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Stop the spread: Empowering students to address misinformation through community-engaged, interdisciplinary science communication training

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Abstract

Teaching science in an age of disinformation and misinformation requires empowering students to address inaccurate information in evidence-based ways. Science communication scholarship highlights the growing importance of inclusive and relational approaches for addressing misinformation. Thus, we developed, implemented, and evaluated an interdisciplinary, graduate-level course for students in STEM, journalism/communication, and public health to learn to address misinformation using community-engaged, evidence-based approaches. We used the Theory of Planned Behavior as a theoretical framework for our mixed-methods analysis of the efficacy of this course, assessing both the behaviors that students planned to utilize in community-engaged science communication to address misinformation, as well as the attitudes, norms, and perceived behavioral control that influenced these planned behaviors. Quantitative self-report metrics indicated that this curriculum increased students' subjective norms for misinformation correction as well as perceived behavioral control of science communication and science civic engagement. Thematic analysis of qualitative student interview data showed that the course helped students increase their plans for inclusive approaches to addressing misinformation. This study indicates the importance of community-engaged curriculum to develop the mindset and self-efficacy necessary for scientists-in-training to address misinformation in their communities.

Keywords

community engaged; graduate; inclusivity; misinformation; science communication

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SUPPORTING INFORMATION

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1 | INTRODUCTION

In an age of science denial and the spread of disinformation and misinformation, it is critical for scientists to develop the skills to address inaccurate information. Training in evidence-based science communication skills should be part of students' formal scientific training (Brownell et al., 2013), allowing students to begin practicing these skills early. In this study, we present the development and implementation of a graduate-level course to train natural science and social science graduate students in community-engaged approaches for science communication to address misinformation. We present a mixed-methods analysis of the efficacy of the intervention in terms of influencing students' planned behaviors in science communication, science civic engagement, and misinformation correction.

1.1 | Disinformation and misinformation: Origins, spreads, and solutions

There is a growing body of research on scientific disinformation and misinformation. While disinformation is intentionally false and designed to cause harm, misinformation may be unintentionally false and disseminated without malicious intent (Wardle & Derakhshan, 2017). This distinction is on the part of the originator of the inaccurate information, rather than on the part of the receiver. Once this inaccurate information is spreading within a community, it can cause negative impacts regardless of its original intent (Borges do Nascimento et al., 2022). Thus, we have conceptualized misinformation as "information that is perceived to be true but is not" (Choi et al., 2023). Scientists should be involved in addressing inaccurate information, which we will henceforth refer to as "misinformation" (Williamson, 2016), regardless of its original intent.

Misinformation correction techniques focusing on emotions have been shown to be more impactful than those focusing on reasoning (Athey et al., 2023), suggesting the critical importance of humanism, emotions, and relationships in combatting misinformation. In this study, we aimed to empower graduate students to use relational strategies to address misinformation, preparing them to continue using these strategies in their careers as scientists, journalists, public health professionals, and more. Relational approaches to addressing misinformation prioritize dialogue and interaction through listening and shared values among community members (Choi et al., 2023). These relational and community-based strategies may be more effective at addressing key science communication challenges like misinformation (Lee et al., 2022; Malhotra, 2020, 2022; Nwanaji-Enwerem, 2023). Evidence suggests that authentic academic-community partnerships and engagement can promote effective, accurate science communication and advance equity (Hudson et al., 2023; O'Mara-Eves et al., 2015). Therefore, increased opportunities for students to practice community-engaged and relational approaches to addressing misinformation is an important piece of science communication education and training.

1.2 | Training STEM students to address misinformation: Inclusive science communication

Science communication educational opportunities are growing in number and depth, with many programs providing experiential learning and training in evaluation (Bennett et al., 2022b). Despite such efforts, the deficit model—or the idea that scientific information should be shared unidirectionally to an ignorant audience and without consideration of audience characteristics that shape how individuals select and process such information—persists in science communication training and practice (Besley & Nisbet, 2013; Simis et al., 2016; Suldovsky, 2016; Vickery et al., 2023). Conversely, public engagement models of science communication—which invite diverse perspectives into dialogic conversations about science—have been identified as a critical component of science communication training (Lewenstein & Baram-Tsabari, 2022). Employing these more participatory, culturally competent, and inclusive approaches to science communication can help bridge divides and enable co-creation of solutions to socioscientific problems (Canfield et al., 2020; Nogueira et al., 2021; O'Mara-Eves et al., 2015; Vickery et al., 2023).

Scholars have dedicated significant time to understanding public trust in science (Besley, Lee, & Pressgrove, 2021; Brewer & Ley, 2013; Funk, 2017; Hunt et al., 2018; Kreps & Kriner, 2020; Nadelson et al., 2014; Pollard & Davis, 2022; Siegrist & Bearth, 2021). Scientists' attitudes toward "the public," however, are also a critical consideration for inclusive science communication approaches (Besley & Nisbet, 2013). How scientists perceive the public and whether they hold a deficit perspective of the public or not influences how they engage in addressing misinformation (Choi et al., 2023). Thus, helping our students examine their mindset toward the public via classroom activities and via community engagement was an important component of the course.

1.3 | Training STEM students to address misinformation: Community-engaged approaches

Community-engaged approaches provide opportunities for students to develop cultural competence and for students and community members to learn about topics together. Many studies have examined the impact of service learning and community-based learning on student motivation and identity (Bosman et al., 2017) as well as science literacy and academic achievement (Hayford et al., 2014; Simonet, 2008). Notably, students who engage in service learning make strong links between their learning in class and their activities in the community (Currie-Mueller & Littlefield, 2018; Strage, 2000). The interdisciplinarity of service learning promotes many of these positive outcomes (Mayes & Rittschof, 2021). In addition to these outcomes on student learning and achievement, participation in service learning increases students' sense of connection to the community (Mann & Schroeder, 2019) and helps them develop social skills that are transferrable to other situations in community engagement (Gupta et al., 2020) such as science civic engagement (Alam et al., 2023). Educating students about science civic engagement has been theorized to include multiple fields, from socioscientific issues, to science and technology studies, to environmental education, to civics (Levy et al., 2021). Additionally, students can engage in science civic issues at multiple levels, from classroom exposure via in-class discussions or activities, to analysis of data related to socioscientific issues, to participation and advocacy in the community (Levy et al., 2021). In this study, we aimed to help students develop their skills in addressing misinformation, a critical civic issue (Kaufman, 2021), via many of these modalities.

We developed, implemented, and evaluated a course to train graduate students from the natural sciences and social sciences in techniques to address misinformation. Specifically, our students partnered with a community organization to perform a group project alongside more traditional classroom activities of lectures, discussions, and guest speakers. While service learning can commonly be a component of courses, it is rarer for entire courses to be built around community engagement (Lancor & Schiebel, 2018) and for effective partnerships between academia and community organizations to be established (McDonald & Dominguez, 2015).

In this study, we partnered with a nonprofit organization and a local government agency that both empower community members to handle information and misinformation related to health and crises. By engaging with established community partners that promote participatory approaches to science communication (President's Council of Advisors on Science and Technology, 2023), we provided students with practice in this important mindset and skillset for science communication. Additionally, civic engagement is a powerful way to connect higher education and informal science educators like these community partners (Mappen, 2018). Importantly, students had conversations with community organization leaders and community members to guide their research, which is a model of community-driven rather than scientist-driven community engagement in science education (Ballard et al., 2023). Students partnered with these community organizations and community members to conduct pilot research projects to address misinformation. In these projects, students used qualitative and quantitative research methods that they had learned in the course. Combining in-class research experiences with civic engagement has been shown to improve student learning (Labov et al., 2019).

In particular, our community-engaged research projects took a critical approach, assessing whether certain groups were more susceptible to misinformation due to power imbalances and systemic disenfranchisement. Research in science education has shown that including ideologically aware material—which highlights how biases and stereotypes impact science and socioscientific issues—in classes is important for students to develop a holistic understanding of socioscientific issues (Costello et al., 2023). In our course for example, some students worked on a community-engaged research project related to misinformation targeting Spanish-speaking communities (Hildreth & Alcendor, 2021). Others analyzed misinformation in rural communities that lacked access to resources like staffing, equipment, and real-time access to accurate information during disasters (Hess et al., 2022). Finally, our course was held at a land-grant university; for these universities, serving the community an institutional obligation and common practice (Jamieson, 2020).

1.4 | Training STEM students in how to address misinformation: Theoretical foundation for examining factors influencing planned behaviors

When determining how to equip natural and social science students to be effective science communicators, science educators should draw from literature in both science communication and science education (Akin et al., 2021; Baram-Tsabari & Osborne, 2015; Kohen & Dori, 2019; McKinnon & Vos, 2015; Vickery et al., 2023) in order to develop effective science communication training, as both fields provide important insights about audience engagement and information processing. In particular, synthesizing insights from the fields of science education and science communication can lead to improved insights about democracy, science literacy, and the deficit model of science communication (Lewenstein, 2015).

In science communication scholarship, many studies have examined scientists' motivations for engaging in science communication activities or public engagement with science (Bennett et al., 2022a; Besley et al., 2015, 2018; Dudo, 2013; Dudo et al., 2018; Dudo & Besley, 2016; Rose et al., 2020; Yuan et al., 2017, 2019). These studies have identified that goals for scientists engaging in public communication activities range from advancing their careers (e.g., meeting tenure requirements) to building public excitement about science. Likewise, while some scientists are focused on informing the public in a top-down fashion (Dudo & Besley, 2016), research shows that other scientists are more willing to try trust-building approaches such as listening, developing hope, and building connections with community audiences (Besley, Newman, et al., 2021). In science education scholarship, studies have examined how students engage in science communication. Many undergraduate STEM students are more motivated to do science education by internal factors like collaboration with members of their communities rather than external factors like building their CV (Murphy & Kelp, 2023; Shah et al., 2022). As they progress in their career, graduate students are often encouraged to do community engagement by institutions (Morin et al., 2016) but also continue to grow their internal motivations to find connection and belonging as science communicators (Bennett et al., 2022a). In examining the impacts of our course, we focused on the science communication behaviors students planned to enact and what goals influenced this behavioral decision-making.

The *Theory of Planned Behavior* (*TPB*) provides a useful theoretical framework for studying human behavior. The TPB posits that a person's *attitudes* toward a behavior, their beliefs about the *subjective norms* surrounding that behavior, and their *perceived behavioral control/self-efficacy* about their ability to perform the behavior predict their intention to perform the behavior (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 & Hankins, 2003). Strategic science communication has been conceptualized in terms of planned behavior, wherein scientists' attitudes, normative beliefs, and self-efficacy influence whether and how they engage in public engagement (Besley et al., 2018, 2019; Besley & Dudo, 2022; Besley, Newman, et al., 2021). Related to research in science communication education, the TPB has been used to investigate how graduate students' perceptions of their science communication self-efficacy and behavioral intentions increased after science communication trainings (Akin et al., 2021; Copple et al., 2020) and to assess undergraduate STEM students' motivations and behaviors in science community engagement (Murphy & Kelp, 2023). The TPB has also been combined with other models, such as Risk Information Seeking and Processing, to assess multiple components of trainees' thoughts, attitudes, and actions regarding science communication (Akin et al., 2021). Framing our study in the TPB allows further examination of many factors involved in training students in science communication and allows us to link our findings to other studies that have used TPB concepts to study science communication training programs for students. For instance, a study proposing a competence model for science communication built on public relations research (Pieczka, 2002) to delineate three competencies necessary for effective science communication: picture of the world, professional norms and roles, and working knowledge (Fähnrich et al., 2021). These categories roughly correspond to the TPB inputs of attitudes, subjective norms, and perceived behavioral control, respectively. For instance, scientists' and students' attitudes toward the world in general and their audience in particular influence the types of science communication behaviors they may plan to undertake (e.g., Yuan et al., 2019). For scientists and graduate students, their professional norms such as progression toward tenure are key drivers of their subjective norms regarding public engagement (Rose et al., 2020). Finally, a scientist or student's experience with science communication, which would increase their working knowledge, has been shown to be a strong driver of their self-efficacy and perceived behavioral control to continue to engage in science communication (Rose et al., 2020).

Beyond science communication, the TPB has been utilized in science education research to better understand students' and teachers' behavioral decisions (Archie et al., 2022; Cooper et al., 2016; Crawley III, 1990; Opoku et al., 2021; Pierce, 2018; Zint, 2002). Similar theories such as the Theory of Reasoned Action and Expectancy-Value Theory have also been utilized in science education and communication research (Butler, 1999; Cline et al., 2022; Cooper et al., 2016; Ray, 1991; Sullins et al., 1995).

We can use the TPB constructs of *behavioral intention and behaviors* to assess the behaviors an individual does or plans to do in order to communicate science, engage in the community, and address misinformation. Does the individual communicate—or plan to communicate—in a unidirectional manner that reflects deficit-based models of science communication, or do they plan to use more inclusive approaches that build bridges among a variety of community members (Fähnrich et al., 2021) and to serve as ambassadors between professional science spaces (e.g., labs, scientific meetings) and community spaces (Nadkarni et al., 2019)?

Past research shows that *attitudes* toward science communication play an important role in predicting science communication engagement. For instance, perceived enjoyment of communicating about science is a positive predicator of willingness to participate in this communication activity (Besley et al., 2018). Furthermore, scientists' past engagement activity is positively correlated to future public engagement and science communication activities (Rose et al., 2020). Thus, providing students positive and multiple opportunities to practice science communication will likely increase their willingness to become science communicators. Additionally, positive attitudes toward the audience (e.g., expecting respect and listening from the audience in the conversation) are positively related to likelihood of engaging in certain types of communication, such as face-to-face communication (Besley et al., 2018).

A scientist's or student's perception of their audience is important. Do they have a deficit view of the public or a more inclusive view? That is, do scientists think they have the information and solutions and are responsible to relay this information to an ignorant public, or do scientists recognize that nonscientists in the community have ideas and perspectives that are valuable to conversations about science and should be listened to by scientists? Like this push in science communication away from deficit views of the public toward inclusion of diverse perspectives in conversations about science (Canfield et al., 2020), there has been a push in science education research to move from deficit views of students from marginalized backgrounds to asset-based views, focusing on the capital students bring from their backgrounds. For example, the Community Cultural Wealth model focuses on the cultural capital that students of color utilize to succeed in STEM as well as contribute new knowledge to better the scientific enterprise (Denton et al., 2020; McGowan & Pérez, 2020; Samuelson & Litzler, 2016; Stanton et al., 2022; Yosso, 2005). Likewise, science students and scientists can focus on the assets that communities have to process information, address misinformation, and empower the integration of science into their decision-making (Feinstein, 2015).

While some authors have suggested that there are “clear moral and professional imperatives for scientists to participate in communicating their research to the public” (Borowiec, 2023), such *subjective norms* have received mixed support as a predictor of willingness to engage in science communication activities (Besley et al., 2018; Copple et al., 2020). Similar to attitudes about behaviors, how students perceive norms may impact their behavioral intentions as theorized in the TPB. Yet, 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 tend to consider more participatory approaches over more unidirectional approaches to this public engagement (Riley et al., 2022). Thus, whether students and scientists perceive that their peers are engaging in science communication at all, and whether they are using science communication strategies that are inclusive of the public’s worldviews and values, may impact the type of science communication activities they plan to do.

Scientists’ *perceived behavioral control* is also an important predictor of their likelihood of participating in science communication and public engagement activities. *Self-efficacy*, or the confidence that one can accomplish a behavior, is an important component of perceived behavioral control (Ajzen, 2002). Self-efficacy is a predictor of prioritizing communication objectives beyond simply increasing knowledge (Besley et al., 2020). In other words, promoting scientists’ belief that they are effective communicators is an important part of encouraging scientists to engage in communication beyond trying to increase public awareness or knowledge, such as in relational or community-based approaches to science communication. Additionally, being trained in inclusive approaches to science communication—which highlight not only the assets of the audience but also the assets of the communicator—has been shown to increase undergraduate STEM students’ self-efficacy as science communicators (Alderfer et al., 2023). Thus, our course focused on helping students practice effective science communication skills in order to help them develop confidence in their abilities to perform these behaviors. In addition, we focused on helping students consider how their background, forms of social capital, and identities provide assets for collaborating with communities to communicate about science and address misinformation. We aimed to empower students as boundary spanners; they are scientists and members of academia as well as being neighbors and community members (Couch et al., 2022; Shah et al., 2022; Vickery et al., 2023). The concept of boundary spanners has evolved from its traditional conceptualization in science and technology studies (Guston, 2001), business knowledge transfer (Pattinson & Dawson, 2023), and science policy (Bednarek et al., 2018; Goodrich et al., 2020) to include a focus on academic-community partnerships with Indigenous communities (Hatch et al., 2023) and on other explicitly social justice-driven goals (Lambert et al., 2019) including in science education (Shah et al., 2022).

However, in order to have perceived behavioral control for a behavior like addressing misinformation via being boundary spanner, science students need not only confidence in their communication abilities but also a belief that they can overcome other barriers, such as time constraints and competing work demands, which have been identified as barriers for young scientists to engage in public engagement (Riley et al., 2022). We incorporated time for students to practice science communication during the course, which provided students with more agency to overcome some of these institutional barriers—at least in the immediate term. Other barriers to science communication cited by scientists and students includes fear of conflict with their audience (Alderfer et al., 2023; Johnson et al., 2014), which can manifest strongly with challenging science communication issues like addressing misinformation. While science communicators cannot control their audience's responses, they can engage in positive communication practices to handle conflict positively (Rogers et al., 2018). Thus, we included explicit teaching on evidence-based conflict management techniques as part of the course, via guest speaker panel from a communication researcher who specializes in interpersonal conflict and a medical communication instructor.

Finally, the concept of *motivation*, which impacts behavioral intentions for science communication and engagement (Murphy & Kelp, 2023), has been previously conceptualized in different ways in terms of the TPB. In one study, motivation was described to incorporate all three components of TPB that impact behavioral intentions (i.e., attitudes, subjective norms, and perceived behavioral control) (Rosenthal, 2018). In another, motivation as a factor was shown to influence constructs measuring perceived behavioral control (Rhodes & Courneya, 2004). More specifically, the type of motivation (Morris et al., 2022) may impact what TPB construct the motivation is most associated with. For example, external motivations to comply are a component of subjective norms (Ajzen, 1991), while internal motivations toward a behavior can be related to attitudes toward that behavior (Murphy & Kelp, 2023; Peters & Templin, 2010). In this study, we conceptualized internal motivation within the TPB construct of attitudes and external motivation within the TPB construct of subjective norms.

Overall, for this study, we framed our research questions in terms of the TPB. We aimed to assess students' planned behavior toward science communication in general, toward community/civic engagement, and toward addressing misinformation. These three concepts are linked and synergistic—especially with using community-engaged science communication strategies to relationally address misinformation. Thus, we assessed these planned behaviors individually via existing survey constructs as well as collectively via interviews.

Specifically, we aimed to answer the following research questions:

RQ1. What factors related to students' planned behaviors in science communication, civic engagement, and addressing misinformation change after participation in a community-engaged course?

RQ2. How do students describe the factors influencing their planned behaviors toward community-engaged science communication to address misinformation?

2 | METHODS

In this quasi-experimental study, a graduate-level science communication course designed around topics of misinformation and community-engaged correction techniques was developed, implemented, and evaluated. To evaluate our course, we used a one group, pre-test/post-test (Privitera & Ahlgrim-Delzell, 2019), within-subjects design, gathering both quantitative (survey) and qualitative (interview) data to answer our RQs.

2.1 | Intervention

Our three-credit, graduate-level course had an interdisciplinary design, both in terms of teachers and students. The course was taught by a co-teaching team of faculty from microbiology and journalism/communication departments, to incorporate the perspectives of both natural sciences and social sciences regarding science communication. Interdisciplinary approaches to teaching science communication that employ the strengths of both STEM/natural science and communication/social science faculty lead to improved student learning in the inherently interdisciplinary topic of science communication (Hall & Birch, 2018). Additionally, the graduate students were recruited from STEM, journalism/communication, and public health graduate programs, which enabled students to learn from students in different disciplines about science communication theory, research, and practice as well as natural science research related to topics prone to misinformation, such as climate change and vaccines.

The course activities included an introduction to science communication theory and methods, engagement with science communication research literature about misinformation, discussions and writing assignments, and collaboration with local stakeholders to perform community-engaged research projects related to addressing misinformation. Overall, the learning objectives for the course were for students to be able to:

1. Overview main tenants of theory and practice in effective risk communication, with an emphasis on health communication.
2. Explain the qualitative and quantitative methods and ethical considerations that are utilized in risk communication research.
3. Identify origins of scientific misinformation on a local and national level.
4. Discuss how scientific misinformation disproportionately affects diverse groups.
5. Discuss and practice evidence-based strategies for addressing misinformation via public health communication and interpersonal communication.

6. Analyze communication case studies for effective and ineffective practices to address misinformation.
7. Discuss and implement strategies for building relationships and collaborations with community members.
8. Consider how scientists play a role in addressing misinformation, both in their professional role and as personal members of their communities.
9. Develop and implement a community-engaged project related to risk/misinformation communication.
10. Consider a plan for addressing misinformation in your field of expertise.

We accomplished these learning objectives via a mix of instructor- and student-led activities. The course was held once a week for a 3-ho period for the 16-week semester. During each 3-h period, a variety of activities were planned. Before class, students read selected articles and responded to a question on a discussion board on the online learning management system. During class, there was a mix of short lectures from the instructors about particular theories or practices in science communication; discussion questions answered by the class about science communication, community/civic engagement, and addressing misinformation; and presentations from guest speakers from other departments (e.g., ethnic studies) relevant to community-engaged approaches to addressing misinformation. Additionally, throughout the semester, students in groups led class presentations and discussions on pre-selected topics, allowing students to practice their presentation, teaching, and discussion-leading skills. Finally, students were able to practice their science communication skills via a World Café approach (Brown & Isaacs, 2005), in which students rotated in groups to discuss ideas for addressing real-life scenarios of misinformation believed by their families and communities.

In particular, we focused on reflexive practices and analysis of how humility and recognition of multiple ways of knowing is critical for interdisciplinary collaboration and academic-community partnerships to address science misinformation. During online and in-class discussions, students were encouraged to consider their identities and motivations for community engagement, science communication, and addressing misinformation. Many discussions implicitly connected to the TPB, such students discussing different types of science communication *behaviors* they may undertake, critically analyzing their *attitudes* toward community members with whom they discuss science and misinformation, considering how others in their field handled these issues (*subjective norms*) or analyzing their personal strengths and weaknesses in different science communication skills (*perceived behavioral control*).

Additionally, students worked on a community-engaged project throughout the semester. This included guest talks from employees of our community partner organizations; students reviewing preliminary data gathered by the faculty teaching team regarding misinformation relevant to vaccines and natural disasters (topics prone to misinformation); student conversations with community members who interact with misinformation regarding these topics; and student gathering and analysis of data for a pilot project related to addressing misinformation in communities of interest.

All of these activities were designed to help students consider their attitudes toward science communication, community engagement, and addressing misinformation; practice these behaviors in order to develop self-efficacy; and discuss how they could utilize these behaviors in their future careers. Thus, the course was intentionally designed around helping students develop the factors impacting planned behaviors in inclusive science communication and relational, community-engaged approaches to addressing misinformation.

A sample syllabus of readings and schedule of lecture/discussion/guest speaker topics is provided in Supplementary Materials.

2.2 | Participants

Our course enrolled 15 graduate students from a mix of fields: STEM (5 students), journalism/communication (6 students), and public health (4 students). The STEM students were PhD students from a variety of departments, including microbiology, ecology, and construction management. The journalism/communication students were a mix of MS and PhD students who identified as communication researchers. The public health students were all MPH (master of public health) students concentrating in a variety of disciplines, such as health disparities or epidemiology.

2.3 | Data collection and analysis

We used a mixed-methods approach to answer our research questions, with concurrent triangulation of quantitative and qualitative data for interpretation (Warfa, 2016). This study was approved by the Institutional Review Board of Colorado State University, and students consented to their course artifacts (including survey and interview data) being used in the research.

We created a survey to measure the key constructs in the TPB (relevant attitudes, subjective norms, perceived behavioral control, behavioral intentions, and behaviors) by utilizing validated metrics used in other studies for the behaviors of science communication, science civic engagement, and addressing misinformation (Akin et al., 2021; Alam et al., 2023; Bode & Vraga, 2021; Copple et al., 2020; Krause et al., 2020; Krause et al., 2021; Morin et al., 2016; Murphy & Kelp, 2023; Park & Smith, 2007; Rodgers et al., 2020; Yuan et al., 2019). While not all of these studies conceptualized their survey items in the TPB, and not every TPB construct for each behavior have existing survey items, many of the previously published items—such as self-efficacy, motivations, and social norms —are established components of TPB constructs. Additionally, utilization of previously published survey items for studies related to scientists' and students' behavioral plans for science communication/public engagement, science civic engagement, and addressing misinformation allowed us to assess the efficacy of our course with validated instruments as well as facilitated comparison to previous and future studies in the field using these instruments. In our sample, we achieved reliability with an average Cronbach's alpha of 0.713, with most constructs having internal consistency of Cronbach's alpha >0.7. These constructs are listed in Table 1, and all survey items, references for constructs, and reliability analyses of constructs are provided in the Supplementary Materials. Students indicated their name in the survey for linking of pre- and post-course survey responses and so that we could make comparisons between STEM, journalism/communication, and public health graduate students. However, the graduate student researcher blinded the survey data before it was viewed by the faculty teaching team so students knew their answers were anonymous to those who made grading decisions in the course. Students took the survey, which took approximately 15 min, during class on the first day of class and the last day of class. All students took the pre- and post-course surveys. Wilcoxon matched pairs signed rank tests were utilized to assess changes before and after the course for these metrics to quantitatively address RQ1.

We performed interviews with each student before and after the course to capture their thoughts about the factors influencing their behavioral plans in science communication, community engagement, and addressing misinformation. While the questions were not specifically worded according to TPB constructs, the questions aimed to help students consider how they collectively engaged in these overlapping behaviors. A copy of the interview questions is provided in Supplementary Materials. A graduate research assistant who was a member of the teaching team but not responsible for grading conducted this data collection to mitigate student-professor power dynamics that could influence students' interview responses. We utilized deductive thematic analysis (Terry et al., 2017) to assess how students describe their behavioral plans for using community-engaged science communication to address misinformation (RQ2) and how these themes changed over the course of the semester (RQ1). After interviews were transcribed, the graduate research assistant who performed the interviews did initial analysis of transcripts to identity codes related to the TPB factors influencing students' planned behaviors (i.e., attitudes, subjective norms, and perceived behavioral control). Multiple discussions with another member of the research and teaching team clarified the coding scheme and organization of key themes emerging from the interview data into the TPB framework. Any discrepancy of insights from these two authors was discussed until consensus, thus improving confirmability of the analysis, or the possibility that other researchers would interpret the data in a similar manner (Korstjens & Moser, 2018). For example, the student quote "I think that I have a responsibility to be able to move into those spaces. I don't think it's my responsibility to start a dialogue with everything that I think is misinformation. But I think that as a public health practitioner, I need to have the skills and the experience to be able to shift into that space if I need to…" was originally coded by one author as exemplifying boundary spanning. Upon discussion with the other coder, however, it was decided that this quote better exemplified an ambassador role, where the student was moving into a space or community where they might not personally identify.

Analysis was performed in MaxQDA and frequency of these codes in pre-course and post-course interviews was determined. We considered planned behaviors of science communication, civic/community engagement, and addressing misinformation collectively, since these behaviors overlap in students use of relational and community-engaged communication strategies to address misinformation. Discussion between the two authors was used to organize the emergent A student in a post-course interview discussed scientists' responsibilities to do science communication, stating that, “it depends on where they are in their journey as scientists, because I think the more you grow in your career as a scientist or as a science communicator, the higher your responsibilities.” One author coded this as “roles and responsibilities,” and via discussion between the two authors this code was organized into the TPB construct of subjective norms and theme of expectations of others.

3 | RESULTS

3.1 | Pre- and post-course survey analyses

To assess RQ1 quantitatively, we analyzed the extent to which each TPB construct for the behaviors of science communication, civic engagement, and misinformation correction changed over time, from before the course to after the course. Results of Wilcoxon matched-pairs signed rank tests are listed in Table 1. The significant differences fell into two of the TPB constructs, specifically *subjective norms* in terms of national social norms of misinformation correction and *perceived behavioral control* in terms of science communication knowledge, science communication self-efficacy, and civic engagement self-efficacy. Overall, many constructs did not change following the course, which could be due to the small sample size, previously high scores with little room for growth, the course not providing enough chances for growth in those areas, or innate stability of these constructs in our students.

In terms of *attitudes* toward *science communication*, we were particularly interested in students’ deficit view of the public, since this measure has been shown to be an inhibitor of scientists engaging in relational strategies to address misinformation (Choi et al., 2023). Of note, in the pre-course survey over half of students agreed or strongly agreed with the statement that “the general public has little knowledge about science.” When comparing the students’ level of agreement with the aforementioned statement post-course, there was less agreement (pre-course mean = 3.27, post-course mean = 2.73; median of differences = 0.000, $W = -23.00$, $p = 0.0781$) (Figure 1). It is likely that small n-values or the single-item survey measure contributed to lack of statistical significance for this construct.

There was a statistically significant change for one construct related to students’ *subjective norms* for *misinformation correction*. Specifically, from pre-course to post-course students’ perceived social norms of the nation regarding misinformation correction increased (median of differences = 0.5000, $W = 77.00$, $p = 0.0129$). The survey items to examine this contrast asked the students to rate their level of agreement with statements like, “A majority of people in the United States approve of correcting misinformation” (Supplemental Materials).

Furthermore, regarding the behavior of *addressing misinformation*, our survey results showed that while students intended to engage in science conversations in their communities in order to address misinformation, their reported behaviors in the past year was significantly lower than their intended future behaviors (Figure 2). This trend of past behaviors to address misinformation ranking lower than intended future behaviors did not change as a result of the course completion (Table 1).

Our analyses revealed that several constructs related to students' *perceived behavioral control* for *science communication* and *science civic engagement* had significant changes following course completion: an increase in science communication knowledge (median of differences = 21.00, $W = 98.00$, $p = 0.0007$; Figure 3a), science communication self-efficacy (median of differences = 0.4000, $W = 71.00$, $p = 0.0251$; Figure 3b), and science civic engagement self-efficacy (median of differences = 0.2500, $W = 49.00$, $p = 0.0117$; Figure 3c). Science communication knowledge and self-efficacy both relate to students' perceived behavioral control in science communication, while science civic engagement self-efficacy relates to students' perceived behavioral control in civic engagement. While the n-value is too low to do meaningful statistical analysis of how these constructs manifested among journalism and communication, public health, or STEM graduate students, data visualization (as shown in Figure 3) suggests no obvious pattern according to student discipline.

3.2 | Pre- and post-course interview analyses

To assess RQ1 and RQ2 qualitatively, transcripts from pre- and post-course interviews with students underwent a deductive thematic analysis using TPB as the theoretical framework by which to understand student perspectives toward their planned behaviors in community-engaged science communication to address misinformation both before and after the course. We aimed to identify how students described the factors influencing their planned behaviors (RQ2), and results from this qualitative analysis are presented in Table 2.

Below, we discuss how these themes changed in response to the course (RQ1).

3.3 | Student attitudes toward science communication increased in inclusivity

In terms of *attitudes* and internal motivations toward science communication, both before and after the course, students indicated that they were motivated to be involved in science communication in order to improve society, to help others improve their decision-making, and to enjoy talking with others about scientific topics about which they have personal interest and curiosity.

> "I'm just hoping to find ways and mechanisms to share science that maybe reach a larger audience or are more understandable for other audiences. Just kind of make it more like a general reach than typical like academia."
>
> (Student 3, MPH, pre-course interview)

> "I would honestly say personal kind of fulfillment and enjoyment, because science is something that I really enjoy and it's helped me form an understanding of the world, and I really wanna help other people be able to make those same—not the same exact conclusions, but to be able to understand the world better and yeah, understand their relationship with the world."
>
> (Student 9, STEM, post-course interview)

In pre-course interviews, many students stated they desired to educate the public, echoing potential *deficit views of the public*. For example:

> "Being able to provide that information for people to make better decisions either in their own lives… I'm really motivated toward guiding others and improving their ability to do things."
>
> (Student 13, journalism/communication, pre-course interview)

However, in the post-course interview, this student specifically referred to *deficit* attitudes as problematic for science communication efficacy.

> "Different cultural ways of knowing things doesn't necessarily mean that they don't know about science or things like the way that society operates. But they have different ways of understanding it. So kind of plays into that deficit model avoidance"
>
> (Student 13, journalism/communication, post-course interview)

Additionally, students mentioned diversity, equity, and inclusion as prominent motivators for their science communication activities moreso during post-course interviews.

> "Yeah, it's a lot of cultural differences and maybe even language barriers or different levels of education within the audience that affects… the perception of information. So even the verified information which [is] given from the experts could be misinterpreted within the audience because…the information was given for the very wide audience without counting the differences between people."
>
> (Student 1, journalism/communication, post-course interview)

3.4 | Students developed nuance in their subjective norms toward misinformation correction

Subjective norms were most clearly discussed when students were asked if scientists in general or if they themselves have a responsibility to address misinformation. In pre-course interviews, the majority of students answered that scientists "yes, absolutely" had a responsibility to address misinformation.

> "Yes, because that goes into a lot of their job title. If they're the ones researching and finding out all of these things and saying that they're fact obviously to back it up with their own research on things that their colleagues have found. So yes, I do believe scientists have a responsibility to address misinformation, especially the larger platform that they have."
>
> (Student 4, MPH, pre-course interview)

In the post-course interviews, most students answered after pause for consideration that scientists did have a responsibility to address misinformation, but that this was highly dependent on "if it's related to their field or their knowledge." Whereas the students perceived that a scientist may be more responsible to address misinformation within their field of expertise, especially if they have a position of authority or power, they also perceived that a non-expert should limit their misinformation correction lest they propagate more misinformation.

> "It depends on where they are in their journey as scientists, because I think the more you grow in your career as a scientist or as a science communicator, the higher your responsibilities. I think in our own little corners, our [own] spheres of influence, there's something that we can do."
>
> (Student 11, journalism/communication, post-course interview)

Students' sense of personal responsibility to address misinformation manifested most assuredly in post-course interviews compared to pre-course interviews. Students mentioned an awareness of their intended audience when engaging in science communication activities and highlighted the ambassador role of science communicators (Nadkarni et al., 2019). Being an ambassador involves knowing the values of the audience and entering the spaces of the audience to engage in conversations about science and misinformation rather than expecting the audience to seek out and blindly believe scientific facts (Nadkarni et al., 2019).

> "I don't think you can ever find a communication flow that's going to equally communicate to all these different niche audiences and sub audiences and whatnot. But, the main thing you can do… is just trying to be cognizant of, like who at any point isn't getting information…"
>
> (Student 2, MPH, post-course interview)

The ability to transition between spaces and communities based on personal identities was seen as a strength of science communication boundary spanners (Shah et al., 2022).

> "My research is in climate change. So, it's very rich in misinformation… My step-father—I don't know how he finds these videos, honestly. He finds this [video on why climate change is incorrect], he sends it to me, and he already has this denialist instinct for climate change… Now, I try to give him the tools to understand what misinformation might look like. And now, just now, I've started actually explaining [to him] how I might look at it [the information in the video]."
>
> (Student 14, STEM, post-course interview)

This same student had responded with more trepidation and less conviction to address misinformation when asked about personal responsibility in the pre-course interview.

> "It's easier said than done to try and address misinformation like that. I think the way I personally kind of feel like I'm making my mark on the world is like doing the research. Kind of to see what the effects are of like how people understand science, so that then maybe we can then address how bad science can affect them, so I don't know. That's how I approach it. Yeah, there's too many social pressures, I think to try and take that on myself. But yes, I to some extent, I think I do have a responsibility to address misinformation."
>
> (Student 14, STEM, pre-course interview)

Students were more able to engage and felt more responsibility to engage interpersonally rather than virtually (on social media).

> "I do when I can, like one-on-one settings I don't feel the responsibility to engage in combating misinformation on things like Facebook or Twitter or, you know, TikTok. On social media, I don't feel as much of a responsibility."
>
> (Student 7, MPH, pre-course interview)

In their post-course interview, this same student recognized boundary spanning as a relational tool for addressing misinformation.

> "I think that I have a responsibility to be able to move into those spaces. I don't think it's my responsibility to start a dialogue with everything that I think is misinformation. But I think that as a public health practitioner I need to have the skills and the experience to be able to shift into that space if I need to… I feel very uncomfortable addressing misinformation on social media. I feel more comfortable addressing it in person, where both of us can like get online and together, look at, you know, like sources, articles, talk about previous experience when it's not behind a computer screen."
>
> (Student 7, MPH, post-course interview)

3.5 | Students increased their sense of perceived behavioral control in science communication, community engagement, and misinformation correction as a results of the course

The TPB construct of *perceived behavioral control* manifested in the acquisition of science communication knowledge over the course. Students cited exposure to science communication theory and practice, improved recognition of misinformation tactics, and identification of effective misinformation corrective techniques as increasing their self-efficacy in addressing misinformation.

> "If I feel like it's [misinformation] an aspect of science that I have knowledge about, I'm motivated to talk about it. If it's something that I feel is not my strong point, then I kind of take a step back."
>
> (Student 11, journalism/communication, post-course interview)

Students' science communication knowledge, a component of perceived behavioral control, was developed via their community-engaged group projects, which were a cornerstone of the course curriculum.

> "One of the things from our [community-engaged] project from the class that we discussed that really makes a lot of sense is like a lot of the psychological roots of why this [misinformation] occurs and a lot of the theory and the frameworks which I didn't feel like I had the language for before."
>
> (Student 6, STEM, post-course interview).

STEM and public health students listed the course as their first exposure to science communication theory and research skills, whereas journalism and communication students viewed this course as an opportunity to reinforce theory and practice they had previously encountered.

> "And so having that [science communication theory and practice] reiterated and explained in different ways was really helpful. So, it definitely, it kind of, you know validated what I already felt like I knew, but it also really helped me incorporate it and understand it a little better."
>
> (Student 13, journalism/communication, post-course)

Before the course, many students identified source-based approaches to addressing misinformation—such as improving the science literacy of the audience or providing corrective scientific information to counter an inaccurate claim—as their primary misinformation correction technique. By the end of the course, students mentioned that they learned specific skills such as debunking and prebunking (Roozenbeek et al., 2020) that are shown to be more efficacious. Additionally, at the end of the course all students mentioned relational strategies—such as trust-building, empathy, and cultural competency—as efficacious for science communication and addressing misinformation. Examples of these strategies cited by students included: "active listening to understand what the person values," having conversations "on an interpersonal level," "being aware of their backgrounds and their reasoning," and "trying to come at it with a sense of like humility."

Both pre- and post-course, students explained that barriers to having conversations with community members about science misinformation were highly dependent on their perceived relationship to their conversant.

Students expected to be met with lack of understanding or respect from their audience, and this impacted their willingness to engage in conversation.

> "I think when people are set in their ways, it kind of hard to change their minds, or even just have like, an adult conversation about [science]. So, I think there's just some hesitancy to learn about other peoples' perspectives. And I also feel like after this class, I've been more likely to listen to other people's perspectives, too, to create that open communication."
>
> (Student 3, MPH, post-course interview)

Additionally, they felt their status as a graduate student could serve as a barrier when talking to more experienced researchers, such as graduate students who were further along in their programs or professors with a longer research career.

> "More recently, I have had friends and family reach out to me and ask me if something on some social media platform [is] true. And before I just say, 'Absolutely not… I know what I'm talking about,' I say something along the lines of. 'Did you check and see if somebody else was saying it? Did you check other sources to see what they were? Does it seem to you—what does your gut tell you?' So, in those instances with and [with] really informal relationships, I feel comfortable saying something, but even then I'm encouraging them to kind of look elsewhere. I think in a professional situation, no, absolutely not, unless I am very comfortable and knowledgeable about what I'm talking about."

(Student 15, journalism/communication, post-course interview)

Furthermore, the students who had teaching experience stated that they felt less of a barrier with science communication and addressing misinformation with their students because of their position of authority and the atmosphere of teaching and correction within the classroom. For example, a student mentioned in a post-course interview:

> "I think that the place where I would probably feel the most confident to fight misinformation right now would first be as like a teacher. If I had a student who said something, I feel very confident in that space to address it. And I also feel like in that space, because of the level of like leadership I would have in that role, I feel like it would be even more so my duty…."

(Student 9, STEM, post-course interview)

This sentiment was also present in pre-course interview. For example, when one student was asked if they have a personal responsibility to correct misinformation, they responded:

> "Definitely because I I'm a teacher, you know? Like I teach undergrad classes… So it's like, I wanna make sure that I'm not giving them something that's false."

(Student 10, journalism/communication, pre-course interview)

Time availability was another barrier mentioned by graduate students, many of whom discussed the research, class, teaching, and personal responsibilities limiting the amount of time they had available for pursuing additional science communication opportunities.

> "Whenever I'm really overwhelmed with, like school and deadlines, it's really hard for me to feel as if I have the energy to be able to meet people the way that I feel like those conversations need to be met with."

(Student 9, STEM, post-course)

Overall, our qualitative analysis revealed that the course helped students adjust some of their attitudes toward misinformation by increasing their considerations of inclusivity issues, their expectations of norms and responsibilities in terms of what type of science communication role to play, and their perceived behavioral control by increasing knowledge about evidence-based science communication techniques to address misinformation. However, there were still barriers—such as level of experience and time—limiting their ability to actually perform the behavior of using community-engaged science communication approaches to relationally address misinformation.

3.6 | Integration of qualitative and quantitative results

We utilized a concurrent triangulation design of our mixed methods research (Warfa, 2016) to examine insights from our quantitative and qualitative data. While there were no significant findings for students' *deficit attitudes* within the quantitative data, there was a decrease in this construct when comparing pre- and post-course survey results (Figure 1). The qualitative data expanded on this point by revealing an increase in inclusive attitudes regarding science communication and misinformation correction. For example, students mentioned factors like audience diversity and personal or cultural knowledge as a consideration when communicating. While survey constructs related to deficit attitudes were limited, the pre- and post-course perception changes toward more inclusive, less deficit mindsets are made evident by qualitative data. Furthermore, survey results indicate that students had increased *subjective norms* for *misinformation correction*, which is a component of TPB that dictates behavioral intentions. The course curriculum exposed students to group projects examining misinformation and to science communication theory and practice (Supplemental). Post-course interview responses highlight the acquired strategies for misinformation correction through exposure to theory and the opportunities to practice these skills within the course. Opportunities for science communication practice increased students' self-efficacy, which was also significantly increased from pre-to post-course surveys (Figure 3). However, pre- and post-course survey results show that students' intended behaviors to engage in misinformation correction were lower than their actual behaviors (Figure 2). Students stated in interviews that their barriers for their actual behavior for misinformation correction include time and status within their position. If students were in a teaching position, this removed barriers for misinformation correction and increased their perceived behavioral control. Perceived behavioral control was increased upon course completion, as exemplified by the significant increases in science communication knowledge and science communication self-efficacy between pre- and post-course surveys (Figure 3). Future studies could utilize sequential explanatory design, in which qualitative interviews are used to delve into reasons for changes or lack thereof in the quantitative survey results (Warfa, 2016).

4 | DISCUSSION

The aim of this study was to assess how an interdisciplinary science communication course focused on community-engaged approaches to addressing misinformation impacted graduate students' planned behaviors in science communication, civic engagement, and addressing misinformation. Using a quasi-experimental design and mixed-methods data collection and analysis, we found that in response to the course, there was a qualitative increase in students' *attitudes* toward their audiences that led to increased desires for inclusivity in addressing misinformation relationally. The course extensively focused on inclusivity and community participation in science communication, which explains this change. In terms of *norms*, students quantitatively increased their perception of national acceptance of misinformation correction. The course curriculum included group projects in which the students' examined real-world instances of misinformation dissemination and response within target communities (e.g., how the Latinx population and how the city school boards in neighboring counties responded to COVID-19 misinformation). These projects may have made students more aware of how others across the country are performing misinformation correction. Finally, students demonstrated a quantitative increase in their *perceived behavioral control* in science communication (specifically science communication knowledge and science communication self-efficacy) as well as perceived behavioral control in science civic engagement (specifically civic engagement self-efficacy). Students having a change to practice science communication, community engagement, and misinformation correction during the course likely explains these changes. Regardless of changes in students' perspectives about addressing misinformation during the course, quantitative measures revealed that while students' intent to correct misinformation was high, their behaviors in these activities was lower. This could be related to barriers cited by students in qualitative data, which included time constraints and fear of judgment or confrontation.

4.1 | Teaching students to address misinformation: Influences on planned behavior

In this study, we used the TPB as a framework to analyze students' planned behavior in the related topics of science communication, civic engagement, and addressing misinformation. In our study, we found that students increased their perceived behavioral control in both science communication and science civic engagement, which are both important for addressing misinformation. This result mirrors previously identified synergy between the development of science communication self-efficacy and the development of other constructs like science self-efficacy and science identity (Murphy & Kelp, 2023). These results highlight the importance of assessing multiple planned behaviors that support a broader behavioral outcome of interest. Future studies can continue to analyze how students' development in one behavior (e.g., science civic engagement) impacts their development in others (e.g., science communication) as it relates to engaging with communities in an age of science misinformation.

In addition to interactions of different behaviors, educators and researchers can continue to analyze how students refine what behaviors they actually plan to do. Evidence from our qualitative analysis suggests that the students' attitudes toward themselves and their profession as well as toward their audience changed as a result of the course. Before the course, students indicated their plans for information-sharing and source-based approaches to addressing misinformation. After the course, students indicated their plans for more relational and inclusive approaches to addressing misinformation. The COVID-19 pandemic highlighted the need for multiple actors, community organizations, and community leaders to participate in science communication for it to be effective (Organizing Committee for Assessing Meaningful Community Engagement in Health & Health Care Programs & Policies, 2022). Thus, it is important to train students in such relational, inclusive, and participatory approaches to addressing science misinformation. Interestingly, scientists have been shown to prioritize addressing misinformation as an objective of their science communication skills, but do not always prioritize building trust and resonance with the public (Dudo & Besley, 2016). By taking a course that teaches effective, inclusive, and relational approaches to addressing misinformation, students in our study began to see these objectives as integrated instead of separate. Qualitative data indicating that students were thinking about diversity and inclusion more after the course than before the course correlated with a quantitative decrease in students' deficit perspective of the public from pre-course to post-course. As students began to think more inclusively about their audiences, they began to plan to grow as boundary spanners (Shah et al., 2022) and ambassadors (Nadkarni et al., 2019; Tuttle et al., 2023) instead of simply as sharers of information. However, even after the course students identified some barriers to addressing misinformation. Mainly, more time for more practice is needed for students to implement the behaviors that they are planning in their communities. This highlights the need for institutions to provide systemic support for students to engage in science communication and community engagement activities (Murphy & Kelp, 2023).

4.2 | Teaching in the age of misinformation: Promoting civic and community engagement to address socioscientific issues

This study contributes to the growing literature on encouraging students to engage in community, including emphases related to civic engagement related to science issues (Alam et al., 2023; Garibay, 2015), which can promote university student development (Farmer-Hanson et al., 2021). As we encourage students to develop their skills in using relational approaches to science communication and addressing misinformation, we also help them partner with community members and build collective agency to address misinformation (Feinstein, 2015). It is equally valuable for students to engage with society as well as for communities to partner with students to address socioscientific issues. Additionally, an interdisciplinary approach where students in STEM disciplines engage with science communicators trains them in evidence-based practices for addressing misinformation that engages multiple disciplines as well as community stakeholders (National Academies, 2022).

In general, our findings correlate with those found in the literature focused on teaching socioscientific issues, in which students consider the social, economic, political, and ethical aspects of controversial issues (Sadler et al., 2017) using diverse knowledge domains across the sciences and social sciences (Menke et al., 2023; Owens et al., 2022). For example, a study of students' engagement with socioscientific issues found that those who do not engage with these issues think negatively of them, while those who consume more media and are exposed more to socioscientific issues think more positively and productively about these issues (Klaver et al., 2023). When students engage in group projects to address socioscientific issues, they increase their sense of personal responsibility to contribute to solving these issues (Hwang et al., 2023). This mirrors our findings; after our students engaged with community members to address misinformation during the course, the students began to have a more inclusive and less deficit view of the public. Our findings thus reinforce the importance of using relational strategies to address misinformation and curbing deficit approaches to science communication. The more that students engage with community members, discuss socioscientific issues, and address misinformation, the more they wanted to perform and planned to engage in these behaviors. There is likely a positive feedback cycle involved in addressing misinformation.

4.3 | Limitations and future research

In this study, we studied the effect of a semester-long course in science communication, community engagement, and addressing misinformation on 15 graduate students who chose to take the course. A larger sample size may reveal different results regarding modulating planned behavior related to science communication and addressing misinformation. For example, there was not a statistically significant quantitative decrease in students' deficit views toward the public, although qualitative data indicates students increasing in their inclusive perspectives toward public community engagement. Different survey measures may reveal more nuanced differences in student attitudes. Additionally, providing a control group to compare the students who choose to take such a course versus other students in the program could help explain some of the data. When survey results were analyzed based on the students' discipline (STEM, journalism/communication, or public health), no statistically relevant conclusions could be made, which was also likely a limitation of the small class size.

Studying other populations and their drivers of behavior to utilize community-engaged science communication approaches to address misinformation—such as undergraduate students or scientists—could reveal valuable insights beyond those we found studying graduate students. Another limitation is our survey metrics; existing metrics for every construct in TPB for every planned behavior (science communication, community/civic engagement, and addressing misinformation) we analyzed in the course do not currently exist. Future development and validation of metrics to further analyze factors affecting students' planned behaviors in these areas is warranted. Finally, we analyzed students' behavioral intents to address misinformation before and after the course, but it would also be valuable to follow participants after such an intervention to see how such training modulates their behavior going forward.

4.4 | Implications for science communication training

Many studies have systemically examined how science communication is performed, such as a categorization of Australian science communication programs as more deficit-focused or more participatory and inclusive (Metcalfe, 2019). Unfortunately, there has often been more of a shift in language than practice (Trench, 2008). Actually making changes on a system-level is driven by individual-level changes in the scientists and others involved in science communication activities. A personal ethnography of a science communicator who examined how to engage with and empower community members in her science communication practice highlights some of these individual changes that must occur, such as studying communication theory, understanding the resilience and power of communities, and recognizing that science must partner with other disciplines to solve wicked problems (Leitch, 2022). Realizing that community members have resources to solve issues like misinformation in their community is a powerful shift for scientists and students. We focused on these reflexive practices (Jensen, 2022; Salmon et al., 2014) in our course so students could consider their perception of themselves and of community members in terms of responsibilities and partnerships for addressing misinformation.

In addition to focusing on their own reflexive practices, it is important for students to be prepared to engage in difficult conversations regardless of how the audience may react. Research on intergroup relations has shown that focusing on factors influencing intergroup behaviors (i.e., TPB factors like norms and self-efficacy) has a bigger impact on positive intergroup relations than focusing on changing prejudiced attitudes (Brauer, 2023). By focusing on helping students develop their behavioral skills in relationally engaging about contentious topics like science misinformation, we aimed to help students contribute toward positive intergroup relations even with audiences who may be influenced by science denial.

Instructors may teach science communication to diverse types of students. Our results suggest that instructors teaching STEM students should focus on teaching theory and research-based evidence for science communication practices as well as giving these students practical tools for fulfilling their perceived responsibility for scientists to correct misinformation. Instructors teaching public health students should similarly focus on teaching the theory behind effective public health and communication practices, which these students may not normally learn. Instructors teaching journalism/communication students should help research-focused students apply their knowledge to actual science communication practice. Finally, instructors teaching any of these students should promote opportunities for interdisciplinary collaboration and peer learning between students of different backgrounds.

4.5 | Implications for science education

Our findings suggest that science educators should help students conceive of science communication in more inclusive and community-engaged ways, which will help students modulate their planned behaviors to engage in complex socioscientific issues such as addressing misinformation. In this age of science denial and misinformation, helping students develop the mindset and skillset to engage in relational and evidence-based approaches to work with societies to address misinformation is critical. A recent report of competencies for students to handle science misinformation and disinformation highlighted the importance of self-regulation and acknowledgment of bias and other nuanced considerations (Allchin, 2023). Our results echo these need for students to consider their own perspectives and the perspectives of others in their communities. Students are often in a position to act as boundary spanners and address misinformation within their own communities and need to be equipped with these critical skills (Bowen et al., 2023). In the course, we engaged in conversations about humility and multiple ways of knowing in an effort to help students develop a more inclusive, non-deficit mindset toward the public and thereby increase their ability to address misinformation effectively in their future scientific careers. Regarding skillset, students need training in evidence-based approaches to overcome barriers such as fear of conflict and engage in relational conversations to address misinformation. Finally, greater institutional investment and support is needed to facilitate students' protected time and opportunities to engage with communities.

This focus on helping students in the science classroom consider community collaboration, cultural funds of knowledge, and multidisciplinary perspectives on socioscientific issues is helpful not only for students' science communication skills but also for their own learning of scientific content itself (Bell, Bricker, et al., 2012; Bell, Tzou, et al., 2012; Tzou et al., 2010) and recognition of important cultural views of science (Bang et al., 2009). Much of this research in place-based and community-engaged approaches to science education has centered at the K-12 level. Our course thus provides important insight into the application of community-engaged teaching at the graduate level, which is a needed area: despite calls for increased community-engaged teaching in graduate school (O'Meara, 2008; O'Meara & Jaeger, 2006), there has been some progress in the area but there remains room for growth (Morin et al., 2016).

Overall, as the broader science education researcher and practitioner field, we must continue to engage our students in social science perspectives in order for them to develop the mindset and skillset needed to employ science communication practices beyond a unidirectional information-delivery approach and toward an inclusive and participatory approach that enables students to partner with communities to address misinformation (Martin-Ortega, 2023; Nogueira et al., 2021; Simis et al., 2016; Suldovsky, 2016).

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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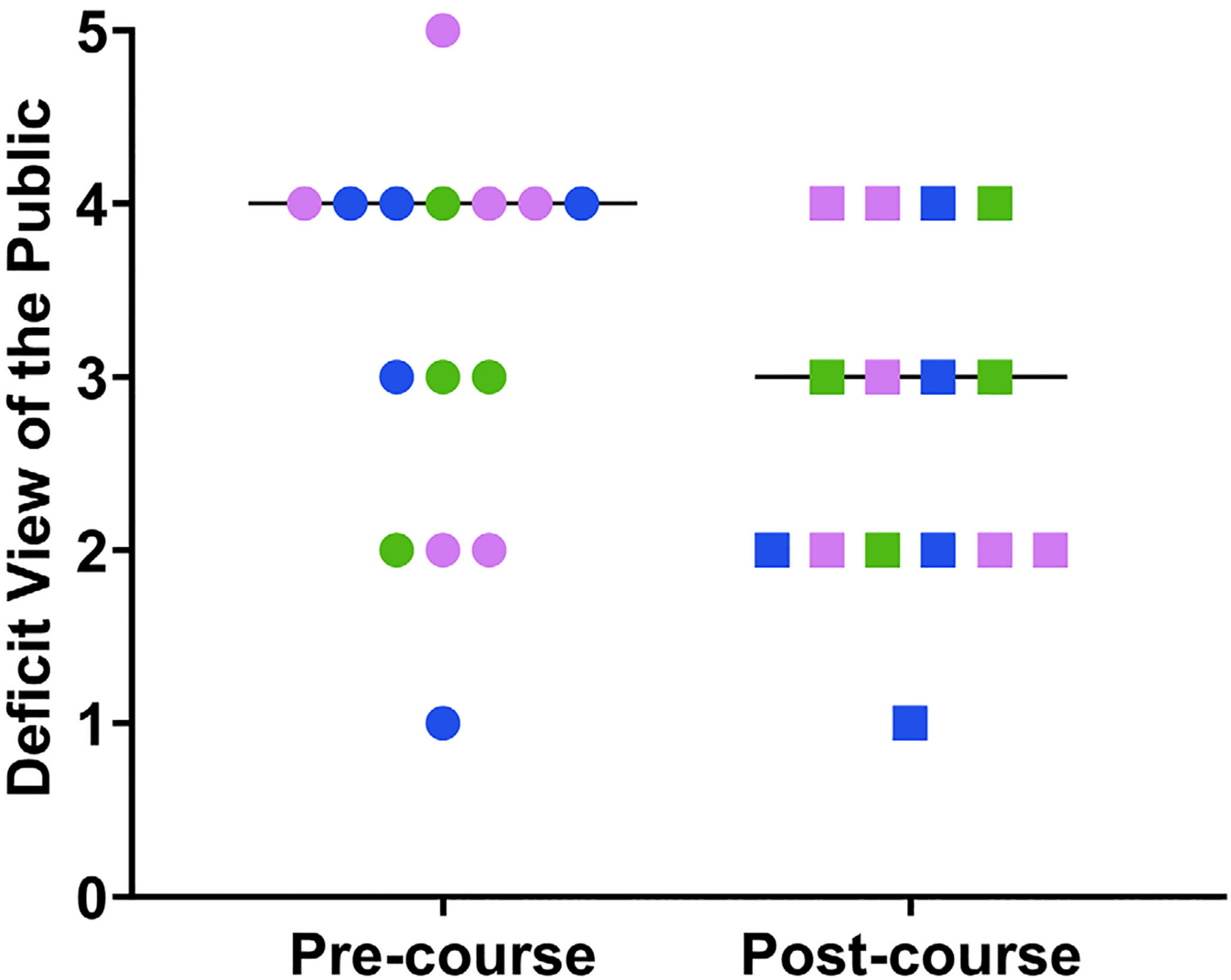

FIGURE 1.
Deficit perceptions did not significantly decrease upon course completion. Graduate students' self-reported deficit view of the public measured a using Likert scale, with 5 being the strongest deficit perceptions. Color-coded based on students' fields of study: magenta represents journalism and communication, green represents public health, and blue represents STEM. Result of Wilcoxon matched pairs signed rank tests.

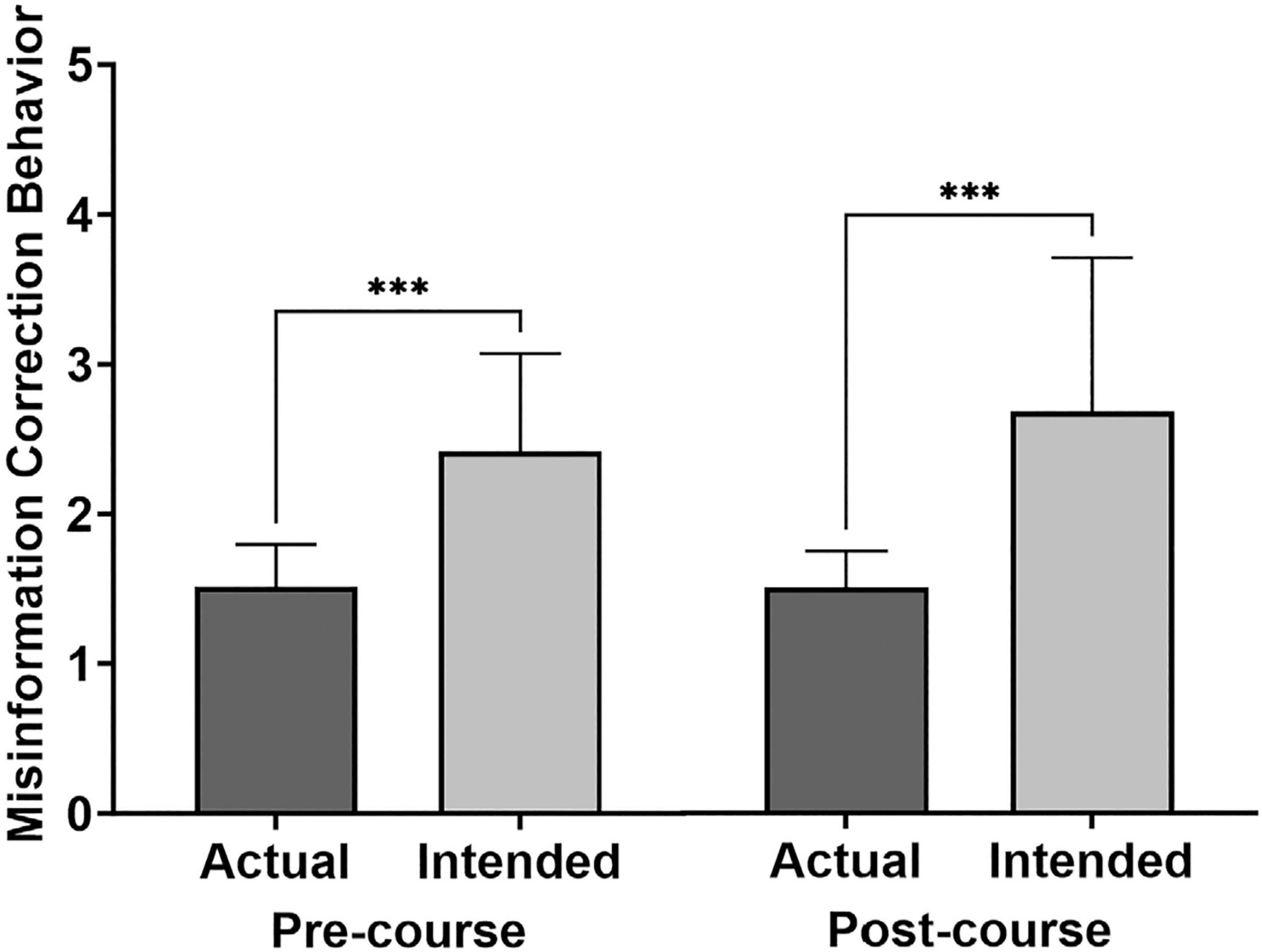

FIGURE 2.
Students' intended misinformation correction behaviors were significantly higher than their actual behaviors both pre- and post-course. Graduate students' self-reported *actual misinformation correction behaviors* (past behaviors to correct misinformation in the last year) and *intended misinformation correction behaviors* (behavioral intents to address misinformation), measured using Likert-scales (survey items in Supplementary Materials), with 5 being the highest likelihood. Asterisks indicate Wilcoxon rank sum test between intended and actual behaviors at each time point. * indicates p from 0.01 to 0.05, ** indicates p from 0.001 to 0.01, *** indicates p from 0.0001 to 0.001, and **** indicates $p < 0.0001$.

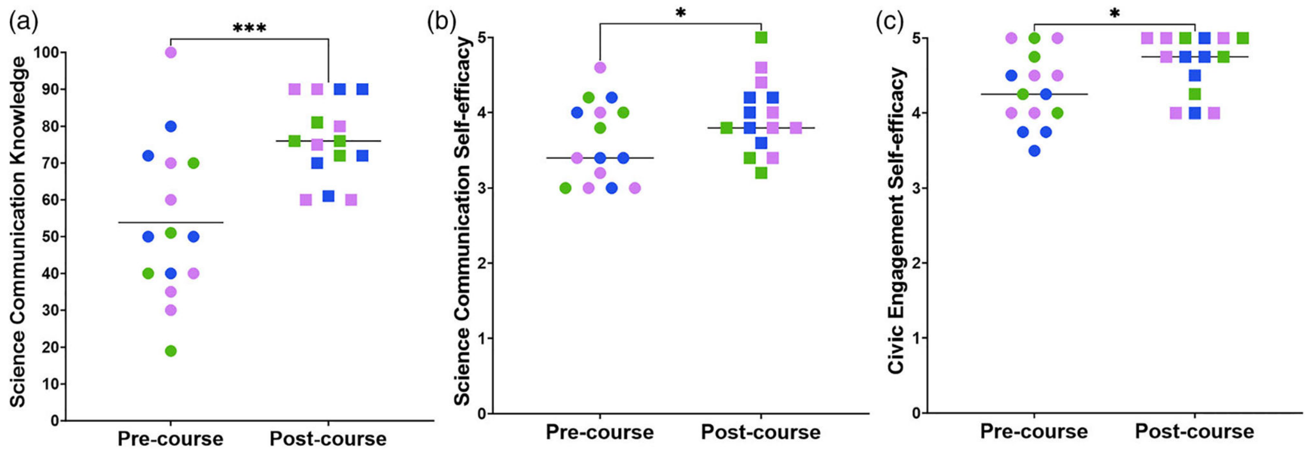

FIGURE 3.
Students' perceived behavioral control in science communication and science civic engagement increased upon course completion. Graduate students' self-reported levels of science communication knowledge (a), on a scale from 0 to 100, with 100 being the highest level of knowledge, show positive increase in science communication knowledge as a result of course completion. Graduate students' self-reported levels of science communication self-efficacy (b) and science civic engagement self-efficacy (c) measured using Likert-scales, with 5 being the highest levels of agreement. Color coded based on students' fields of study: magenta represents journalism and communication, green represents public health, and blue represents STEM. Results of Wilcoxon matched pairs signed rank tests. * indicates *p* from 0.01 to 0.05, ** indicates *p* from 0.001 to 0.01, and *** indicates *p* from 0.0001 to 0.001.

TABLE 1

Wilcoxon matched pairs signed rank tests of pre- and post-course survey constructs related to TPB for science communication, civic engagement, and addressing misinformation. Bolded and starred *p*-values indicate significantly different values from pre-course to post-course. All constructs were on a Likert scale from 1 to 5 other than science communication knowledge, which was rated on a scale from 1 to 100, per previously published use of these metrics.

Theory of planned behavior		Survey constructs	Pre-course mean ± SD	Post-course mean ± SD	Median of differences	Sum of signed ranks (W)	*p*-Value for Wilcoxon matched-pairs signed rank tests
Planned behavior: Science communication	Attitudes	Internal motivation	4.63 ± 0.29	4.63 ± 0.43	0.000	−4.000	0.8916
		Deficit view of the public	3.27 ± 1.10	2.73 ± 0.96	0.000	−23.00	0.0781
	Norms	Social norms	3.73 ± 0.76	3.78 ± 0.59	0.000	6.000	0.8047
		External motivations	4.16 ± 0.47	4.15 ± 0.57	0.000	1.000	0.9985
	Perceived behavioral control	Science communication knowledge	53.80 ± 21.47	76.20 ± 10.79	21.00	98.00	**0.0007***
		Science communication self-efficacy	3.61 ± 0.53	3.95 ± 0.48	0.4000	71.00	**0.0251***
	Behavioral intent	Intent to participate in science communication	4.33 ± 0.49	4.33 ± 0.62	0.000	0.000	>0.9999
	Behaviors	Frequency of science communication activities	2.80 ± 1.08	3.00 ± 0.85	0.000	9.000	0.3750
Planned behavior: Science civic engagement	Norms	Civic engagement values	4.33 ± 0.72	4.20 ± 0.56	−0.2500	−23.000	0.4597
	Perceived behavioral control	Civic engagement knowledge	4.11 ± 0.72	4.29 ± 0.47	0.000	17.00	0.4258
		Civic engagement self-efficacy	4.32 ± 0.49	4.65 ± 0.40	0.2500	49.00	**0.0117***
	Behavioral intents and behaviors	Civic engagement action	3.84 ± 0.62	3.84 ± 0.63	0.000	−3.000	0.9512
Planned behavior: Addressing misinformation	Attitudes	Misinformation source concerns	4.38 ± 0.43	4.21 ± 0.47	−0.1667	−26.00	0.4772
		Misinformation effects concerns	4.76 ± 0.31	4.79 ± 0.28	0.000	−2.000	0.9463
		Negative effects of misinformation correction	3.18 ± 0.35	3.21 ± 0.39	0.000	8.000	0.8267
	Norms	Social norms toward misinformation correction on social media	3.32 ± 0.88	3.17 ± 0.52	0.000	−17.00	0.5708
		Social norms toward misinformation correction: relational	3.57 ± 0.64	3.79 ± 0.53	0.2000	31.00	0.3481

Theory of planned behavior		Survey constructs	Pre-course mean ± SD	Post-course mean ± SD	Median of differences	Sum of signed ranks (W)	*p*-Value for Wilcoxon matched-pairs signed rank tests
		Community social norms of misinformation correction	3.38 ± 0.66	3.57 ± 0.44	0.1667	25.00	0.3628
		National social norms of misinformation correction	2.80 ± 1.08	3.02 ± 0.97	0.5000	77.00	**0.0129***
	Perceived behavioral control	Misinformation correction self-efficacy	3.30 ± 0.68	3.48 ± 0.56	0.2500	23.00	0.3813
	Behavioral intent	Behavioral intents to address misinformation	2.42 ± 0.66	2.68 ± 1.03	−0.1250	12.00	0.7493
	Behaviors	Past behaviors to address misinformation	1.52 ± 0.28	1.50 ± 0.25	0.000	−14.00	0.6321

TABLE 2

Table of themes identified in interview data, as mapped to the Theory of Planned Behavior. Subthemes and examples of how students discussed the factors (attitudes, subjective norms, and perceived behavioral control) influencing their planned behaviors are shown.

Theory of planned behavior construct	Themes	Sub-themes	Examples
Attitudes	Motivation	Improve society and help others	• Improved decision-making
		Inclusivity	• Audience diversity • Reaching marginalized people
		Personal interest and curiosity	• Science is interesting
Social/subjective Norms	Expectations of self	Ambassador	• Scientists engaging those who cannot access science
		Boundary spanner	• Identity as scientist and also community member
	Expectations of others	Roles and responsibilities	• Field of expertise
		Limitations	• Non-expert
Perceived behavioral control	Science communication knowledge	Theory and practice	• Exposure to theory • Opportunity to practice through class assignments
		Recognizing misinformation	• Cherry-picking • False experts
		Misinformation corrective techniques	• Debunking and prebunking • Source-literacy • Empathy • Cultural competency • Trust
	Barriers	Perceived receptiveness of others	• Confrontational • Close-minded
		Status	• Education • Level of experience • Teaching removes barrier
		Time	• Time is a limited resource