ARTICLE
Interactive Notebooks Improve Students' Understanding of Developmental Neurobiology, Attitudes Toward Research, and Experimental Design Competency in a Lecture-Based Neuroscience Course

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https://doi.org/10.59390/NQCA2038

Recent efforts to engage postsecondary science, technology, engineering, and mathematics (STEM) students in the rigors of discovery-driven inquiry have centered on the integration of course-based undergraduate research experiences (CUREs) within the biology curricula. While this method of laboratory education is demonstrated to improve students' content knowledge, motivations, affect, and persistence in STEM, CUREs may present as cost- and/or resource-prohibitive. Likewise, not all lecture courses have a concomitant laboratory requirement. With these caveats in mind, we developed the *NeuroNotebook* intervention, which provided students enrolled in a standalone Developmental Neurobiology course with an immersive, semester-long "dry-lab" experience incorporating many of the same elements as a CURE (e.g., collaboration, use of experimental design skills, troubleshooting, and science communication). Quantitative and qualitative assessment of this intervention revealed positive pre-/post-semester gains in students' content knowledge, attitudes toward the research process, and development of science process skills. Collectively, these data suggest that interventions such as the *NeuroNotebook* can be an effective alternative to a "wet-lab" experience.

Key words: Developmental Neurobiology; Project-based Learning; Experimental Design; Science Process Skills; Undergraduate Research Experience; Laboratory Notebook

National efforts to advance undergraduate science, technology, engineering, and mathematics (STEM) education have long emphasized the importance of engaging students in authentic practices inherent of those disciplines (National Research Council [NRC], 2003; American Association for the Advancement of Science [AAAS], 2011). Historically, this has occurred largely through immersion of students in faculty-mentored, apprenticeship-style undergraduate research experiences (UREs). While these experiences are important for student development, previous studies demonstrate that UREs are often only accessible to high-achieving students or those students who are confident in seeking out faculty mentors (Rodenbusch et al., 2016; National Academies of Sciences, Engineering, and Medicine [NASEM], 2017).

Recently, course-based undergraduate research experiences (CUREs) have emerged as an inclusive mechanism to involve undergraduates in research at scale (Auchincloss et al., 2014; Bangera and Brownell, 2014). Within CUREs, students are prompted to develop their own research questions, analyze the resultant data, and communicate their findings—practices that have been shown to positively impact their knowledge, affect, and psychosocial growth at levels comparable to UREs (Jordan et al., 2014; Olimpo et al., 2016; Esparza et al., 2020; Ing et al., 2021; Donegan et al., 2022; Smith et al., 2022).

Despite these promising outcomes, it is arguably infeasible for all institutions to adopt CUREs, as such curricula are time- and resource-intensive (Shortlidge et al., 2016; Shortlidge et al., 2017). Likewise, it cannot be assumed that all lecture courses have an associated laboratory course—a phenomenon attributable to a variety of causes ranging from time and resource needs to scheduling and course enrollment constraints (Cawley, 1992; Matz et al., 2012). Consequently, innovative alternatives must be deployed to immerse students in equivalent learning processes and experiences.

Regardless of the pedagogical approach, the literature clearly demonstrates that adoption of student-centered, active learning strategies (e.g., case studies, roleplay, think-pair-share) is essential in promoting student success, interest, and retention (Olimpo and Esparza, 2020). In their meta-analysis of the active learning literature in STEM, Freeman and colleagues (2014) note, for instance, that undergraduates' exam scores were observed to increase an average of half a letter grade under active learning conditions. Further, students in course sections employing active learning strategies were 1.5 times less likely to fail than students enrolled in classes with traditional lecturing.

In this article, we describe a novel, semester-long project – referred to as the *NeuroNotebook* – that aims to address the need for inquiry-driven exercises in standalone lecture environments while simultaneously promoting many of the same outcomes described in the CUREs and active learning knowledge base. Specifically, our research was guided by the following central question:

What impact does participation in the NeuroNotebook *project have on students' development of disciplinary content knowledge, experimental design skills, and attitudes toward research?*

We anticipated that gains in content knowledge and experimental design skills would be observed given previously reported outcomes in the literature with respect to student engagement in interactive neurobiology activities (e.g., Zwick, 2018). Similarly, we anticipated that students would self-report positive attitudes toward research following participation in the project due to the collaborative and hands-on nature of the *NeuroNotebook*.

MATERIALS AND METHODS

Participant Sampling and Recruitment Procedures

Participants represented a sample of convenience consisting of individuals (N = 44) enrolled in a cross-listed (i.e., undergraduate- and graduate-level) Developmental Neurobiology course at a research-intensive, Hispanic-Serving Institution in the Fall 2018 and Fall 2021 semesters. No other inclusion or exclusion criteria were employed in this study. Participants primarily self-identified as women (n = 30; 68.19% of respondents) and Hispanic/Latin@ (n = 36; 81.81% of respondents), with the majority of those individuals (n = 39; 88.64%) majoring in the biological sciences. Furthermore, most participants self-identified as undergraduates, with nearly half of all individuals reporting no prior research experience (see Table 1 for a comprehensive summary of participants' demographic information). This study was classified as exempt by The University of Texas at El Paso's Institutional Review Board and approved under protocol #1253605.

Course Context

Developmental Neurobiology is a three-credit, lecture-based course that meets twice weekly for 80 minutes each session. Students entering the course are required to have completed the two-semester introductory biology sequence (i.e., a survey course on cell/molecular biology and a second survey course on organismal biology) offered at our institution (or the equivalent). Minimal, if any, pre-requisite knowledge in the field of neurobiology is assumed.

Accordingly, there is substantial breadth in the learning goals and objectives for the course, which range from students developing an understanding of the basic structures of the nervous system to the ability of students to describe the signaling pathways that influence neuronal differentiation and axon guidance (see Supplemental Materials 1 for the course syllabus). With the exception of group projects – including the *NeuroNotebook* intervention described below – these objectives are assessed using summative measures (e.g., exams, quizzes).

Structure of the *NeuroNotebook* Intervention

Building upon the research expertise of the instructor (A.Q., a developmental neurobiologist and geneticist specializing in the use of zebrafish models to study multiple congenital anomalies), the *NeuroNotebook* intervention was structured around a case study involving a patient with a congenital disorder leading to defects in neural development. Working in teams of six or seven, students were prompted to: (a) describe the cellular and molecular mechanisms necessary for normal neural development, (b) generate a hypothesis regarding those factors likely contributing to the defects documented in the case study, (c) design an experiment to address that hypothesis, and (d) provide an interpretation of anticipated outcomes in a manner accessible for both lay and scientific audiences. Each of these foci constituted a single entry in the notebook, and student teams were provided with at least one week of in-class time to complete each entry before submitting it to the instructor. Scaffolding activities, notebook prompts, and associated grading rubrics can be found in Supplemental Materials 1 and 2.

Category	% Participants (n)
Gender Identity	
Man	31.81% (14)
Woman	68.19% (30)
Non-Binary	0.00% (0)
Race and/or Ethnicity	
White	9.10% (4)
Black/African American	2.27% (1)
Hispanic/Latin@	81.81% (36)
Asian	0.00% (0)
Multiracial or Multiethnic	6.82% (3)
Student Status	
Undergraduate	75.00% (33)
Graduate	22.73% (10)
Not Reported	2.27% (1)
Generational Status	
First-Generation	45.45% (20)
Continuing-Generation	54.55% (24)
College Major	
Biological Sciences	88.64% (39)
Other Science	6.82% (3)
Engineering or Math	2.27% (1)
Psychology	2.27% (1)
Other	0.00% (0)
Prior Research Experience	
No Prior Experience	45.45% (20)
Prior Experience	52.28% (23)
Not Reported	2.27% (1)

Table 1. Participant demographic characteristics. Note that the demography of the Fall 2018 and Fall 2021 cohorts was not substantially different; hence, data were aggregated. Note also that first-generation status indicates an individual who is the first in their family to attend college, and prior experience conducting either wet-bench or field research was self-reported by participants.

Engaging Students in Collaborative Work

As indicated earlier in this article, the *NeuroNotebook* intervention necessitated that students work cooperatively in teams to achieve all assignment objectives. This structuring was intentional given previous empirical evidence that suggests an important role for collaborative groupwork in promoting student learning gains, affect, and professional dispositions (Tanner et al., 2003; Johnson et al., 2014; Kagan, 2014). Specifically, each team consisted of both undergraduate and graduate students (ideally, five undergraduates and two graduate students), where the role of the graduate students was to oversee and facilitate group discussion. These groups remained fixed over the course of the semester to minimize the potential confusion associated with switching to a new team with a new investigatory approach. For each of the four *NeuroNotebook* prompts, groups met to discuss their initial thoughts and approaches prior to submission of the corresponding assignment. Importantly, these assignments were submitted individually and received individual grades, rather than a group submission/grade, as the intent was for each student to demonstrate the ability to synthesize discussions/course content in a logical manner, in alignment with the course goals and objectives (see Supplemental Materials 1).

Assessment of Student Outcomes

Developmental Neurobiology Assessment (DNA)

To evaluate the impact of the course on students' understanding of developmental neurobiology content, a 10-item quiz, referred to hereafter as the Developmental Neurobiology Assessment (DNA), was created in house by A.Q. Iterative revisions were made to increase the clarity of individual questions following consultation with N.G.R-N., D.E., and J.T.O. until a final version of the assessment was approved by all parties (see Supplemental Materials 3). Student responses on the DNA were first scored as either correct ('1') or incorrect ('0') and a composite score created prior to analysis of pre-/post-semester shifts in average student performance using a paired *t*-test approach (SPSS v.27, IBM).

Scientific Process Flowchart Assessment (SPFA)

Given that the overarching foci of the *NeuroNotebook* intervention were experimentation and the implications of scientific research, we employed the SPFA (Wilson and Rigakos, 2016) to assess the impact of the semester-long activity on students' scientific process skills development. Specifically, the SPFA prompts students to construct a visual representation of (a) the steps involved in the scientific process; (b) factors that contribute to making a "good" experiment; (c) why science is done; and (d) the factors that influence science and that, in turn, science itself influences.

Pre-/post-semester responses obtained from consenting participants were first blinded to reduce researcher bias. These responses were then scored using the rubric criteria published alongside the instrument, with one exception—an *a priori* decision was made to exclude the "Connections" criterion, as previous use of the SPFA indicated to us that lines/arrows could be drawn by students without any meaningful intent (e.g., students drawing arrows to connect every term to every other term without any description of the relationship between the connected terms). Note that, for all other rubric dimensions, an **item score** (total number of items) and **rating score** (naïve to expert) were tabulated, unless otherwise noted by the rubric.

Two researchers (N.G.R-N. and J.T.O.) with expertise in either neurobiology or biology education randomly selected and scored 50% of all participant responses, with the same subset of responses being scored by both researchers and with equal representation of responses across timepoints and semesters. Strong interrater reliability (Krippendorf's $\alpha = 0.980$; 95% CI [0.963, 0.993]) was observed. All remaining submissions were coded by J.T.O. Disputes that arose during the coding process were resolved through conversation with a third researcher (V.S.) until consensus was achieved.

Developmental Neurobiology Student Assessment of Learning Gains (DN-SALG) Survey

As a complement to the cognitive measures cited above, we created a 20-item student assessment of learning gains survey (hereafter referred to as the DN-SALG) that was designed to investigate potential pre-/post-semester shifts in student affect in three areas: 1) understanding of and attitudes toward developmental neurobiology, 2) confidence in engaging in the experimental design process, and 3) confidence in communicating developmental neurobiology concepts both orally and through written work. Survey items were adapted from Zwick (2018), Brownell et al. (2012), and Weston and Laursen (2015) and were subjected to face validation (Elliott and Timulak, 2021) by neuroscience/biology education experts ($N = 2$) and students ($N = 3$) external to this research prior to their inclusion in the assessment.

Student responses were recorded on a five-point Likert scale ('1' = strongly disagree, '5' = strongly agree), which were entered verbatim into SPSS (v.27, IBM). Paired *t*-tests with Bonferroni correction were subsequently performed to identify statistically significant shifts in student affect across the aforementioned areas.

One additional open-ended item was included on the post-semester DN-SALG: *In what ways did completion of the Notebook Project this semester impact your understanding of the research process (i.e., what it means to do research and what is involved in doing research)?*. Student responses to this item were first blinded and then inductively coded by two researchers with expertise in biology education or neuroscience (J.T.O. and N.G.R-N.) to identify emergent themes in the dataset (Elliott and Timulak, 2021). Strong interrater reliability was observed ($\kappa = 0.902$; 95% CI [0.848, 0.956]), with all disputes resolved through discussion between the two raters during the consensus coding phase.

RESULTS

Course Participation Increases Students' Disciplinary Knowledge

Given the variability in lecture format (i.e., face-to-face vs. hybrid) observed between the first and second semesters in which the Developmental Neurobiology course was offered, an *a priori* decision was made to stratify data concerning participants' content knowledge by term. Paired *t*-test comparisons of students' pre-/post-semester responses on the DNA revealed a statistically significant increase in performance for students enrolled during the Fall 2018 semester ($t(23) = 3.00$; $p = 0.006$; Cohen's $d = 0.620$, following adjustment for paired data). A similar shift in performance was not observed for the Fall 2021 cohort

($t(19) = 0.191$; $p = 0.850$).

Students Develop More Sophisticated Views of the Scientific Process Following the *NeuroNotebook* Intervention

Comparison of participants' pre-/post-semester responses on the SPFA revealed a statistically significant increase in the number of items used and rating assigned for the Experimental Design category of the rubric (Table 2). *A posteriori* analyses indicated that the increase in items was predominantly confined to the "general terms" (e.g., question, hypothesis, experiment) dimension of the category. A significant pre-/post-semester increase in the item count for the Nature of Science category of the rubric was likewise observed. Collectively, these factors contributed to statistically significant gains in participants' overall item count and rating.

Engagement in the *NeuroNotebook* Project Promotes Positive Student Affect Toward the Discipline and Enhances Students' Experimental Design and Science Communication Skills

Paired *t*-test analyses with Bonferroni correction were performed to assess for pre-/post-semester shifts in aggregated (i.e., Fall 2018 and Fall 2021) student responses on the DN-SALG survey with respect to three constructs: (a) understanding and application of developmental neurobiology concepts, (b) experimental design skills, and (c) science communication skills.

Results are summarized in Table 3 and suggest, first, that the *NeuroNotebook* intervention positively impacted students' perceived understanding of course content, including the applicability of that content to other areas of study. Relatedly, students reported increased confidence in their ability to engage in the experimental design process, with significant gains observed for items related to student confidence in generating hypotheses that address key questions in the field as well as in their ability to interpret experimental data. These observations corroborate those findings reported above regarding students' SPFA performance. Lastly, DN-SALG analyses indicated statistically significant gains in students' development of science communication skills, particularly their ability to describe concepts to diverse audiences.

The *NeuroNotebook* Intervention Positively Influences Students' Understanding of the Scientific Process

In addition to the closed-ended survey data described above, we sought to examine students' perceptions of the ways in which the *NeuroNotebook* intervention influenced their understanding of what it means to engage in the research process. Thematic analysis of open-ended responses provided by participants supported our earlier observations, namely that most students ($n = 34$; 77.27%) reported that they had experienced gains in experimental design competency, with a smaller percentage ($n = 10$; 22.73%) indicating improvement in their scientific literacy and critical thinking skills (Table 4).

Notably, although the intervention did not include any wet-lab experiences nor did students execute their proposed studies, a moderate number of participants ($n = 17$; 38.64%) stated that they developed a better appreciation for the iterative and time-intensive nature of the scientific research process.

For instance, one individual reported that "[the notebook project] allowed me to understand and appreciate the thought process and energy exerted [by] scientists. It allowed me to have a better understanding of the rigorous process and steps researchers must take to complete and even start a project." Relatedly, some students ($n = 4$; 9.10%) felt that the intervention was sufficient enough to confidently prepare them for "actual" (i.e., apprenticeship-style) research opportunities in the discipline. The complete list of themes and exemplar quotes for each theme can be found in Table 4.

DISCUSSION

Promoting student engagement through active learning pedagogies has been shown to foster growth in their knowledge, affect, and motivation in STEM—each of which has the potential to further impact retention in the disciplines (Freeman et al., 2014; Olimpo and Esparza, 2020). While active learning approaches can assume many forms (e.g., think-pair-share, case studies), one of the more recent advents has been the course-based undergraduate research experience (CURE), which seeks to immerse students in identifying their own research questions to iteratively pursue, working collaboratively with their peers, and communicating their findings beyond the boundaries of the classroom (Auchincloss et al., 2014). Yet, while CUREs are argued to be an inclusive means to involve undergraduates in research (Bangera and Brownell, 2014), it is ostensibly infeasible for all institutions to deploy CUREs due to financial, time, and resource limitations (Shortlidge et al., 2016; Shortlidge et al., 2017). Further, it cannot be assumed that all lecture courses have a concomitant laboratory requirement.

In consideration of the above caveats, we sought to replicate the research-driven experience within the context of a standalone Developmental Neurobiology lecture course through use of the *NeuroNotebook* project described herein. Our aim was to positively impact student knowledge, experimental design skills, and affect, similar to what has previously been documented for CUREs and other inquiry-oriented laboratories (e.g., Jordan et al., 2014; Olimpo et al., 2016; Esparza et al., 2020). More broadly, these data were intended to provide us with evidence regarding the suitability of a "dry"/hypothetical laboratory component in cases where incorporation of a wet-lab experience would not be possible.

Quantitative analysis of student responses on the DNA and SPFA revealed statistically significant gains in students' content knowledge (Fall 2018 participants) and skills related to various facets of the experimental design process (Fall 2018 and Fall 2021 participants). These latter results are consistent with previous studies documenting student growth in science process skills following engagement in inquiry- and discovery-based laboratory curricula (e.g., Thompson et al., 2016; D'Arcy et al., 2019; Smith et al., 2022). While we anticipated gains in content knowledge for

SPFA Construct	**Item Score**			**Rating Score**		
	Pre-Semester *M (SEM)*	**Post-Semester *M (SEM)***	***p*-value**	**Pre-Semester *M (SEM)***	**Post-Semester *M (SEM)***	***p*-value**
Experimental Design	7.61 (0.36)	10.48 (0.51)	< 0.001	1.95 (0.12)	2.84 (0.15)	< 0.001
Reasons for Doing Science	0.43 (0.13)	0.73 (0.15)	0.124	1.39 (0.11)	1.64 (0.12)	0.102
Nature of Science	0.52 (0.11)	0.93 (0.18)	0.040	1.41 (0.08)	1.59 (0.09)	0.088
Interconnectivity[a]	-	-	-	0.98 (0.09)	1.09 (0.12)	0.280
Total Score	8.57 (0.44)	12.14 (0.58)	< 0.001	5.73 (0.22)	7.16 (0.28)	< 0.001

Table 2. Pre-/post-semester comparisons of student performance on the SPFA. [a]The interconnectivity metric does not include an item score, as per the SPFA rubric.

Item	**Pre-Semester *M (SEM)***	**Post-Semester *M (SEM)***	***p*-value**
Developmental Neurobiology Concepts[a]			
I understand the main concepts in the field of developmental neurobiology.	2.43 (0.15)	4.11 (0.12)	< 0.001
I understand the relationship *between* various concepts in the field of developmental neurobiology.	2.52 (0.15)	4.09 (0.10)	< 0.001
I understand how concepts in developmental neurobiology relate to ideas in other science classes.	3.55 (0.15)	4.48 (0.09)	< 0.001
I can think through a problem or argument related to concepts in developmental neurobiology.	2.93 (0.17)	3.98 (0.11)	< 0.001
I am interested in learning more about the field of developmental neurobiology.	4.75 (0.07)	4.48 (0.12)	0.013
I appreciate the topic of developmental neurobiology.	4.59 (0.09)	4.75 (0.07)	0.090
I am enthusiastic about studying developmental neurobiology.	4.55 (0.12)	4.41 (0.14)	0.323
I am confident in my ability to understand developmental neurobiology research.	4.07 (0.11)	4.07 (0.11)	1.000
I can describe one or more developmental pathways that impact neural crest cell formation.	1.75 (0.12)	4.32 (0.10)	< 0.001
I can describe how mutations influence developmental pathways that impact neural crest cell development.	2.02 (0.16)	4.36 (0.12)	< 0.001
I understand the societal impacts and implications of neurodevelopmental diseases.	3.05 (0.20)	4.52 (0.10)	< 0.001
Experimental Design Skills[b]			
I am confident in my ability to develop scientific questions in the field of developmental neurobiology.	3.34 (0.14)	4.02 (0.11)	< 0.001
I am confident in my ability to develop hypotheses that address key questions in the field of developmental neurobiology.	3.18 (0.15)	3.98 (0.11)	< 0.001
I am confident in my ability to design an experimental protocol to address key questions in the field of developmental neurobiology.	2.98 (0.15)	3.93 (0.11)	< 0.001
I am confident in my ability to interpret experimental data.	3.66 (0.12)	4.27 (0.09)	< 0.001
Science Communication[c]			
I am confident in my ability to keep a detailed research notebook.	4.30 (0.12)	4.43 (0.11)	0.349
I am skilled at writing scientific text.	3.45 (0.11)	3.75 (0.10)	0.026
I am confident in my ability to defend an argument when asked questions.	3.64 (0.12)	3.95 (0.10)	0.025
I am confident in my ability to communicate developmental neurobiology concepts to scientists in the field of developmental neurobiology.	2.61 (0.16)	3.59 (0.14)	< 0.001
I am confident in my ability to communicate developmental neurobiology concepts to my peers.	2.86 (0.16)	4.07 (0.12)	< 0.001

Table 3. Pre-/post-semester comparisons of students' DN-SALG responses. [a]Adjusted α = 0.0045 following Bonferroni correction; [b]Adjusted α = 0.0125 following Bonferroni correction; [c]Adjusted α = 0.010 following Bonferroni correction.

both participant cohorts, we suspect that the reformatting of course lectures to be hybrid in the Fall 2021 semester and the continued impact of the COVID-19 pandemic on students' personal and academic lives likely influenced their engagement with and understanding of lecture content (Neuwirth et al., 2021).

With respect to student affect and their perceptions of the *NeuroNotebook* experience, our data indicate that participants reported positive gains in their confidence as it pertained to designing and interpreting data obtained from experiments. Further, they believed that the *NeuroNotebook* project enhanced their critical thinking and science literacy skills—findings that align with previous empirical studies on project-based learning in STEM contexts (e.g., Krajcik and Blumenfeld, 2006; Movahedzadeh et al., 2012; Zwick, 2018). More broadly, several participants stated that they had developed a better appreciation for what "doing science" entails, with some acknowledging that the project prepared them for the rigors that would likely be encountered should they join a faculty laboratory in the

Major Theme (% of Respondents)[a]	Subthemes (% of Major Theme)[a]	Exemplar Quote
Enhanced Content Knowledge (20.45%)	-	"Completing the notebook made the information of the class itself much clearer for me. I'm a person that needs to learn in other methods other than just memorizing information in order to actually learn something, and the notebook was really helpful with [that]."
Experimental Design Competency (77.27%)	Background Research (38.24%)	"I now understand how much initial research and reading of previous research is necessary in conducting a valid research project."
	Approaches and Analytics (76.47%)	"I believe that the notebook process allows you to see the progress of a real research process. It began with Notebook 1 that allowed you to identify the problem and formulate your hypothesis. Notebook 2 then allowed you to further back up your hypothesis. Notebook [3] focused on the experimental design and how to test your hypothesis. Notebook 4 consisted of the results and conclusion. This clearly demonstrates the research process."
Nature of Science (38.64%)	Role of Collaboration (47.06%)	"The notebook project allowed me to combine my efforts with a group in order to produce detailed discussion, which came from personal research and bettered our way of doing so."
	Detailed Nature of Research (47.06%)	"From the notebook project, I was able to get a grasp of what it looks like to be an actual researcher and gather important data in a small amount of time. Every researcher starts from the ground up and develops new hypotheses and methods as they go. Of course, the research process is very difficult; [it] takes so much time and analyzing."
	Iteration/Troubleshooting (11.76%)	"Research is a lot of trial and error and figuring out what you can do to improve."
Scientific Literacy/Critical Thinking (22.73%)	-	"The notebook project allowed me to get a better grasp on critically reviewing articles and papers to find answers for specific questions. It taught me how to use various resources like PubMed and OMIM. It also showed me the process [of being] able to refine a developed hypothesis as more information is acquired."
Science Communication (9.10%)	-	"The notebooks assisted me in the format of placing data and information down on paper in a manner that could be understood [by others]."
Research Confidence/Self-Efficacy (9.10%)	-	"The notebook assignments gave me a significantly better overview on the research process and broke it down for me in a way that makes it easier for me to understand. Now, I think that I can carry [out] research on my own."

Table 4. Student responses to the question: "In what ways did completion of the Notebook Project this semester impact your understanding of the research process (i.e., what it means to do research and what is involved in doing research)?" [a]Note that the percentage values do not sum to 100%, as student responses could be coded into multiple categories, as appropriate.

future.

Collectively, these outcomes suggest that the *NeuroNotebook* intervention was successful in exposing students to the experimentation process within the field of Developmental Neurobiology and in enhancing their knowledge, affect, and skillset in this area. While several measures were taken to minimize bias in our study, we find it important to acknowledge that our findings may have limited generalizability—particularly given our institutional demographic and the fact that some data were collected during the COVID-19 pandemic. External replication of our intervention would serve to address these concerns. Regardless, the work presented herein reflects an impactful mechanism for promoting collaborative student engagement in the research process under resource-limited conditions, thereby enhancing their ability to understand how developmental neurobiology content can be applied in real-life situations.

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Received September 22, 2023; revised June 21, 2024; accepted June 22, 2024.

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