Development of a Scale to Measure Planned Behavior in Inclusive Science Communication: Validity Evidence in Undergraduate STEM Students

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ABSTRACT
Science communication has historically been inequitable, with certain voices and perspectives holding the power and dominant ways of knowing being promoted over others. Recently, there has been a push toward inclusive science communication, which values diverse perspectives and ways of knowing in collaborative conversations to solve complex socioscientific issues. However, there is a lack of both trainings in inclusive science communication for undergraduate science, technology, engineering, and mathematics (STEM) students as well as established ways to evaluate the efficacy of these trainings. To address this need, we designed a new multifactorial survey based on the Theory of Planned Behavior to assess students' attitudes/norms, self-efficacy, behavioral intents, and behaviors in inclusive science communication, which we termed the Planned Behaviors in Inclusive Science Communication (PB-ISC) Scale. We utilized expert review, exploratory factor analysis, confirmatory factor analysis, cognitive interviews, and quantitative measures to gather evidence of validity supporting the proposed use of the final 4-factor, 26-item survey. This survey can be used as a tool by science communication educators and researchers to assess students' planned behavior in inclusive science communication in response to trainings or experiences in science communication or related topics like socioscientific issues, civic engagement, and citizen science.

INTRODUCTION

Inclusive Approaches to Science Communication as a Means to Expand Justice in STEM

Traditionally, science communication has focused on deficit approaches, with scientists being considered the rational experts and nonscientists considered as an ignorant monolith with a deficit of knowledge about science (Simis *et al.*, 2016; Suldovsky, 2016). However, more participatory and inclusive approaches to science communication recognize the need for diverse ways of knowing, multidisciplinary perspectives, Indigenous and other non-Western scientific knowledge, and cultural funds of knowledge all being utilized together in order to solve socioscientific issues (Berkes *et al.*, 2000; Trench, 2008; Berkes, 2009; Suldovsky, 2018; Nadkarni *et al.*, 2019; Canfield *et al.*, 2020; Judd and McKinnon, 2021; Callwood *et al.*, 2022; Choi *et al.*, 2023; Vickery *et al.*, 2023). While there is clear evidence on the efficacy of more participatory and inclusive approaches in science communication (O'Mara-Eves *et al.*, 2015; Metcalfe *et al.*, 2022), science communication training and practice for science, technology, engineering, and mathematics (STEM) students and researchers tends to focus on more unidirectional, deficit approaches to science communication

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(Besley and Tanner, 2011; Besley et al., 2016; Simis et al., 2016; Vickery et al., 2023).

Beyond the need to make science communication training more inclusive for STEM students so that they develop the skillset for inclusive and collaborative science communication in their future careers (Nogueira et al., 2021), inclusive science communication training has an important impact on the students themselves. Training in science communication increases factors such as students' science identity and science self-efficacy (Cameron et al., 2020; Alderfer et al., 2023), which are correlated with increased STEM persistence, especially for students of historically marginalized backgrounds (Estrada et al., 2011). Because inclusive science communication by definition values the assets provided by people of diverse backgrounds, it is a tool to support students' consideration of their own and others' community cultural wealth (Yosso, 2005; Alderfer et al., 2023). Similarly, because inclusive science communication aims to combat the traditionally exclusionary and deficit approaches in Western science (Callwood et al., 2022; Perez et al., 2023), inclusive science communication is a tool to support students in combatting factors like perfectionism and fear of conflict that can hamper their science communication practice and their educational journeys (Alderfer et al., 2023). Overall, an emphasis on inclusivity and justice in our science communication training helps STEM students holding traditionally marginalized identities to consider the assets they themselves provide, while helping students holding traditionally dominant identities to consider the assets of others. Training, practice, and experience in inclusive science communication can help students of excluded identities not just assimilate into the culture of science but actually be empowered to change the culture of science and science communication.

Developing, Implementing, and Evaluating Science Communication Training for STEM Students

Based on the efficacy of inclusive science communication practice as well as the impact of inclusive science communication training on students, it is important to provide more training and experience in inclusive science communication for students. However, most published science communication curricula for STEM undergraduate and graduate students focus on more deficit approaches such as removing jargon rather than more inclusive approaches such as listening to and learning from diverse perspectives (Vickery et al., 2023). Much of the science communication training and practice implemented by STEM faculty does not build upon social science fields (Simis et al., 2016; Suldovsky, 2016) such as psychology, ethnic studies, science communication, and others that inform more just, equitable, and anti-racist practice in science communication. Thus, STEM faculty and students tend to utilize deficit approaches that lack cultural competence and that focus on unidirectional transmission of scientific findings instead of collaboration during the scientific process.

Additionally, there are limited frameworks and scales for evaluating and measuring the efficacy of inclusive approaches to science communication training (Vickery et al., 2023). What is measured is what is valued. If science communication is only measured according to Western science and deficit model approaches, this indicates that only these perspectives are valued. Conversely, if science educators and communicators move toward measuring inclusive mindsets and practices in science communication, more justice-centered approaches toward science and science communication can be appreciated. In this study, we aimed to provide a new tool for science communication educators and researchers to measure more inclusive approaches to science communication. This tool helps move the field of science communication education toward recognition of multiple ways of knowing instead of deficit views toward nonscientists, those with less education, or those from non-Western cultures.

Previous studies have been performed to develop survey constructs for science communication training and students' perspectives on science communication. For example, the Science Communication Training Effectiveness (SCTE) scale has been validated to measure several constructs related to students' science communication motivation, self-efficacy, cognition, affect, and behavior (Rodgers et al., 2020). However, the authors recognize that this scale specifically measures the efficacy of a training course to help graduate students explain their research to a nonexpert audience, and "it cannot be concluded that the SCTE scale is the 'be-all-end-all' tool" (Rodgers et al., 2020). While it is very important for graduate students to be able to explain their research to various audiences, this is simply one form of science communication and does not emphasize other inclusive forms of science communication such as coproduction between scientists and other interested parties to solve a problem (Nogueira et al., 2021) or boundary spanning conversations by undergraduates of marginalized identities with their families (Couch et al., 2022; Shah et al., 2022). Similarly, the Science Networking Scale focuses on how undergraduate students discuss their course-based undergraduate research with diverse audiences (Hanauer and Hatfull, 2015), but is similarly limited to how a STEM student explains their personal research projects to others, one component but certainly not the entirety of science communication.

The Student Attitudes Towards Communication Skills Survey (SATCSS) measures how undergraduate students value learning communication skills according to Expectancy-Value Theory (Cline et al., 2022). Validity evidence for these survey items was collected with undergraduate students and has a focus on how they perceive the value of verbal, written, and nonverbal communication in their future science careers (Cline et al., 2022). While a focus on use of science communication in a future career can certainly maximize students' self-assessment of factors, such as confidence in future work selves (Strauss et al., 2012), these scales do not explicitly reference inclusive approaches to science communication.

The Essential Elements for Effective Science Communication (EEES) Framework was developed to incorporate both desired student communication skills according to Vision & Change as well as evidence-based goals for science communication according to the science of science communication literature (Wack et al., 2021). This framework is helpful for evaluating both student plans for science communication as well as their behaviors in science communication via thematic and content analysis (Shivni et al., 2021). While this framework captures important elements in inclusive science communication, it has not been operationalized as a survey scale.

These scales and frameworks provide helpful background for the ways in which science communication training has been previously evaluated, including survey validation techniques and theoretical foundations. In this study, we aimed to build on this foundation by developing a survey scale that more explicitly assessed students' attitudes toward and behavior in inclusive approaches to science communication. We also aimed to gather validity evidence for the use of these scales (Kane, 1992) to assess student growth in response to inclusive science communication training.

Theory of Planned Behavior in Inclusive Science Communication

We utilized the Theory of Planned Behavior (TPB) to guide development of our multifactor survey. The TPB is a model that integrates how perception of attitudes toward a behavior, social norms about a behavior, and perceived behavioral control impact an individuals' behavioral intentions as well as behaviors (Ajzen, 1991). The TPB is based on an expectancy-value framework, where an individual's behavior is based on how much they value the task as well as how much they expect to succeed in the task (French and Hankins, 2003). The Expectancy-Value Theory was utilized to guide the SATCSS scale as described previously (Cline *et al.*, 2022) and as a component of a framework for evaluating students' motivations to engage in reading primary scientific literature, which is just one type of science communication (Chatzikyriakidou and McCartney, 2022). More specifically to TPB, strategic science communication has been conceptualized in terms of planned behavior, wherein scientists' attitudes, normative beliefs, self-efficacy, and behavioral intentions influence how they engage in public engagement (Besley *et al.*, 2019, 2021; Besley and Dudo, 2022). Related to science communication education research, the TPB has been previously used to conceptualize how graduate students perceptions' of science communication self-efficacy and behavioral intentions increase after science communication trainings (Copple *et al.*, 2020; Akin *et al.*, 2021) and to assess undergraduate STEM students' motivations and behaviors in STEM community engagement (Murphy and Kelp, 2023).

With TPB, it is important to consider not only the factors influencing behavioral intentions, but also the behavior that the individual plans to do. We developed items that specifically addressed inclusive mindsets and behaviors toward inclusive approaches to science communication. For example, what behaviors do students plan to do? Do they value listening to and reciprocally learning from people of diverse perspectives (Besley and Downs, 2024)? Reciprocity, intentionality, and reflexivity have been theorized to be key tenets of inclusive science communication (Canfield *et al.*, 2020), so examining whether students plan to engage in these mindsets in order to impact their science communication behaviors is critical. Do they consider socioscientific issues and how inclusive approaches to science could help improve the community (Alam *et al.*, 2023) and redress past harms (Callwood *et al.*, 2022)?

The TPB outlines three main influencers of behavioral intents and behaviors: attitudes toward the behavior, subjective norms, and perceived behavioral control. *Attitudes* toward a behavior encompasses the beliefs that an individual has about a behavior and their evaluation of the outcome of the behavior (Ajzen, 1991). Attitudes have been shown to be the strongest predictor of some scientists' willingness to prioritize the behavioral goal of eliciting community members perspectives in their research (Besley and Downs, 2024), which is an important manifestation of inclusive approaches to science communication. *Subjective norms* refers to an individual's perception of whether others consider the behavior valuable (Ajzen, 1991). For example, an interview study of early-career scientists found that they held differing opinions on whether public engagement is an integral part of a scientists' professional role, and they did not consider inclusive approaches to science communication in this role (Riley *et al.*, 2022). Thus, in our creation of a multifactorial survey, we conceptualized attitudes, beliefs, and values toward inclusive science communication as well as these social norms toward the behavior in one construct. To assess what students think of inclusive science communication, we considered not only what they personally think, but what they consider the field of science and their peers to value in terms of science communication.

Perceived behavioral control includes the concept of self-efficacy, or the confidence that one can accomplish a behavior (Ajzen, 2002). Self-efficacy as originally conceptualized by Bandura includes components of mastery experience, social modeling, improving emotional states, and verbal persuasion (Bandura, 1997). Self-efficacy was an important component of transitioning Social Learning Theory into Social Cognition Theory (SCT) (Bandura, 1986), and is also now an important component of TPB. The link between SCT and TPB is useful for our study, since behavioral planning for science communication relates to learning of science communication. Additionally, one of the tenets of inclusive science communication is reciprocity (Canfield *et al.*, 2020), and SCT highlights the importance of reciprocal interactions between a person and their environment (Bandura, 1986). Thus, for our survey items measuring perceived behavioral control, we focused on self-efficacy in inclusive and reciprocal/dialogic approaches to science communication.

The factors of attitudes and norms as well as self-efficacy influence the *behavioral intentions* an individual has. It is important to analyze the intentions behind science communication behaviors, since planned science communication is more strategic and effective (Besley *et al.*, 2019) and intentional science communication is more inclusive (Canfield *et al.*, 2020) Understanding the factors influencing scientists' intentions in science communication can also reveal important mindset issues (Choi *et al.*, 2023). However, there can be discrepancies between behavioral intentions and actual *behaviors* (Sheeran and Webb, 2016), with effective interventions causing a medium-to-large effect on intentions and a small-to-medium effect on behavior (Webb and Sheeran, 2006). Fortunately, stronger intentions have been shown to be more stable and better predictors of behavior (Conner and Norman, 2022), so working to more greatly increase STEM students' and scientists' behavioral intentions toward engaging in inclusive science communication will have a larger impact on their eventual behavior. Measuring intentions can be useful as a more immediate metric of intervention efficacy, and longitudinal assessment of both intentions and behaviors can be useful to assess maintenance of student growth in response to science communication training.

Overall, in this study we aimed to develop a multifactorial scale to measure key constructs related to planned behavior in inclusive science communication. We gathered validity evidence for use of this scale for undergraduate STEM students using expert review, confirmatory factor analysis (CFA) and exploratory factor analysis (EFA), cognitive interviews with members, and comparison of scale metrics as pre/post measurement after inclusive science communication training. This survey is designed to be a tool to evaluate the efficacy of future training and experience in inclusive science communication, socioscientific issues, civic engagement, citizen science, and other related issues. This survey can assess how such trainings and experiences impact students' planned behaviors in inclusive science communication as a means by which to collaborate to solve complex socioscientific issues.

METHODS AND RESULTS

We followed a collection of methodological resources regarding construct validity (Messick, 1995), including (American Educational Research Association *et al.*, 2014; Knekta *et al.*, 2019; Reeves and Marbach-Ad, 2016) for guidelines on developing a survey and gathering validity evidence for inferences drawn from the proposed use of the survey scale. We also referred to examples of similar scale development, such as the Predictors of Science Civic Engagement (PSCE) survey (Alam *et al.*, 2023). In brief, we performed initial item generation, expert review, EFA, CFA, cognitive interviews, and pilot implementation of the scale to assess changes in student responses to the scale after a science communication training. Overall, we aimed to gather evidence for the validity of inferences that can be drawn from the quantitative scores provided by students' responses to this self-report attitudinal and behavioral scale (American Educational Research Association *et al.*, 2014). Such evidence is necessary for this scale to be a useful instrument for instructors and science communication education researchers. This study was approved by the Institutional Review Board of Colorado State University, and students consented to their survey responses being used for research.

Initial Scale Development and Expert Review

Author N.C.K. developed the scale based on literature on the topics of inclusive science communication, TPB, and socioscientific issues. We utilize Sadler's definition of socioscientific issues, which are real-world societal problems informed by science and often including controversial, equity, or ethical considerations (Sadler *et al.*, 2007). Initial scale items are listed in Table 1, along with information about the results from the EFA and CFA as described below.

Discussion with undergraduate and graduate student researchers in science communication education served as expert review of the scale, which is a form of validity evidence based on test content (Reeves and Marbach-Ad, 2016). The expert review panel (n = 8 individuals) was comprised of STEM student researchers in the field of science communication education research. These individuals have expertise from both their research experience as well as their lived experiences as STEM students who are the intended survey participant population (Beames *et al.*, 2021; National Academies of Sciences *et al.*, 2023; Vázquez *et al.*, 2023) as well as expertise in the discipline of science communication research. Additionally, these students were both life sciences and engineering majors, helping ensure transferability of the survey across STEM fields. During the expert review process, the research team read through each survey item and discussed their interpretation of the item. More than half of the reviewers found the item "I think that scientists make the best decisions about solving socioscientific issues" to be vague, based on the perspective that "best" can be interpreted in multiple ways. Thus, this item was removed based on this discussion. No other items were considered by multiple expert reviewers to be problematic.

EFA and CFA

To provide evidence for validity based on internal structure, we performed EFA and CFA according to established practices (Watkins, 2018; Knekta *et al.*, 2019, 2020).

A survey was built in the online, secure Qualtrics environment. All items were presented in the order listed in Table 1, and instructions were provided as described in the first column of Table 1. All response points were labeled for the Likert scale.

For the EFA, we had $n = 598$ responses from undergraduate STEM students from a variety of upper- and lower-level classes across the life sciences and engineering at a large R1 land grant university. The students were recruited to complete the survey from disciplinary STEM courses in which the instructor had invited author N.C.K. to do a guest lecture on science communication, but the courses were not otherwise focused on science communication and the surveys were not administered immediately after the training in order to avoid impact of training on student responses. The surveys were administered in five courses (three life sciences courses, two biomedical engineering courses) across two semesters. Response rates from each course varied from 50% to 90%. Students were compensated via a $10 gift card for completing the survey. The demographics of the EFA data included: 46.9% responses from engineering majors and 53.1% responses from life sciences majors; 19.5% responses from students in upper-division courses and 80.5% responses from students in lower-division courses; and 35.5% responses from marginalized students (students identifying as Black, Indigenous, or Person of Color [BIPOC], low socioeconomic status, and/or first-generation college students) and 64.5% responses from students not identifying in one or more of these categories.

Barlett's test for sphericity (Bartlett, 1951) indicated a nonrandom correlation matrix ($\chi^2(378) = 15425.6$, $p = < 0.0001$). The Kaiser–Meyer–Olkin (KMO) statistic (Kaiser, 1974) was 0.90, indicating that the data were an excellent candidate for factor analysis. Analyses were conducted with the open source software R version 4.3.1 (2023-06-16 ucrt) (R Core Team, 2023). Finding number of factors to use and construction of the models were conducted using the nFactors package version 2.4.1.1 and the psych package version 2.3.6. The correlation matrix was created using the polycor

TABLE 1. Survey items. Items included in final survey are shaded in colors corresponding to CFA path diagram (Figure 1). The item "I think that scientists make the best decisions about solving socioscientific issues" was removed based on expert review. Statements "I think science is the only means to solve the world's problems" and "I think that science is the only way to produce valuable knowledge" were intended to be reverse coded. However, EFA revealed that these items, reverse coded or not, did not scale with any other items. Thus, these items were removed before CFA. ISC = Inclusive Science Communication

Construct	Item	Final outcome
ISC Beliefs/Attitudes/Norms. "Rate your agreement with the following statements." (Likert scale, 1 = strongly disagree, 5 = strongly agree)	I think science is an important tool to help solve the world's problems.	Kept in final scale. Q01 in EFA. Q01 in CFA path diagram.
	I think science is the only means to solve the world's problems.	Removed during EFA. Q02 in EFA.
	I think that scientists need to listen to people from other disciplines and expertises.	Kept in final scale. Q03 in EFA. Q02 in CFA path diagram.
	I think that science benefits when people with diverse perspectives contribute.	Kept in final scale. Q04 in EFA. Q03 in CFA path diagram.
	I think that nonscientists are important contributors to conversations about science.	Kept in final scale. Q05 in EFA. Q04 in CFA path diagram.
	I think that science is the only way to produce valuable knowledge.	Removed during EFA. Q06 in EFA.
	I think that diverse perspectives are needed to help solve socioscientific issues.	Kept in final scale. Q07 in EFA. Q05 in CFA path diagram.
	I think that community input is important to solving socioscientific issues.	Kept in final scale. Q08 in EFA. Q06 in CFA path diagram.
	I think that scientists make the best decisions about solving socioscientific issues.	Removed during expert review before EFA.
	I will need to discuss socioscientific issues with diverse people in my future.	Kept in final scale. Q09 in EFA. Q07 in CFA path diagram.
ISC Self-efficacy. "Rate your agreement with the following statements." (Likert scale, 1 = strongly disagree, 5 = strongly agree)	I feel confident learning about socioscientific issues from people with diverse expertise and experiences.	Kept in final scale. Q10 in EFA. Q08 in CFA path diagram.
	I feel confident explaining socioscientific issues to people with diverse experiences.	Kept in final scale. Q11 in EFA. Q09 in CFA path diagram.
	I feel confident considering diverse perspectives about socioscientific issues.	Kept in final scale. Q12 in EFA. Q10 in CFA path diagram.
	I feel confident discussing socioscientific issues with people from different backgrounds than me.	Kept in final scale. Q13 in EFA. Q11 in CFA path diagram.
	I feel confident seeking out diverse perspectives about a socioscientific issue.	Kept in final scale. Q14 in EFA. Q12 in CFA path diagram.
ISC Behaviors. "Rate how often you have done the following in the past month." (Likert scale, 1 = never, 5 = very frequently)	Discuss socioscientific issues with people who I consider to be "scientists."	Kept in final scale. Q15 in EFA. Q13 in CFA path diagram.
	Discuss socioscientific issues with people who I do not consider to be "scientists."	Kept in final scale. Q16 in EFA. Q14 in CFA path diagram.
	Learn about a socioscientific issue from someone with a different background than me.	Kept in final scale. Q17 in EFA. Q15 in CFA path diagram.
	Explain a socioscientific issue to someone with a different background than me.	Kept in final scale. Q18 in EFA. Q16 in CFA path diagram.
	Think about socioscientific issues in my community.	Kept in final scale. Q19 in EFA. Q17 in CFA path diagram.

(*Continued*)

TABLE 1. Continued

Construct	Item	Final outcome
	Encourage others to listen to diverse perspectives about socioscientific issues.	Kept in final scale. Q20 in EFA. Q18 in CFA path diagram.
	Listen to the perspectives of nonscientists about socioscientific issues.	Kept in final scale. Q21 in EFA. Q19 in CFA path diagram.
ISC Behavioral Intents. "Rate how often you plan to do the following in the next month." (Likert scale, 1 = never, 5 = very frequently)	Discuss socioscientific issues with people who I consider to be "scientists."	Kept in final scale. Q22 in EFA. Q20 in CFA path diagram.
	Discuss socioscientific issues with people who I do not consider to be "scientists."	Kept in final scale. Q23 in EFA. Q21 in CFA path diagram.
	Learn about a socioscientific issue from someone with a different background than me.	Kept in final scale. Q24 in EFA. Q22 in CFA path diagram.
	Explain a socioscientific issue to someone with a different background than me.	Kept in final scale. Q25 in EFA. Q23 in CFA path diagram.
	Think about socioscientific issues in my community.	Kept in final scale. Q26 in EFA. Q24 in CFA path diagram.
	Encourage others to listen to diverse perspectives about socioscientific issues.	Kept in final scale. Q27 in EFA. Q25 in CFA path diagram.
	Listen to the perspectives of nonscientists about socioscientific issues.	Kept in final scale. Q28 in EFA. Q26 in CFA path diagram.

package version 0.8.1. Due to the ordinal nature of the data, responses were coded as factors and a polychoric correlation matrix using pairwise complete observations was used. Analyses were conducted using common factor analysis models, with an iterated principal axis method. Initial communalities were estimated by squared multiple correlations. Because the factors are assumed to be correlated, a Promax (oblique) rotation method was used, with Kaiser normalization. In the exploratory analysis, parallel analysis on the correlation matrix suggested five factors; empirical Bayesian information criterion (BIC), minimum average partial (MAP), and the Kaiser criterion suggested five factors; and theory suggested four factors. For thoroughness, 3-, 4-, and 5-factor solutions were evaluated and a 5-factor solution was chosen based on the parallel analysis and Kaiser criterion (i.e., number of eigenvalues $\geq$ 1) as well as higher loading factors, lowest BIC and root mean square residual (RMSR), and highest Tucker–Lewis index (TLI). The five factors together explained 68% of the variance. ISC Behavioral Intent accounted for the largest explanation of variance, almost twice that of any other single factor. The EFA allowed us to identify a problem with items Q02 and Q06: these two items did not load onto any of the other factors; had poor internal consistency reliability (Guttman's $\lambda = 0.6$); were not theoretically meaningful; and resulted in a factor with fewer than three variables. These criteria led us to remove this factor from the final 4-factor solution. Table 2 shows the pattern coefficient matrix for the five factors after promax rotation, and the communality for each item (the proportion of variance in each item that is explained by the five factors). The larger the communality, the better the model performs for that item. The correlation between PA1 (intent) and PA5 (behavior) is high, as is the correlation between PA2 (beliefs/attitudes/norms) and PA3 (self-efficacy). This is expected based on the TPB. However, correlations were all < 0.70, therefore not so high as to question factors (Table 3).

For reliability estimates, while Cronbach's α is popular, it underestimates the reliability of a test and overestimates the first factor saturation. Guttman's λ_6 considers the amount of variance in each item that can be accounted for the linear regression of all of the other items (the squared multiple correlation) (Guttman, 1945). As shown in Table 4, reliability is high for all factors except PA4, the two-item factor that was removed before CFA.

Our average loading for EFA was 0.71. Wolf indicates that CFA for loadings of 0.65 with three factors and six indices per factor requires a sample size of at least 150 for CFA (Wolf et al., 2013). For the CFA, since we had four factors with five to seven indices each, we aimed to exceed this standard. We built another online Qualtrics survey with items in the same order and excluded the two items that were removed after the EFA. We collected $n = 378$ responses for the CFA from a similar population of undergraduate students across diverse courses and majors. These participants were recruited via the same methods as for the EFA data. Students were recruited from four courses (three life sciences, one biomedical engineering). Response rates for each course ranged from 50% to 75%. Students were compensated with a $10 gift card for completing

TABLE 2. EFA pattern coefficient matrix. Note that the pattern coefficients are > 0.40 consistently in a single factor for each group (PA1 = intent; PA2 = beliefs/attitudes/norms; PA3 = self-efficacy, PA5 = behavior), except Q02 and Q06, which load onto PA4 instead of PA2.

Item	PA1	PA2	PA5	PA3	PA4	Communality
ISC beliefs/attitudes/norms						
Q01	0.1	**0.63**	−0.15	0.06	−0.17	0.49
Q02	0.02	−0.09	−0.07	0.1	**0.81**	0.63
Q03	−0.19	**0.87**	0.13	−0.02	0.06	0.68
Q04	−0.04	**0.97**	−0.01	−0.09	−0.01	0.83
Q05	−0.15	**0.67**	0.25	−0.07	0.07	0.41
Q06	0.01	0	−0.03	−0.08	**0.77**	0.64
Q07	0.12	**0.78**	−0.18	0.09	0.02	0.77
Q08	0.03	**0.84**	−0.1	0.02	−0.1	0.73
Q09	0.21	**0.51**	0	0.17	0	0.54
ISC self-efficacy						
Q10	0.03	0.17	−0.08	**0.66**	0.1	0.57
Q11	−0.16	−0.17	0.34	**0.7**	−0.07	0.59
Q12	0.07	0.11	−0.09	**0.81**	0.05	0.76
Q13	−0.09	0.01	0.11	**0.82**	−0.02	0.7
Q14	0.05	0.1	−0.04	**0.72**	−0.02	0.63
ISC behavior						
Q15	0.16	−0.12	**0.6**	0.06	−0.1	0.57
Q16	0.3	0	**0.57**	−0.02	−0.05	0.63
Q17	0.21	0.1	**0.68**	−0.05	−0.03	0.69
Q18	0.13	−0.07	**0.78**	0.05	−0.05	0.79
Q19	0.36	0.1	**0.49**	0.01	0.07	0.63
Q20	0.32	0.04	**0.51**	0.07	0.03	0.63
Q21	0.29	0.09	**0.63**	0	0.11	0.73
ISC intent						
Q22	**0.81**	−0.07	0.08	−0.03	−0.06	0.7
Q23	**0.89**	−0.05	0.05	−0.05	−0.02	0.78
Q24	**0.92**	0	0.03	−0.04	0.01	0.84
Q25	**0.83**	−0.17	0.09	0.05	−0.03	0.75
Q26	**0.9**	0.07	−0.02	−0.05	0.02	0.79
Q27	**0.85**	0	0.02	0.04	0.06	0.78
Q28	**0.84**	0.09	0.06	−0.04	0.05	0.8

TABLE 3. Interfactor correlations from EFA. (PA1 = intent; PA2 = beliefs/attitudes/norms; PA3 = self-efficacy, PA5 = behavior)

	PA1	PA2	PA5	PA3
PA1				
PA2	0.36			
PA5	0.61	0.08		
PA3	0.48	0.55	0.39	
PA4	−0.09	0.13	−0.16	−0.19

TABLE 4. Factor reliability. Cronbach's α and Guttman's λ_6 are shown for each factor. Reliability is high (>0.8) for all factors except PA4 (Q02, Q06).

	α	λ_6
PA1	0.96	0.96
PA2	0.91	0.91
PA3	0.88	0.87
PA4	0.78	0.64
PA5	0.93	0.93

the survey. The demographics of the CFA data included: 36.2% responses from engineering majors and 63.8% responses from life sciences majors; 15.8% responses from students in upper-division courses and 84.2% responses from students in lower-division courses; and 39.2% responses from marginalized students (students identifying as BIPOC, low socioeconomic status, and/or first-generation college students) and 60.8% responses from students not identifying in one or more of these categories.

For our CFA, the survey items were assigned a priori to presume latent factors. Two CFA models were fit to the data using these four factors, using the lavaan package version 0.6.17 allowing for correlated factors and using a variance standardization method. Missing data were removed by listwise deletion. A model using robust maximum likelihood (RML) estimation, with responses treated as continuous variables, was compared with a model using diagonally weighted least squares (DWLS) estimates, with responses treated as ordinal variables. The RML model was a moderate fit; however, the responses for two of the factors were skewed (beliefs/attitudes/norms was skewed high, as was self-efficacy) and the data failed a test of multivariate normality. The DWLS model performed well as indicated by goodness-of-fit measures: comparative fit index

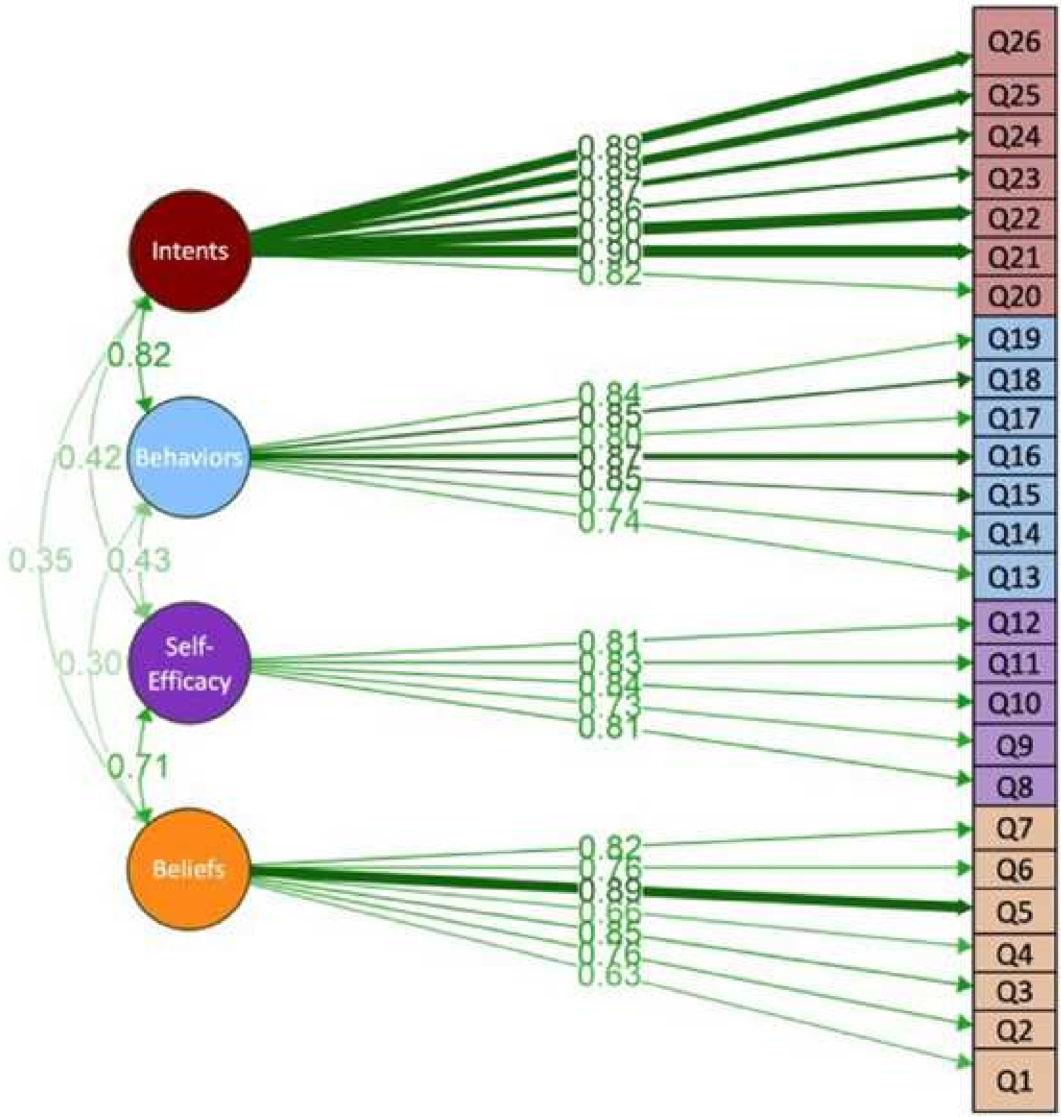

FIGURE 1. CFA path diagram. Path diagram of the ordinal model showing loadings for each item and covariances between factors. Lines are weighted based on size of loading or covariance.

(CFI) = 0.99 (ideal > 0.95), TLI = 0.99 (ideal > 0.95), root mean square error of approximation (RMSEA) = 0.06 (acceptable < 0.08), and standardized root mean square residual (SRMR) = 0.06 (ideal < 0.08). A path diagram with loadings and covariances for the preferred ordinal model (DWLS) is shown in Figure 1, and loadings with standard errors are given in Table 5. The final 4-factor, 26-item scale we termed the Planned Behaviors in Inclusive Science Communication (PB-ISC) Scale.

Other Validity Evidence: Quantitative

The proposed use of the PB-ISC instrument is to assess changes in the measured factors after science communication, civic engagement, and/or socioscientific issues training. To gather evidence of validity based on consequences of testing, which is evidence for the soundness of proposed interpretation of the scale for its intended use (American Educational Research Association *et al.*, 2014; Reeves and Marbach-Ad, 2016), we utilized a sample of $n = 112$ students (pooled across two semesters) who had participated in an introduction to inclusive science communication workshop as described by (Alderfer *et al.*, 2023). Briefly, this workshop included discussion about models of science communication from deficit to inclusive, analysis of science communication case studies, practicing interdisciplinary communication using a role-play activity, and making a plan to be an inclusive science communicator in the next month. This workshop has been shown to increase student science identity and science self-efficacy survey metrics (Alderfer *et al.*, 2023). To gather validity evidence for the PB-ISC, we analyzed students' responses to the scale before and after the workshop using paired t tests to assess the pretest and posttest changes in PB-ISC factors. There was a significant increase in each of the factors in the PB-ISC in response to the training (Figure 2). This finding suggests that

TABLE 5. Loadings, standard error, and 95% confidence interval for each item are shown for each factor in the DWLS ordinal model.

Item	Loading	SE	CI
ISC Beliefs/attitudes/norms			
Q01	0.63	0.02	(0.58–0.68)
Q02	0.76	0.02	(0.72–0.80)
Q03	0.85	0.02	(0.80–0.89)
Q04	0.66	0.02	(0.62–0.70)
Q05	0.89	0.02	(0.85–0.93)
Q06	0.76	0.02	(0.72–0.80)
Q07	0.82	0.02	(0.78–0.86)
ISC Self-efficacy			
Q08	0.81	0.02	(0.78–0.84)
Q09	0.73	0.02	(0.69–0.76)
Q10	0.84	0.02	(0.81–0.87)
Q11	0.83	0.02	(0.80–0.86)
Q12	0.81	0.02	(0.78–0.84)
ISC Behaviors			
Q13	0.74	0.01	(0.72–0.77)
Q14	0.77	0.01	(0.75–0.80)
Q15	0.85	0.01	(0.83–0.87)
Q16	0.87	0.01	(0.85–0.89)
Q17	0.8	0.01	(0.78–0.83)
Q18	0.85	0.01	(0.83–0.87)
Q19	0.84	0.01	(0.82–0.86)
ISC Behavioral Intents			
Q20	0.82	0.01	(0.80–0.84)
Q21	0.9	0.01	(0.88–0.92)
Q22	0.9	0.01	(0.89–0.92)
Q23	0.86	0.01	(0.84–0.87)
Q24	0.87	0.01	(0.85–0.89)
Q25	0.89	0.01	(0.87–0.91)
Q26	0.89	0.01	(0.88–0.91)

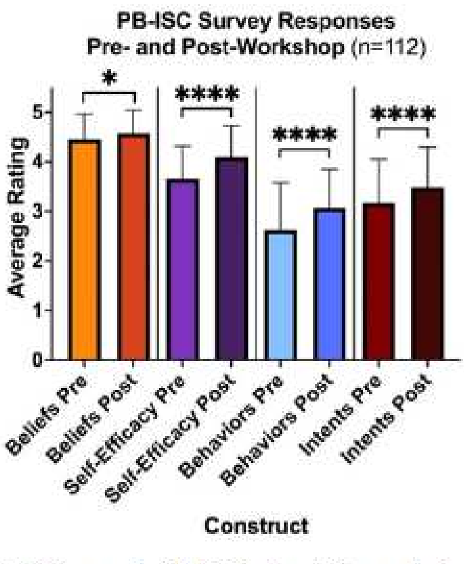

FIGURE 2. Differences in PB-ISC factors before and after a training workshop in inclusive science communication. Results of paired *t* tests. * = $p<0.05$, **** = $p<0.0001$

the PB-ISC is sensitive enough to detect incremental differences in students' planned behavior in response to training in inclusive science communication, which provides both validity evidence for the proposed use of scale as well as a demonstration of the proposed implementation for biology education researchers and practitioners.

Because identities are integral to inclusive science communication (Rodrigues *et al.*, 2023), we wanted to assess how students who belong to historically marginalized groups may interpret this scale compared with students belong to historically dominant groups. For the CFA data, we split students who identified as BIPOC, first generation college student, and/or low socioeconomic status (which we collectively termed "marginalized students") and compared them with students who did not identify in one of these categories ("nonmarginalized students") using tests for measurement invariance (Cieciuch *et al.*, 2019; Rocabado *et al.*, 2020; Svetina *et al.*, 2020). To establish configural (structural) invariance, the CFA model was fit including a group structure of marginalized (i.e., identifying as BIPOC, first-generation college student, or low socioeconomic status, $n = 148$) and nonmarginalized respondents (not identifying in any of those categories, $n = 230$). However, six of the items were empty in one of the two lowest responses in the marginalized group, so responses of "1" and "2" had to be merged into a single level in order to build the model. To assure that our model fit the combined data well, a new CFA model without a group structure was built using the merged responses, and then evaluated for fit statistics (CFA = 0.99, TLI = 0.99, RMSEA = 0.05, SRMR = 0.07). Subsequently, a model built with the group structure was evaluated; the good fit statistics (CFI = 0.99, TLI = 0.99, RMSEA = 0.02, SRMR = 0.06) indicated that the model fit the data across both groups, and that structural invariance was retained (Kline, 2016; Putnick and Bornstein, 2016). For extra confirmation, separate models were fit to each of the groups, and compared. Comparisons of these separate models showed ΔRMSEA = 0.004 and ΔSRMR = 0.02. Additional constrained models were built using the lavaan package and model fits were compared using likelihood ratio tests following recommendations by Vandenberg (Vandenberg and Lance, 2000). Comparisons of a model constrained for group and factor loadings (metric invariance) to that of one constrained for group only failed a likelihood ratio test ($\Delta\chi^2 = 158.64$, df = 22, $p < 0.0001$; RMSEA = 0.18). Because the *p*-value is significant, we concluded that weak/metric invariance (equal factor loadings) is not supported in this dataset. Due to lack of metric invariance, scalar invariance testing was not pursued.

Attempts were made to analyze invariance using individual identities (BIPOC [$n = 48$ BIPOC, $n = 327$ non-BIPOC], first generation [$n = 62$ first generation, $n = 316$ non-first generation], or low socioeconomic status [$n = 114$ low SES, $n = 264$ not low SES]) instead of a single "marginalized" group, but the number of empty responses within groups meant that a wide range of answers would have to be combined. We felt that the loss of information in merging answers would result in misleading results and did not proceed further.

Other Validity Evidence: Qualitative

Resources such as (Reeves and Marbach-Ad, 2016; Knekta *et al.*, 2019) indicate that evidence based on response processes includes respondents' understanding of the scale items as intended by the researcher. To assess this, we performed a combination of solo and dyadic cognitive/think-aloud interviews (Ryan *et al.*, 2012; Morgan *et al.*, 2013; Willis and Artino, 2013). Students ($n = 209$) were recruited via email from STEM courses in life sciences and engineering who had previously taken the survey for EFA or CFA and consented to be recruited for interviews. In response, $n = 5$ students were interested in participating in an interview and followed through on scheduling an interview. Researchers D.W. and H.G. performed two dyadic interviews and one solo interview, totaling $n = 5$ STEM students, who each received a $15 digital gift card after completing the interview process. During the interviews, the researchers showed students the survey items again, asking them which items had resonated with them, why they answered the way they did, whether they found any items confusing, and what they thought these concepts looked like in practice.

Interviews were transcribed, then, D.W. and H.G. utilized emergent coding to identify key themes about the items and use of the items as discussed by students. Across the interviews, feedback about flow, terminology, and purpose of the survey, which yielded no major issues with the survey items but did provide insight for instructors and researchers on implementation of the survey. Students recommended rearranging some of the survey items. For example, in the Behavior section, students recommended arranging the items in the order which they would likely be done (i.e., students are more likely to "think" and "learn" about socioscientific issues before they "discuss" or "explain" them).

Students expressed that the term "socioscientific issue" felt abstract and difficult to define. However, when prompted, students were able to define the term in ways that align with currently established definitions (Sadler *et al.*, 2007). Some examples from students included, "how scientific issues were related to society;" "the humanity of [how science is] gonna affect people;" and "inequality with… different aspects of science… [it is] a social issue affecting people involved with science." Despite initial hesitation with the term "socioscientific issue," students did not express issues with their overarching interpretation of the items containing it.

Some students mentioned that while taking the survey, they had difficulty understanding the rationale behind the behavioral intents section which asked them to rank their intended behaviors over the next month. When asked about the frequency of these future conversations, students said "I would say it's more organic and just when something comes up then I'll have a discussion." Another student responded, "But I don't plan on doing those things… they will just happen if they happen." These statements were echoed throughout the other interviews and showed how conversations surrounding socioscientific issues may not be regularly planned components of students' daily lives. This reveals that students potentially have a weakness in planning science communication activities, which presents an opportunity for training students, as we discuss below. However, students did say that they agreed that discussing socioscientific issues is important to do and to think about.

Overall, the cognitive interviews did not reveal any issues with particular items in the PB-ISC, supporting their validity.

DISCUSSION

Summary of Results

In this study, we successfully developed and gathered validity evidence for a multifactorial scale, the PB-ISC, to measure students' planned behavior and impacts on their behavior regarding inclusive science communication. This PB-ISC scale is useful to assess how students consider the importance of multiple ways of knowing in science and society, which are critical components of increasing justice and changing the culture of STEM. EFA and CFA confirmed four factors based on the TPB constructs of attitudes/norms, self-efficacy, behavioral intents, and behaviors. The factors in the PB-ISC have high factor loadings, and the factors covary as theoretically supported by the TPB. Validity evidence shows theory-supported correlations between these factors, with attitudes/norms and especially self-efficacy correlating with students' planned behaviors. It is unsurprising that self-efficacy are associated with behaviors more so than attitudes/norms did (i.e., higher covariance, see Figure 1), since perceived behavioral control is theorized to moderate the effects of attitude and norms on behaviors (La Barbera and Ajzen, 2020). Students tended to have higher behavioral intents in inclusive science communication than behaviors, but this is expected based on other studies (Murphy and Kelp, 2023), since students often have desire to participate in science communication but less opportunities to actually do so. Additionally, in focus groups, students revealed that they did not always consciously plan or intend some of their science communication behaviors, but the literature on behavioral intents has highlighted that nonconscious processes are important in behavior change (Papies, 2017). Validity evidence also indicates that these four factors increase in response to training in inclusive science communication, as anticipated. This work contributes to the field of science communication research by continuing the growing emphasis on strategic science communication as planned behavior (Besley *et al.*, 2019; Besley and Dudo, 2022; Besley and Downs, 2024) and contributes to the field of science communication education by creating a survey scale for measuring students' plans for inclusive science communication, which can be utilized to evaluate the efficacy of science communication trainings (Vickery *et al.*, 2023).

Our cognitive interviews revealed an important need for science communication training, specifically in planning behaviors. While some students said that science communication conversations happen organically, the literature on science communication indicates that planning communication activities can make them more strategic and effective (Besley *et al.*, 2019), and intentionality is needed for science communication to be inclusive (Canfield *et al.*, 2020). The PB-ISC, specifically the behavioral intent factor, could be used before and after a training focused on the importance of planning science communication activities in order to evaluate the efficacy of the training on students' intentions and planning.

Limitations

We collected validity evidence for the PB-ISC using undergraduate STEM students from diverse majors at an R1 institution. Assessing validity of these indices for students at other institution types would be valuable. Additionally, gathering larger datasets from more diverse institution types would enable analysis for measurement invariance across multiple demographics that are relevant to science communication, such as race (Rodrigues *et al.*, 2023) or gender (Lewenstein, 2019; Rasekoala, 2019). Although there was configural invariance, we did not achieve metric invariance. Measurement noninvariance could indicate important findings about how students of different groups think about inclusive science communication, which could also be a valuable finding (Cieciuch *et al.*, 2019). Future collection of PB-ISC responses from larger samples of students with diverse identities would enable analysis of presence or absence of measurement invariance and facilitate further examination of student perceptions of inclusive science communication.

Some limitations of our data indicate a high skew on the beliefs/attitudes/norms scale, and a slight skew on the self-efficacy scale. However, this is expected based on students' overconfidence in their beliefs and skills compared with their actual ability to perform a behavior; such Dunning–Kruger effect has been shown in regards to communication-related skills like information literacy (Mahmood, 2016). These are common struggles for students with self-assessment surveys in general (Dunning *et al.*, 2004; Brown *et al.*, 2015), rather than the PB-ISC in particular.

Our cognitive interviews, while limited to $n = 5$ in number, indicated some important considerations for utilization of the PB-ISC scale. Some students mentioned that the term "socioscientific issue" is vague, although they were able to define the term. In future studies, it would be valuable to test administration of the survey with "socioscientific issue" replaced with something specific that students are considering in their major, such as climate change or vaccines; there is precedent for making a survey specifically referencing student fields of study (Alam *et al.*, 2023).

Implications for Biology Education Researchers and Practitioners

What are our goals of science communication education? Is it just helping students report their Western science findings to "nonscientist" audiences? Or can our science communication training help students consider new perspectives in how they do science? We support the claim that the culture of science communication education needs to be more justice-oriented (Judd and McKinnon, 2021), and that measuring how students are considering communication within and beyond scientific communities is critical. The PB-ISC can help us as researchers and practitioners assess the efficacy of science communication training, which is currently lacking in the field (Vickery *et al.*, 2023). Additionally, this tool can help researchers and practitioners assess the efficacy of related instruction or experiences in adjacent topics that have been shown to support students' moral reasoning and scientific argumentation, like socioscientific issues (Zeidler and Nichols, 2009; Sadler *et al.*, 2017; Romine *et al.*, 2020; Owens *et al.*, 2022; Klaver *et al.*, 2023), citizen science (Bonney *et al.*, 2014; Phillips *et al.*, 2019; Roche *et al.*, 2020), and science civic engagement (Garibay, 2015; Labov *et al.*, 2019; Dauer *et al.*, 2021; Alam *et al.*, 2023). Finally, the PB-ISC could be used longitudinally once measurement invariance is established across timepoints, to assess students' growth in their inclusive science communication mindsets and skillsets in response to diverse training or experiences in science communication and community engagement. Additionally, longitudinal tracking could help assess whether increases in students "intents" factor leads to increases in their "behaviors" factor, which would help assess how science communication intentions lead to science communication behaviors.

The Importance of Self-Assessment Surveys in Inclusive Science Communication Education

In addition to the utility of a survey scale for summative evaluation and research purposes, a self-assessment survey can be helpful for student formative assessment and feedback as well as the opportunity to practice reflexivity. While some students may perceive that self-assessment surveys lack utility (Yan *et al.*, 2023), encouraging students to recognize the value of self-assessment is critical. Self-assessment can be formative in helping students evaluate their own perspectives, strengths, and weaknesses in inclusive science communication (Andrade, 2019). Reflexivity challenges people to consider how their identities and goals influence their research and actions, and is an especially important tenet in science communication (Chilvers, 2013; Salmon *et al.*, 2014; Canfield *et al.*, 2020; Jensen, 2022), and self-assessment is an important tool for reflexivity. Guiding students in the importance of self-assessment can increase their reflection abilities (Kangaslampi *et al.*, 2022). Additionally, using the PB-ISC to help students assess their own behavioral intentions in science communication could also help students recognize any lack of intention or planning in their science communication and increase this vital skill (Besley *et al.*, 2019). Coupling PB-ISC self-assessment data with other metrics on students' actual behaviors in science communication, such as what is included in science communication products that students create (Shivni *et al.*, 2021), could also provide helpful insight to both instructors/researchers as well as students themselves on how accurate their self-assessment was.

The goal of inclusive science communication education is to help students focus on their own assets as well as value the assets of others for collaborating to cocreate solutions to socio-scientific issues. Utilizing the PB-ISC items as a self-reflection exercise could be powerful for improving students' mindsets and skillsets in inclusive science communication. Social Cognitive Theory (Bandura, 1986) highlights the importance of an individual's environment and social ecology in learning. Callwood and colleagues have highlighted the importance of practicing inclusive science communication at multiple levels of influence and groupings in order to help combat exclusionary cultures in these spaces (Callwood *et al.*, 2022). By focusing students' self-reflection on their current and future uses of inclusive science communication in relationships and in society, the PB-ISC helps students consider their attitudes, norms, and self-efficacy in order to plan behaviors in inclusive science communication. Overall, helping students grow in these TPB constructs can help students practice inclusive science communication at multiple levels of influence in their lives.

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