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Developing Collaborative Communicators: A Qualitative Case Study of Student-Scientist Partnerships and Project-Based Learning Experiences

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Abstract

As scientists are called upon to communicate their research, it is important to prepare upcoming science communicators to collaborate with science experts to develop effective communication. Agricultural and natural resources (ANR) communication college students could gain experience working with scientists through project-based learning (PjBL). However, little is known about the experiences of scientists and students collaborating in PjBL courses. The study evaluated scientists' past science communication experiences, how they prepare to communicate with the public, and their perceptions of collegiate students' science communication projects featuring their research. We conducted pre-/post-interviews with ANR scientists (n = 18) who participated in student-created photo essays and electronic field trips via three PjBL courses. Results included the following themes: a) Scientists' past science communication experiences were influenced through media consumption and education, sharing science with others, and prior work experiences before their current position, b) Some scientists did not prepare for science communication and engagement, while others tailored their messages to the audience and practiced ahead of time, c) Scientists were satisfied with the overall products the students created, yet they suggested future improvements to time management and writing quality. Future recommendations include science communication training for scientists to: a) develop skills in simplifying complex scientific concepts while maintaining accuracy and building confidence and b) tailor the message to the audience, with adjustments to language, content depth, and delivery style. Finally, we recommend implementing an ANR communication PjBL curriculum to foster collaboration between scientists and college students, co-constructed communication, and real-world project development.

Keywords

project-based learning, science communication, scientists, students, collaboration, media, multimedia, writing, interviews, electronic field trips, communication training

Cover Page Footnote/Acknowledgements

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Introduction

Science communication is a growing area of research and analysis (Burns et al., 2003; Guenther & Joubert, 2017; NASEM, 2017; Nisbet & Scheufele, 2009). The pace of science communication has become immensely faster, information is conveyed in smaller units, and the modes and mediums of delivery are far more numerous (Côté & Darling, 2018). Science communication can be defined as the identification of science knowledge gaps and use of appropriate skills, media, activities, and dialogue to produce science awareness, enjoyment, interest, opinion, and understanding (Burns et al., 2003; Fischhoff, 2013). Prior research has indicated the public has limited knowledge about scientific research and findings, and it appears scientists also perceive a gap exists between the public's science knowledge, valuation of the scientific profession, and how citizens are informed about science (Burns et al., 2003; Llorente et al., 2019). Therefore, it is critical to leverage science communication to increase awareness, connection, and engagement between scientists and the public (Burns et al., 2003; Dudo, 2015; Howell & Brossard, 2021).

Scientists and engineers today have the funds, opportunities, and often the desire for public engagement (Cerrato et al., 2018; MORI, 2000). Thus, it is vitally important to explore how scientists conceptualize and negotiate ideas of the public and public communication. As Lévy-Leblond (1992) argued more than 15 years ago, "scientific understandings of publics" are just as important an area of study as "public understandings of science" (Davies, 2008). Since at least the mid-20th century, leaders have noted a disconnect between scientists and the public (Davies, 2008). Scientists are often labeled out of touch with the public, yet there is opportunity for scientists and citizens to come together to dialogue and act together for policy change (Davies, 2008; Riesh et al., 2017). However, science communication trainers have suggested scientists rarely focus on applying two-way dialogic communication techniques, such as listening to their audiences or tailoring messages based on their audiences' needs (Yuan et al., 2017). Scientific leaders have increasingly urged the science community to improve its efforts in science communication and engagement with the public (American Association for the Advancement of Science, 2018; Davies, 2008). Research has shown scientists perceive the public as being uninformed about science, leading to misunderstandings that can result in errors in judgment and policy preferences (Besley & Nisbet, 2011; Davies, 2008). Additionally, research has shown that while scientists are often critical of media coverage, such as potential negative impacts on scientist portrayals on public perception, they acknowledge that engaging with the media is important to promote scientific literacy (Besley & Nisbet, 2011; Donois et al., 2025; Dudo, 2015).

The study explored scientists' previous experiences with science communication, their typical preparation methods for such activities, and their experiences participating in agricultural and natural resources (ANR) college students' communication and outreach projects. The study also examined the implementation and impacts of the project-based learning (PjBL) instructional design model in collegiate ANR communication to prepare the next generation of science communicators to collaborate with scientists. Although previous research has shown PjBL positively influenced students' development of science communication skills (Loizzo & Beattie, 2019; Krebs et al., 2021), little is known about how participating scientists perceive the students' completed work about their research. Furthermore, there is limited information on how scientists prepare for public science communication efforts. The findings of this research could significantly influence the field of ANR science communication, education, and PjBL as an instructional method for scientists, students, and educators nationwide. Additionally, the study contributes to a deeper understanding of the processes and perceptions involved in science communication and PjBL.

Literature Review

Literature from the fields of science communication, the role of scientists in science communication, and the teaching of science communication guided the study.

Science Communication

Science communication is a growing field of practice and research, involving scientists and others in the dissemination of science-related knowledge (Bucchi & Trench 2021; Burns et al., 2003; Cooke et al., 2017). More specifically, science communication is the use of proper skills, media, activities, and dialogue to produce awareness, enjoyment, interest, perception forming, and understanding (Burns et al., 2003). Over the past two decades, science communication has become an increasingly used practice (Bucchi & Trench 2021; Burns et al. 2003; Sturzenegger-Varvayanis et al., 2008). Science communication techniques and the individuals involved are diversifying, partly due to innovations in media (Bucchi & Trench, 2021). New tools such as smartphones and emerging platforms such as social media, podcasts, and online video have allowed for a broader range of people beyond professional communicators to participate in shaping and sharing science information. Science communication products are featured in professional academic conferences and professional development workshops for peer review, and products are also shared beyond academia via news media and online platforms for public review (Cooke et al., 2017).

There is no single approach to science communication (Bucchi & Trench 2021; Cooke et al., 2017). Achieving effective science communication is often strongly linked with applying concepts of strategic communication, such as tailoring messages to specific audiences (Bautista et al., 2022; Bucchi & Trench, 2021). For the last half century, science communication has primarily fallen under the responsibility of educators, extension agents, or trained science journalists, communicating complicated science as easily understandable concepts to the public (Cooke et al., 2017). More recently, scientists moved to sharing their peer-reviewed research beyond publications, to interact more with the public through infographics, blogs, video summaries, Twitter, and the media (Cooke et al., 2017).

Scientists and Science Communication

Science communication enables scientists to share their discoveries with the public, thereby enhancing overall knowledge and understanding (Burns et al. 2003; Hu et al., 2018). Thus, science communication is of the utmost importance for issues and scientific discoveries that closely relate to or affect the public (Hu et al., 2018). However, most scientists lack formal training in science communication (Cooke et al., 2017). As a result, scientists' engagement in science communication is not always productive or effective (Hu et al., 2018). Science communication can be tailored to align with an individual's motives, time constraints, resources, personality, and the specific subject they wish to convey (Cooke et al., 2017). Currently, there is limited understanding of scientists’ attitudes and perceptions regarding public engagement with science as well as the institutional barriers that may hinder such engagement (Sturzenegger-Varvayanis et al., 2008).

Science communication is inherently academic and often inefficient in its delivery of key concepts to the public (Webb et al., 2012). Engaging with the public through science communication has increasingly been perceived as a responsibility of scientists (Brownell et al., 2013). Although scientists are extensively trained in research methodologies, analytical skills, and communicating with their peers, they typically do not receive explicit training in conveying scientific concepts to the public (Brownell et al., 2013). Communicating with the public is often regarded as a challenging skill many practicing scientists lack, primarily due to increased specialization over time and a lack of formal training in science communication (Brownell et al., 2013). Researchers argue incorporating formal communication training into undergraduate and graduate curriculum for aspiring scientists and/or individuals within the STEM field will enhance the quality of dialogue and understanding between scientists and the public (Besley & Tanner, 2011; Brownell et al., 2013;). Moreover, researchers maintain science communication training enhances scientists' influence on public understanding of science and perceptions of scientists (Webb et al., 2012). It is essential to not only teach scientists how to communicate effectively but also to train professional science communicators to collaborate with scientists.

Teaching ANR Science Communication

Effective communication of scientific information to the public requires strong partnerships between communicators and scientists (Bennett et al., 2019; Bowater & Yeoman, 2012). One way to teach and cultivate solid science communicator-scientist partnerships could be to offer real-world opportunities for ANR communication college students to work alongside scientists to develop skills for partnering with experts to co-construct communications products (Loizzo et al., 2018; Loizzo et al., 2016). Throughout the years, scholars have examined what content is typically taught in college ANR communication curricula and what competencies employers and stakeholders expect ANR communication graduates to have (Cannon et al., 2016; Leal et al., 2020; Morgan, 2012). Results have shown ANR communication curricula often focus on a mixture ANR issues and contextual information, technical skills such as writing, videography, and design, public relations, media relations, and risk communication (Cannon et al., 2016). Employers and alumni expect ANR communication graduates to be strategic writers, creative storytellers, and proficient with new media (Leal et al., 2020; Morgan, 2012). Internationally, a curriculum visioning study in Australia found agricultural industry and faculty members (n = 29) identified the ideal ANR communication graduate to have knowledge of agricultural issues, strong writing skills, the ability to communicate research, problem-solving skills, and technical design and visual skills (Thorn et al., 2022). Leal et al. (2019) also found ANR graduates should have social skills such as trustworthiness, trainability, professionalism, strong oral communication, and behave ethically in the workforce.

As a response to the need to cultivate professional ANR communicators with ANR science knowledge, technical communication skills, and social skills, *The Streaming Science Project* was created as an approach and platform to engage ANR communication students in real-world experiences to strengthen their development (Streaming Science, 2021). The media platform is a college student-driven project-based learning (PjBL) science literacy program and was used as the context for the study. *The Streaming Science Project* and its supporting college courses follow a PjBL approach to encourage students to use critical thinking skills and analysis to explore ANR contexts in partnership with experts to create real-world communication products (Loizzo et al. 2018).

Conceptual Framework

The instructional design framework of project-based learning (PjBL) guided this scholarship of teaching and learning study. Research has suggested education should foster students' innovation by supporting their autonomy during learning tasks (Martín et al., 2017). Researchers suggested PjBL can meet learner-centered instructional needs (Guo et al., 2020). PjBL is a student-focused form of teaching characterized by students' autonomy, constructive investigations, goal setting, collaboration, communication, and reflection within real-world practices (Guo et al., 2020; Kokotsaki et al., 2016). PjBL is a specific form of inquiry-based learning where the learning context is framed by authentic questions and real-world problems, leading to meaningful learning experiences and deeper understanding (Holobova, 2008; Kokotsaki et al., 2016).

Furthermore, PjBL is grounded in constructivist learning theory, which identifies learning becomes deeper and more meaningful when students actively construct their own knowledge and understanding. Therefore, students are given the opportunity to select a topic of interest within a given set of guidelines to create their projects (Holubova, 2008). Completed projects are often in the form of videos, photographs, sketches, reports, models and other collected research and information (Holubova, 2008). Researchers argue the autonomy and challenges students encounter through PjBL, as they design and develop their projects, lead to high levels of student engagement (Wurdinger et al., 2007). The distinctiveness of PjBL lies in the project construction, which reflects students' new understandings, knowledge, and attitudes about the topic of interest (Kokotsaki et al., 2016).

PjBL can be used to teach the next generation of science communicators. Collegiate science communication programs should aim to provide dynamic, student-centered education to cultivate a workforce with strong critical thinking skills and a scientifically literate public (Ernst & Monroe, 2006). Research shows PjBL challenges and further develops students' communication skills (Krebs et al., 2021). Further research suggests PjBL is an effective method for engaging students in real-world contexts, enabling them to take charge of their learning experience. This approach fosters a deeper understanding of agricultural and natural resource issues, enhances communication and digital skills, and supports the development of projects created for real-world audiences (Loizzo et al., 2018).

Purpose and Research Questions

The purpose of this research was to use video and email interviews to determine how scientists prepared for science communication and perceived college students' media production and outreach projects published on *Streaming Science*. This research is beneficial in determining the impact of science communication and PjBL. The study aimed to answer the following research questions (RQs):

- RQ1: What are scientists' past science communication experiences?
- RQ2: How do scientists typically prepare for science communication/engagement?
- RQ3: What are scientists' perceptions of final products science communication college students created about the scientist and their work?

Together, RQs 1 and 2 provided essential context for interpreting RQ3. Understanding scientists' prior experiences and preparation for science communication helped explain how they engaged with students in PjBL and how they evaluated student-created communication products. Without this background, it would have been difficult to assess the alignment between scientists' expectations and the outcomes of student work.

Methods

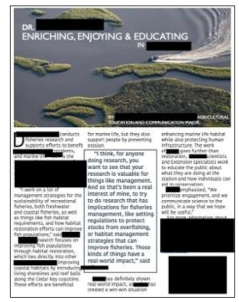
Research Design

This research followed a qualitative case study design including pre-/post-semi-structured interviews with participating scientists. A case study design is often used to examine a real-life phenomenon in context and in-depth (Yin & Campbell, 2018). The phenomenon under study was scientists' science communication experiences and their collaboration with collegiate science communication students. The three research questions were designed to work in tandem to provide a holistic understanding of the scientist-student collaboration in PjBL contexts. RQs 1 and 2 established a baseline of scientists' communication experiences and preparation, which was critical to interpret their feedback on student-created products (RQ3). This layered approach allowed for a more nuanced analysis of how scientists' backgrounds influenced their perceptions of student work, and how future PjBL instruction can be tailored to better support both parties. The study was bound to a single university focusing on three different research groups and involved interviews, researcher observations, and artifacts from science communication student projects. The study received human subjects' approval from the University of Florida's (UF) Institutional Review Board (IRB#202002202).

Research Context

Streaming Science is a science literacy program driven by college students through PjBL. The mission of *Streaming Science* is to introduce public audiences to scientists and critical ANR research through multiple interactive communication platforms. Through a series of courses and experiences, ANR undergraduate and graduate students develop videos, photo essays, virtual reality tours, podcasts, and live interactive electronic field trips for *Streaming Science* audiences (*Streaming Science*, 2021). Most of the participating students had previous communication knowledge and experience from foundational writing and public speaking college courses, while some had advanced knowledge in writing, photography, and video from coursework and internships. The study included PjBL contexts where students worked with scientists to develop real-world media and programming (Table 1).

Table 1
ANR Courses

Course	Project Overview	Roles and Tasks	Project Samples
AEC 4035 (Fall 2020, Spring/Fall 2021, and Fall 2021)	Undergraduate students collaborated with scientists to create photo essays about them and their work.	Scientists: interviewee, provide previous photos, review project drafts. Students: interviewer, photographer, writer, and designer.	
AEC 5032 (Fall 2020, Spring 2021, and Fall 2021)	Cross listed with the above course. Graduate students also collaborated with scientists to create photo essays about them and their work.	Scientists: interviewee, provide previous photos, review project drafts. Students: interviewer, photographer, writer, and designer.	
AEC 5541 (Fall 2020 and Fall 2021)	Graduate students collaborate with scientists to develop, implement, and assess an electronic field trip for middle and high school audiences and them and their work.	Scientists: co-construct content/script, live video guest, co-construct assessment, provide feedback. Students: website and registration design for audience recruitment, development of Teachers' Guide for educators, co-construct content/script, prepare visuals, live video production, co-construct and implement assessment.	 

Participants

For the study, we analyzed in-depth interviews conducted by author Loizzo (instructor) and author Stone (doctoral student at the time of data collection) with approximately 18 scientists from three labs at the UF. (Pseudonyms are used for the labs). Those who participated in an interview were then followed up with an additional interview via email. Plant Lab worked with

AEC 4035/5032 *Communication Practices for Agricultural and Life Sciences* and AEC 5541 *Instructional and Communication Technologies in Agricultural and Life Sciences* in Fall 2020, Coastal Lab worked with AEC 4035/5032 in Spring 2021, and Bee Lab worked with AEC 4035/5032 and AEC in Spring 2021. The study is based on an analysis of video and text-based email interviews with 18 scientists from across the three labs. The video and text-based email interviews were followed by a coding-based data analysis. Scientist participants were actively involved in research (Table 2).

Table 2
Participant Data by Interview and Course Activity

Participant	Lab	Pre-Interview	Post-Interview	AEC 5541 Electronic Field Trip	AEC 4035/5032 Photo Essay
Scientist #1	Plant	x	x		x
Scientist #2	Plant	x	x		x
Scientist #3	Plant	x	x	x	x
Scientist #4	Plant	x	x	x	x
Scientist #5	Plant	x	x	x	x
Scientist #6	Bee	x	x	x	x
Scientist #7	Bee	x			x
Scientist #8	Bee	x			x
Scientist #9	Bee	x			x
Scientist #10	Bee	x			x
Scientist #11	Bee	x	x	x	x
Scientist #12	Bee	x	x		x
Scientist #13	Bee	x	x	x	x
Scientist #14	Coast	x	x	x	x
Scientist #15	Coast	x	x	x	x
Scientist #16	Coast	x			x
Scientist #17	Coast	x			
Scientist #18	Coast	x			

Note: "x" indicates participation in the respective activity.

Data Collection

Through the pre-and post-interviews, scientists were asked to share stories about their past experiences with science communication, science communication preparation, and perceptions of science communication students' EFTs and/or photo essays. Lead author Murphy developed themes through a coding process as described in the following Data Analysis sub-section to capture the underlying patterns amongst the scientists to inform design of future PjBL ANR communication courses for scientist-student partnership cultivation. Loizzo and Stone conducted one-on-one pre-interviews with the scientists via Zoom. Scientists were asked a series of questions throughout the interview. Each interview followed a semi-structured interview guide. Each interview started and ended with the same questions; however, the questions in between were dependent on how the conversation progressed. The semi-structured interview guide’s questions focused on prior experiences, current communication and research efforts, science communication, and preparation for science communication. Each interview started with a question asking the scientists to talk about themselves and their careers. From there, questions were then focused on educational experience and more in-depth questioning about their current position. After these initial questions, scientists were prompted with the question “How do you typically prepare to communicate with the public or interviews such as this?”

After the interviews were conducted, students enrolled in AEC 4035/5032 and AEC 5541, facilitated by Loizzo, were instructed to create photo essays and/or electronic field trips. These projects were to then be evaluated by the scientists in a post-interview conducted in a follow-up email. The follow-up email included open-ended questions for the scientist to reflect on the students' work and provide their insight. More specifically, the scientists were asked the following eight questions:

1. Please describe what *Streaming Science* student projects you participated in this semester. What was your role? What did you do?
2. How did you prepare to communicate your research with our students and *Streaming Science* audiences?
3. What three pieces of information do you hope our students and online audiences learned about you and your research?
4. What went well working with our students and *Streaming Science*?
5. What could be improved about working with our students and *Streaming Science*?
6. Describe your thoughts about how their final projects turned out. Consider their writing, photography, video, and overall efforts to explain your research.
7. What advice/recommendations do you have for our upcoming science communicators?
8. What advice/recommendations do you have for the development of future *Streaming Science* programs?

The authors acknowledge seven of the scientists did not complete the post-interview after multiple nudges. The scientists were with the Bee and Coastal labs. Due to increased workload responsibilities and timing at the end of a semester, scientists’ time was limited to complete the study.

Data Analysis

Coding involves the systematic arrangement of data through bracketing chunks (or text or image segments) and assigning a descriptive term to represent each category (Creswell & Creswell, 2018; Rossman & Rallis, 2012). This process entails analyzing text data or images acquired during data collection, dividing sentences, paragraphs, or images into distinct categories, and labeling them with a term, also referred to as an in vivo term (Creswell & Creswell 2018; Rossman & Rallis, 2012). To properly analyze the results of this research, interview transcripts were qualitatively open, axial, and thematically coded. Once all data were collected and analyzed, the data were coded for the top themes to answer the research questions about prior science communication experience, science communication preparation, and student work perception. To arrive at the themes, Murphy read through each transcript and made memos recurring points participants made in the interviews. Murphy then open-coded the transcripts, making notes of initial and repeating descriptions of science communication past experiences, preparation, and perceptions. While Murphy was reviewing the transcripts, she made notes of the recurring codes in a separate document. Once she had a solidified list of codes, all data relevant to each code was color coded. In a separate document from the transcripts, Murphy constructed code books with her notations of codes, additional notes, and color meaning. Once open-ended coding was complete, she began the process of axial coding. The process included chunking codes together to reveal larger themes across the transcripts. The coding process was completed the same way for the pre- and post- interviews. For research question one, an example of open codes included *personal experience*, *professional experience*, *inspiration from friends/family/educators*, *extension and research backgrounds*, and *undergraduate degree*. The codes then collapsed into categories such as *varied pathways*, *variety of past experiences*, and *anyone can be a science communicator* to emerge at a thematic level addressing scientists' different science communication backgrounds and perspectives. Coding was completed once all research questions were addressed. The themes addressed the initial research questions concerning past experiences with science communication, preparation for science communication, and perceptions of the students' work.

Credibility

In qualitative research, establishing credibility is crucial because the researcher serves as the primary instrument in the design, data collection, and analysis processes (Tracy, 2010). Researcher triangulation methods were applied in the study to minimize biases and establish credibility as the authors worked to compare and contrast their perspectives and interpretations of the data collection observations and analysis of the interview transcripts (Denzin, 1978; Patton, 1999). During the research design phase, Murphy relied on their advisor, Loizzo, and her doctoral student Stone to evaluate the design, data collection, and analysis process. The second and third authors facilitated the pre-interview and created the questionnaire for the post-interview to reduce bias during the data collection. Once all interviews were completed and sorted into their appropriate folders, Murphy read through each transcript. The transcripts were then qualitatively open, axial, and thematically coded. The themes were established from coding and evaluated by Loizzo by referencing the research questions of the study and the transcripts of the pre- and post-interviews. The research team also followed recommended practices to establish thick description in the study. To establish thick description, methods and results should be reported with thorough details for the reader to gain a rich understanding of the research context and participants' voices (Ponterotto, 2006). Thus, the authors have reported contextual information about the study's participants, relationships to university labs, connections to students' projects, and data collection and analysis procedures for transferability to future research studies.

Research Subjectivity

Subjectivity is a guiding force behind the study from the choice of the research topic, formulation of the research questions, selection of appropriate methods, and interpretation of the data (Mruck & Breuer, 2003). At the time of this research, Murphy was an undergraduate student at UF pursuing a Bachelor of Science in Agricultural Communication. Murphy firmly believes effective science communication is achievable by anyone, emphasizing the importance of bridging the gap between scientists and the public. While acknowledging the potential influence of her perspective on the study, Murphy incorporated strategies throughout the coding and analysis process to mitigate any bias. Loizzo taught the courses examined in the research and founded *The Streaming Science Project*. She also advised Murphy and Stone and assisted in data collection, analysis, and publication writing. Loizzo is a constructivist with an appreciation for the natural world and scientific enterprise. She worked with her co-authors to check biases and maintain transparency throughout the research process. Stone's epistemology is emancipatory, which emphasizes collaboration, participatory methods, and is change-oriented (Patton, 1990). Within the educational sphere, research should be inclusive of non-dominant voices in discourse. By working with her co-authors with differing worldviews, Stone was able to check her own biases and her team's to ensure trustworthiness.

Limitations

To enhance the credibility of the study, several limitations were acknowledged. First, a non-response error may have influenced the results regarding the perception of the science communication students' work, as some scientists (n = 7) did not complete the follow-up email interview. Additionally, the small sample size was recognized as a limitation. Furthermore, Murphy recognizes not conducting the interviews personally reduced the opportunity to engage directly with participants and ask clarifying follow-up questions, which could have helped interpret any challenging points from the recordings and transcripts.

Results

Thick description is used to present the following thematic results. Thick description in qualitative research is a way to be transparent, allowing the data to speak for itself through the use of longer verbatim quotes from the participants to gain a richer sense of their emotion, voice, and perspective (Ponterotto, 2006).

RQ1: Scientists' past science communication experiences were influenced by media consumption and education, sharing science with others, and prior work experiences before their current position.

Scientist participants across all three lab groups (n = 18) described their past science communication experiences in the following sub-themes.

Media Consumption and Education

Many scientists addressed how they changed their original major because it did not match their career interest. Several participants described how passion and inspiration from others pushed them to consider different career paths. Scientist #10 discussed how becoming involved in research and watching their professor conduct research sparked their interest:

> My undergraduate was in a small liberal arts school in [State], and there was only one person in my entire department, the department of biology, that was actively doing research, and he was doing bat research. I was doing bat research with him for about a year and a half, and I really loved it. That is where I caught the research bug. I knew then that I wanted to keep going and continue research.

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Some of the scientists discussed how their higher education involvement in research, such as Scientist #10 working in the bat lab, led to a connection with science communication. As they participated in science, several scientists described how watching mentors and colleagues communicate research in their field influenced them to get involved in sharing science with others. Scientist #14 addressed when they were younger their science communication involvement was as a media consumer reading magazines and speaking with those involved in the scientific field. The consumption of such magazines transformed into their knowledge of science communication and their passion for their career path. Scientist #14 said:

> I started out as a business major. I did not even know you could be a fisheries biologist. I grew up in West Texas and learned about careers in fisheries from a news magazine article, a popular article, something like your students might write. It was an article about graduate students in Texas that were electrofishing with a shocking boat, sampling fish on a river in Central Texas. It opened my eyes, and I realized I could have a career in this field. I ended up meeting with the Texas Parks and Wildlife Biologist at the time, and because of that, I changed my major.

Scientist #16 became involved in science communication as a consumer and through the influence of others, which transformed into their education, career path, and passion. They described:

> My dad was in the National Park Service. So, there was a natural component there. I think the catalyst of the seed that was planted was Jacques Cousteau. *National Geographic* occasionally would have a feature for Jacques Cousteau and his latest around-the-world investigations. It had beautiful work. That was when the seed got planted. I was just fascinated by this. I think the exposure to the marine environment through the adventures and words of Jacques Cousteau and his team on the Calypso got the seed planted.

Scientist #1 described how an assignment they did not want to do ended up sparking their passion for plant science which eventually transformed into a career in science communication. She originally started her undergraduate degree as a Wildlife Ecology major and switched to Plant Science after completing an assignment on invasive plants. She said:

> Eventually, I had to take a longleaf pine ecology type class for my degree, and we had to do a ten-page term paper, which as you can imagine, I was not very enthusiastic about. As I was writing it and learning more about the plant, I thought it was the coolest thing I had ever learned about. It was totally fascinating to me and really changed the way that I viewed plants. I completely changed my degree and my whole career path from there. So, an assignment I did not want to do was life-changing for me.

Sharing Science with Others

Scientists addressed how their past science communication experiences revolved around word of mouth, the idea of sharing their ideas aloud with others. Scientist #1 spoke about how their curiosity and interest in science as a child led them to want to share scientific information they had learned with others:

> I was the kind of kid that always asked 1,000 questions about everything and drove my parents insane doing that. Eventually, they got to the point where they would just take me to the library to look for books to try and answer my questions. Every time I would learn something about sharks or plants, I would run around and tell everybody in my family what I had learned. That is really kind of what my job is now on a bigger scale asking questions, finding an answer, and then, telling other people.

Scientists shared their experiences with public speaking increased from childhood to adulthood. Scientist #8 described how their academic path placed an emphasis on sharing their science with others. They said, “I decided to do the master beekeeper program but, it required a lot of public speaking, and it was a phobia of mine. Now, I do not have a problem speaking to the public. Originally, I was very afraid of public speaking.” Scientist #8 described the more they practiced public speaking, the more they enjoyed it and became comfortable doing it.

Prior Work Experience before Current Position

Scientists' prior work experience before their current career positions involved science communication practices as part of their responsibilities. Scientist #3 worked in multiple different scientific field positions prior to their current position, requiring science communication within each position. They described:

> I worked very closely with the biologists at the state and conducted the infield research aspects of what we do. Prior to that, I worked for a private company that manufactured aquatic herbicides. I spent five and a half years there on the private side. It was a great learning experience and then, prior to that, I worked for [state wildlife organization] as a biologist in chronic pain management.

Scientist #4 discussed their experience as a park ranger and the responsibilities the position included:

> I did a variety of things, one of which was a park ranger at [county park]. I was able to do some nature interpretation, curriculum development, activity design, lesson planning, and just interacting with people. This had led me to the [their role].

Scientist #11 noted how much of their experience before their current position was mostly developing the program in place now at [their previous university]:

> I am the first person here in the lab, I created the master bee keeping program, the [University] Bee College; we have a South [State], a [Region] Bee College, a Regular Bee College, and we even held a [Region] Bee college as well, at different Islands in the [Region]. In the past, we have judged honey programs, wrote informational documents about bees, created a podcast with Scientist #13, [Podcast Name], and travelled the world speaking to different bee keeping groups. I have been on every continent except

> Antarctica, talking to beekeepers about bees and answering questions about bees. Much of my work, over the last 15 years, has been establishing and building the program we now have.

Scientist #13 talked about the opportunities they pursued after graduating from college:

> After I had graduated, I moved down to [county] to become an extension agent and my focus in [county] was really on horticulture. It was plant science and working with the expert gardeners and on the side with that job I started working with beekeepers. I then started working with the Bee Lab, and so I have been collaborating with the lab for quite a bit even before I worked here.

Scientist #18 discussed their involvement in science communication through their work in the clam and oyster industry:

> I moved to [Location] in the 1990s to help with a training program to train fishermen that were being increasingly put out of work through regulations, and to teach them how to farm oysters and clams. It is a particularly important industry, and as a relatively new industry my job is to help with various aspects whether it is doing applied research to solving an industry problem, improve production management practice, be an educator, work with the industry/regulators/ policy makers on various aspects of the business, to just being a convener, or to bring people together to address various needs.

RQ2: Some scientists did not prepare for science communication and engagement, while others tailored their messages to the audience and practiced ahead of time.

Scientists (n = 18) described their preparation efforts for science communication and engagement through the following three sub-themes.

No Preparation

Some scientists, when asked how they typically prepare for science communication, answered they did not need to prepare. Scientist #9 explained, “I do not do any formal preparation. I rely on my previous experience and maybe that is the trick.” This response was quite common among many of the scientists as they believed because of their prior experiences there was no need to prepare for science communication/engagement opportunities. While some scientists chose not to prepare because they felt their experience would guide them, others argued they did not prepare to feel more confident and authentic. Scientist #7 chose not to prepare to come across as “more authentic.” Scientist #7 talked specifically about how they prepared for the study’s pre-interview:

> I actually didn't prepare at all for this [interview] because I knew my answers would be more authentic. I would keep saying to myself that I have the confidence to answer these questions. The whim gives me more confidence in myself. I am not a huge fan of public speaking, yet I do not mind working on the skills. That is how I handle smaller encounters or even if I speak in front of other clubs or beekeepers’ associations. It is okay to have confidence in what you are talking about because I know I am knowledgeable

> about it, and I am not trying to be arrogant. If I overthink it, I get myself so psyched up and nervous.

Scientist #14 would review questions if provided beforehand, otherwise, they did not find themselves preparing for smaller interviews such as for the pre-interview for the study:

> I do not have to do a lot of preparation for an interview like this. But I do think about it beforehand, and you did your homework and sent me the questions. So, I had a sense of, okay, here is what we are going to talk about and think about that.

On the other hand, Scientist #14 addressed how preparation may look different for an interview with the media:

> An interview with the press is where, I must, really, and I think all of us must really be careful, because if there's political implications of the topic, I think that we as, as part of as a scientific university, should stay out of politics. I do not get into social media and political views. Our role is to say, 'Here is the science, and here are the tradeoffs of different decisions.' But in those kinds of interviews, I am careful not to get into politics and stick to the facts of what we know and what the science is telling us.

Scientists appeared to prepare for media interviews by looking into the outlet ahead of time to know who would interview them and their position. Then, during the media interview, as Scientist #14 cautioned, scientists were careful of what they said to media outlets.

Tailoring their Message to the Audience

At least one scientist from each of the organizations mentioned tailoring their message to the audience was important. Scientist #2 stated:

> The first thing that I want to understand and know who the audience is, you know, and that helps gauge, at what level do you need to communicate. Because a lot of people struggle with that. They will either speak at an elevated level, or people feel that they are being talked down to. Or they speak at such a basic level people feel that they are being disrespected.

Scientist #12 further supported this point and addressed how they "adapt themselves and how they present their information" based on to whom they speak with. Scientist #14 discussed how tailoring to the audience is an essential part of getting the message across. More specifically Scientist #14 said:

> But you are never going to have the impact unless you can effectively communicate that out to the public in a way that they can use it. And that is why I think part of being in a place like us that has extension in our mission, and agriculture communications as a department is important because teaching students how to communicate in a way that is effective is important.

Scientist #6 provided a specific example of how they may tailor their message to best communicate to their specific audience:

> It is difficult because there are two different audiences that you are talking with. First, the public, who do not keep bees and will never keep bees. It is not bad if they know about the Varroa [a bee parasite] but, there is not much that they can do about it because treating for Varroa and monitoring for Varroa is what beekeepers need to do. Therefore, if I am ever addressing a group of beekeepers, I always tell them that the most important thing they can do is monitor Varroa treatment when necessary. On the other hand, if it is a group of garden clubs, for example, I tell them to make sure they are following the label when they are administering pesticides or make sure they are planting native plants or pollinator friendly plants.

Practice

Many of the scientists in the study made it evident it was important to be comfortable with speaking or to have experience with public speaking as a form of preparation. Scientist #8 addressed how their phobia of public speaking became a strength:

> The biggest thing I remember was that when I was a sea turtle rehabilitator was that I went out and talked to the public. That was the first step, and I was like, ‘Oh, man’, but I did it, and I realized it is not that awful, public speaking. You just must do public speaking. The more you do it, the more comfortable you will get with it. Practice is so important.

Scientist #9 spoke about giving themselves opportunities to speak and about what they do to gain confidence and comfort in front of audiences. They described:

> I continuously give myself opportunities to talk about what I am doing and talk about my research, so it is a familiar skill and topic. I am comfortable talking in an interview setting because I am also comfortable talking about what I do in a tour or teaching a class for bee college. I also think in general being comfortable with communicating, whether that is when I was younger in middle school and high school, I did a lot of speaking competitions and things like that and being more comfortable with choosing words in the moment.

Scientist #11 shared three ways they have practiced communicating with various audiences over the years:

> These days, there is not much preparation, so that is why I am scared to answer that question, how do I prepare? So, two things really helped me with that, well a few things. Number one, I know my topic. I have been working with honeybees for 30 years now. I really know the topics I am comfortable talking about. Number two, I learn the theatrics of it. I realized a long time ago that you can be incredibly intelligent, but a terrible communicator and not make an impact on anybody's life. I consciously lecture in a way that I know people will stay engaged. Number three is so important so, so, so, so important, it helped me professionally more than the other two things, I continue professional development so that I can refine my skills and make sure that I am doing it well. And being willing to listen to experts.

Scientist #1 talked about how they ensured they are prepared before engaging in science communication through public speaking even if it is something they are uncomfortable with:

> I just try to make sure I know what I am going to say before I start talking. Because otherwise, that is when you get in trouble. I try to practice and do as much public speaking as possible because it is not something that I was ever trained in and it is not something that a lot of scientists, I think, are comfortable doing. We like to be in the lab or in the greenhouse or writing in our office and be behind the scenes. It is uncomfortable but forcing yourself to get out there and do it over and over until you are better at it is important.

Scientist #4 prepared for science communication by practicing dialogue with themselves rather than reflecting upon prior experiences or practicing with other individuals. They also described the importance of their physical appearance and how it corresponds to their confidence within an interview setting:

> I got a facial yesterday so I would feel confident. I thought about my shirt, and I wanted it to be comfortable. I washed my hair and styled it because I did not want to be insecure about my hair being a mess. Then I thought about what kinds of questions you might ask me, and I had a little dialogue with myself about what I do to make sure that I knew what I wanted to discuss.

RQ3: Scientists were satisfied with the overall products the students created, yet they suggested future improvements to time management and writing quality.

Scientists (n = 18) described they enjoyed working with the students and found them to be prepared, professional, and pleasant collaborators.

Overall Pleased with the Final Product

A common theme amongst all scientists was they were happy with the overall final product. There were some comments about what could have been improved, but overall, they were pleased with the finished products the students created. Scientist #1 noted, “The projects were enjoyable to see! It was fun to see the students’ interpretation of my work. Overall, their writing was good, and the photos were used effectively.” Scientist #4 thoroughly enjoyed their experience and the overall product created:

> I had the A Team! The students I worked with were very motivated and eager to work on this project. They were organized, had wonderful ideas, offered a great deal of support and were knowledgeable about how to navigate the project. The overall quality of the students’ work was great.

Scientist #2 was surprised by the work the students produced:

> The students did a surprisingly good job synthesizing this information. I know these topics and concepts were new to them, so their quick mastery of the topic was

> impressive. Their [Adobe] Spark pages also looked great. They had a great balance of images versus text and the writing was both brief and informative.

Scientist #13 said, "I thought the social media posts, photography and videos were great. Overall efforts were fantastic, and the students were a joy to be with."
Scientist #12 was incredibly pleased with students work:

> I genuinely believe that they did an incredible job with their projects. They made significant efforts to truly understand the research we had done, and I appreciate their communication with me throughout the entire process. The final projects were professional, concise, and appropriate.

Scientist #11 said, "The social media and live stream products were well done. I also appreciate that my lab was highlighted by the students. It was exciting to work with the students who worked to communicate our outputs in numerous ways." Scientist #14 had no complaints and was incredibly pleased with the overall outcome:

> From my perspective this whole project has worked seamlessly and effectively. No criticisms from me on this one! The video and transcript came out terrific. They did a great job of emphasizing the most important points, of using my quotes effectively and accurately, and for making the process very relaxed and conversational. Excellent job on the final product! Overall, this is an excellent set of products that will help us in communicating science to the public.

Time Management Improvement

Some scientists noted there could have been improvements along the way with time management, which may have created a better experience and final product. There were also comments about managing time better not only during the creation of the projects but also during the editing process. However, some found time management to be an asset to the quality of the final product.

When asked what could have been improved or what they recommended Scientist #1 said, "Some of the students seemed to put their projects off until the last minute and needed immediate responses during a hectic time of the year. Have the students reach out to participants earlier in the semester, if possible." Similarly, Scientist #5 found time management to be an issue for some students when it came to completing the projects in a timely manner and with quality, "Students could have taken on more of the workload. The format of the online seminar largely relegated me developing the content. The photo essay required significant late editing." The work having to be done by the scientists and staff rather than the students was also a time management and writing issue addressed by Scientist #13 in their post-interview.
Scientist #11 would have liked to get more of an advanced notice from students to make the necessary edits:

> Some students often emailed, asking me to provide edits of documents/websites/etc. I would try to provide timely edits, but occasionally, the students would email when the assignments were due and/or did not make requested edits prior to publication. So, I feel I could have had more lead time to provide edits of the material that was ultimately used. It

> would have been good to be given a bit more lead time when asked to edit written final outputs produced by the students.

While time management was an issue for some, Scientist #12 was very appreciative of the time management of the students and found it helped with the overall product. Scientist #12 said, "The students were incredibly well prepared and thorough. I appreciate that I was always given a timeline so that I could manage my personal time with what was asked of me by *Streaming Science*." Similarly, Scientist #15 was also pleased with to the students' time management:

> The *Streaming Science* team made it so easy to participate. They set up/scheduled all the programs, recruited participants, tracked attendance, drafted materials, ran the Zoom, did program evaluation, etc. They made it easy for me to focus on being the scientist and giving the content. It was very nice for me to be able to focus on just one part of program delivery. I really have no complaints at all. The student team provided ample time to correct misinformation/misquoted facts in the draft material. Some of the supplemental content contained factual errors or slight exaggerations of material, but I believe those were mostly corrected.

Writing Improvement

Scientists mentioned the quality of students' writing when asked about what improvements could have been made or what recommendations they had from the project. When asked to reflect on their perceptions of the final products, Scientist #5 addressed how it may have been beneficial if more edits were made during the drafting phase, "I thought the products were great. I think they could have been improved with multiple draft revisions." Similar to Scientist #15, Scientist #13 noted how the writing quality of the students was not at its best:

> I thought the social media posts, photography, and videos were great. Overall efforts were fantastic, and the students were a joy to be with. The writing piece could have been worked on, as I heard from many of our lab members that they felt like they had to "rewrite" many of the written articles, and the articles were not well captured or written the first time around. Many felt like they were doing someone's class work for them because of the quality of writing.

Scientist #11 also found the quality of the writing pieces to be lower than that of the social media products, "The social media and live stream products were well done. Some initial drafts of text provided to me needed more edits than I was prepared to make. That said, this is common among students."

Discussions and Conclusions

The study explored scientists' science communication experiences, perceptions, and reflections of working with emerging science communication professionals in PjBL collegiate courses. The research aimed to provide recommendations for ANR scientists to enhance their communication of research as well as to offer guidance for science communication educators and students working with science experts with varying backgrounds and experiences in science communication to create products and foster engagement about their work. The first research question investigated scientists' past experiences with science communication and engagement.

Then, the second research question examined how scientists prepare to communicate and engage with the public. The third research question sought to receive feedback from scientists about students' science communication projects (electronic field trips and photo essays).

Prior Science Communication Experiences

In the pre-interview, scientists were asked a series of questions about their scientific and professional backgrounds. The results indicated scientists' prior science communication experiences were media consumption and education, sharing science with others, and prior work experience. Results support prior research indicating there is no single approach to science communication (Cooke et al., 2017). As demonstrated throughout the results, scientists' past science communication experiences varied; however, science communication training was not typically mentioned as a part of their science communication background. Most scientists lack formal training in science communication (Cooke et al., 2017). Most of the scientists discussed their prior communication experiences in relation to their childhood or in the workforce. It is imperative to note none of the scientists involved in the study received science communication training.

Science Communication Preparation

In the pre-interview scientists were also asked to discuss how they prepare for science communication. The results indicated some scientists did not prepare for science communication and engagement, while others tailored their messages to the audience and practiced ahead of time. The results varied in terms of the extent to which scientists prepared themselves before participating in science communication. While scientists are thoroughly trained in research methodologies, analytical skills and procedures, and the ability to communicate with other scientists, they usually receive no explicit training in communication of scientific concepts to the public (Brownell et al., 2013). Public communication has been identified as a challenging skill many practicing scientists lack, largely due to growing specialization over time and the lack of formal training in science communication (Brownell et al., 2013). Therefore, it can be expected some scientists would indicate they do not prepare at all for science communication. Because many scientists do not receive formal communication training, they may lack the knowledge and skills needed to prepare for a science communication engagement.

There were instances when scientists, despite lacking formal training, incorporated preparation techniques into their science communication efforts. Achieving effective science communication is often strongly linked with applying concepts of strategic communication, such as tailoring messages to specific audiences (Bucchi & Trench, 2021). Tailoring the message to the audience was indicated as an important piece of preparation for science communication by four scientists in the study. Science communication enables scientists to share discoveries with the public, enhancing overall knowledge and understanding of the scientific field (Burns et al. 2003; Hu et al., 2018). Tailoring the message to the audience is a crucial aspect of science communication to effectively convey information and ensure audience understanding. Overall, the results showed the most common approach used by scientists was to rely on their experience and the belief they were qualified to speak on the content they presented. Not all scientists explicitly addressed the importance of tailoring the message to the audience, which further supports science communication trainers, and their suggestion scientists rarely focus on applying two-way communication techniques, such as listening to their audiences or tailoring messages based on their audiences' needs (Yuan et al., 2017).

Science Communication Project Perceptions

In post-interviews, scientists were asked to provide their views on ANR communication students' electronic field trips and photo essays projects that featured the scientists and their research. The results indicated while scientists were generally satisfied with the students' final products, they recommended improvements in time management and writing quality for the future. Scientists highlighted the need for improvement in writing quality, addressing both grammatical accuracy and the content itself. Some of their feedback aligns with previous research, suggesting scientists perceive the public, in this case the student ANR communicators, as being uninformed about science. Research has demonstrated scientists believe the public is uninformed about science, which can lead to misunderstandings and subsequently result in errors in judgment and policy preferences (Besley & Nisbet, 2011; Davies, 2008). In their feedback, scientists noted students may have misinterpreted some of the scientific information provided, leading to errors in the written feature stories that necessitated revisions. This once again highlights a gap exists between scientists and the public. In this situation, scientists were unable to effectively convey their message to the audience, resulting in misunderstandings among the students. However, this was not the case for all participants involved.

Scientists noted their overall positive experiences with the students and expressed satisfaction with the final projects. Many of the scientists related their satisfaction and overall positive experience with the productive communication efforts between themselves and the students. The findings from RQs 1 and 2 contextualized scientists' feedback provided in RQ3. Scientists who lacked formal communication training or preparation strategies often had different expectations or critiques of student work compared to those with more experience. This suggests that understanding scientists' communication backgrounds is essential for designing effective PjBL experiences and for preparing students to collaborate with diverse scientific partners. The diverse range of science communication experience among the participant sample reinforces the assertion there is no single approach to science communication (Cooke et al., 2017). More recently, scientists themselves have engaged in science communication beyond peer-reviewed publications, to interact more with the public (Cooke et al., 2017). Therefore, offering scientists opportunities to engage with the public, such as through interactions with college students, enables both parties to bridge the gap between them and foster a better overall understanding of the messages being communicated.

Recommendations

Recommendations for Scientists and Collegiate ANR Communication

The study gave practical insight into areas of improvement for scientists in relation to their science communication efforts and collegiate PjBL science communication educators and students. It is recommended scientists attend communication training, tailor their message to the audience, and practice communicating their research in a variety of settings and formats. The study results indicate while it is not necessary to require scientists to attend communication training, it is strongly recommended. An effective training method could be to adopt a PjBL approach to enhance engagement and foster higher levels of understanding and collaboration. Scientists should be able to communicate their research findings to both expert and non-expert audiences. Thus, it is important to tailor scientific communication efforts to the intended audience to ensure their understanding (Hutchins, 2020). To reach the public, scientists should be able to communicate in a variety of settings, mediums, and for a variety of different audiences (Hutchins, 2020). To effectively execute tailoring the message to the audience it is recommended to analyze the audience, purpose, and format of the message being communicated (Hutchins, 2020). It is recommended scientists interact with the public more frequently to practice and become more comfortable with different audiences. Scientists' participation in PjBL ANR communication courses and student projects could be another form of training as they practice establishing partnerships with student communicators, answer interview questions, and review final projects for accuracy, visuals, and storytelling techniques.

ANR communication educators should consider implementing a PjBL instructional design approach into their curriculum. PjBL can be used to teach the next generation of ANR communicators. Collegiate science communication programs should aim for dynamic, student-centered education to cultivate a workforce equipped with critical thinking skills and a scientifically literate public (Ernst & Monroe, 2006). Research shows PjBL challenges and further develops students' communication skills (Krebs et al., 2021). Based on the scientists' feedback regarding their experiences with the students, it is recommended when students develop projects for *Streaming Science*, there should be more structured planning and communication between the students and the scientists. Students and scientists when working with one another must remain transparent about understanding of the content and their scheduling availability. To foster students' skills in scientist partnership building, instructors of PjBL courses should build in content and steps for students to have pre-meetings with scientists to learn about their backgrounds and prior science communication experiences, knowledge, and comfortability. That way, students can develop scientist-centered interview methods and project approaches to increase the scientist's confidence and skills in sharing their research with a variety of audiences.

Recommendations for Future Research

If the study were to be expanded or replicated, it would be recommended to form a larger sample size to accumulate data that can be applied to broader demographics. Including more participants from different states would make the results more generalizable. Additionally, to minimize nonresponse bias, it is recommended to either implement an alternative technique for the post-interview or provide more frequent and timely reminders to complete it. Future research should focus on evaluating scientists who have undergone communication training and their reflections, examining how ANR communication classes and collaboration with ANR collegiate communicators may have influenced their experiences, and exploring scientists' perspectives on attending science communication training.

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