Introduction and Literature Review

Science must be accessible to public audiences. Funding, public debate, behavior change, and policy support often depend upon effectively communicating scientific relevance and research outcomes to many diverse groups. Scientists are increasingly expected to be able to translate their work to lay audiences (Greenwood & Riordan, 2001) to be influential leaders in their field, further the goals of the scientific community, and impact their entire field of study (Blickley et al., 2012). Robust science communication skills are so important in the life sciences that organizations like the BioSharing initiative have formed to make resources more accessible for scientists to improve their communication and make scientific resources widely available (McQuilton et al., 2016). Unfortunately, the public's experience with science is often through mass media and entertainment channels, which lack accuracy and scientific perspective (Besley & Tanner, 2011). It is important that science experts are involved in promoting public understanding of science, listening to audiences, and contributing their expertise and credible information to debates on scientific topics.

While the need for scientists to have communication skills is clearly documented, many graduate programs in the natural sciences do not build the skills needed for graduates to confidently engage public audiences and to share their work using different communication channels and methods (Brownell et al., 2013). Future scientists need science communication experiences that prepare them to communicate about their science outside of the scientific community (Kuehne et al., 2014). The interdisciplinary and ever-evolving nature of science communication is underscored by the need for sustained communication efforts between scientists and the public to increase trust in the sciences and promote the incorporation of science into policy decision-making (O'Keeffe & Bain, 2018). This interdisciplinary aspect is particularly relevant in addressing global scientific challenges such as climate change and food insecurity (Gawryla & Curry, 2022). The perception of science communication among science, technology, engineering, and math (STEM) graduate students has been widely analyzed, highlighting the need for effective science communication training from the perspective of graduate students (Ritchie et al., 2022). Science communication offers an opportunity for students to be creativ e, problem solve, think critically, and enhance their STEM learning (Okwara & Pretorius, 2023; Paolucci et al., 2016).

As such, the importance of teaching science communication curriculum to STEM graduate students such as those in agricultural, food, life, and natural resource sciences is increasingly recognized as a crucial component of their education. However, many graduate education programs in STEM fields generally lack formal training in public communication (Simis et al., 2016). This gap in formal training is significant, as it impacts how STEM graduate students perceive science communication and their future development and involvement in this area (Ritchie et al., 2022). Further, providing graduate students in science and mathematics with independent teaching opportunities that prepare them to effectively teach and communicate STEM subjects to the public is not common, highlighting the need for more comprehensive science communication training for STEM students and scientists (Schwab et al., 2018).

While literature continues to document the lack of training opportunities for graduate students in science communication, because of its critical role in shaping the future of scientific research and public engagement with science, some programs have emerged to teach graduate students science communication and public engagement. The approaches of programs vary, but many include interpersonal science communication and outreach experiences (Kompella et al., 2020; Loizzo et al., 2019; O'Keeffe & Bain, 2018). Science communication training opportunities often allow scientists to educate young students about research while improving their science communication skills and sharing their enthusiasm for science (Clark et al., 2016; Loizzo et al., 2019). Research has shown that interactive youth science workshops not only benefit student participants but also provide opportunities for graduate students to engage with the public, improve their science communication skills, and enhance public understanding of science (Kompella et al., 2020; Loizzo et al., 2019). However, no previous work has quantified how many programs and experiences exist for graduate students and how many students are offered or expected to engage in these learning experiences.

As society becomes increasingly dependent on STEM, the importance of STEM education, including effective science communication, becomes more pronounced (Maiorca & Mohr-Schroeder, 2020). It is clear there is a growing consensus on the need to enhance science communication training for STEM graduate students. This is further supported by the National Science Foundation (NSF) and the U.S. Department of Education's substantial investments in creating resources supporting STEM learning (Elliot et al., 2013). Therefore, it is imperative to address the deficit in formal training in public communication within STEM graduate education programs to ensure that future scientists are equipped with the necessary skills to communicate their research effectively to diverse audiences.

Conceptual Framework

The conceptual framework in this study was guided by science communication frameworks and science communication skills documented in the literature. Science communication skills are essential for influencing attitudes, making scientific resources widely accessible, addressing global scientific challenges, and shaping the future of scientific research and public engagement. Many researchers and science institutions have explored the goals and overall importance of science communication. The National Academies of Science, Engineering, and Medicine (2017) advises that science communication should be used to improve knowledge and impact perceptions. Borchelt (2001) contends that science communication should be used to support more informed decision-making by the public and policymakers.

Multiple studies have documented the specific science communication skills needed to effectively communicate science to the public. Mercer-Mapstone and Kuchel (2015) specifically explored skills that should be taught in science communication. Based on a modified Delphi study, Mercer-Mapstone and Kuchel identified 12 core skills of effective science communication. These skills were then ranked for essentiality by science communication experts. The ranking results from the highest to the lowest are as follows: 1) identify and understand a suitable target audience; 2) use language that is appropriate for your target audience; 3) identify the purpose and intended outcome of the communication; 4) consider the levels of prior knowledge in the target audience; 5/6) separate essential from non-essential factual content in a context that is relevant to the target audience; 5/6) use a suitable mode and platform to communicate with the target audience; 7/8) consider the social, political, and cultural context of the scientific information; 7/8) use/consider style elements appropriate for the mode of communication; 9) understand the underlying theories leading to the development of science communication and why it is important; 10) promote audience engagement with the science; 11) use the tools of storytelling and narrative; and 12) encourage a two-way dialogue with the audience.

Leal et al. (2020) identified similar skills that are necessary for agricultural communication graduates. Leal et al. surveyed agricultural communication graduates, industry professionals, and agricultural communication faculty to determine the most important technical skills. While there were differences among the three groups, the following skills were determined to be the most important overall: communicate in written form, concise and clear writing, communicate verbally, proper punctuation, grammar, and spelling, ability to use technology, active listening, ability to adapt to contemporary media, understand client needs and goals, ability to use different information sources, reading, and researching. While science communication skills have been documented in the literature, it is important to note that the majority of these studies were conducted with undergraduate education in mind, which continues to leave gaps in understanding around graduate science communication skills.

Purpose and Objectives

The purpose of this exploratory study was to understand graduate students' perceptions of the need for science communication skills, their perceived science communication abilities, and the opportunities they are seeking to gain these skills at their institutions of higher education. This study was specifically guided by the following research objectives:

1) Determine the level of importance placed on science communication skills for career success by agricultural science graduate students
2) Determine the perceived ability of agricultural science graduate students to perform individual science communication skills
3) Determine agricultural science graduate students' participation in science communication skill development opportunities.

Methods

The participants in this study were agricultural science graduate students from two large land grant institutions. Land-Grant Institution A (LGA) was in the North Central United States and Land-Grant Institution B (LGB) was in the Southeastern United States. A total of 158 students voluntarily participated in the survey with 67 from LGA and 91 from LGB. A census sampling procedure was used to gain perspectives from as many agricultural science graduate students as possible at the two participating institutions. The numbers of graduate students enrolled in agricultural sciences in spring 2023 at LGA and LGB were 510 and 2,185, respectively, indicating a 13% and 4% response rate. Participants were recruited through university email listservs of the graduate student populations specifically enrolled in each university's college of agriculture. No incentives were offered to graduate students who completed the survey. Three waves of the survey were sent to graduate students at both institutions before the survey was closed (Dillman et al., 2014). Data were collected from April 26, 2023, to June 8, 2023.

Survey Instrument

A structured questionnaire was developed specifically for this study to assess the study objectives. Questions were designed using the Dillman Tailored Design method (Dillman et al., 2014). The questionnaire consisted of three sections:

1. Importance of Science Communication Skills: This section comprised Likert-scale items (ranging from 1 to 5) where participants rated the perceived importance of the 12 science communication skills (Mercer-Mapstone & Kuchel, 2015) for their career success in agricultural science.
2. Self-Assessment of Science Communication Skills: Participants were asked to self-assess their perceived ability to perform the 12 science communication skills (Mercer-Mapstone & Kuchel, 2015).
3. Participation in Skill Development Opportunities: This section explored the extent of participants' engagement in science communication skill development activities available at their institutions. It included questions related to workshops, seminars, courses, and other relevant opportunities attended by participants to enhance their science communication skills based on the format of known available opportunities (Clark et al., 2016; Kompella et al., 2020; Loizzo et al., 2019; O'Keeffe & Bain, 2018) and recommended opportunities (Besley et al., 2011; Blickley et al., 2012; Brownell et al., 2013; Greenwood & Riordan, 2001; Ritchie et al., 2022; Schwab et al., 2018).

Additionally, data on demographic and academic backgrounds were collected to compare responses based on participant characteristics. Respondents were also asked about science communication opportunities currently offered to them and one qualitative question asking about previous science communication experiences prior to enrolling in their degree program.

Data Collection Procedure

The survey was administered online using Qualtrics to ensure easy access and convenience for participants. Participants were provided with information about the study's objectives, voluntary participation, and confidentiality of responses before they began the survey.

This study obtained approval from the Institutional Review Board (IRB) at LGA and LGB institutions. Participation was voluntary, and informed consent was obtained from all participants before they proceeded with the survey. Confidentiality and anonymity of responses were maintained throughout data collection and analysis.

Data Analysis

Descriptive statistics (mean, standard deviation) were used to analyze the Likert-scale responses regarding the perceived importance of science communication skills and self-assessment of skills. Additionally, frequency distributions were used to analyze the extent of participation in science communication skill development opportunities.

Limitations

This study is limited by the focus on only two land-grant institutions in the United States and results may not be generalizable to all land-grant institutions. Additionally, the sample size may not allow for generalizations beyond the participants within this study; however, patterns within the data can still allow for the development of science communication skill offerings within LGA and LGB Institutions.

Results

The total number of usable responses of 134 was split 43% (*n* = 57) from LGA and 58% (*n* = 77) from LGB (Table 1). Overall, 42% (*n* = 56) were master's students. At LGA, 63% (*n* = 36) of responses came from doctoral students, compared to 55% (*n* = 42) at LGB. Master's students were in their degree program for 3 terms on average, while the average among doctoral students was 5.7 terms (and both institutions are semester-based). The respondents represented most of the program areas offered by respective colleges, including economics; animal, food, and plant sciences; natural resources and environmental sciences; biology; and engineering. LGB offers graduate programs in agricultural communication and there were responses from students in that field (9.7% of total usable responses; *n* = 13), but LGA does not offer graduate programs in agricultural communication so there were no agricultural communication students sampled from LGA.

Roughly 64% of respondents (*n* = 86) completed their K-12 schooling in the U.S. at both institutions and identified English as one of their first languages. Forty-two percent of LGB respondents were in their thirties or older, compared to 33% of LGA respondents. Seventy percent of masters' students (*n* = 41) were in their twenties, compared to 54% of doctoral students (*n* = 42) (not reported in Table 1). In terms of educational attainment by adults at home during childhood, 79% of LGA students (*n* = 45) indicated baccalaureate or higher, compared to 70% among LGB students (*n* = 54).

Table 1
Demographic and Academic Backgrounds of Sample Graduate Students

	All	LGA	LGB
Number of responses (*n*)	158	67	91
Response rate (%)	5.9%	13.1%	4.2%
Number of complete responses	134	57	77
% Masters students	41.8%	36.8%	45.5%
Average duration in the program (# terms)	4.6	5.3	4.0
Master's students	3.0	3.3	2.9
Doctoral students	5.7	6.5	5.0
K-12 in the United States	64.2%	63.2%	64.9%
English is (one of) first language(s)	69.4%	68.4%	70.1%
Gender			
Male	22.6%	23.2%	22.1%
Female	73.7%	75.0%	72.7%
Non-binary	3.8%	1.8%	5.2%
Under 30 years of age	61.9%	66.7%	58.4%
Educational attainment of grown-ups during childhood			
Bachelor's degree	36.6%	35.1%	37.7%
Graduate or professional degree	37.3%	43.9%	32.5%

The open-ended responses to previous science communication experiences were recoded and varied ranging from opportunities to use oral and writing skills, including leadership and teaching (Table 2). The two most common experiences mentioned were professional outreach

(22%; n = 30) and technical (academic) presentations (20%; n = 27), followed by work or internship (19%; n = 25) and collegiate coursework outside agricultural communication (13%; n = 17). Only 4.5% (n = 6) mentioned collegiate coursework in science or agricultural communication.

Table 2

Previous Science Communication Experience Before Starting the Current Degree Program

	Number of responses (*n*)	Percent of 134 responses (%)
Outreach as professional	30	22.4%
Technical presentations	27	20.1%
Work/ internship	25	18.7%
Collegiate coursework (non-ag communication)	17	12.7%
Teaching	16	11.9%
Communication as professional/training/internship	15	11.2%
Low/none	15	11.2%
Academic/ popular press writing	13	9.7%
Non-academic conversations about research	8	6.0%
Interviews/ non-academic presentations	7	5.2%
Collegiate coursework in sci/ag com	6	4.5%
Attending professional conference	5	3.7%
Committee /team leadership	2	1.5%
Pre-college extracurricular (e.g., 4-H, FFA)	2	1.5%

In terms of career aspirations, 57% (*n* = 76) indicated academia in agriculture, food and natural resources (Table 3). The interest was high in the field of agriculture, food and natural resources across other sectors including private sector (43%; *n* = 57) and Cooperative Extension (42%; *n* = 56). Two other fields of significance were education and training (14% academia, *n* = 19; and 13% cooperative extension, *n* = 18) and STEM (13% academia, *n* = 18; and 14% private sector, *n* = 19). Interests expressed across all fields, suggesting the breadth of how agricultural degrees can be applied.

Table 3

Career Aspirations Indicated by Participants (n = 134)

Subject area	Academia (research and/or teaching appointments)	Cooperative Extension	Other public sector	Private sector	Non-profit sector
Agriculture, Food and Natural Resources	57%	42%	40%	43%	31%
Architecture & Construction	1%	0%	0%	1%	0%
Arts, Audio/Video Technology & Communication	3%	1%	4%	3%	2%

Business Management & Administration	2%	1%	0%	2%	0%
Education & Training	14%	13%	4%	6%	7%
Finance	1%	1%	2%	4%	1%
Government & Public Administration	5%	6%	8%	3%	6%
Health Science	7%	2%	4%	8%	1%
Hospitality & Tourism	0%	0%	1%	3%	1%
Information Technology	0%	0%	0%	2%	0%
Law, Public Safety, Corrections & Security	1%	0%	1%	1%	1%
Manufacturing, Engineering & Mining	1%	0%	1%	2%	0%
Science, Technology, Engineering & Mathematics	13%	7%	9%	14%	8%
Transportation, Distribution & Logistics	0%	0%	1%	1%	0%

Objective 1: Level of importance placed on science communication skills for career success

The ranking of importance of the 12 science communication skills were largely consistent with the science communication experts (Mercer-Mapstone & Kuchel, 2015), with several notable exceptions. The top two were the same, with students ranking “Use language that is appropriate for your target audience” slightly more important than “Identify and understand a suitable target audience. The next two were consistent: “Identify the purpose and intended outcomes of the communication” and “Consider the levels of prior knowledge in the target audience.” The latter was ranked virtually the same as “Use suitable mode and platform to communicate with the target audience.” Then, students ranked “Promote audience engagement with the science” and “Encourage a two-way dialogue with the audience” as 6th and 7th important, respectively, compared to the 10th and 12th ranking given by the science communication experts. They also rated “Use the tools of storytelling and narrative” as the 9th, compared to the 11th by experts. The three skills students rated the lowest were “Understand the underlying theories leading to the development of science communication and why it is important,” followed by “Consider the social, political, and cultural context of the scientific information” and “Use/consider style elements appropriate for the mode of communication.”

Table 4

Perceived Importance and Self-Assessment of Science Communication Skills

Skill	Average score for perceived importance[a]	Ranking of importance by experts[b]	Average score for self-assessed ability[c]	Ranking by self-assessed ability scores
1. Use language that is appropriate for your target audience	3.88	2	3.36	2
2. Identify and understand a suitable target audience	3.85	1	3.31	3
3. Identify the purpose and intended outcomes of the communication	3.78	3	3.42	1
4. Consider the levels of prior knowledge in the target audience	3.72	4	3.10	5
5. Use a suitable mode and platform to communicate with the target audience	3.72	5.5	3.11	4
6. Promote audience engagement with the science	3.60	10	2.94	8
7. Encourage a two-way dialogue with the audience	3.54	12	2.85	11
8. Separate essential from non-essential factual content in a context that is relevant to the target audience	3.52	5.5	3.06	6
9. Use the tools of storytelling and narrative	3.43	11	2.94	9
10. Consider the social, political, and cultural context of the scientific information	3.40	7.5	2.90	10
11. Use/consider style elements appropriate for the mode of communication (such as humor, anecdotes, analogy, metaphors, rhetoric, images, body language, eye contact, and diagrams)	3.39	7.5	3.05	7
12. Understand the underlying theories leading to the development of science communication and why it is important	3.19	9	2.77	12

[a] 4 = “High importance”, 3 = “Moderate importance”, 2 = “Low importance”, 1 = “No importance”, 0 = “I don’t know what this means.”
[b] Mercer-Mapstone & Kuchel, 2015.
[c] 4 = “High ability”, 3 = “Moderate ability”, 2 = “Low ability”, 1 = “No ability”, 0 = “I don’t know.”

Objective 2: Perceived ability to perform individual science communication skills

The student self-assessment of skills correlated somewhat to the importance they perceived. The top 5 were in general accordance, although they perceived that they were most skilled at “Identify[ing] the purpose and intended outcomes of the communication.” The skills with the largest discrepancy in terms of their self-assessment and perceived importance were “Use/consider style elements appropriate for the mode of communication,” which they were more comfortable with, relative to their perceived importance, and “Encourage a two-way dialogue with the audience” which they rated second from the bottom in terms of ability but thought that they were relatively more important.

Objective 3: Participation in science communication skill development opportunities

Table 5 presented opportunities to strengthen science communication skills that students are aware of in the order of familiarity. The other columns report the percentage of respondents who have participated in the opportunities and would participate if offered. The percentage of students who have participated in these opportunities are lower than those who recognize their existence. The types of opportunities that were recognized as being available and still excited students if offered includes “International/national/regional research conferences” and “High impact in-class experiences including oral, written and team-based assignments.” The opportunities that were less commonly available, but students were indicated interest if offered included “Fellowships: short-term paid opportunities focused on academic and professional development,” “Experiential learning as part of the course work that takes place outside the classroom,” and “Apprenticeships: paid experiences that will likely lead to more permanent employment.”

Table 5

Opportunities for Developing Science Communication Skills (n = 134)

	Aware of their availability	Have participated	Would participate if available
Assistantships: research or teaching opportunities that result in a stipend and/or tuition assistance	77%	68%	54%
International / national / regional research conferences	66%	54%	63%
High impact in-class experiences including oral, written and team-based assignments	54%	47%	54%
Fellowships: short-term paid opportunities focused on	34%	18%	63%

	Aware of their availability	Have participated	Would participate if available
academic and professional development			
Internships: paid or unpaid employment that is short-term	26%	12%	40%
University research days	26%	21%	40%
Experiential learning as part of the course work that takes place outside the classroom	25%	22%	62%
Apprenticeships: paid experiences that will likely lead to more permanent employment	4%	2%	58%

Conclusions and Recommendations

The results of this study support the importance of science communication skills and experiences for graduate students in agricultural and natural resources fields. Overall, the graduate students that participated in this study ranked the perceived importance of science communication skills similarly to the expert ranking reported by Mercer-Mapstone and Kuchel (2015). The graduate students and science communication experts ranked the same skills in the top five. Differences in the ranking started to appear in skill six through twelve. Most notably, graduate students in this study ranked “promote audience engagement with the science” in sixth place, while experts in the Mercer-Mapstone and Kuchel study ranked this skill in tenth place. Additionally, graduate students in this study ranked “encourage two-way dialogue with the audience” in seventh place, while experts in the Mercer-Mapstone and Kuchel study ranked this skill last - in twelfth place. Graduate students and science communication experts may place a differing emphasis on different skills due to their unequal participation in science communication or demographic factors, such as age. It is also possible that since 2015 some of the available opportunities for science communication have changed. Graduate students in this study in 2023 have a lot more access to social media than experts did in 2015, which may be reflected in the different priority place on “encourage two-way dialogue with the audience”. Since 2015 new platforms like TikTok have emerged that allow for two-way communication of scientific information in an entirely new format. Additionally, in a post-COVID world, graduate students may place more importance on “promote audience engagement with the science” than experts did in 2015.

Many of the skills students ranked as less important were also skills where they indicated lower perceived ability. A lack of formal and specialized training in these skills could impact students’ ability and, in turn, their perceptions of the importance of these skills (Ritchie et al., 2022; Simis et al., 2016). Graduate students would benefit from science communication skill development in all areas, but particular attention should be paid to skills that were self-assessed lower than others, including underlying theories of science communication, encouraging two-way dialogue, consideration of social, political, and cultural contexts, and use of storytelling tools.

Unsurprisingly, most graduate students in this study indicated they have participated in assistantships or research conferences as an opportunity to develop science communication skills. A smaller portion of students participated in fellowships, internships, or apprenticeships but many indicated they would participate in these opportunities if available. These opportunities may be less available but would be valuable in providing students with real-world experience in science communication, which is necessary to build their skills in science communication (Kuehne et al., 2014). There is a wealth of opportunities available to create science communication skill development experiences for graduate students with 40-63% of graduate students in this study indicating they would participate in all types of science communication skill development experiences if these were made available to them at their institution.

Future research should consider surveying science communication experts again to compare differences in priorities from 2015 to present and compare to current graduate student rankings. Additionally, research should be conducted with the public to compare the views of graduate student scientists' preferences for science communication strategies with the preferences of the public for engaging with scientists and scientific content. Moreover, as more opportunities for science communication training emerge for graduate students, this study should be repeated to measure changes and continually measure the landscape of opportunities available for graduate students in this space. Additionally, this research should be conducted at other colleges of agriculture and land-grant universities beyond the two specific institutions in the present study.

Agricultural and science communication instructors are encouraged to include more instruction in the classroom related to science communication, particularly including skills related to underlying theories of science communication, encouraging two-way dialogue, consideration of social, political, and cultural contexts, and use of storytelling tools. Agricultural and natural resource communication faculty designing curriculum and experiences for graduate students in science communication should integrate these in their courses and experiences. Moreover, students should be given opportunities to practice these to improve their skills and become effective science communicators. More specifically, academic units and individual instructors can expand their offering of experiential learning as part of the coursework. Paid opportunities require sponsorship and relationship building with off-campus partners, which should be pursued at the academic department and/or college level, but instructors have more control about what skills and high-impact experiences are included in their course curriculum. Communication units at universities could provide learning experiences for graduate students to learn and practice science communication skills.

Agricultural communication units and offices of research are ideal entities to provide opportunities to graduate students to develop science communication through real-world experiences, while also reaping the benefits of skilled support staff. Moreover, opportunities may exist with science centers within colleges and universities to offer long or short-term learning experiences or fellowships for graduate students to gain science communication experiences. Communication professionals in these units should provide mentorship to graduate students participating in science communication to ensure best practices are adopted by the aspiring science communicator.

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