

Evolution Acceptance in Puerto Rican High School Students: Lessons Learned on Transferring Professional Development into Classroom Activities

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ABSTRACT: The theory of evolution is the foundation of biology. However, it faces opposition and backlash due to deep-seated social, cultural, religious, and political reasons. These have led to poor learning and acceptance of the topic. To address these challenges, we designed a two-year professional development (PD) program for high school biology teachers in Puerto Rico that integrated targeted instruction, authentic research experiences, and classroom transfer of evolution-focused modules. In this paper, we describe the PD program and, using a quantitative design, evaluate students' acceptance of the theory of evolution after teachers implemented lessons and activities related to the PD program through pre- and post-administration of the Spanish version of the Measure of Acceptance of the Theory of Evolution (MATE-E). Although our previous report showed that teachers' acceptance of evolution increased following PD participation, the present study found no statistically significant gains in students' acceptance. These results were likely influenced by variation in implementation fidelity, uneven exposure to evolution content, and identity-related factors. Our findings highlight the need for stronger alignment between PD instruction and classroom transfer. We share key lessons learned and propose corrective actions to strengthen the PD program and inform the design of future initiatives with similar goals.

INTRODUCTION

Evolution has been well established as the unifying framework that helps explain life and its diversity (Dobzhansky, 1973). Therefore, teaching this fundamental theory is essential to help students comprehend other biological concepts (Alters & Alters, 2001). However, the teaching and learning of the theory of evolution has faced resistance from diverse social, religious, political, and cultural groups (Barnes et al., 2020; Berkman et al., 2008; Bertka et al., 2019; Newall & Reiss, 2023; Plutzer et al., 2020; Sánchez Salazar et al., 2019; Stahi-Hitin & Yarden, 2022a, 2022b).

One of the more prominent reasons for the low acceptance of the theory of evolution comes from individuals' religious views. Students often identify discrepancies between their creationist religious beliefs and the theory of evolution (Wingert et al., 2023). Additionally, misconceptions might make the theory more difficult to understand and, conse-

quently, more difficult to accept (Miller et al., 2006; Newall & Reiss, 2023). Teachers then face the challenge of providing students with theory-clad lessons that both close learning gaps and aid in students' acceptance of the theory of evolution. Yet when it comes to teaching evolution, teachers face many other challenges.

Nehm and Schonfeld (2007) identified that in-service teachers present similar misconceptions about natural selection to those of K-12 students. This means that there are also gaps that must be addressed through in-service professional development to strengthen both content knowledge and acceptance (Rutledge & Mitchell, 2002; Tekkaya et al., 2012). Additionally, the quality of biology instruction may suffer when teachers, like students, find it difficult to accept the theory of evolution. Consequently, it has been progressively difficult to integrate the theory of evolution into the K-12

teaching of biology.

In the United States of America, there have been some efforts to address this problem; i.e., via the design and development of the Next Generation Science Standards (NGSS) (NGSS Lead States, 2013). These standards provide performance expectations for K-12 students in an effort to standardize their learning of STEM subject areas. Although there have been some observed improvements after the adoption of NGSS, achieving conceptual change regarding the theory of evolution remains a challenge due to deeply held beliefs (Plutzer et al., 2020; Sinatra et al., 2003).

The same is true in Puerto Rico. Despite having state-wide common-core standards aligned with the NGSS, the acceptance of the theory of evolution remains an issue, complicated by the acceptance of alternative accounts of the origin of species. Specifically, misconceptions about biology contribute to low student performance, with only 30% of tenth-grade students demonstrating proficiency in biology standardized tests (Departamento de Educación de Puerto Rico, 2024).

Research consistently shows a positive relationship between increased scientific content knowledge and acceptance of controversial scientific concepts, including the theory of evolution (Rice et al., 2015; Rutledge & Warden, 2000; Weisberg et al., 2018). This relationship is further strengthened when gains in content knowledge co-occur with an improved understanding of the Nature of Science (NOS), which helps learners evaluate evolution as both a logically consistent explanation and a testable form of scientific knowledge (Dunk et al., 2017; Nelson et al., 2019; Rutledge & Mitchell, 2002; Scharmann, 2018; Sloane et al., 2023; Weisberg et al., 2020). To address this disparity in evolution acceptance, we designed and implemented a professional development (PD) program for in-service high school biology teachers in Puerto Rico that operationalized the Cognitive Reconstruction of Knowledge Model (CRKM) (Dole & Sinatra, 1998).

Building on Conceptual Change Theory (Posner et al., 1982), CRKM postulates that acceptance of scientific ideas depends not only on conceptual understanding and plausibility judgments but also on affective and motivational factors, including personal relevance, interest, and emotional engagement. Accordingly, the PD was intentionally structured in two phases to align with these cognitive and motivational dimensions. Phase 1 focused on helping teachers understand evolution as a logically consistent and scientifically credible explanation through targeted instruction and authentic research experiences, addressing CRKM's cognitive requirements for conceptual change. Specifically, authentic research experiences were included because direct engagement with scientific practices has been shown to strengthen understanding of the NOS, which in turn supports judgments of scientific credibility and increases acceptance of evolution. Phase 2 emphasized mentored classroom transfer,

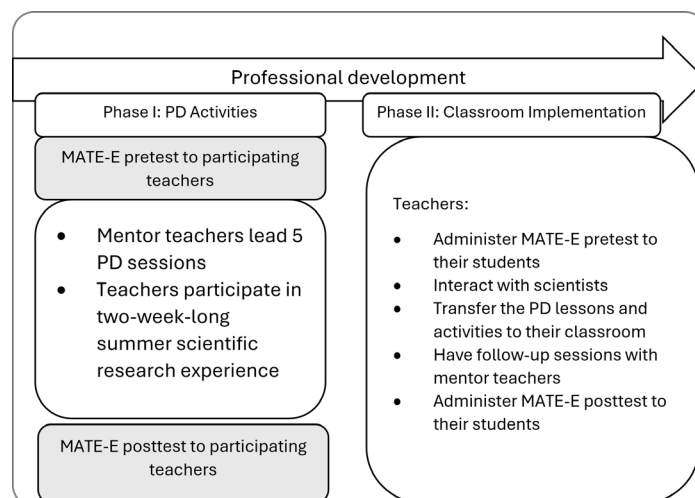


Figure 1. Teacher professional development program.

designed to enhance teachers' motivation, self-efficacy, and perceived relevance by positioning them as active agents applying evolution concepts in their own instructional contexts (Figure 1).

Guided by this theory of action, we hypothesized that engaging teachers in evolution-focused instruction and research experiences that were both intellectually rigorous and personally meaningful would increase their acceptance of evolution. Further, consistent with CRKM's focus on continued engagement with evolution and on helping teachers see it as a well-supported scientific explanation, we anticipated that translating these experiences into classroom practice would consolidate teachers' conceptual change while fostering parallel gains in evolution understanding and acceptance among their students.

METHODS

Overview. The following protocol was approved by the University of Puerto Rico, Río Piedras Campus' Institutional Review Board (CIPSHI #2021-018). A quantitative research design was used in this study. Teachers received training in human research best practices and ethical handling of research data. Participating teachers collaborated in the student data gathering process. Teachers handed out assent forms to their students and consent forms to the students' parents. To evaluate changes in teachers' and students' acceptance of evolution, we administered the MATE-E (Pérez-Vega et al., 2025), a Spanish translation and adaptation of the Measure of Acceptance of the Theory of Evolution (Rutledge & Warden, 1999) as a pretest and posttest. The MATE-E is a 20-item, 5-point Likert scale instrument in which respondents determine their level of agreement with each premise. All students participated in the lessons and activities that their teachers implemented, but only students with affirmative assent and consent forms took the MATE-E.

Table 1. Description of teacher participants.

Teacher	School	Highest Academic Preparation	Years of Experience	School Type	Enrollment (2022-2023)
1	República del Perú, San Juan	Master's	14	6-12	312
2	Luz A. Calderón, Carolina	Master's	19	9-12	397
3	Adela Rolón Fuentes, Bayamón	Master's	13	9-12	610
4	Francisco Gaztambide, Bayamón	Master's	22	9-12	385
5	Ramón Vila Mayo, San Juan	Bachelor's	33	6-12	271

Study Participants

Teachers. PD participants were recruited through a call for applications that was sent to public high school biology teachers from a database provided by the Center for Science and Math Education Research at the University of Puerto Rico, Río Piedras Campus. Nine teachers responded to our invitation. Selection criteria included a commitment to attending PD sessions and the summer research experience, teaching high school biology, and a willingness to enact PD lessons in the classroom as well as to administer research instruments under IRB protocols; prior research experience was not required. Six teachers were selected for the first cohort, which represented the maximum number of participants the program could accommodate due to space limitations within the laboratories where teachers conducted their summer research experience. Five teachers completed the first year of the PD program and four of these submitted portfolios and student assessments that were included in the data analysis (Table 1).

Students. Students attended five schools from five municipalities in Puerto Rico's metropolitan (urban) area. The sampling used was non-probabilistic and by convenience; the inclusion criterion was that participating students must be taking biology with one of the teachers who participated in the PD program. In the Puerto Rican public school system, biology is taught in tenth grade when students are usually 14-16 years old; no demographic data was gathered as part of this study. A total of 297 students were invited to participate in the study. Among these, 81 had both parental consent and student assent to participate, yielding a total response rate of 27.3%. Participating students completed the MATE-E before and after the lessons and activities carried out by their teachers. Students did not receive an incentive for their participation. Surveys were self-administered on paper, and responses were anonymous.

Teacher PD Program. Given the topic's complexity and the need for a multi-dimensional approach, a two-year-long PD program was designed using the train-the-trainer model. Two master science teachers were identified to collaborate with biology faculty from the University of Puerto Rico, Río Piedras Campus, to identify, design, develop, and offer learning modules on topics related to the theory of evolution. This collaboration yielded five modules on the following topics: natural selection, adaptation, evolution, heredity, and gene expression (Center for Science and Math Education Research, 2025). The modules used best teaching practices and were aligned with the Puerto Rico Department of Education's Science Standards, which are equivalent to the NGSS.

PD for teachers in the study consisted of two phases: PD activities and classroom implementation (Figure 1). During the first phase (year 1), teachers received instruction on concepts related to evolution (Table 2). Each PD session was three hours long and was offered on Saturdays. During these

Table 2. Sample topics discussed throughout the professional development program.

Learning Module ^a	Title	Main Concepts	Example Hands-on Activities	NGSS Alignment
1	Natural selection	Species, biological interactions, biodiversity	Simulation of the effect of predation in a population through time	HS-LS4-1, HS-LS4-2, HS-LS4-5, LS4.B, LS4.C
2	Adaptation	Genetic variation, environmental conditions	Identification of characteristics that prove to be adaptations to different organisms; Classify the adaptations and explain the advantage they confer	HS-LS4-2, HS-LS4-4, HS-LS4-5, LS4.B, LS4.C
3	Evolution	Speciation, isolation	Simulation of speciation by geographical isolation	HS-LS4-1, HS-LS4-2, HS-LS4-4
4	Heredity	Genetics, chromosomes, mutations	Construction of a human karyotype and identification of chromosomal mutations; Application of the law of probability and genetic crosses using Punnett squares	HS-LS4-5, LS4.A, LS4.B, LS4.C HS-LS4-3, LS4.C
5	Gene expression	Genome, phenome	Development of graphic organizers about the genome; Analysis of a phage viral sequence; Simulation of gene expression	HS-LS4-4 LS4.B, LS4.C

^aTo access the learning modules in English and Spanish, visit https://csmer.uprrp.edu/?page_id=4470.

Table 3. Description of research experiences for teachers.

Project Description	Number of Teachers (<i>n</i> = 5)
Functional genetic techniques will be used to examine the role of genes in butterfly wing development. The goal is to genetically remove a gene from a butterfly genome and observe whether this change affects wing color patterns. Concepts related to genetic manipulation through CRISPR/Cas9 will be discussed and applied experimentally.	1
The molecular and neural mechanisms underlying drug addiction disorders using the fruit fly, <i>Drosophila melanogaster</i> , as a model organism will be investigated. Experimental work with this species will be conducted to identify genetic markers, perform genetic crosses to manipulate gene expression, and design experiments to analyze the effects of different drugs on animal behavior.	2
The molecular mechanisms by which proteins recognize and bind to DNA and RNA to interpret genetic information will be studied. Experiments targeting the multiple aspects of the biophysical characterization of human transcription factors, including molecular cloning methods, protein expression/purification, protein characterization, and DNA-binding assays will be used to accomplish research goals.	2
Field experience that will integrate concepts of ecology, evolution, and physiology in the context of climate change to assess its potential effects on Puerto Rican biodiversity. Different experimental designs used in field research will be discussed while providing a biological framework from the perspective of Puerto Rican organisms in the context of climate change. Concepts of biology and mathematics (data management, graphs, measures of dispersion, and mean trend) will be used to describe the current abiotic and physiological conditions of organisms and predict the impact of climate change.	4

sessions, trainers (i.e., the master science teachers) taught in-service teachers activities to promote deep understanding of the targeted concepts. They also addressed misconceptions, provided learning materials, modeled sample classroom lessons, carried out learning activities, and offered ideas to modify lessons and activities to accommodate students' learning needs.

The teachers then engaged in a summer research experience in laboratories at the Department of Biology at the University of Puerto Rico, Río Piedras Campus that work on the overarching theme of the genome to phenome relationship. Participants were assigned in pairs to a science research laboratory group that supported them in developing research skills and understanding how to apply these skills in their classroom to help students comprehend and accept the theory of evolution. In addition, they spent three additional days doing fieldwork relevant to the topics developed in the PD sessions (Table 3). These experiences were designed to increase teachers' exposure to scientific research practices and the NOS.

Lastly, teachers prepared a portfolio as part of the PD program to demonstrate what they had learned throughout the PD's first phase, as well as the activities that they chose to implement in their classes as part of the second phase. We administered the MATE-E as a pretest and posttest, before and after the first year experiences, to evaluate changes in teachers' acceptance of evolution.

During the second phase of the PD program (year 2), teachers were mentored by their trainers, as well as the research team, on the transfer of evolution module activities from the PD into their classrooms. Teacher mentors met with participants periodically (in person and online) to support classroom implementation. All learning modules contained at least three hands-on activities, and teachers were asked to implement at least one activity from a learning module in their classrooms. Table 4 summarizes the activities enacted

by each teacher, which helps contextualize students' exposure to evolution-related content. The study team also facilitated interactions by scientists with the students through classroom visits and/or student visits to campus. These were designed to engage students with the nature and joy of science while building relationships with "real" scientists (i.e., graduate students and researchers).

The MATE-E was administered to their students by the participating teachers. Pre-administration of the MATE-E was conducted at the beginning of the first semester (August-September). After administering the pretest, teachers carried out their classroom transfer of lessons from the PD. The MATE-E was again administered late during the second semester to measure the lessons' impact on the students' acceptance of the theory of evolution.

Statistical Analyses. All statistical analyses were conducted using IBM® Statistical Package for the Social Sciences (SPSS®) version 29.0. Data was analyzed using descriptive statistics. Data was also tested for normality using the Kolmogorov-Smirnov test. Lastly, a Wilcoxon signed-ranks test was conducted to determine whether pretest and posttest data were statistically significant ($\alpha = 0.05$).

RESULTS

The professional development (PD) program produced measurable changes among participating teachers, who showed increased acceptance of the theory of evolution following the instructional and research components of the PD (Pérez-Vega et al., 2025). Building on these outcomes, we examined how teachers transferred PD activities into their classrooms and evaluated the resulting impact on students' acceptance of evolution.

During the PD's second phase, teachers implemented activities from the PD learning modules with varying scopes

Table 4. Teacher utilization of learning modules.

Learning Module	Teacher ^a			
	2	3	4	5
1: Natural selection			X	X
2: Adaptation				X
3: Evolution			X	
4: Heredity	X	X	X	X
5: Gene expression		X	X	

^aInformation was available only from four of the five teachers who completed portfolios.

across schools. In Table 4, we summarize the extent of implementation, based on teacher portfolios and logs. At least one of the available activities was implemented from each learning module that a teacher used. All teachers implemented activities on the topic of heredity, two teachers implemented activities on natural selection and gene expression, and only one teacher each implemented activities on adaptation and evolution.

Data from teacher portfolios provided further insights into their experience enacting the activities in their classrooms. For example, Teacher 2 explained that her students had the opportunity to learn about heredity and gene expression with a hands-on approach, using the microscope and experimentation. Meanwhile, Teacher 3 reported the design and implementation of additional complimentary activities to further discuss evolution, heredity, and gene expression, for a total of seven implemented activities, in addition to the four activities that were reported as being transferred from the PD. Teacher 3 also mentioned that not only could her students recall prior concepts when teaching more complex topics, but also that the implemented activities helped students develop skills such as collaborative learning, attention to detail, and data analysis. In contrast, Teacher 4 reported many interruptions during the semester that limited the time to fully develop the activities, while Teacher 5 highlighted the enrichment of the curriculum through the various activities and the support received from scientists and the project staff during the implementation process.

Descriptive analysis showed that, on average, participating students scored 3.16 points higher on the MATE-E posttest (71.04, $SD = 12.079$) than on the pretest (67.88, $SD = 8.259$). Additional descriptive data is presented in Table 5.

Pretest and posttest data were tested for normality, producing mixed results. While skewness, kurtosis, and Shapiro-Wilk statistics suggested approximate normality, the Kolmogorov-Smirnov test indicated statistically significant deviations. The pretest dataset shows a significant departure from normality ($D(81) = .105, p = .027$). Similarly, the posttest dataset also shows a significant departure from normality ($D(81) = .102, p = .036$). Given these mixed findings, and in the interest of adopting a conservative analytic strategy, a non-parametric Wilcoxon signed-rank test was next used.

The Wilcoxon signed-rank test was conducted to evaluate differences between pretest and posttest MATE-E scores. The analysis indicated no statistically significant difference in students' acceptance of the theory of evolution following participation in teacher-implemented lessons and activities ($Z = -1.805, p = .071$). The median score among students during the pretest was 67, whereas the median score for the post-test was 69. In both cases, scores fall within the "moderate acceptance" category as defined by Rutledge and Sadler (2007). Table 5 summarizes the results for the Wilcoxon signed-rank test.

Because teachers implemented different numbers and types of activities from the PD modules (Table 4), students' exposure to evolution-related content varied across classrooms. To examine whether aggregation masked classroom-level effects, the analysis was repeated separately by classroom (Table 6). Across the four classrooms with analyzable data, three showed no statistically significant differences between pretest and posttest scores (Teachers 1, 2, and 4; p values = .267, .501, and .078, respectively). In contrast, Teacher 5's classroom demonstrated a statistically significant increase in scores ($p = .016$).

Table 5. Statistics for MATE-E administration to students ($n = 81$).

Descriptive Statistics						Wilcoxon Signed-Rank Test			
Assessment Period	Min. Score	Max. Score	Mean		Std. Dev.	Ranks	n	Avg. of ranks	Sum of ranks
			Statistic	Std. Error					
Pretest	51	90	67.88	.918	8.259	Negative (Post < Pre)	34	32.78	1114.50
						Positive (Post > Pre)	42	43.13	1811.50
Posttest	36	97	71.04	1.342	12.079	Ties (Post = Pre)	5		
Statistical analysis of the signed ranks for MATE-E administration to students ($n = 81$)									
Z score (based on negative ranks)						-1.805			
Significance (2-tailed hypothesis)						.071			

Table 6. Descriptive statistics and Wilcoxon Signed-Rank Tests results for MATE-E administration per classroom.

Descriptive Statistics								Wilcoxon Signed-Rank Test			
Teacher ^a	Assessment Period	<i>n</i>	Min. Score	Max. Score	Mean		Std. Dev.	Ranks	<i>n</i>	Avg. of ranks	Sum of ranks
					Statistic	Std. Error					
1	Pretest	15	57	89	68.27	2.055	7.959	Negative	6 ^b	6.75	40.50
								Positive	9 ^c	8.83	79.50
	Posttest		62	99	73.87	2.692	10.426	Ties	0 ^d		
								Z score	-1.110	Sig. (2-tailed)	.267
2	Pretest	21	56	91	74.10	1.895	8.683	Negative	11 ^b	11.18	123.00
								Positive	9 ^c	9.67	87.00
	Posttest		51	93	72.71	2.392	10.960	Ties	1 ^d		
								Z score	-.673	Sig. (2-tailed)	.501
4	Pretest	16	52	78	66.50	1.853	7.412	Negative	4 ^b	6.13	24.50
								Positive	10 ^c	8.05	80.50
	Posttest		38	87	71.00	3.338	13.352	Ties	2 ^d		
								Z score	-1.760	Sig. (2-tailed)	.078
5	Pretest	29	57	88	66.72	1.330	7.161	Negative	10 ^b	10.65	106.50
								Positive	19 ^c	17.29	328.50
	Posttest		53	98	73.97	2.474	13.324	Ties	0 ^d		
								Z score	-2.401	Sig. (2-tailed)	.016

^aDatasets from Teacher 3 did not produce valid responses. ^bPosttest < Pretest; ^cPosttest > Pretest; ^dPosttest = Pretest

DISCUSSION AND CONCLUSIONS

This study examined whether a PD program for biology teachers in Puerto Rico increased teachers' and students' acceptance of the theory of evolution. We previously reported (Pérez-Vega et al., 2025) that participating teachers demonstrated increased acceptance following the PD's instructional and research components, which is in accordance with the existing literature on the effects of professional development on in-service teachers (Rutledge & Mitchell, 2002; Tekkaya et al., 2012). However, as we show in this report, implementation of classroom activities varied considerably across teachers, and overall students' acceptance of the theory of evolution did not show a statistically significant gain after teachers transferred what they had learned in PD into their classrooms. Nevertheless, when the data were analyzed by classroom, Teacher 5's students showed a significant increase in acceptance ($p = .016$). Thus, from a Cognitive Reconstruction of Knowledge Model (CRKM) (Dole & Sinatra, 1998) perspective, the PD successfully supported teachers' cognitive and motivational reconstruction of evolution. However, classroom transfer did not consistently provide students with the conditions of plausibility, motivation, and emotional engagement necessary for achieving comparable gains in acceptance.

The isolated significant gain in evolution acceptance found in Teacher 5's classroom is consistent with the variability in implementation documented in Table 4, where teachers differed in both the number and types of activities transferred into their classrooms. Because activities focused on evolution and adaptation were implemented by few-

er teachers, classrooms in which these concepts were emphasized more extensively, such as Teacher 5's, may have provided students with richer opportunities to engage with evolution content, resulting in greater increases in acceptance. Although causality cannot be established, this pattern suggests that fidelity and depth of transfer may play a critical role in shaping student outcomes and should be examined explicitly in future iterations.

To better understand why increases in teachers' acceptance of evolution did not translate into significant gains among students, it is necessary to consider several factors that shaped how the PD activities were implemented across classrooms. First, there was significant variation in the intervention experienced by student participants. We were aware that the profiles and needs of each school were different (Departamento de Educación de Puerto Rico, 2024), which made the potential population for the study more diverse, despite all of them belonging to Puerto Rico's metropolitan area. Hence, teachers were given full autonomy in transferring or adapting the activities from the PD lessons into their classrooms. Teacher portfolios indicated substantial variation in the scope and emphasis of classroom transfer. All teachers implemented at least one activity from the heredity module, whereas far fewer activities were transferred from the evolution and adaptation modules. Because topics on evolution were often scheduled toward the end of the academic year, students likely received inconsistent exposure to the targeted concepts, limiting their impact on acceptance. Furthermore, the PD transfer took place as the world was recovering from the COVID-19 pandemic, which further complicated imple-

mentation and might have potentially compromised student participation.

Our findings align with evidence that the theory of evolution is one of the most enduring examples of public resistance to a well-established scientific theory (Miller et al., 2006; Miller et al., 2021; Newall & Reiss, 2023). Multiple studies show that identity-related factors (e.g., political and religious beliefs) strongly influence people's resistance to accepting the theory of evolution, as well as other controversial scientific topics like climate change and vaccination (Funk & Kennedy, 2016; Hawley et al., 2011; Moore et al., 2011; Nadelson & Hardy, 2015). Hence, resistance to evolution does not occur in isolation; rather, it reflects broader patterns of mistrust in science, scientific institutions, and scientific authority (Nadelson & Hardy, 2015; van der Meer & Hamelers, 2026). Thus, moderate acceptance of the theory of evolution—as indicated by the lack of statistically significant changes among participants—may stem from these same reasons, which should be addressed in future iterations of this type of intervention.

Furthermore, many studies show that acceptance of the theory of evolution increases when learners develop a stronger understanding of the nature of science (NOS) (Dunk et al., 2017; Lombrozo et al., 2008; Nelson et al., 2019; Rutledge & Mitchell, 2002; Scharmann, 2018; Sloane et al., 2023; Weisberg et al., 2020). Thus, our results for teacher participants (Pérez-Vega et al., 2025) are consistent with the literature. However, when NOS is not explicitly addressed, gains in evolution content knowledge alone do not reliably translate into higher acceptance. Furthermore, Nehm and Schonfeld (2007) have shown that even when teachers improve their content knowledge and acceptance of evolution, these changes do not necessarily increase their willingness to teach evolution in the classroom, indicating that additional factors influence instructional decisions. Thus, although teachers experienced NOS through research and instructional activities during PD, the classroom transfer did not necessarily match that emphasis, which may have attenuated effects on student acceptance. Importantly, the classroom in which we observed significant gains (Teacher 5) was the one that provided students with the greatest exposure to evolution content and enriched experiences with support from research scientists (as described in the teacher portfolio). These results show that helping students trust science requires more than just content; it calls for purposeful work with NOS, classroom conversations with awareness of student identity, and authentic inquiry experiences. These elements need to be central to instruction, not treated as extras, to achieve significant conceptual knowledge change and acceptance of controversial concepts like evolution.

Limitations. The study had a low student participation rate. The inclusion criterion was that the students must be taking

biology with one of the teachers that participated in the PD. Out of 297 possible participants, only 27.3% had both affirmative consent and assent forms ($n = 81$). We cannot rule out that some students or their parents may have opted out of participating due to deep-seated cultural or religious beliefs. This low number of participants lowered statistical power to detect small-to-moderate effects and limits generalizability. Hence, for future iterations of the PD, the number of participating teachers should increase as a means to reach more students as potential participants. Also, to mitigate the risk of low participation and further improve student response rate, the IRB protocol could be revised to request a waiver of the consent form.

The variation in classroom transfer of lessons from the PD by teachers (Table 4) likely affected student outcomes and may explain why the overall results were not statistically significant. Our analysis relied on nonparametric pre-post comparisons at the student level. Given the nesting of students within classrooms and the heterogeneous fidelity of implementation, future analyses should employ cluster-aware models (e.g., multilevel modeling or clustered permutation tests) to capture classroom-level variance.

A significant limitation of the study is that we only considered acceptance as a measure for students' learning and understanding of the theory of evolution. Other measures, such as evolution content knowledge, NOS understanding, or students' attitudes toward science, would help to triangulate and correlate data. This has the potential to provide more conclusive findings on how PD transfer influences students' learning and acceptance. Future work should also consider a mixed-methods design that pairs pre-post surveys with classroom observations, teacher fidelity logs, and student interviews to capture mechanisms of change.

Implications and Future Directions. The lessons drawn from this teacher PD can guide researchers and practitioners seeking to strengthen evolution education. Although the PD successfully increased teachers' acceptance of evolution, fidelity of classroom implementation was inconsistent, limiting its impact on students. These findings suggest that CRKM-informed PD must not only support teachers' conceptual change but also equip them to intentionally design student learning experiences that address motivation, identity, and epistemic trust alongside content and NOS. These challenges underscore the need to refine the PD design, particularly by reinforcing the transfer of instructional strategies into classrooms, explicitly integrating NOS, and proactively addressing concerns related to identity that shape students' responses to evolution instruction.

Under the CRKM framework, to help students understand evolution, it is necessary to help them “see the world differently” (Sinatra et al., 2008). Thus, it is essential to address misconceptions as well as intersections between faith

and science to improve the understanding and acceptance of the theory of evolution. Framing evolution education within this broader context positions it as a valuable case study for understanding how learners negotiate scientific knowledge, evidence, and trust. To this extent, in the future, integrating resources that acknowledge these relationships, such as Cultural and Religious Sensitivity Teaching Strategies (Bertka et al., 2019) should be taken into consideration when mentoring teachers in developing lessons and activities for their classrooms as part of a PD program. Doing so will help create learning environments where students can grapple with evolution in ways that respect their identities while engaging meaningfully with scientific evidence. The lessons learned in this project provide a roadmap for revising PD structure, mentoring, and research design to better align instructional intent with measurable student outcomes for future iterations.

In conclusion, we offer a refined theory of action that builds deep teacher learning in evolution and NOS, paired with mentoring that equips teachers to connect respectfully with students' cultural and religious identities. We also call for concrete supports that make high quality classroom transfer possible and evaluation models that acknowledge the unique context of each classroom.

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Author Contributions

The manuscript was written through contributions of all authors. All authors have given approval to the final version of the manuscript.

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ABBREVIATIONS

CRKM: Cognitive Reconstruction of Knowledge Model; MATE-E: Measure of Acceptance of the Theory of Evolution-Español; NGSS: Next Generation Science Standards; NOS: Nature of Science; PD: Professional Development

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