was largely positive, with undergraduates expressing gained confidence in their ability to educate a younger audience on complex topics. Pre- and post-assessments were given to the younger students to compare their learning outcomes, and surveys were given to both undergraduates and their students to assess their experiences in this type of environment. Other programs had undergraduates participating in learning activities, such as Brain Games or attending academic conferences to reaffirm their interest in learning newfound neurology-related concepts (31).

# Programmatic assessment

In the case-study or project-based programs, one program (14) utilized qualitative methods of measurement, largely analyzing students' feedback after completing the program. While the remaining five programs (6, 15–18) utilized a mixed methods analysis of the programs. Qualitative data came from student feedback, with many expressing increased knowledge of neurological concepts and lasting positive impressions. Many students appreciated the case studies, as they allowed a stronger grasp of learning objectives and application of their knowledge to real-life scenarios. Quantitative data came from surveys rating students' experiences (usually on a Likert scale), comparison of grades on pre-and post-assessments, and completion of assignments. All six programs concluded that students felt more confident in their abilities to understand neurological concepts.

Of the eight pipeline programs (19-26) with interactive learning tools in neuroscience courses or labs, only two (19, 22) utilized

## TABLE 3 Learning tools-based programs.

Title, First Author, Year, Journal	Program type	Program goals	Developers/ Participants	Program duration	Program measures	Program outcomes
Learning Neuroscience: An Interactive Case-Based Online Network (ICON) (16) Journal of Science Education & Technology	ICON, interactive case-based online network, that is introduced to undergraduate curriculum to bring a different focus on reshaping their thinking in neuroscience	Enhance students' approach to problems, solutions, and insights in neuroscience	Faculty members wrote the cases in the program, expert faculty from FAS, Harvard Medical School, Harvard's teaching hospitals and other academic institution also invited in the development of the program / 12 undergraduates	Applied in Harvard Faculty of Arts and Science curriculum as an honors elective (for 1 semester), students met face to face for 2 hours 1x week in two tutorial groups of 6 students each.	letter grades for the tutorials were assigned according to online participation, contributions to discussions, written case summaries, and final examination - also had students and faculty submit an evaluation of the program as a learning tool	full participation in all modules; thoughtful analysis of the each other's scientific reasoning in the case studies, weekly face to face meetings were lively and conversation picked up from the previous meetings (ICON supported the active participation of the faculty and students' learning)
Online Teaching Tool Simplifies Faculty Use of Multimedia and Improves Student Interest and Knowledge in Science (19) <i>CBE - Life Sciences</i> <i>Education</i>	Developed Online Multimedia Teaching Tool (OMTT) in Neuroscience for faculty to use to help deliver online resources in a similar format used in their lectures. Students had unlimited online access for self-exploration on the topic of neuroscience	Developed to help increase student knowledge and interest in neuroscience + simplify instructor adaptation by giving a lecture-based method of digital curriculum	Developed by funding agency, scientists, and programmers. Student participants - 221 Faculty - 5	Supplemented existing curricula in multiple courses, -1st Beta phase released on Parkinson's disease, 2nd phase released OMTT chapters on Ion channels, Synapses. 3rd phase released Functional Biogenic Amines developed over 2 years which students and faculty had access to, giving instructional login at the beginning of the semester and results compared at the end of the course	Comparing outcomes for students who volunteered to participate in the program to a control group of students in that class who did not choose to register for OMTT for the course. Conducted survey of user opinion on use of OMTT. Also compared whether students who used OMTT had better performance on traditional in-class forms for assessment.	OMTT used at USC during Fall Semester of 2009 showed registered students did significantly better when instructor used OMTT in lectures and when exam covered material in the OMTT, OMTT in neuroscience viewed positively by students across all 4 courses, also felt instructors' use of OMTT in class helped them understand material better and made them want to self- explore OMTT in their free time
The Lateralizer: A Tool for Students to Explore the Divided Brain (15) Advances in Physiology Education	A tool that implements the divided visual field (DVF) technique, introduced as a problem-based learning module in a research methods course, students designed DVF experiments.	To help students explore the differences between the left and right cerebral hemispheres	Participants: 240 upper-level undergraduates, developed by neuroscientists	Program was introduced during a 2-week module in a large research methods course halfway into the semester, large weekly lecture (50 minutes), 2hr laboratory classes a week	Research reports, multiple-choice questionnaires about the lateralization of cognitive function, the anatomy of the brain, and the spatial frequency hypothesis to test student learning outcomes, pretest and posttest.	significant improvement in scores from pretest to posttest, students gained a new knowledge of brain anatomy and connectivity, project added to students' research skills

Title, First Author, Year, Journal	Program type	Program goals	Developers/ Participants	Program duration	Program measures	Program outcomes
The Open PicoAmp: an open-source planar lipid bilayer amplifier for hands- on learning of neuroscience (18) <i>PLOS ONE</i>	An open-source lipid bilayer amplifier was developed for use in neuroscience introductory courses.	Hands-on approach to learning neuroscience to teach about different electrical properties of the cell membrane.	Sessions coordinated by adjuncts instructors and older students that were trained. Study approved by Institutional Ethical Committee of the School of Medicine of the Université Libre de Bruxelles	It was about a 4-hour laboratory session. Usually, one group of two students is assigned per bilayer setup. To allow the session to run smoothly and maximize the interactions with the students, one instructor for two groups of students is an optimal configuration. Lab sessions at our institution are run with ten bilayer setups working simultaneously.	Program was studied by the adjuncts instructors and older students which have been previously trained.	In a typical four hours session, all students were able to obtain the lipid bilayer formation and study its electrical properties. Also, a majority of attendees could actually succeed to observe the single channel currents. This was a good performance, as it is a rather delicate experiment and for many students this was their first experience in such a laboratory environment.
Neurogaming Technology Meets Neuroscience Education: A Cost-Effective, Scalable, and Highly Portable Undergraduate Teaching Laboratory for Neuroscience (12) <i>The</i> <i>Journal of Undergraduate</i> <i>Neuroscience Education</i> ( <i>JUNE</i> )	A teaching lab with equipment to incorporate into an introductory neuroscience curriculum. The devices used to EEG machines for the students to use as a research tool and enhance student's' introduction into neuroscience	Use cost-effective tools and implement a teaching lab to be able to expose students to laboratory/research experience	Participants: 268 undergraduates, but only 150 students fully completed the evaluation survey	EEG headsets and software were incorporated to students' lab sessions over the course of their semester, with each lab session about 1-hour long	Students took in- class surveys with a 5-point Likert scale with responses consolidated into three findings: enjoyment, usefulness, and improvement on understanding; and their completed labs were looked into	Students have shown that the EEG-incorporated labs were enjoyable and increased their knowledge in neuroscience concepts and EEG, as well as provided them firsthand research experience.
Using A Contrast Illusion to Teach Principles of Neural Processing (13) <i>The Journal</i> of Undergraduate Neuroscience Education (JUNE)	an interactive laboratory exercise to challenge undergrads to use observational measurements of a visual contrast illusion to study neural activity	to understand the effectiveness of this active learning exercise in increasing student understanding of how perception is shaped by neural circuits in the retina	Developed by neuroscientists. Participants: 112 students.	Students conducted simple psychophysical experiments to measure thresholds for detecting illusory spots under various conditions and described their results in a laboratory assignment.	in a pre and post survey, students' confidence and practical understanding of 3 main concepts neural processing were evaluated on a Likert Scale.	students had significant improvements in content knowledge and increased confidence in ability to demonstrate understanding after the lab. students had overall positive attitudes towards the lab.

Title, First Author, Year, Journal	Program type	Program goals	Developers/ Participants	Program duration	Program measures	Program outcomes
Hands-on Undergraduate	Implementing	To determine whether	Participants: 13	Students utilized	Students reflected	Students felt more
Experiences Using Low-	EEG through	or not EEG can help	juniors and 13	EEG in classrooms	on their own EEG	motivated to work
Cost	MUSE headbands.	students learn better	seniors.	to see how the	data and filled out	on their current
Electroencephalography		about their brain		brain functioned	surveys to	tasks and projects
(EEG) Devices (17) The				while doing several	determine whether	due to the EEG.
Journal of Undergraduate				different brain	or not the	Many students
Neuroscience Education				exercises. This	implementation of	expressed
(JUNE)				consisted of trying	EEG had an effect	enthusiasm and
				new tastes and	on understanding	excitement for
				answering different	the brain.	learning more.
				questions.		Ũ
Signal: A	use of a board	game-based learning	Angel W. Kaur/ 36	participants were	After completing	80.5% (n=24)
Neurotransmission Board	game designed to	serves an effective and	students (38 played	undergraduate	the board game,	agreed or strongly
Game (14) The Journal of	test students'	engaging tool to	the game but 2 opted	students enrolled in	students asked to	agree (n=5) that the
Undergraduate Neuroscience	understanding of	review fundamentals	out)	"Fundamentals of	complete survey on	game helped them
Education (JUNE)	core concepts of	of neurotransmission		Neuroscience"	their impressions of	assess their
	core concepts	in science courses -		course; students	the exercise (rated	knowledge and
	covered in	allowed students to		played signal	their agreement to	understanding of
	introductory	develop skills and		during week 13 of	statements)	action potential and
	neuroscience	gained a greater		semester an in-class		83.3% (n=22) +
	courses - action	understanding of		activity in groups		(n=8) agreed that it
	potentials and	neuroscience		4-5 players -		helped their
	synaptic			carried out in 2		understanding of
	transmission			sections of course		synaptic
				in 1 semester		transmission. 30
						students agreed that
						it allowed to develop
						communication
						skills as they talked
						to their peers about
						scientific concepts

qualitative data from student feedback and overall completion of the modules or activities to measure program outcomes. Four programs (21, 24–26) were assessed with quantitative methods, evaluating students' recorded answers from pre- and post-surveys, questionnaires, and exams. Two programs (20, 23) used a mixed methods approach, with qualitative data from student feedback and quantitative data from Likert-scale ratings, completed lab reports, and a comparison of course performance with a control student group. All programs reported students having increased content knowledge and confidence in conveying this comprehension.

Of the six pipeline programs (4, 7, 11, 27–29) designed to expose undergraduate students to extracurricular research experience, four programs (11, 27–29) were assessed using qualitative methods, largely from student performance in the labs and feedback from working in a lab. Two programs (4, 7) were measured with mixed methods, assessing qualitative data from student impressions and feedback and quantitative data from survey responses. All programs concluded that participation in labs left students with positive impressions and enriched their experiences by gaining research exposure.

In the five pipeline programs (8–10, 12, 13) that involved interdisciplinary neuroscience courses, three programs (9, 12, 13) were measured with only quantitative methods, assessing students'

pre- and post-exam scores and numerical ratings from surveys or questionnaires. Two programs (8, 10) were measured with a mixed methods approach, with quantitative data from examination scores after course completion or numerical ratings from questionnaires and qualitative data from students' quality of portfolio work from the courses, written reflections, or verbal feedback and attitudes.

In the eight capstone-based programs (5, 30-36), six of these programs (5, 30, 33-36) were measured using a mixed methods approach, with quantitative data from numerical surveys, statistical analyses, or pre-and post-exam score comparisons, and qualitative data from students' verbal feedback or open-ended questionnaires. Two programs (31, 32) were measured with solely qualitative data, using anecdotal evidence or open-ended questionnaires.

# Discussion

Our systematic review introduced a diverse range of pipeline programs and experiences that can inspire undergraduate students to pursue a career in neuroscience or neurology. Ranging from collaborative projects to interdisciplinary approaches, all programs are intended to deliver neuroscience concepts and potential careers.

## TABLE 4 Multidisciplinary undergraduate courses.

Title, First Author, Year, Journal	Program type	Program goals	Developers/ Participants	Program duration	Program measures	Program outcomes
Neuroscience and Sustainability: An Online Module on "Environmental Neuroscience" (8) The Journal of Undergraduate Neuroscience Education (JUNE)	Neuroscience concepts were incorporated into a mid-level biopsychology course through an online "Environmental Neuroscience" module	To enhance students' understanding of neuroscience and how it can contribute to both sustainability efforts and other scientific disciplines (e.g.: environmental psych)	Created by university faculty in Dept. of Psychology, Program of Neuroscience at U St. Thomas. Participants: 26 students	The module was conducted over the course of the semester, with an "Environmental Stewardship Portfolio" due at the end of the term. Students wrote reflection papers based on five articles of their choosing, each due every 2–3 weeks. Most of the work was done outside of class, meaning the module did not take up class time.	Students' papers were given critiques for revisions, completed an anonymous evaluation of the module, and took a knowledge test with results compared to a control group (n = 27) of students who did not take the online module but the same course.	Students mostly showed significant increase in knowledge and awareness of neuroscience and how it connects to other disciplines of science, like environmental issues, and also scored higher than the control group on the knowledge assessment (median score of 67.8, SD of 16.9).
Integrating Brain Science into Health Studies: An Interdisciplinary Course in Contemplative Neuroscience and Yoga (9) The Journal of Undergraduate Neuroscience Education (JUNE)	Undergraduate health class combining contemplative neuroscience with yoga practice to introduce students who might otherwise avoid taking explicit neuroscience classes to elements of neuroscience in an integrative and accessible manner	Engage a broader student population in neuroscience learning, beyond those already interested in science, by relating neuroscience to health concepts through the interdisciplinary field of contemplative neuroscience	Developed by faculty/researchers at University of St. Thomas in MN; 80 students participated between fall 2012 and spring 2015 in sections of 10–16 students	Semester-long course that met for 1 h and 45 min once a week with ~50- 55 min of lecture/ discussion followed by yoga practice relevant to the contemplative neuroscience topics previously discussed; required readings were accessible to a lay audience; students were required to complete a weekly journal and one final exam	One cohort of 12 students was administered a 10- item multiple choice neuroscience pre/ posttest; at the end of the semester, students complete a course rating assessing their progress in course objectives on a Likert scale	Significant increase in scores on neuroscience knowledge posttest; average student course ratings indicated that students had more positive feelings about the field of neuroscience after taking the course
Reading the Brain: An Interdisciplinary First-Year Seminar on the Intersection of Neuroscience, Literature, and Popular Culture (10) <i>The Journal of</i> <i>Undergraduate</i> <i>Neuroscience</i> <i>Education (JUNE)</i>	interdisciplinary 1st-year seminar that is taught on the intersection of neuroscience, literature, films, plays and advertisement + ways that brain science can help people understand why and how we read taught by cognitive neuroscientist and literary scholar	to highlight benefit of using non-technical sources to introduce students to scientific concepts and value of teaching collaboratively across disciplinary boundaries. Engaging students in cross- disciplinary thinking and helping neuroscience students grasp difficult topics (achieve better learning outcomes)	Developed by neuroscience instructors. Participants: 32 students (for 2 years)	course was a part of first- year seminar program that is limited to small # of students. Course was taught in 2 subsequent academic years. Class met weekly for two 75-min periods. Used discussion format course was divided into 8 segments	<ul> <li>- assessed the degree</li> <li>to which the student's</li> <li>writing has improved</li> <li>over the semester</li> <li>(compared results on</li> <li>students' 1st</li> <li>analytical paper to</li> <li>performance on</li> <li>students' 2nd</li> <li>analytical paper),</li> <li>- assessed analytical</li> <li>paper over 3 metrics:</li> <li>literary analysis,</li> <li>brain literacy and</li> <li>interdisciplinary to</li> <li>see impact</li> <li>- administered mid-semester evaluation</li> <li>to assess degree of</li> <li>which the course was</li> <li>successfully</li> <li>implemented</li> <li>according to students</li> </ul>	students had positive view on course content and course interdisciplinary writing improved over the course and ability to make interdisciplinary connections in both class and written assignments. 68% (11) of students went on to declare majors, 11% of students declared minors in STEM disciplines

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Title, First Author, Year, Journal	Program type	Program goals	Developers/ Participants	Program duration	Program measures	Program outcomes
Drugs, the brain, and	2 semester upper-	expose students to	Participants: 240	run and taught by Ph.D.	students enrolled in	in the fall semester,
behavior: a graduate	level course that	neuroscience +	students in their	students in the	fall semester filled	students showed
student-run	employs an	knowledge in	second/third year,	Interdisciplinary program	out a questionnaire	significant
comprehensive course	interdisciplinary	neurological and	developed by	in Neuroscience at	after the midterm	improvement (21%) in
in neuroscience (12)	approach to	neuropsychiatric illness;	neuroscientists	Georgetown	(agreements with 9	raw scores between
The Journal of	normal and altered	promote scientific		University/24 students	statements of	the midterm and final
Undergraduate	nervous system	literacy in			proficiency in topics	examinations, all
Neuroscience	function; aimed	undergraduates and			taught) – asked to	students rated
Education (JUNE)	toward both	provide pedagogical			estimate agreement	themselves at a higher
	undergraduates	experience for PhD			prior to start of the	level in their
	and PhD students	students			course and at the	proficiency of the
					time of the midterm	topics taught
					compared final and	compared to the
					midterm exam scores	beginning of the
						course
Social neuroscience at	a new	to develop an effective	Participants: 15	traditional lecture-style	students were given a	students reported
the college of saint	undergraduate	team-taught course in	students,	course with seminar-style	anonymous	gaining a better
rose: the art of team	level course for	social neuroscience at	neuroscience	course combination,	questionnaire and	understanding of the
teaching in emerging	neuroscience that	the undergraduate level,	faculty at The	students were assigned	demographic survey	material through team
areas of psychological	merges psychology	provide undergraduate	College of Saint	readings from text and	at the end of the	teaching vs. single
science (13) The	and neuroscience	students with access to	Rose developed the	one student was deemed	course, two-tailed	teacher teaching,
Journal of		new, developing content	program	discussion leader for that	one sample t-tests	students reported
Undergraduate		merging social		text, three exams	used to analyze data	enjoying taking the
Neuroscience		psychology and		delivered throughout the		newly designed course
Education (JUNE)		neuroscience		term, students required to		
				develop research proposal		
				and present it to the class		

Programs that exhibited the greatest support in facilitating undergraduates' interest in neuroscience prioritized partnerships with other student populations and offered primary research experience.

Uniquely, involving undergraduates in teaching younger students proved to be valuable. Undergraduates could improve their presentation and communication skills by teaching younger children about neuroscience, and the younger students gain exposure to new concepts in neurology that may inspire them to explore the field in the future. Capstone projects and research opportunities allowed students to immerse themselves in first-hand research and develop their own curriculum, leaving them with a firmer grasp of learned skills and experiences they can build upon.

The continuation of these programs can enhance students' knowledge of neurology and career opportunities within the field. The integration of other disciplines was a unique aspect of neurology pipeline programs, which attracted students and enabled interactive learning. By incorporating these methods into existing curricula, we can cultivate a diversified and knowledgeable group of students to pursue neurology-related specializations. It can also broaden opportunities for students who are uncertain about their career paths or are underrepresented in these areas of study.

Another relevant consideration from this systematic review is the effects of the COVID-19 pandemic on attracting undergraduates into the field of neurology, as well as the delivery and availability of pipeline programs. As a result of the pandemic, undergraduates may feel anxious or uncertain about future careers, employment prospects, and continuing education. In a recent survey regarding the future of neurological practice post-pandemic, neurology residents expressed concern about the significant proportion of patients forced to postpone appointments, a lack of training in emergency response, and the need to adapt to teleneurology (4). Undergraduates already involved in patient care or neurology research during the pandemic may develop similar concerns about pursuing a neurology career. At the same time, those just learning about the field may be discouraged from getting involved with pipeline programs. Furthermore, the pandemic has had an impact on the delivery and availability of neurology pipeline programs. A systemic review of neurology training programs during the pandemic indicated a change in clinical routine for neurology residents, reduced research activities, and delivery of education via online services rather than in-person (11). Yet, many neurology residents reported having sufficient facilities to continue neurology research remotely. This offers a mixed outlook on pipeline programs during and post-pandemic. On the one hand, there may be limited access to in-person and clinical activities for undergraduate students. On the other hand, they may have increased access to virtual opportunities for research that may not have been available before. Even if virtual neurology pipeline programs are more available, that does not mean that all undergraduates will have equal financial opportunity or time to participate (11).

# TABLE 5 Research opportunity programs.

Title, First Author, Year,	Program type	Program goals	Developers/ Participants	Program duration	Program measures	Program outcomes
Journal						
Evaluation of an	neuroscience	*Expose undergraduate	Members at the	throughout the	annual end of	participation in this
undergraduate	summer research	students to various	University of Kentucky,	summer in 5 different	summer survey	program may have
neuroscience research	experience	graduate careers, inform	department of Anatomy	components - 1.		strengthened students'
program at the		them of neuroscience	and Neurobiology,	neuroscience course,		applications to graduate
University of		opportunities, increase	Participants: 10 selected	2. independent		schools, high satisfaction
Kentucky (7) The		URM students, give	from applicant pool	research projects, 3.		with the material students
Journal of		them research project of	every - which is about 50	lunchtime seminars,		were exposed to,
Undergraduate		their own	students, overall, 80	4. summer		successfully increased URM
Neuroscience			students	symposium, 5. oral		in neuroscience research,
Education (JUNE)				presentations at the		participation in program
				end of the summer		increases chances students
						will apply to graduate
						school
Partnerships in	Neuroscience	Goal is to provide	Participants: 35 total	An intern would then	Program studied	Many stayed consistent with
Neuroscience	internship	students in smaller	interns have completed	work 8–12 h/week	based on student	where they wanted to go
Research Between	program for	colleges a program	this program and went	during the school	performance and	versus where they ended up,
Small Colleges and	students (ideally	within a larger	onto graduate programs;	year, but then increase	completion of the	specifically with doctoral
Large Institutions: A	2nd or 3rd years)	institution with	25 responded to a survey	their workload to full	program. Survey	programs (i.e.: medical
Case Study (4) The	at Stonehill	resources to enrich their	done by the authors	time for 10 weeks	was done	school) with ~13. Many
Journal of	College to	curricula and		(35 h/week) during	comparing the	more students actually went
Undergraduate	participate in	extracurricular		the summer typically	interns' initial	into research with masters
Neuroscience	either the Basic	experience; helps to give		through the Stonehill	goals once leaving	or PhD, with not many
Education (JUNE)	Research or	students an experience		Undergraduate	the program versus	having that as an initial goal
	Clinical Research	they can utilize when		Research Experience	actual outcomes	(2-3 responded as a goal,
	division of the	applying to graduate			on where they are	8-10 responded as an
	Laboratory of	programs			after college. Also	outcome)
	Neuroscience in				largely studied on	
	the Department of				student feedback	
	Psychiatry, at				and impressions	
	Harvard Medical					
	School					
Integrating Research	This article	To figure out different	N/A	Studied different	Program was	Found that it is beneficial to
into the	expands upon the	benefits and challenges		articles and	studied based on	support students as they
Undergraduate	information	of implementing		information from	how students from	discover science, grow in
Curriculum: 1. Early	presented in	research in the		workshops to sort out	different	confidence and competence,
Research Experiences	workshop	undergrad experience		details of what is	backgrounds	and move toward a future
and Training (27) The	discussions,			beneficial or not for	(experienced or	that will be well served by a
Journal of	focusing on ways			students.	non-experienced)	diverse group of thoughtful,
Undergraduate	to promote early				were able to	curious, well-prepared
Neuroscience	research				perform in their	individuals as they are able
Education (JUNE)	opportunities.				research.	to enter the workforce.
Integrating Research	This article	To figure out different	N/A	Studied different	Program was	Found that it is beneficial to
into the	expands upon the	benefits and challenges		articles and	studied based on	support students as they
Undergraduate	information	of implementing		information from	how students from	discover science, grow in
Curriculum: 3.	presented in	research in the		workshops to sort out	different	confidence and competence,
Research Training in	workshop	undergrad experience		details of what is	backgrounds	and move toward a future
the Upper-level	discussions,			beneficial or not for	(experienced or	that will be well served by a
Neuroscience	focusing on ways			students.	non-experienced)	diverse group of thoughtful,
Curriculum (28) The	to promote early				were able to	curious, well-prepared
Journal of	research				perform in their	individuals as they are able
Undergraduate	opportunities.				research.	to enter the workforce.
Neuroscience						
Education (JUNE)						

Title, First Author, Year, Journal	Program type	Program goals	Developers/ Participants	Program duration	Program measures	Program outcomes
Building the	Article studies	This article discusses	Program was developed	Various different	Various different	We incorporated
Neurology Pipeline	different logistics,	how working with	by Dr. Minen, and a	articles and data	articles and data	undergraduate student
with Undergraduate	potential benefits	undergraduate students	group of undergraduate	collected from	collected from	perspectives regarding the
Students in Research	and challenges on	represents a unique	students that were able to	previous research was	previous research	impact of their experiences
and Clinical Practice	implementing	opportunity to expose	access through different	studied to determine	was studied to	on their personal and
(29) American	undergrad	students to neurology	articles in order to	the different	determine the	professional lives. In total,
Academy of Neurology	neuroscience	through research and	accumulate enough data	implications of	different	we received reflections
	clinical research.	clinical care while also	to reason that clinical	clinical neuroscience.	implications of	(n = 32), emails $(n = 4)$ ,
		generating many	neurology is important.		clinical	applications for
		beneficial experiences			neuroscience.	opportunities ( $n = 7$ ), and a
		for the student and the				program feedback survey
		neurologist. We outline				(n = 1). In a process
		potential benefits, and				considered exempt by the
		logistical considerations,				Wake Forest Baptist
		involved in working				Institutional Review Board,
		with undergraduates.				we qualitatively analyzed
						these data into themes with
						representative examples to
						best understand each
						theme.
Understanding How	Focused on input	In order to seek how to	Program was developed	study was comprised	results from an	Qualitative results include
to Strengthen the	from undergrad	implement more	by Dr. Minen and	of 1,085	anonymous cross-	student perspectives from
Neurology Pipeline	students on their	neuroscience into	undergrad students to	undergraduates in	sectional online	those who did and did not
With Insights From	experiences with	classrooms based on	help improve pipeline.	either neuroscience	survey were	work with a neurologist,
Undergraduate	neuroscience. The	undergrad student		courses or majoring/	studied	describing how they were or
Neuroscience	survey	experience with science/		minoring in		were not able to obtain such
Students (11)	quantitatively and	neuroscience.		neuroscience from		opportunities. We discuss
American Academy of	qualitatively			across the		translating the survey
Neurology	assessed students'			United States to better		findings into actionable
	clinical neurology			understand their		results with opportunities to
	exposure, research			clinical neurology		target the undergraduate
	experiences, and			experiences and		neuroscience interest to
	career goals.			perspectives.		improve the neurology
						pipeline

# Limitations

The screening process of this systematic review has resulted in the exclusion of multiple articles that presented promising pipeline programs designed for an undergraduate audience due to a lack of implementation or no measurable/irrelevant outcomes. Of those implemented, some programs were excluded from this systematic review as they were not designed to inspire students to explore neurology but to teach general skills, such as reading scientific journals, enacting collaboration, or simply passing a class.

Of the programs studied, a significant limitation was the extent to which undergraduate encouragement into neurology was achieved. Most programs were short-term; therefore, no insight was provided after program completion into how these students went on to strengthen their interests. Longitudinal investigations could provide deeper insight into whether these programs do play a transformative role in students' career preparation or decision to pursue neurology. However, this raises significant challenges due to numerous reasons. In the time between students' participation in an early-exposure pipeline program and their ultimate career choice, they may undergo various educational and/or personal experiences that may ultimately shape their decision, whether in or out of neurology, making it harder to gage the success of a particular program. Data collection on the long-term career trajectories of program participants can also be logistically challenging. It often requires sustained tracking efforts, which may not be feasible for all pipeline programs, especially those with limited resources. Also, due to the duration these programs can entail, students may face attrition in wanting to continue participating beyond a program's formal conclusion.

Another drawback to these programs is the geographical accessibility to certain neurology pipeline programs. Limited access to neurology pipeline programs may be especially prevalent in more rural or underserved areas, of which underrepresented students may reside as well, ultimately impacting program representation and participation. Additionally, some programs may be limited in their funding or resources available to extend to a broader student population and thus, provide them with enriching opportunities. These caveats in geographical and resource inaccessibility should

## TABLE 6 Extracurricular Programs.

Title, First Author, Year, Journal	Program type	Program Goals	Developers/ Participants	Program duration	Program measures	Program outcomes
Everyday Neuroscience: A Community Engagement Course (30), The Journal of Undergraduate Neuroscience Education (JUNE)	service-learning course "Everyday Neuroscience" in which undergraduate students developed 10 neuroscience- relevant for under- resourced high school students; students rand these lab activities with small groups of high-school students	engage interest in neuroscience in the high schoolers; undergraduates increase their awareness of social disparities; improve communication skills in conveying neuroscience principles to a non- specialist audience *	collaboration with faculty of university + teacher and admin of nearby high school/43–44 undergraduate students	undergrad students assigned to 1 of 5 team, all teams charged with developing lesson plans for 2 hands-on activities; 10 visits to the high school	undergraduates were asked to write 4 1-page reflections to link community engagement experiences with students' personal growth + survey at the beginning and end of the about their impressions, what contributed to their learning, what was most interesting and what skills were developed	Compared to the beginning of the course (77%) at the end, 88% of students thought they had something important to contribute to society. For psychological well-being, there was no change in the frequency for students feeling challenged to grow. Attitudes toward teaching and feeling confident to expression their ideas were more positive at the end of the course (77% v 96% p < 0.05)
Strategies for the Introduction of Neuroscience for Underrepresented University Students (5) <i>Journal of College</i> <i>Science Teaching</i>	series of learning experiences during Brain Awareness Week to increase interest in the field of neuroscience	*To encourage URM students to specialize in the neuroscience field by increasing their knowledge of the neuroscience field	Participants: 12,893 registered for BAW, 250 students counted in attendance at academic conferences, developed by members at The University of Puerto Rico (URM)	Series of four activities – 1. Brain games, 2. Learning activities, 3. Academic conferences, 4. A research poster session during Brain Awareness Week	qualitatively and quantitatively and quantitatively: Likert-scale survey, open-ended questionnaires, Spanish-English bilingual questionnaire	students highly rated presentations on stroke rehabilitation and fMRI in neuroscience, 100% students who responded to open ended questions thought the conference was meaningful, increased knowledge about research techniques
A proposal for undergraduate students' inclusion in brain awareness week: promoting interest in curricular neuroscience components (31) <i>The</i> <i>Journal of</i> <i>Undergraduate</i> <i>Neuroscience Education</i> <i>(JUNE)</i>	proposal for the Brain Awareness Week to be a neurophysiology teaching strategy to include undergraduate physiology students in the organization and presentation of BAW events	use Brain Awareness Week (BAW) to increase interest in neuroscience and physiology	Participants: 300 undergraduate and graduate students, physiology focused researchers developed the proposal	BAW lasted for a week	questionnaire given to students to assess if involvement in BAW activities increased their interest in physiology/ neuroscience	90% of physiology students said the BAW activities increased their interest in physiology and neuroscience
Introducing high school students to neurophysiology (32) Advances in Physiology Education	undergrads present physiology research projects to high school seniors	Developed by graduate student volunteers and physiology undergrads. Participants: ~100 high school students each year, unspecified number of undergrads (>100 per year).	Participants: 240 students in their second/third year, developed by neuroscientists	Neurophysiology lab, undergrads conduct an experiment over three weeks and present to high school seniors at a 3-h event. All students have the opportunity to both present and hear their classmates present. High schoolers receive a basic pre-lab tutorial to learn basic physiology concept and then ask questions during presentations. The event takes place over	students gave comments on their experiences anecdotally	Quantitative analysis from student comments: high school students claim to become very excited about physiology and leave the campus with a greater feeling of confidence in their ability to succeed in university science. Undergrad presenters feel inspired and appreciate the ability to showcase their work.

Title, First Author, Year, Journal	Program type	Program Goals	Developers/ Participants	Program duration	Program measures	Program outcomes
Neuroscience Workshops for Fifth- Grade School Children by Undergraduate Students: A University- School Partnership (33) <i>CBE - Life Sciences</i> <i>Education</i>	University-school partnership: scientist-in-the- classroom visits from undergrads to elementary students on brain structure, disorders, perception. Undergrads develop and implement a fieldwork study.	undergrads learn how to conduct field research using an inquiry-based approach and elementary students learn basic neuroscience concepts	Developed by undergrads. Participants: 99 elementary school students, 8 undergraduate students	As part of a senior seminar course, undergrad psychology students developed a research study to deliver workshops to elementary students and evaluate effectiveness of their teaching. Undergrads created and practiced lessons over the course of 15 weeks, and delivered a single 1-h neuroscience lesson to elementary school students.	pre- and post-test developed by undergrads delivered one week before and after visit testing elementary student's knowledge of neuroscience concepts. Undergrads evaluated their experience with Likert scale and open-ended	Mixed ANOVA showed workshops improved the children's knowledge of neuroscience concepts; qualitative analysis of open-ended questions by undergraduates showed they also found their learning experience engaging and productive
Teaching about the brain and reaching the community: undergraduates in the pipeline neuroscience program at the university of Pennsylvania (34) <i>The</i> <i>Journal of</i> <i>Undergraduate</i> <i>Neuroscience Education</i> ( <i>JUNE</i> )	Called the Pipeline Neuroscience Program, this is an educational outreach and mentorship program where undergraduate students teach neuroscience concepts to high school students	This pipeline program mutually serves benefit to the high school students who are being taught neuroscience concepts and career options by undergraduate students, as well as the undergrads who are taught and guided by medical students and neurology residents	Developed at University of Pennsylvania School of Medicine; participants: 8 undergraduates, around 26 high school students*	Program was a semester long on a weekly basis, with classes about 90 min long. Upper and lower- level medical students took turns in delivering the lessons, and undergraduates were teaching assistants (TAs) to the high school class and held small group activities.	questions. Students provided informal feedback to their program coordinators; some were selected to take videotaped exit interviews recounting their experiences. Undergraduates were also tested on their knowledge from their seniors from pre- and post-program quizzes. 2007 also introduced a longitudinal evaluation of the students' college matriculation into neuroscience careers.	Overall feedback from the high schools, undergraduate TAs, medical students, and residents, have been positive with the goals and outcomes of the pipeline program. Many expressed the program increased knowledge of neuroscience, positive impacted on mastery of material, and influence on career goals or plans for a medical subspecialty.
Bridge to neuroscience workshop: An effective educational tool to introduce principles of neuroscience to Hispanics students (35) <i>PLOS ONE</i>	full-day hands-on workshop in neuroscience education	to identify promising students for the Bridge to the PhD in Neuroscience Program, to increase awareness of neuroscience as a discipline and a career option	Participants: 200 high school students and 424 undergraduate students overall, each session has about 30 students, developed by 9 graduate students at Michigan State University	*Targeted URM, one-full day workshop, 4 sessions in the workshop	pre and post evaluations, feedback forms	participation in the workshop increases understanding and enthusiasm for neuroscience as a field, high schoolers had more incorrect answers on the pretest than undergraduate students did, mean percentage of correctly answered questions increased for both high school and undergraduates in the posttest

Title, First Author, Year, Journal	Program type	Program Goals	Developers/ Participants	Program duration	Program measures	Program outcomes
A Capstone Course	neuroscience	For undergrads to	Program course	as part of a semester-long	Undergrads rated	Over 3 years, course ratings
Where Students Present	capstone course	apply their	developed by	senior course, undergrads	the capstone course	averaged 3.87, 4.45, and
Contemporary	where students	neuroscience	neuroscientist/	developed a research	in a course	4.61 with a positive trend.
Neuroscience Research	choose and study	knowledge and	professor;	project by reading	evaluation	Anecdotally, undergrads
to High School Students	contemporary	communication	presentations	through scientific	quantitatively and	find it a meaningful
(36) The Journal of	neuroscience	skills. High	developed by	literature. Undergrads	qualitatively with	culminating experience of
Undergraduate	research articles in	schoolers also	undergrads.	adapted presentations for	open ended	their undergraduate
Neuroscience Education	depth and then	benefit from	Participants: over	their high school	questions and 1-10	neuroscience education
(JUNE)	present them to high	presentations.	three years, number	audience in the form of	ratings. High	
	school students in		of undergrad students	posters or videos.	schoolers were not	
	short videos		varied each year	Presentation was an hour	evaluated.	
			between 10-15. 1	long.		
			high school class each			
			year.			

be addressed toward efforts in the improvement of neurology pipeline programs and their overall effectiveness.

# **Future directions**

Future research is necessary to investigate interactions between mixed student populations and how this can help further deepen undergraduates' interests in neurology. While this review discussed programs including students outside of undergraduates, they highlighted the benefit in fostering engagement and encouragement to undergraduates. Collaboration between trainees at different educational levels can provide a better scope on the effects of the neurology pipeline by facilitating undergraduate student interest in neurology, and thus provide a wider view of programs' benefits. Emphasizing the importance of mentorship and networking between undergraduate trainees and physicians or graduate students can be integral in facilitating students' interest and pursuit of neurology. Programs should work to actively connect students to neurology professionals and establish these bonds so that they can help guide students throughout their academic and professional careers (5). Current strategies in tracking the efficacy of neurology pipeline programs, from progress tracking, student feedback collection, and long-term impact assessments, can also shed insight into how students feel more assured in their academic and career choices if augmented with this developed connection and resource of a neurology professional with which they can turn to for guidance. Overall, these programs can be expanded to include programs specifically designed for undergraduates' professional readiness in neurology, with mentorship and personal connections sustaining their interest and building relevant knowledge and skills for the workforce.

More importantly, future programs should target the inclusion of underrepresented minorities, as only 15% of programs in this review did so. Diversification within neurology not only introduces unique perspectives and problem-solving skills but also improves the workforce of practicing neurologists and promotes broader undergraduate interest, diminishing the gap within the workforce (6). To improve in fostering diversity and inclusion of underrepresented undergraduate students in neurology pipeline programs, programs should actively prioritize the recruitment of students from underrepresented backgrounds and advocate for the support and guidance of these students into neurology-related careers, thus contributing to a more inclusive and representative workforce, with people bringing to the table a wide array of expertise and unique talents that benefits the field as a whole.

To address the challenges posed by geographical and funding or institutional limitations, we must consider innovative approaches to improving neurology pipeline programs. As shown through some program outlines in this study, designing interdisciplinary programs that integrate neurology with other fields of student interests, such as psychology, art, or technology, can provide students with a more comprehensive view of neurology and its applications, but more importantly, it allows smaller institutions to implement programs still relevant to neurology, and utilize available resources to garner a broader student population (9). These institutions can also conduct collaborative efforts with local community colleges or high schools in designing pipeline programs that not only sustain undergraduates' interests in neurology but also identify and encourage younger students' excitement about neurology, broadening the reach of these programs and diminishing geographical disparities. Furthermore, embracing a hybrid or remote format for existing or prospective programs, as we have seen from the COVID-19 pandemic, also improves accessibility for students who may be unable to attend in person and even participate in programs that may not be offered at their institution (4). In closing, the need to improve undergraduatetargeted neurology pipeline programs lies not only in the recognition and mitigation of these discussed limitations but also in the pivotal role these programs can play in shaping a dynamic and equitable future for the field of neurology, driven by the talent and diversity of the next generation of neurologists.

# Data availability statement

The original contributions presented in the study are included in the article/supplementary materials, further inquiries can be directed to the corresponding author.

# Author contributions

MM: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Project administration, Resources, Supervision, Validation, Writing - original draft, Writing review & editing. RA: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Writing - original draft, Writing - review & editing. IY: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Writing - original draft, Writing - review & editing. KO: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Writing - original draft, Writing - review & editing. JE: Data curation, Formal analysis, Investigation, Methodology, Writing - original draft, Writing - review & editing. AK: Data curation, Formal analysis, Investigation, Writing - original draft, Writing - review & editing. NL: Data curation, Formal analysis, Investigation, Writing - original draft, Writing - review & editing. CP: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Project administration, Resources, Software, Supervision, Validation, Writing - review & editing.

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# Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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# Supplementary material

The Supplementary material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fmed.2023.1281620/ full#supplementary-material

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