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Considerations for Science Communications in a Changing Media Landscape

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CONSIDERATIONS FOR SCIENCE COMMUNICATIONS

IN A CHANGING MEDIA LANDSCAPE

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Technology development has radically shaped science communication techniques. Science communicators should be prepared to face these changes as they provide valuable new methods for increased engagement. Currently, communicators rely on deficit models (top-down transmission) and dialogic models (bottom-up transmission) to present information. The decision on which model to use is reliant upon the communicator's skill level and impression of the relationship between scientists and the general public. Developing effective communication relies on communicators determining goals (long-term aspirations) and objectives (short-term aspirations) while maintaining a clear view of the public's attitudes and evaluation frames. The tools available to science communicators and the likelihood of information becoming misinterpreted have both increased with technology improvements. Communicators should understand how to leverage traditional media, online media and social media to maximize engagement and outreach. Two retroactive assessments of internship case studies reflect upon the efficacy and application of science communication concepts through face-to-face and online methods.

Author's Acknowledgements

To those who stood behind and beside me: thank you for being there when I needed you to nudge me on.

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PREFACE

This document is a Doctoral Document, intended to reflect on lessons learned between coursework and internship experiences throughout my four and a half years in the Doctor of Plant Health program at the University of Nebraska – Lincoln. The incorporation of lessons into practice presents an opportunity for reflection.

This document contains an assessment of science communication as it applies to agricultural and horticultural sciences, though it can be broadly interpreted to most science communication strategies. Assessing the intent, audience and tools available provides development into spaces not previously considered.

The two case studies included in Chapter 4 are internships I completed during my tenure as a Doctor of Plant Health student. These internships are designed to provide real world application of knowledge learned within the classroom and provide insight into potential career opportunities.

The first internship with Denver Botanic Gardens occurred during the summer of 2018. As the Doctor of Plant Health Horticulture Intern, it was my task to provide diagnostic support to the horticulturalists, coordinate and develop Science Chats for the Science Pyramid, and act as a garden liaison regarding plant health related topics.

The second internship was with the University of Nebraska Panhandle Research and Extension Center in the summer of 2019. Here, as the Science Communication Graduate Intern, I developed a multi-media communication strategy designed to highlight research occurring in the Panhandle. That program has been titled “Farm Sci-Ed.” I also provided communication support to researchers and specialists at the center and engaged in many public science communication opportunities beyond this program development.

Both of these opportunities developed and furthered my passions for science communication, prompting me to pursue a career in science communication following graduation.

CHAPTER 1: SCIENCE COMMUNICATION HISTORY AND CURRENT PRACTICES

Introduction

Science communication is an interdisciplinary field of science focused on exchanging scientific information between scientists and the public. With a wide range of approaches to transmit information to engage audiences, science communicators must effectively integrate ideas from across disciplines to maximize the impact of their information (Baram-Tsabari and Lewenstein, 2017; Schiele et al., 2012). The integration of disciplines may include using concepts from communication, psychology, philosophy, education, policy, and sociology to develop science communication techniques and tools. These techniques and tools are used to then build programs designed to share discoveries in the natural, physical, and computational sciences (Bray et al., 2012; Mulder et al., 2008). In the last 50 years, science communication has become an independent field of science. This shift has allowed the relationships between communicator and audience to be analyzed, determining how information is transmitted between parties.

Historical Development of Science Communication

As long as there has been curiosity and discovery, scientists have been sharing their concepts and ideas. One of the earliest surviving instances of science communication in European history is *De rerum natura* (On the Nature of

Things) recorded by the Roman philosopher and poet Lucretius (Carus and Titus, 1995). In a series of poems published, Lucretius explored what is now recognized as Epicurean physics, the foundation of the Laws of Thermodynamics. It was received with a combination of public support, scientific approval, and political scrutiny (Tetro, 2018). Science continued to be predominantly philosophical and theoretical, but the need for systematic methods to produce evidence became more essential. In 1534, Copernicus published *De Revolutionibus Orbium Cœlestium* (On the Revolutions of the Heavenly Spheres), highlighting the concept that the Earth revolved around the sun (Tetro, 2018). Here, social and religious values began to conflict with science, and Copernicus' work was banned by the Catholic Church. This conflict between religious values and the sciences in European society continued with the trial and conviction of Galileo Galleilei. These developments resulted in the restriction of science communication to academic journals, textbooks, and other resources not readily available to the public (Gower, 2012).

Few scientists were able to bypass this restriction. One scientist that did was Charles Darwin, the author of two very diverse yet notable publications. The first, published in 1836, was *Journal of Researches*, a series of publications highlighting the biological findings on his journeys upon the *HMS Beagle*. This publication was not popular because of the scientific findings; instead it became known for its detailed and complex illustrations showing locations and creatures that were worlds away from the public (Thomson and Rachootin, 1982). Because his aspirations to fame were aspirations of scholarly recognition not artistic talent, he published *On the Origin of Species by Means of Natural Selection* in 1894 (Darwin, 2004). This publication expanded on his concept of evolution using examples from his travels. These concepts were rejected by the Church of England, because they placed questions on the concept of creationism and effectively undermined the religious authorities in place.

Starting in the 1800's and into the early 1900's, science became synonymous with marketing tools as the divide between the scientific communities and the general public widened (Agnew et al., 1994). The development of patent medicines (e.g. tinctures, salves and alcoholic beverages) claiming an impressive number of health benefits based on "scientific evidence" were rampant and undisputed. Much of the necessary research to understand these claims was not readily available. To counter this, Ludwik Fleck (1935) published *Entstehung und Entwicklung einer Wissenschaftlichen Tatsache* (Genesis and Development of a Scientific Fact) in 1935. His publication highlighted the ways evidence can be interpreted, manipulated, and shifted to accomplish a goal. He pushed for an accurate portrayal of evidence and the development of public science education to combat the trend of misinformation (Sensevy et al., 2008).

During the Space Race and Cold War Era of American history (1955-1975), science was used to promote support for space exploration, a global communications system and political support (Hayden et al., 2017). Scientists hoped that science would become exciting and novel to the public again through events like the return of Sputnik and the US lunar landing (Logan, 2001). In the

UK, the BBC capitalized on the space race, facilitating their shift away from radio broadcasts into television broadcasting (Farry and Kirby, 2012). The fascination with this novel scientific exploration, combined with celebrity hosts and scientists that became household names, dramatically shifted science communication in the public sphere, and the results remain tangible today.

Televised science began to be highly accepted with exploratory shows geared toward children and young adults becoming key science communication avenues. One of the key shows, *Mr. Wizard*, aired first in 1951. Don Herbert, the host, invited viewers to participate alongside him doing simple and impressive science activities with “Mr. Wizard,” the titular character of the show (Wilczek, 2008). His incorporation of “Mr. Wizard’s Science Club” encouraged members to be participants in science, not just observe by providing interactive activities and simple science lessons. By combining the show’s demonstration and club activities, *Mr. Wizard* began to pave the way for citizen science program development and implementation (Stocklmayer et al., 2010). In 1959, the “*Why Is It So?*” show hosted by Julius Sumner Miller, a physicist, used a kooky eccentric scientist character to explain physics to a broad audience (Potter, 1987). Learning was encouraged outside of the show through “homework” and do-it-yourself experiments, providing further opportunities for learning (Maarschalk, 1988). Another key science communication television show was *Bill Nye the Science Guy*, which aired in 1994 and ran through 1999. *Bill Nye the Science Guy* became a staple in many science classrooms (Long and Steinke, 1996). Through a scientist’s stereotypical appearance (including a white lab coat, bow tie, and lab setting) and his fast-paced entertaining bits and catchphrases, Bill Nye introduced viewers to a myriad of scientific topics and provided experiments that could be done at home. All three of these shows set the groundwork for future educational scientific shows that both entertained and educated.

Other shows that have become common forms of televised science communication include *Planet Earth*, *Planet Earth II*, *The Blue Planet*, and *The Blue Planet II*, all narrated by David Attenborough and created by the BBC Natural History Unit. This series of nature documentaries explored distant locations and ecological systems the public would otherwise not be privy to, sparking similar nature documentaries produced by the History Channel, Discovery Channel and other related educational programming television channels.

With the increase in public accessibility of information, science communication underwent a transformation. Some scientists became celebrities for their abilities to share, explain and explore scientific topics with the public. They became household names and were perceived as the representative experts in their fields (Goodell, 1985; Johnson et al., 2018). These “celebrity scientists” include individuals like Carl Sagan, Jane Goodall, Neil DeGrasse-Tyson, and Stephen Hawking. These “celebrity scientists” leverage their clout to direct scientific conversations. High interactions with the public lead to public perceptions of the scientific community that may or may not be correct (Giberson and Artigas, 2007).

Science in the public's eye in the early 2000's was focused on continued space exploration and ecological understanding. In subsequent years, the focus has shifted among the increase in biotechnology research, conservation efforts and the effects of climate change. Research has taken advantage of the public's interest in being involved through the development of citizen science and participatory science programs (Bonney et al., 2014; Haywood and Besley, 2014). Outreach plans like the transcontinental monarch butterfly programs spanning from Mexico to Canada that rely on citizen information to track population movement, flight patterns and other aspects of monarch butterfly behavior have become more common and widespread, with positive results (Solis-Sosa et al., 2019). Avid hobbyists can get involved with the scientific community to assist in collecting weather data through the National Weather Service, count bird species in conjunction with the National Audubon Society, among other opportunities available at the local level.

The advent of social media has provided avenues for direct communication between scientists and the public, changing the ease and accessibility for two-way interaction (Jayashree, 2018). Videos, pictures, short messages, and direct conversations have become common forms of sharing information between interested parties through digital applications such as Facebook, Twitter, and Instagram. This easy access to scientists and information enables discussions to occur between interested and knowledgeable parties. Social media also facilitates developing relationships between the public, journalists, and scientists to maximize their reach (Liang et al., 2014).

Science Communication as an Information Exchange

Science communication aims to communicate complex information to individuals in areas outside of specific scientific fields (Priest, 2010). Communication researchers have been attempting to quantify these relationships for more than 50 years by identifying the techniques and strategies science communicators can develop (Gascoigne et al., 2010; Trench and Bucchi, 2015). One conclusion that regularly emerges from this research is that existing paradigms, regional contexts, and cultural priorities all influence the methods and techniques that are effective for different groups of individuals (Schiele et al., 2012).

Science communication can occur through a number of different methods, depending upon the scientist's communication skill level, the intended audience, and the purpose of the communication. Specific goals for communication will affect success. Goals are often sorted into one of four categories: public awareness, public engagement, public participation and public understanding (Van der Sanden and Meijman, 2008). Within each of these categories, communication may range from written scientific journals, informal education, science museum displays, outreach events or individuals involved in research-focused experiences (Baram-Tsabari and Lewenstein, 2017). Outreach is sometimes identified as "scientific communication that engages an audience outside of academia" (Poliakoff and Webb, 2007).

Regardless of the intent and type of activity, there is a consistent need to take into account the limitations of the engagement during design. One of the most common limitations is the small size and scope of outreach opportunities (Nisbet and Goidel, 2007). Individuals that attend science-geared events are often vocal, well-informed and committed to the issue at hand, making it simple for science communicators to engage with them (Wynne, 2006). When the audience is engaged in an event, it is possible to provide a space to have interactions and reach mutual understanding between parties (Bubela et al., 2009). Science communicators should be cognizant of external factors that impact engagement and work to maximize opportunities with changes in schedules, online resources, and other accessibility means. Skilled science communicators can develop initiatives to create dialogue between parties, forming trust between the scientists and the public to achieve the goal.

Models of Science Communication

Existing science communication paradigms, especially in academia, are founded in academic tradition. Information is customarily disseminated through the deficit model, where knowledge passes unidirectionally from the expert to the non-expert. Science communication occurring between experts and non-experts on a conversational level occurs through the dialogue model. Both of these models explore how scientists engage with the public audiences and describe the assumptions that are made about the communication techniques in use. With the increase in participation across social settings, a pedagogical shift from a reliance on the deficit model to a reliance on the dialogue model has been observed (Nisbet and Scheufele, 2009). These two aforementioned models are often complicated with external contexts including human nature, sociopolitical context, and cultural norms, but they impact the results of the programming (Scheufele, 2014; Simis et al., 2016).

Deficit Model

The deficit model was borne out of work done by Claude Elwood Shannon and Warren Weaver in 1949 in communication sciences and continues to persist today (Bray et al., 2012). The deficit model is the basic model of science communication, where those that know present information to those who don't (Bray et al., 2012). Scientists regularly rely on the deficit model, especially since it is based on the intuitive, logical approach of "provide more information and attitudes will change" (Bauer, 2008; Bubela et al., 2009; Nisbet and Scheufele, 2009; Osmond et al., 2010). The efficacy of this method of information sharing is limited, and evidence of clear success is lacking (Kahan et al., 2012; Nisbet and Scheufele, 2009). The top-down technique of expert to non-expert of the deficit model is insufficient to modify an audience's beliefs, as gaining knowledge does little to change an individual's attitude or behavior alone.

Described as a top-down information transmission model, the deficit model approach is based on improvised and intuitive goals set by the communicator. The assumption is that the lack of the public's scientific knowledge is the reason for little scientific support and overall progress (Gross, 1994). According to this model, scientists have a duty to educate the public. The provided information will shift public attitudes to increased support and immediately reverse any negative attitudes (Besley and Nisbet, 2013). The communicator is assumed to be authentic and honest in their presentation of information, while the receiver is a passive partner absorbing the information. To do this, the scientist must reduce their information to a “simplified, sensationalized, [and] strategically constructed” message in an attempt to prevent disinterest, misinterpretation or outright hostile reactions by the audience (Davies, 2008).

Within the context of the deficit model, when it seems the message delivery has failed, the failure does not lie with the presenter. Instead, the blame rests on the interpretation of the information by the receiver, “irrational” public beliefs, or some combination (Nisbet and Goidel, 2007). By placing the blame on other individuals, scientists are able to shift the responsibility of adequate communication skills away from their own deficits onto the receiving party. This shift in responsibility furthers the boundary between scientists and the public. The perceptions of all involved are shifted to view the scientist as the authority in a given subject while the audience seems to lack the understanding or desire to learn.

The deficit model provides simplicity to both presenter and audience while working within existing frameworks of political systems, making it well suited to influence public policy (Simis et al., 2016). While policy tends to be slow-moving, the assumption seems sound that lagging public and subsequently policy support leads to less scientific support. The deficit model sticks to the status quo by promoting trust in established institutions and deferring to authorities qualified to talk about certain scientific topics.

Dialogue Model

The dialogue model focuses on bottom-up information transmission where multiple people shape the conversation (Van der Sanden and Meijman, 2008). By focusing on gathering feedback and incorporating those results into developing the questions scientists ask in a feedback loop, there is a pronounced positive effect on public interest and support.

The increase in audience involvement within the dialogue model allows for more diverse and involved conversations to occur. When scientists extend trust to others to contribute to developing knowledge through tasks like the collection and assessment of data, they help increase trust between parties (Berkowitz et al., 2005). When brought in early on projects, the public is better prepared to learn about technical aspects of science and provide input on implications that may have been initially overlooked by the scientist (Einsiedel, 2008).

Some of the most successful science communication efforts began with the recruitment of an involved public. In one example, participants received scientific proposals and background information to look over. In response, they provided input on research questions to be asked and recommended actions to take following the completion of the project (Einsiedel, 2008). By ensuring public inclusion from the formative stages of researched science, both scientist and the public benefit. Matters of information regarding ownership, regulation, use, application, benefits and risk require consensus or compromise. The involved public are uniquely positioned to provide this information to researchers. Because of the transactional and collaborative nature of the dialogue model, the public benefits by increasing their motivation to become active in the science community. In turn, participants become more confident in their abilities to advocate for the science (Einsiedel, 2008). Scientists benefit by receiving more information through expert knowledge and perspectives that would otherwise be missed. Without this teamwork, information exchange defaults to the deficit model, where knowledge is thrown into the world, with the hope it inspires a change.

Ideal Attitudes and Interactions

Science communication requires buy-in from both communicating scientists and audiences to be effective and meaningful. These interactions are key, as disconnects have the potential to result in negative impacts on markets and policy that persists for years (Scheufele, 2013). Scientists communicating about new research technologies and breakthroughs influence decisions on funding, use, and regulation as much as current scientific practices.

Skilled communicators understand that respect leads to increased trust. For audiences to respect them, there is an inherent need for honesty and empathy on behalf of the presenter (Bray et al., 2012). To effectively do this, educators need to be prepared to acknowledge the context of the communication activity – who is in the audience, what their background is, and what they intend to get out of the communication. In addition to understanding the audience, the communicator should be cognizant of how their personal biases and values could influence the presentation of information. The communicator is also responsible for being aware of the explicit purpose of the activity or presentation, as that guides the means of communication.

There are expectations of the audience participating in the communication as well. The audience is coming with the expectation they will be given tools to make informed decisions (Bray et al., 2012). As such, it is key that communicators give the presentation the same degree of focus the research itself was given. By focusing on the quality of the presentation, the researcher and the topic both gain credibility.

Challenges for Science Communication

Science communication strategies continue to rely on the deficit model, even though it is less effective than the dialogue model for successful engagement and learning. The challenges to overcome this existing paradigm are complex, and they come down to how scientists and non-scientific public process and transmit information (Simis et al., 2016).

Scientists are trained to be objective decision makers. Their knowledge and understanding stem from empirical, data-driven information in their field (Simis et al., 2016). In contrast, non-experts rely on heuristics or shortcuts developed over time to facilitate learning to reach similar conclusions. This disparity in how individuals learn leads to frustration because neither group follows similar thought processes, but they end up at the same conclusion. This leads to the continued reliance on the deficit model by communicators, because the perceived simplicity and ease of breaching the assumed gap in understanding. Scientists can also feel unprepared to interact with audiences, as there is often a lack of training for science communication readily available (Besley and Nisbet, 2013). Data on effective techniques for science communication is scattered across disciplines, e.g. education, communication, psychology, and public health, leaving swaths of information unavailable (Carleton-Hug and Hug, 2010). There are significant gaps in metrics and criteria for evaluating a scientist's skills at relaying messages encompassing different disciplines.

Institutional structures continue perpetuating the use of the deficit model through intentional and unintentional limitations place upon communicators. One of the largest hurdles is the lack of formal training provided to scientists to increase their skills in science communication. This lack of training stems from multiple places: educational requirements, expectations of superiors, and the perceived hierarchy of "hard" versus "soft" sciences. Educational requirements and degree programs often have limited coursework dedicated to science communication, whether overlooked by program design or from lack of institutional course availability. This leads to a lack of exposure, skill development, and comprehension of the best tools, techniques and practices available to science communicators. Training opportunities post degree are few, and little infrastructure is available for scientists to build upon (Varner, 2014). The lack of training, changing media landscapes, and higher institution expectations often means communicators rely on the deficit model to achieve some meaning. To compensate for these challenges, many institutions are beginning to include and develop more in depth science communication courses (Simis et al., 2016).

Another key component to the reliance on the deficit model is the perceived hierarchy between “hard” sciences and “soft” sciences (Campbell, 2005). Sciences that are more technical, like chemistry, mathematics, and medicine are perceived in a positive way, whereas sciences like social sciences (explored later in this paper) and communication science tend to have a more negative connotation associated with them. Individuals who operate within the “hard” science disciplines, like bench scientists and engineers, are most likely to see the public as a homogenous group. As such, they tend to rely heavily on the deficit model to communicate their knowledge (Besley and Nisbet, 2013). Scientists that express a positive attitude toward “softer” sciences like social sciences and communication science tend to rely more heavily on the dialogue model as there is a deeper understanding of the human component. Removing or changing the perceived stigma against science communication and other related disciplines serves to decrease the reliance on the deficit model.

Perceptions of the public by scientists affect how interactions occur and how information is transmitted between parties. In a survey completed in 2012, scientists were asked to elaborate on how they perceived the public when engaging with them (Besley and Nisbet, 2013). Of those surveyed, 22% viewed the public as a collection of groups separate from themselves. Twenty percent echoed the group separation concept but classified the public as “non-scientific.”

“Non-scientific” was defined as individuals outside of academic and research circles. This group of scientists did not have positive nor negative impressions of the public, just the distinction of groups. Another 18% continued with the separation between “scientific” and “non-scientific” groups but voiced negative perceptions of the public. These scientists continue using the deficit model to educate and use their access to information as a way to mark their superiority to achieve results. In contrast, 15% of the interviewed scientists had a positive perception of the public and celebrated them as a group eager to learn and help further science discovery. This group of scientists continued to see the separation between science and non-scientists, but they saw the public as a group for which they are privileged to do research.

Unlike all of the previous groups, 12% of the interviewed scientists identified themselves as part of the public. In doing so, they agreed the public is made up of many different kinds of individuals. They see many similarities between themselves and the collective “public.” Finally, the remainder (13%) stated that the concept of “the public” should not exist. They viewed the distinction as outdated and patronizing, creating an unnecessary schism. The term “public” is too general to provide any useful meaning to them, and this generality could instead be harmful to further science developments. Understanding how different scientists perceive the public enables science communicators working with both parties to better engage and share information effectively.

These conflicting views of the public complicate providing adequate training to scientists. There is no simple training method to cover all of the perspectives provided by the public of scientists. “The public” does not have the homogenous, negative perception of science in the same way the science community expects (Besley and Nisbet, 2013). Instead, “the public” are a diverse collection of individuals, each with their own knowledge, beliefs, values and worldviews (Fischhoff, 2013). These differences act as mental filters, influencing the individual’s response to the presentation of new info (Scheufele, 2013). Communicators should be prepared for varying interpretations of the same information within differing groups of individuals and recognize that these differences affect the reception of their work.

Science Communicator Misconceptions

To maximize success in gaining credibility, science communicators tend to operate under a number of assumptions in defining and determining their strategies for science communication (Scheufele, 2013). In doing so, these communicators are able to make decisive and intuitive decisions to shape their curriculum and programs.

One assumption is that knowledge deficits account for the low volume of public support for science. In the United States, public understanding of basic science is limited. A multi-year survey produced by the National Science Board between 1992 and 2010 resulted in approximately 60% of questions being answered correctly by participants (National Science Board, 2012). This lack of understanding is not limited to only information recall, as only 18% could sufficiently understand scientific processes. For example, as of 2006, one-third of United States adults interviewed rejected the concept of evolution (Miller et al., 2006). These statistics make it simple to jump to the assumption that making more information available will attract audiences and increase science comprehension and support (Scheufele, 2013). This assumption operates on the concept that the knowledge deficit can be corrected by "selling science" – improving the explanation and making it more exciting (Nelkin, 1990). This assumption fails to take into account the sociodemographic and socioeconomic contexts that limit engagement with science communication. Individuals with higher levels of education are better able to extract information and integrate it into their lives (Tichenor et al., 1970). The assumption that the knowledge gap is the only limiting factor (and it is not), while failing to address additional failings in social infrastructure, limits the reach of science communication to those that can access resources. This widens the gap and reduces engagement overall (Scheufele, 2013).

Another assumption surrounding scientific communication is that the perceived declining levels of trust in science are threatening public support. As there is so much conflicting misinformation readily available to the public, it is a simple leap to a perceived decrease in trust. Polarization and partisan divides appear to decrease confidence in science, but these temporary fluxes do not tend to shape attitudes over time (Scheufele, 2013). Instead, university research and science remain one of the most trusted sources of information and that confidence continues to be stable over long periods of time. The trust associated with new technologies and developing science continues to maintain a positive attitude with the public (Sjöberg, 2002). Evidence that trust in science remains high, regardless of social polarization, suggests that there is an external cause to the decrease in public support. Increasing trust in science alone is insufficient to combat the apparent loss of public support, as the level of trust has remained constant throughout recent history, debunking this statement.

The third assumption science communicators operate on is that the media's main function is to inform the public about science. While the media is an information conduit between scientists and the general public, its reach and efficacy are limited (Scheufele, 2013). Less than 20% of individuals in 2010 surveys stated that they paid "very close" attention to science news in media coverage (National Science Board, 2012). Because of this low volume of engagement, media refrains from covering traditional science news in favor of other higher reward and engagement stories. Additionally, individuals rely on "short-cuts" to maximize their information uptake and retention from sources, a tool that media developers exploit regularly (Gerbner, 1987). The consistent portrayal of a social reality through media sources allows those shortcuts to be used to identify or signal context to viewers. This in turn shapes the general skewed perception of science. Science as an overarching field has repeatedly portrayed scientists as quirky, eccentric, and odd and the heterogeneity of characters further that perception. Many fictional scientific characters are portrayed as white adult males, and are either socially inept and awkward, old and wacky, or some combination of those traits. The settings they are consistently found in are stereotypical lab settings, using chemistry glassware, regardless of their actual field of study. This portrayal has decreased in recent years, but the link between science being portrayed as an exclusive club that is too challenging for individuals to comprehend well, and the overall trust in science has maintained a negative trend (Nisbet et al., 2002).

The final assumption science communicators rely upon is that science and personal values need to remain separate in debate arenas (Scheufele, 2014). Individual values define and shape interpretation, but new developments and scientific discoveries cause reassessment and analysis of values. Nanotechnology, biotechnology, information technology and cognitive science (NBIC technologies) discoveries initiate debates about ethical, legal, and social implications surrounding use and regulation as they are novel and unexplored. Personal values act as a filtering mechanism, causing facts to have different weights to different audiences (Kunda, 1990). Trying to separate values from science is not possible; scientists possess their own biases and opinions, which can shape research objectives and presentations. To that end, audiences also ascribe to their own individual perceptions, coloring their interpretations. Both value and scientific results are necessary to have engaging and informational science communication.

Public's Perception of Science

Just as scientists have a general perception of the public, the public has opinions and ideas about the science being communicated. There are differing categories of support and interactions, but 85% of the public feels that "even if it brings no immediate effects, scientific research that advances the frontiers of knowledge is necessary and should be supported by federal government" (Nisbet and Scheufele, 2009). This overall support reduces the claim that the public is not interested in science, and instead suggests that there is overwhelming support within the public as a whole.

The public relies on criteria to judge and assess validity of the presented science (Marris, 2001; Marris et al., 2001; Wynne, 1992). The more criteria the information meets, the more likely they will incorporate the information into their individual worldviews. Many of these steps happen simultaneously or in a different order, often within the context of community science initiatives that rely on the public to provide data or locations for further study.

One of the first criteria that the public assess is how the presented knowledge aligns with their current knowledge. Should predictions given by scientists in public forums seem to be supported by tangible evidence that aligns with current knowledge, the public will tend to support them. Should predictions fail or be incorrect, people are less likely to support research in that sector in the future. They also determine how well the presented knowledge fits within the current system operated by the public participants.

Secondly, the public assesses the scientist delivering the information (Marris, 2001; Marris et al., 2001). With science occurring at a regional or local level where public input is welcomed, individuals observe how scientists pay attention to existing knowledge. Scientists that are cognizant of what is and is not available in terms of support from their public partners are scientists that garner greater amounts of support from the public. When a scientist receives criticism or suggestions from the public on their intended work with openness and appears willing to adjust their plan accordingly, then individuals partnering with the scientist are more likely to buy-in to the research. Trust and support increases among the public and among individuals when scientists demonstrate a willingness to admit and correct oversights and errors. A scientist's track record with statements, retractions, and corrections becomes a prominent deciding factor on how much support the public might offer. When there is integration between the public and science, there is an improved relationship and a more cohesive approach to the work (Varner, 2014).

Along the same concept, the public examines the affiliations of the scientist – both social and institutional – to determine if there are potential conflicts of interest with other groups or ideologies that the scientist engages with. These conflicts of interest are typically within the context of industry, government, university or advocacy involvements. Looking at the scientist's historical track record, statements, and affiliations allow individuals to make complex decisions on the trustworthy nature of the scientist.

Finally, the issue is directly judged. Concepts that individuals in the public may use include examining what issues overlap, border or intersect with the research proposal, and how those connect to the public's perception of the issue. Understanding how issues interact and relate to each other helps reveal potential conflicts, potentially raising overall trust between involved parties. Determination of whether long-term and irreversible effects have been examined, and who did the examination prior to suggesting novel research, also increases the likelihood of developing trust. The final questions of who is ultimately responsible for the regulation of organizations and companies involved, who is in charge of reparations if harm occurs, and who determines subsequent development and enactment of research, are examined. All of these determinations and assessments can help create an atmosphere of openness and honesty or of deception and mistrust, depending upon the assessment by the involved public.

Understanding many of the questions that may arise from the general public when attempting to understand how science discoveries applies to their lives enables communicators to adapt their message as needed. Communicators are then also prepared to interact with the audience in a way that is logical and engaging, creating excitement and buy-in, regardless of the scientific context.

Conclusion

Science communication has always been essential to the effective dissemination of information following discovery. As the world becomes more globally connected and technology increases the speed of discovery, science communication adapts to new cultural norms. At its core, science communication is an exchange of information between two parties. Skilled science communication relies upon the dialogue model to reinforce and engage the intended audience. However, scientists often rely upon the deficit model to communicate their information, assuming the audience has limited knowledge of the topic. They feel unprepared to do more and that the most effective way to transmit information is to give their audience as much as possible. Many of the complications and challenges that science communication faces as a field reveals how unprepared many scientists are as communicators. Understanding how scientists perceive the public enables developers of training modules and workshops to increase learning opportunities and adjust expectations. By building their strategy based upon the misconceptions and questions the public has, communicators encourage involvement in the development of effective communication and work to develop trust between parties. As the field continues to expand, science communication has many opportunities for growth and development by using new technologies and methods coupled with better understanding of the relationship between expert and non-expert.

References

Agnew N.M., Ford K.M., Hayes P.J. (1994) Expertise in context: personally constructed, socially selected, and reality-relevant? International Journal of Expert Systems 7:65-88.

Baram-Tsabari A., Lewenstein B.V. (2017) Science communication training: What are we trying to teach? International Journal of Science Education, Part B 7:285-300.

Bauer M.W. (2008) Paradigm change for science communication: Commercial science needs a critical public, Communicating science in social contexts, Springer. pp. 7-25.

Berkowitz A.R., Ford M.E., Brewer C.A. (2005) A framework for integrating ecological literacy, civics literacy, and environmental citizenship in. Environmental education and advocacy: Changing perspectives of ecology and education:227.

Besley J.C., Nisbet M. (2013) How scientists view the public, the media and the political process. Public Understanding of Science 22:644-659.

Bonney R., Shirk J.L., Phillips T.B., Wiggins A., Ballard H.L., Miller-Rushing A.J., Parrish J.K. (2014) Next steps for citizen science. Science 343:1436-1437.

Bray B., France B., Gilbert J.K. (2012) Identifying the essential elements of effective science communication: What do the experts say? International Journal of Science Education, Part B 2:23-41.

Bubela T., Nisbet M.C., Borchelt R., Brunger F., Critchley C., Einsiedel E., Geller G., Gupta A., Hampel J., Hyde-Lay R. (2009) Science communication reconsidered. Nature biotechnology 27:514.

Campbell P. (2005) In praise of soft science. Nature 435:1003.

Carleton-Hug A., Hug J.W. (2010) Challenges and opportunities for evaluating environmental education programs. Evaluation and program planning 33:159-164.

Carus T.L., Titus D. (1995) On the Nature of Things, trans. Anthony M. Esolen. Baltimore: Johns Hopkins.

Darwin C. (2004) On the origin of species, 1859 Routledge.

Davies S.R. (2008) Constructing Communication: Talking to Scientists About Talking to the Public. Science Communication 29:413-434. DOI: 10.1177/1075547008316222.

Einsiedel E.F. (2008) Public participation and dialogue. Handbook of public communication of science and technology:173-184.

Farry J., Kirby D.A. (2012) The Universe will be televised: Space, science, satellites and British television production, 1946–1969. History and Technology 28:311-333.

Fischhoff B. (2013) The sciences of science communication. Proceedings of the National Academy of Sciences 110:14033-14039.

Fleck L. (1935) Entstehung und Entwicklung einer wissenschaftlichen Tatsache: Einführung in die Lehre vom Denkstil und Denkkollectiv B. Schwabe.

Gascoigne T., Cheng D., Claessens M., Metcalfe J., Schiele B., Shi S. (2010) Is science communication its own field? Journal of science communication 9:C04.

Gerbner G. (1987) Science on television: How it affects public conceptions. Issues in Science and Technology 3:109-115.

Giberson K., Artigas M. (2007) Oracles of science: Celebrity scientists versus God and religion Oxford University Press.

Goodell R. (1985) Problems with the press: Who's responsible? BioScience 35:151-157.

Gower B. (2012) Scientific method: A historical and philosophical introduction Routledge.

Gross A.G. (1994) The roles of rhetoric in the public understanding of science. Public understanding of science 3:3-24.

Hayden J.M., Geras M.J., Gerth N.M., Crespin M.H. (2017) Land, Wood, Water, and Space: Senator Robert S. Kerr, Congress, and Selling the Space Race to the American Public. Social Science Quarterly 98:1189-1203.

Haywood B.K., Besley J.C. (2014) Education, outreach, and inclusive engagement: Towards integrated indicators of successful program outcomes in participatory science. Public understanding of science 23:92-106.

Jayashree B.J.C.S. (2018) Social media and communication by scientists: MS Swaminathan on Twitter 114:1-6.

Johnson D.R., Ecklund E.H., Di D., Matthews K.R. (2018) Responding to Richard: Celebrity and (mis) representation of science. Public Understanding of Science 27:535-549.

Kahan D.M., Peters E., Wittlin M., Slovic P., Ouellette L.L., Braman D., Mandel G. (2012) The polarizing impact of science literacy and numeracy on perceived climate change risks. Nature climate change 2:732.

Kunda Z. (1990) The case for motivated reasoning. Psychological bulletin 108:480.

Liang X., Su L.Y.-F., Yeo S.K., Scheufele D.A., Brossard D., Xenos M., Nealey P., Corley E.A. (2014) Building Buzz: (Scientists) Communicating Science in New Media Environments. Journalism & mass communication quarterly 91:772-791.

Logan R.A. (2001) Science mass communication: Its conceptual history. Science Communication 23:135-163.

Long M., Steinke J. (1996) The thrill of everyday science: images of science and scientists on children's educational science programmes in the United States. Public Understanding of Science 5:101-119.

Maarschalk J. (1988) Scientific literacy and informal science teaching. Journal of Research in Science Teaching 25:135-146.

Marris C. (2001) Public views on GMOs: deconstructing the myths: Stakeholders in the GMO debate often describe public opinion as irrational. But do they really understand the public? EMBO reports 2:545-548.

Marris C., Wynne B., Simmons P., Weldon S. (2001) Public perceptions of agricultural biotechnologies in Europe. Final report of the PABE research project:5.

Miller J.D., Scott E.C., Okamoto S. (2006) Public acceptance of evolution, American Association for the Advancement of Science.

Mulder H.A., Longnecker N., Davis L.S. (2008) The state of science communication programs at universities around the world. Science Communication 30:277-287.

National Science Board. (2012) Science and technology: Public attitudes and understanding. Science and Engineering Indicators 2012.

Nelkin D. (1990) Selling science. Physics Today 43:41-49.

Nisbet M.C., Goidel R.K. (2007) Understanding citizen perceptions of science controversy: bridging the ethnographic—survey research divide. Public Understanding of science 16:421-440.

Nisbet M.C., Scheufele D.A. (2009) What's next for science communication? Promising directions and lingering distractions. American journal of botany 96:1767-1778.

Nisbet M.C., Scheufele D.A., Shanahan J., Moy P., Brossard D., Lewenstein B.V. (2002) Knowledge, reservations, or promise? A media effects model for public perceptions of science and technology. Communication Research 29:584-608.

Osmond D.L., Nadkarni N.M., Driscoll C.T., Andrews E., Gold A.J., Allred S.R.B., Berkowitz A.R., Klemens M.W., Loecke T.L., McGarry M.A. (2010) The role of interface organizations in science communication and understanding. Frontiers in Ecology and the Environment 8:306-313.

Poliakoff E., Webb T.L. (2007) What factors predict scientists' intentions to participate in public engagement of science activities? Science communication 29:242-263.

Potter F. (1987) Julius Sumner Miller. Physics Today 40:114.

Priest S.H. (2010) Encyclopedia of science and technology communication Sage Publications.

Scheufele D.A. (2013) Communicating science in social settings. Proceedings of the National Academy of Sciences 110:14040-14047.

Scheufele D.A. (2014) Science communication as political communication. Proceedings of the National Academy of Sciences 111:13585-13592.

Schiele B., Claessens M., Shi S. (2012) Science communication in the world: practices, theories and trends Springer Science & Business Media.

Sensevy G., Tiberghien A., Santini J., Laubé S., Griggs P. (2008) An epistemological approach to modeling: Cases studies and implications for science teaching. Science education 92:424-446.

Simis M.J., Madden H., Cacciatore M.A., Yeo S.K. (2016) The lure of rationality: Why does the deficit model persist in science communication? Public Understanding of Science 25:400-414.

Sjöberg L. (2002) Attitudes toward technology and risk: Going beyond what is immediately given. Policy Sciences 35:379-400.

Solis-Sosa R., Semeniuk C., Fernndez-Lozada S., Dabrowska K., Cox S., Haider W. (2019) Monarch Butterfly Conservation Through the Social Lens: Eliciting Public Preferences for Management Strategies Across Transboundary Nations. Frontiers in Ecology and Evolution 7:316.

Stocklmayer S.M., Rennie L.J., Gilbert J.K. (2010) The roles of the formal and informal sectors in the provision of effective science education. Studies in Science Education 46:1-44.

Tetro J.A. (2018) Learning from History to Increase Positive Public Reception and Social Value Alignment of Evidence-Based Science Communication. Journal of microbiology & biology education 19.

Thomson K.S., Rachootin S.P. (1982) Turning points in Darwin's life. Biological journal of the Linnean Society 17:23-37.

Tichenor P.J., Donohue G.A., Olien C.N. (1970) Mass media flow and differential growth in knowledge. Public opinion quarterly 34:159-170.

Trench B., Bucchi M. (2015) Science communication research over 50 years. Patterns and trends. Science communication today—2015: Current strategies and means of action:15-27.

Van der Sanden M.C., Meijman F.J. (2008) Dialogue guides awareness and understanding of science: an essay on different goals of dialogue leading to different science communication approaches. Public Understanding of Science 17:89-103.

Varner J. (2014) Scientific outreach: toward effective public engagement with biological science. BioScience 64:333-340.

Wilczek F. (2008) My wizard. Phys Today 23:42.

Wynne B. (1992) Misunderstood misunderstanding: social identities and public uptake of science. Public understanding of science 1:281-304.

Wynne B. (2006) Public engagement as a means of restoring public trust in science–hitting the notes, but missing the music? Public Health Genomics 9:211-220.

CHAPTER 2: DEVELOPING EFFECTIVE SCIENCE COMMUNICATION PROGRAMMING

Introduction

Science communication consists of an exchange of information between experts with specialized knowledge and individuals that lack that information. This exchange can take many forms, but those developing science communication programs start with identifying the desired goals and outcomes, while regarding the level of understanding the audience has. Assessment of the audience and classifying the frames they receive information through influences the goals and outcomes developed. This chapter will examine the process of developing goals and outcomes, keeping in mind the audience's view, in order to create a communication strategy.

Setting Science Communication Goals

Goals are overarching, broad aspirations for a program that tend to be long-term in nature. They may be non-specific and simple to explain, for example "increase science literacy" or "expose individuals to science." Objectives then refine goals into actionable and measurable components. Specific goals should be identified before activity development occurs, because they dictate what techniques and tools should be used within the program (Baram-Tsabari and Lewenstein, 2017). The focus when developing goals for science communication is less about building a consensus between parties, than more about developing trust and understanding around the relevant science (Varner, 2014).

The large umbrella goal of science communication is to “develop science learners” within the audience (Bell et al., 2012). To develop these learners, there are six categories of goals that narrow the scope educators can use to develop objectives (Baram-Tsabari and Lewenstein, 2017). These categories each build upon each other in intensity and have specific qualities that direct and guide the intended outcomes (Baram-Tsabari and Lewenstein, 2017; Bell et al., 2012). They are, in order from lowest engagement necessary to highest engagement levels: affective goals, content goals, methods goals, reflective goals, participatory goals, and identity goals.

Goals that shift interest and motivation within the target audience are considered *affective goals*. Affective goals are related to moods, feelings, and attitudes. These goals are characterized through phrases, including “experiences excitement, interest and motivation about activities,” “attitude is supportive of science,” or “excited to learn about phenomena in the natural and physical world” (Baram-Tsabari and Lewenstein, 2017; Bell et al., 2012). These statements show a positive change in attitudes and feelings of the participants toward science.

Content goals focus more on the development and usage of facts related to the subject. The active usage of facts, concepts, and arguments surrounding the explored topic is key to operating with content goals. Ideally, the language identifying these goals includes the terms “generate, understand, remember and use” in connection to concepts within the program (Bell et al., 2012). These goals are intended to alter the comprehension and understanding of the topic within the target audience.

When science communication programs involve teaching opportunities, *method goals* are useful. These goals focus on the usage of science communication methods to create and sustain dialogue with others. These methods typically include the development or exploration of written, oral, or visual tools for effective science communication (Baram-Tsabari and Lewenstein, 2017; Bell et al., 2012). These types of goals often contain phrases like “uses science communication methods” or “capable of fostering fruitful discussions” when stated.

When individuals begin to reflect upon the roles of science and science communication within their spheres of influence, they are addressing *reflective goals*. These goals emphasize the capability for individuals to apply science to different situations and concepts. Phrases common to reflective goals could be some variation on “reflect on science’s role within society,” “examine their own process of doing science communication,” or “self-reflection on personal learning” (Baram-Tsabari and Lewenstein, 2017). The individual that completes reflective goals owns the process of science communication and can make it into their own, seeing science as a way of comprehending information about the world around them.

Setting goals that provide opportunities for participants to engage in dialogues is one way to meet *participatory goals*. Participation is necessary for many science communication programs to succeed. In meeting participatory goals, audience members are encouraged to create written, oral, and visual messages for audiences in which they could interact. While this is similar to methods goals, participation goals require audience members to engage with and use messaging tools. Folks that complete participatory goals are willing to be involved in activities and discussions with the scientific language and tools at their disposal. Participatory goals may use words like “participates in,” “creating and using,” and “engaging in dialogue with” (Baram-Tsabari and Lewenstein, 2017).

The final goal science communication developers should consider are *identity goals*. These are the most long-term of the related goals. They are not typically met within a single event, but rather over the course of multiple interactions. Individuals that accomplish identity goals feel competent as science communicators and contribute to science. Those that meet identity goals identify as a science learner and incorporate that description into their identity. Goals written with the intent to meet identity goals may be written with phrases like “thinks about themselves as a science communicator” or “develops an identity as a science communicator” (Baram-Tsabari and Lewenstein, 2017).

Many of these goals provide a framework for multiple interactions rather than being in a single event. The complexity of goals scales upward, with affective goals being the simplest to achieve, and identity goals the most complex. The increasing complexity of these goals allow them to be built upon if programming is intended to be repeated or occur regularly. Because attendance, time available, and audience participation varies by all events, meeting all six sets of goals every single time is not possible. Science communication developers need to assess which types of goals are feasibly and appropriately met by the activity.

Setting Science Communication Objectives

Objectives are actionable and specific. They have measurable outcomes as a result of a science communication program (Tetro, 2018). Objectives are activity based aspirations that are limited to the scope of specific engagement. For successful completion of objectives, they should be clearly identified prior to program development and then used to shape the lessons. Collaboration with non-expert individuals in the target audience helps refine and delineate objectives.

One way to identify and outline objectives is to use the 5E approach of science communication. This approach provides a simple roadmap to confirm objectives are reached (Tetro, 2018). The 5E approach focuses on 5 key terms: education, enrichment, engagement, entertainment, and empathy. These concepts do not necessarily stack upon themselves in the way that the goals described above do; they are related and could be considered a continuum of efforts. Each of the 5E's have a specific applicability to science communication, and appropriate selection and determination should improve the overall communication structure.

Education is the most frequent set of objectives science communication programs strive to accomplish. Education is the foundation of science communication efforts. Educational objectives strive to fill the gaps that may be lacking within the audience’s knowledge. They are typically unidirectional, stemming from the knowledgeable party (the scientists or communicator) to the less informed party (the audience). Bringing all participants to the same level of knowledge before introducing new topics allows the provision of further background information, history or context that is relevant to the topic. Providing and simplifying information without reducing the quality is a challenge to meeting educational objectives. The use of imagery and other descriptive tools enables the audience to relate without reducing the quality of information. If the message is oversimplified and quality reduced, misinterpretation is likely. Education objectives are not about trivializing information, but rather bringing all involved to the same level of understanding.

Enrichment objectives focus on encouraging the audience to comprehend the information and determine how it influences them. Like educational objectives, enrichment objectives tend to be delivered in a one-directional manner, deficit-model-manner of expert to non-expert. Determining how information affects an individual encourages them to assess how new information aligns with their values. The participant compares their interpretation of social issues to their personal beliefs and attempt to reconcile them. For adequate reconciliation, the presented information should add to personal assessment of social issues without conflicting with personal beliefs. If these are found to be in opposition, personal values consistently overshadow the evidence provided.

Merely providing more information is insufficient to sway the reconciliation, as facts alone are insufficient to sway decisions (Fischhoff, 2013).

Engagement objectives shift the communication style from unidirectional to bi-directional information transmission. This two-way conversation aspires to spark participation between the communicators and the participants of a science communication program. With large groups, this may manifest as “homework” or club involvement, where semi-personalized attention can be given to smaller groups of individuals. Small groups may be involved in engagement objectives through hands-on training and demonstrations. Though it may seem easiest, engagement objectives are not limited to face-to-face communication. In an audio medium like podcasts or a radio show, the communicator may opt for question and answer sessions led by listeners and their questions, while written communication (e.g. blogs, print articles, etc.) may provide contact information for further engagement. Social media has become a tool used to spark dialogue between scientists and audience members, though usage has implications to be explored later.

Entertainment objectives strive to increase the participant’s desire for more knowledge. Presenting information through relevant, engaging contexts increases the likelihood of aligning with social values. If the audience can relate to the communicator, typically through assessment of the communicator’s talent and intent, a firm foundation for success will be established. One difficulty when establishing entertainment objectives is that different audiences respond to similar approaches in different ways. There is no one approach that maximizes success in communication. Instead, they should be tailored to specific audiences and events (Tetro, 2018).

The final objective group is *empathy*. These objectives are designed to facilitate the empathetic skillset of the audience, enabling them to place themselves in the shoes of others (Decety et al., 2016). This enables individuals to expand their reach after leaving the event, because they are better able to empathize with others. This reach has rippling effects that expand out beyond the initial science communication event.

Other Key Considerations

The environment created by the science communicator has a massive effect on the success of the science communication event. When referring to an environment, the emphasis is not on the physical location but rather on the attitudes and openness of the participants. A good environment provides the opportunity to acquire new ideas and develop new meanings over the course of the event (Davies and Horst, 2016). Allowing individuals to make informed judgements in participation, involvement and interpretation enables folks to adapt.

The communicator should be conscious of external and internal factors that could affect the audience's perspectives and interpretations. Understanding the audience's experiences and the way they view the world ensures the program will adequately addresses their needs (Davies and Horst, 2016).

To understand responses from audiences, science communicators use the “AEIOU” acronym: awareness, enjoyment, interest, opinion, and understanding (Burns et al., 2003). These five aspects stack in complexity and are linked together. Increasing the latter typically indicates an increase in the earlier sets of responses. These five aspects define an individual or a group’s general approach to a science communication event. Assessing these and making likely inferences about the audience in this context can be useful to program development.

Awareness is a measure of how much a person is aware of about a given topic (Burns et al., 2003). This is the foundation of their knowledge and provides for both personal and public opportunities to broaden minds, depending on the level of involvement. Individuals may fall into one of three categories, depending upon their knowledge about a topic: uninformed, interested and specialist (Shore, 1999). At each level, their awareness about specific topics range from exposure to new ideas, aspiration to attain higher levels of science literacy or engagement in new research developments. Within these awareness levels, goals and objectives should shift appropriately.

The groups classed as uninformed or disinterested are assumed to not know what they don’t know. The goal with uniformed audiences is to bring awareness about a subject, and how it relates to their lives. Informed and interested parties within this audience group are aware of their gaps in knowledge and are searching out more information. The ideal goals and objectives for this group should encompass the aspiration to expand their levels of understanding beyond where it currently is. Most opt-in to engagement events occur at this or higher levels of understanding. Finally, specialists and attentive audiences are familiar with and have detailed knowledge of the subject. Event programmers should have goals and objectives that are focused less on expanding understanding or comprehension but are directed more to enhancing their experiences and facilitating the development of related skills. The goal for any event that has a variety of awareness levels is to “identify and communicate the fundamentals of the subject which are relevant to the uninformed, have enough variety to intrigue the informed, and reinterpret the content with freshness and humor to surprise and entertain the specialists” (Shore, 1999).

Audience members factor *enjoyment* into assessing science communication events. Enjoyment is the evocation of positive feelings and attitudes. Within the context of audience responses, this is an effective response to learning. Enjoying the event itself can be part of a valid learning outcome when the presenter understands the difference between superficial and deeper enjoyment. “Superficial enjoyment” includes having a pleasurable experience and seeing science equal to that of entertainment or art installations. In contrast, “deeper enjoyment” involves personal involvement and the ability of the audience member to explore and resolve science related matters within their life.

The more involved audience members already are with science communication efforts, the higher the *interest*. This is a logical result of science communication, because many goals are focused on helping individuals become more involved with scientists (Jenkins, 1994). Interest taps into a personal fascination, sparking a situational awareness increasing recall and understanding (Renninger et al., 2014). Having audience members volunteer to be involved repeatedly with science is a strong indicator of their interest.

Opinions of audience members are complex, personal, and multifaceted. They are influenced and linked by prior knowledge, individual beliefs and emotional reactions to provided information (Bagozzi and Burnkrant, 1979). An individual's opinions are revised regularly, especially when understandings are challenged, alternative views presented, or relevant information provided. Science communication strives to cause participants to reflect on their opinions and incorporate their new learning into current opinions.

The audience's *understanding* of the scientific content should be assessed prior to development of programs. Getting a scope of how the participants view the process and social factors involved within science allows for direction and guidance that may otherwise be overlooked. Relying on science literacy skills as a measurement of understanding is one common metric used. To maximize the time provided in programs, communicators should work to first bring everyone in the audience to the same level of comprehension prior to covering new topics.

Every individual participating in science communication assesses information through a number of frames. These frames are schemes of interpretation people use to understand the perspective and intent of a storyteller. In the case of science communication, it helps define how science-related issues become relevant to their experiences (Goffman, 1974). Science communicators assess likely frames audiences may be viewing information through, to understand how the audience will receive information (Nisbet and Scheufele, 2009). When a science communicator assesses what frames the audience is likely to be using, they are able to comprehend an individual's perception, understanding and participation goals in learning opportunities. When audiences are prompted with new information, frames are used to filter and compare this new information to past experiences to make decisions (Scheufele, 2013). Assessing likely frames is not about determining the intended "spin" of a story. Rather, it is about presenting information in a way that is most accessible and impactful to the individual (Scheufele, 2013). Within the scope of scientific communication program development, assessing frames used by the audience allows the tailoring of messaging tools to maximize impact (Scheufele, 1999). When the likely framing the audience will be using is understood by a science communicator, they are better prepared to adjust their programs as appropriate. One of the complications with framing is that while the programming may remain constant, different audiences may filter information through vastly different frames and take away different parts of information from the communication event (Bray et al., 2012). The use of appealing to different frames provides unique contexts to promote dialogue and further learning opportunities. They allow for the recognition of points of agreement and contention, and facilitate compromise when appropriate. Understanding the framing audience members are likely to be employing when evaluating information facilitates the refinement of a specific science communication program.

Common framing used by individuals range from those that benefit an individual to those that have large-scale or community-wide impacts (Nisbet and Scheufele, 2009). Three main groups of framing are fairly common: social development frames, scientific impact frames, and public integration frames. Interpretation is not limited to one frame per concept, but instead are combined and integrated as information is presented.

Social development frames includes social progress frames, economic development frames, and alternative path frames (Nisbet and Scheufele, 2009). *Social progress frames* examine science and related impacts by determining whether the research improves the quality of life or provides a solution to identified problems. Terms like “sustainability” or “harmony with nature” often appear when assessing topics through social progress frames. *Economic development frames* look at science as an investment, taking into account market benefits or risks along with competitiveness at local, regional, national and global scales. Economic development frames are often concerned with the overall cost-benefit analysis of the science information. *Alternative path frames* (also referred to as middle way frames) examine scientific presentations and information to see if there is a possible compromise to be reached between current practices and suggested implementations. Those that heavily employ alternative path framing are trying to find a third, possible unconventional, path to avoid conflicts.

Scientific impact frames focus on the outcomes science development brings to the community. These frames include looking at developing science in a very critical way, assessing potential pitfalls and issues that may arise with an emphasis on lack of knowledge and the development of contingency plans (Nisbet and Scheufele, 2009). *Pandora's Box frame* (also referred to as the runaway science or Frankenstein's Monster frames) focuses on the need for caution to prevent the science from getting out of hand and creating catastrophes. This frame often contains an air of catastrophe that the science will become out of control, if it does not proceed according to plan. *Scientific uncertainty frames* focus on what the experts claim to know and what limitations that information contains. This frame also raises concerns about what is not understood or what knowledge is not yet known and becomes apparent throughout the scientific process. There's a high volume of discussion around what is and is not known by the experts.

Public integration frames examine the moral and ethical questions around scientific discovery and communication. Common frame types in this category include morality and ethics frames, public accountability and conflict and strategy frames. *Moral and ethical framing* examines science in terms of right versus wrong, defined by the individual examining the issue. Those that process information through this frame are concerned whether the science respects or crosses thresholds set by the involved or affected individuals. *Public accountability frames* assess scientific discussions by determining whether public or private interests benefit more from specific scientific developments. *Conflict and strategy frames* examine scientific developments as a measurement of whether one research group is ahead of another in discovery. This air of conflict between researchers or scientists becomes prevalent when it comes to important discoveries in very visible fields (e.g. medicine, biotechnology, etc.), even when there is no genuine conflict between researchers.

Identifying specific frames individuals may be examining information through can happen through interacting with individuals and discussing related topics, or by making educated inferences about them. These methods are not foolproof, however. Since frames can be overlapped, the intent of identifying these frames is not to pigeonhole individuals, but rather to recognize that individuals may be receiving a topic filtered through different lenses. Understanding this technicality when developing science communication events that range from news interviews to conference planning provides insight into how different groups of individuals may receive, interpret, and act upon information provided. Science communicators can use this knowledge about audience framing to adapt presentations to encourage participants to become engaged and responsive (Goffman, 1974; Scheufele, 1999; Scheufele, 2013).

Conclusion

To effectively develop science communication, it’s paramount to first understand and develop goals and objectives while assessing how the audience will interact with the information. Goals are usually long-term, multiple interaction opportunities, typically with a focus on understanding relevant science (Varner, 2014). Goals can be sorted into a few categories, depending on intended engagement level. These groups each stack upon each other, building in complexity as they become more involved. Goal groupings include affective, content, methods, reflective, participatory and identity based goals (Baram-Tsabari and Lewenstein, 2017; Bell et al., 2012). Objectives are short-term and usually focus on a single interaction. Like goals, objectives should be outlined prior to the event. The 5E approach provides a roadmap to setting and achieving objectives, which are somewhat building in complexity, but are more interrelated in use. The 5E approach asks science communication programmers to focus on completing goals surrounding education, enrichment, engagement, entertainment, and empathy (Tetro, 2018). Science communicators should be cognizant of the general background of their audience and what frames they may be processing information through. Understanding the AEIOU concepts of the audience (awareness level, enjoyment, interest, opinions and understanding) ensures the event planned meets the needs of the audience (Burns et al., 2003). The frames an audience uses to parse information are not easily recognized but explain how different audiences interpret information in different ways. This understanding allows communicators to adapt their presentations to maximize the impact on their audience (Bray et al., 2012; Scheufele, 1999; Scheufele, 2013).

References

Bagozzi R.P., Burnkrant R.E. (1979) Attitude organization and the attitude–behavior relationship. Journal of personality and social psychology 37:913.

Baram-Tsabari A., Lewenstein B.V. (2017) Science communication training: What are we trying to teach? International Journal of Science Education, Part B 7:285-300.

Bell P., Lewenstein B., Shouse A., Feder M. (2012) Learning Science in Informal Environments: People, Places, and Pursuits. 2009. Washington, DC: Nat Acad Pr. 336p.

Bray B., France B., Gilbert J.K. (2012) Identifying the essential elements of effective science communication: What do the experts say? International Journal of Science Education, Part B 2:23-41.

Burns T.W., O'Connor D.J., Stocklmayer S.M. (2003) Science Communication: A Contemporary Definition. Public Understanding of Science 12:183-202. DOI: 10.1177/09636625030122004.

Davies S.R., Horst M. (2016) Science communication: Culture, identity and citizenship Springer.

Decety J., Bartal I.B.-A., Uzefovsky F., Knafo-Noam A. (2016) Empathy as a driver of prosocial behaviour: highly conserved neurobehavioural mechanisms across species. Philosophical Transactions of the Royal Society B: Biological Sciences 371:20150077.

Fischhoff B. (2013) The sciences of science communication. Proceedings of the National Academy of Sciences 110:14033-14039.

Goffman E. (1974) Frame analysis: An essay on the organization of experience Harvard University Press.

Jenkins E.W. (1994) Public understanding of science and science education for action. Journal of curriculum studies 26:601-611.

Nisbet M.C., Scheufele D.A. (2009) What's next for science communication? Promising directions and lingering distractions. American journal of botany 96:1767-1778.

Renninger K.A., Hidi S., Krapp A., Renninger A. (2014) The role of interest in learning and development Psychology Press.

Scheufele D.A. (1999) Framing as a theory of media effects. Journal of communication 49:103-122.

Scheufele D.A. (2013) Communicating science in social settings. Proceedings of the National Academy of Sciences 110:14040-14047.

Shore J. (1999) Chocolates, fireworks, dollars and scents: Chemical informalities, International conference on learning science in informal contexts, Canberra. pp. 112-118.

Tetro J.A. (2018) Learning from History to Increase Positive Public Reception and Social Value Alignment of Evidence-Based Science Communication. Journal of microbiology & biology education 19.

Varner J. (2014) Scientific outreach: toward effective public engagement with biological science. BioScience 64:333-340.

CHAPTER 3: NAVIGATING CHANGING COMMUNICATION MEDIA

Introduction

Science communication relies on journalistic media tools to rapidly spread awareness and incite action beyond in-person communication. Because the public's decisions are influenced by a vast number of factors, having a broad spectrum of tailored strategies allows for effective interactions by science communicators (Dijkstra and Gutteling, 2012; Nisbet and Scheufele, 2009). With the introduction of internet-based communication and social media, the media industry has undergone a massive change in how information is spread and how these new internet-based technologies can be used (Brossard, 2013). Even with this increase in information availability and accessibility, science communicators face many of the same issues they faced before the internet. These issues include information dilution and oversimplification, misinterpretation and polarization in audiences (Liang et al., 2014). Science communicators should understand the changes this shift in media technology has brought to their capability to engage with their audience and how to leverage it to their advantage.

Changes in Scientific Journalistic Media

Determining the best methods to communicate science to the public is challenging. There are several journalistic avenues available to science communicators at any given point, ranging from print media, audio, and video platforms. When developing a communication strategy, planning should "begin by first considering an entity's communication objectives and then focusing on the groups of media best suited to attain those desired outcomes" (Hallahan, 2010). This is not to say that other types of media should be excluded from use, but those that will best serve the intent of the goals and objectives should be prioritized.

Prior to the advent of the internet, the public relied upon science reporters acting as journalistic gatekeepers to determine newsworthiness (Lee and VanDyke, 2015). This limitation was removed with the development and acceptance of the internet in the early 2000's. The internet has enabled science organizations and researchers to more directly communicate with the public through social media (Kent, 2013). However, this accessibility places the responsibility on the public to seek out and find credible information much on their own. The internet has become the preferred source for science and technological information by the majority of the public (Lee and VanDyke, 2015). The introduction of blogs, wikis, social media, and the ability to share live-time information has redefined the scientific journalism mediascape. This has shifted audience members from passive consumers to active participants (Brossard, 2013; Welbourne and Grant, 2016). These tools brought alternatives to traditional content distribution and challenged existing paradigms surrounding science journalism. Now, scientists, interest groups, professional organizations, and passionate amateurs are able to interpret and share science alongside professional communicators and journalists (Claussen et al., 2013; Lo et al., 2010; Nisbet and Scheufele, 2009).

The Development of Science Hype and Misinformation

Regardless of how carefully crafted and intentionally selected each facet of a science communication campaign is, there is the propensity for the messaging to be warped. Misunderstanding, the desire to follow promising results, or the excitement surrounding possible developments pose high risks to changes in the original scientific message (Caulfield and Condit, 2012). Commonly, these changes develop into “hype” and are incorporated into advertisements, news coverage, and research agendas emphasizing benefit-heavy results. This often results in the benefits being exaggerated and the risks and costs associated with the development minimized (Caulfield and Condit, 2012). No one entity is responsible for what is referred to as the “hype pipeline”, but collective actions taken by scientific researchers, science community, press, and public spur on and develop this phenomenon (Caulfield and Condit, 2012). Understanding the hype pipeline and how it develops can assist science communicators in preparing for the surge in engagements and how it affects their messaging.

As new developments emerge and novel technologies become closer to reality, hype is a natural part of the scientific process. The scientific community, the media, and private investments benefit from hype in the short-term by stimulating public and political interest to secure more support and continue research (Ransohoff and Ransohoff, 2001). Hype begins with scientific researchers and the pressure to publish in high-impact journals consistently. This expands the possibility to shift that research into actionable technologies through commercial entities and partnerships. Before marketing this new development, research institutions publish press releases that increase public interest and expectations. Finally, other researchers begin to get on the scientific bandwagon, and this cascades into other related hype pipelines (Caulfield and Condit, 2012).

If expectations from the hype pipeline are not met, there are negative consequences. There may be a loss in public trust in the scientific community and lowered expectations as a result (Petersen, 2009). Especially in novel and new health related technologies like stem cell research, there is a tendency to prematurely implement research before understanding the full scope and results (Wilson, 2009). As hype around a new concept or technology begins to grow, researchers in other departments and institutions begin to divert their energies into the hyped research, leaving behind other essential research topics (Petersen, 2009; Wallace, 2010). Implementation and technology spark policy debates on who, what, and how the information can be used, but with incomplete understanding of potential complications, the debates do not capture the true benefits and harms of results (Caulfield and Condit, 2012).

The interaction between the media and the public in developing hype is a reciprocal relationship. The public plays a large role in determining the content of journalistic media and the attitude displayed toward scientific discovery (Du Gay and du Du Gay, 1997). The media strives to reach the broadest audience possible to turn a profit. In doing so, they slant their reporting to serve that purpose (Fiske, 1986). As an entity, the public readily latches onto “silver bullet” and quick fixes that focus on short-term successes rather than long term strategies to prevent issues (Caulfield and Condit, 2012). Often, the media’s emphasis on profit turns possibilities into optimistic hype that engages an active portion of the public with a potential “cure concept,” even though scientific results may be preliminary.

In addition to the media and the public, the scientific bandwagon contributes to the hype pipeline by committing to one promising approach (Fujimura, 1988). These researchers, their labs, and the funding all commit to tackling the same issues, emphasizing the outcomes that match or exceed expectations and minimizing those that do not. The scientific bandwagon perpetuates a feedback loop, commonly referred to as “the promising approach” cycle. Here, a disappointment with the failure of gathering expected results with this promising approach causes a shift to a new to chase the answer. This new promising approach follows a similar path of failure and disappointment before being forgotten in favor of another promising approach (Fujimura, 1988). This cycle feeds into the hype pipeline, keeping it active and functioning.

Distortion of the scientific message can occur at any stage in the hype pipeline, although there is usually not malicious intent to misrepresent the information (Caulfield and Condit, 2012). Instead, this distortion occurs because of the combination of external pressures, message simplification, and the overall fragmentation of the media. Institutional pressures are placed on researchers in the form of dissemination. Many times, this is tied to employment opportunities (e.g. tenure and pay), encouraging researchers to publish early and frequently to avoid being “scooped” (a term used to refer to someone publishing over someone else). When the research institution releases a press release about new developments, the science is simplified to fit into a default template. When the media picks up the news from the press release, it is usually further simplified and morphed into a slightly skewed message. In a study examining the difference among published peer-reviewed research papers, institutional press releases, and journalistic media publications covering genomic and other emerging sciences, the information between the institutional press release and media publications had the highest degree of difference. In contrast, the research paper and the institutional press were more similar in explaining the notable science results (Brechman et al., 2011). The simplification of the information emphasizes the positive results of the research and includes little, if any, discussion of potential issues, risks, or negative impacts.

The print journalistic practices and factors associated with science communication journalism influences the distortion and slanting of the media’s information. Current practices advocate for objectivity of ‘both sides’ around a controversy (Tuchman, 1972). In part, this is due to the need for economic support to continue publishing. Providing affirmation to multiple audience perspectives ensures that a greater number of individuals will invest in that media. Journalism’s standard of “if it bleeds, it leads” forces competition for space and attention (Caulfield and Condit, 2012). For a story to sell, writers are encouraged by editors to lean toward sensational pieces that highlight personal stories with positive spins and downplay potential risks and limitations. Science reporters have the added advantage of having scientific backgrounds, and thus, the capability to understand and appreciate the finer details of the work. However, their pieces are often sensationalized or skipped over because of the need to sell the news. A narrow core of experts is regularly turned to as primary sources, limiting the scope of understanding. Print journalism is currently observing a decline in readership and subscriptions, partially due to the diversity of publications available (Dudo et al., 2011). In turn, the media corps decreases scientific journalists on staff, resulting in a decline in the volume of scientific articles and stories. As the media becomes more fragmented through expanded availability and diversity of target audiences, science communicators can find it difficult to broadly inform the public with consistent messaging (Allgaier et al., 2013). This broad base poses challenges to share a consistent, unified message across media types. With the rapid updates social media ascribes to, misinformation, distorted and incorrect details are shared just as fast, if not faster. The introduction of the internet brought on a fundamental change to the modern print media environment and to the consumption habits of target audiences. This has disrupted long-held paradigms about how it should best function (Brossard, 2013).

Social Media as a Communication Tool

Kaplan (2010) defined social media as a “group of internet based applications that build on the ideological and technological foundations of Web 2.0, and that allow the creation and exchange of user-generated content.” Social media has become an essential tool of public relations and science communication, allowing users to share, critique, and modify ideas rapidly with a broad audience (Kent, 2013). Because of the ease of developing dialogue in these spaces, public relations of organizations rely heavily on social media to communicate externally to their stakeholders (Wright and Hinson, 2013). Blogs, wikis, video sharing, and other social media tools have become commonplace and have created an alternative to traditional content distribution (Brossard, 2013). This massive change has redefined the mediascape.

The low barrier to entry with social media in comparison to traditional media makes it easy for science communicators to become involved. The simplicity of creating profiles and starting to share information makes social media a vital tool for science communication (Juhasz, 2009). Increasing science literacy and the public’s general understanding of science over social media has been shown to have positive outcomes (Kent, 2013). When including dialogic models in communication, the positive relationship between strategically inviting conversation and a favorable perception of the organization increases (Yang et al., 2010). Those engaging in dialogue with the science communicator in good faith over social media have an increased likelihood of listening to and trusting the scientific information and the communicator can engage with the public. In addition, the communicator may be better positioned to identify and correct points of contention or misunderstanding by listening directly to those being engaged. Unfortunately, there can be misuse of social media to create limited dialogue. Communicators may limit their audiences and exclude voices that would be valuable to the conversation (Bortree and Seltzer, 2009). Other individuals may troll, harass or consistently argue with science communicators, making it difficult to communicate effectively. With the technological advances regularly being released, there are increased opportunities for individuals to contribute to the conversation and become involved in science communication dialogues.

Too often, science communication tends to be used in 1-way communication between the science communicator and the audience, rather than facilitating two-way dialogues (Bortree and Seltzer, 2009; Rybalko and Seltzer, 2010). Having dialogic conversations in social media is challenging. Communication professionals tend to rely on social media technology that was designed for use in sales. This limits its usefulness and reach (Kent, 2013).

Science communicators choosing to use social media ought to recognize that media sites like Facebook and Twitter are not ideal for dialogue-based conversation. These sites involve a high level of distraction because they are reliant on user engagement and advertisements to continue operating. Ideally, focused engagement with stakeholders should occur one-on-one, not one-to-many. Science communicators and their affiliations should be identifiable because anonymity tends to impede dialogue and reduce trust. If discussion is encouraged, rules should be set, and the dialogue moderated to enable most of the engaged voices to be heard in a respectful manner. If there are divergent views, the communicator and audience should be encouraged to work to share meaning and engage thoughtfully.

Examples of Social Media Science Communication

Social media covers a wide variety of websites and applications. Each of these have specific methods of engagement and suggestions for quality science communication opportunities to thrive. Blogging, posting on Twitter, or creating videos for YouTube are three common methods science communicators employ to share information and create dialogue.

Science blogging provides science communicators direct control and individual autonomy to determine how research is shared and explained. Blogging enables the circumnavigation of traditional media outlets while communicating with peers and the non-scientific public alike (Brossard, 2012; Colson, 2011). Science blogging also facilitates the exposure of issues not yet popularized in mainstream media. In doing this, scientists benefit from discovering potential collaboration or funding partners, while reporters are able to directly acquire information from the researcher to create better developed stories (Cacciatore et al., 2012). Beyond that, the expansion of professional networks as a result of actively updating and posting content can lead to multi-discipline, multi-institutional collaboration, something frequently sought after in academia (Colson, 2011). Science blogging allows scientists and communicators alike to engage in thoughtful, reflective sharing of their research and expose a vast audience to a unique way of looking at science.

Twitter, a short-form “micro-blogging” website, strictly limits users to 280 characters to an individual message (called Tweets). Videos, images, and websites can be linked, multiple tweets can be combined into “threads” and “hashtags” (keywords or phrases following the hash symbol - #) used to collect thoughts on a given topic. Scientists often use Twitter as a way to discuss academic conferences and newly published articles. In doing this, they provide insights that may otherwise be obscured from the non-scientific public. The sheer number of users, the relatively open access of creating an account, and the relative ease of composing a Tweet all allow for information to be shared immediately and reach a fairly wide, diverse audience (Reed and Keech, 2018; Rybalko and Seltzer, 2010). Hashtags like “#UniqueScientist,” “#WomenInSTEM,” “#QueerInSTEM,” and “#ScienceIsForEveryone” showcase the diversity of scientists and disciplines involved. Hashtags like “#WSSA2020” are used to track conferences and aggregate tweets about talks, discussions, and networking opportunities. The visibility Twitter provides often leads to increased impact, whether measured by the number of followers, collaborations sparked, or other engagement metrics. Retweets (the sharing of another person’s Tweet), Quote Tweets (sharing another’s Tweet with your comments attached) and Likes are all part of these engagement metrics.

YouTube is a video hosting website that allows both user generated content and professional generated content to be uploaded and shared with the public. It is a fantastic tool for science communicators to demonstrate and share science-based lessons (Welbourne and Grant, 2016). A science communication channel enables a communicator to deliver and interact with the viewer base. This fosters a connection and allows for the development of a participatory community. This regular face (or faces) allows for the identification of the communicator as a trusted source by the audience. This lends credibility to the communicator as having expertise, impartiality, experience, affinity and trust within their social networks (Borgatti and Cross, 2003). The rapid delivery of information via videos increases views, engagement, and interest. However, slower delivery rates during public speaking improve comprehension of the information. It is unclear if the ability to rapidly replay video nullifies this loss in comprehension. The video length also affects user engagement. Studies differ on whether longer videos (ranging between 10 and 15+ minutes) or shorter videos (less than 5 to 9 minutes) provide greater success (Welbourne and Grant, 2016).

Considerations for Developing Science Communication for Social Media

When developing science communication designed for social media sharing, the largest hurdle to overcome is the potential for misinterpretation or misunderstanding (Bubela et al., 2009). To minimize this, communicators should take a balanced approach – balancing positive and negative news about results. In doing this, science writers have the ability to use both aspects to reduce positive-only spins in reporting (Bubela et al., 2009). Often, there tends to be an entrenchment in the experts relied upon to provide commentary and perspectives on new research. Encouraging media to seek more diverse sources for comment increases the potential for a more comprehensive understanding. Using all available resources and ensuring there is a concerted approach across all media types maximizes the likelihood of individuals encountering and understanding the message.

Even with all of these considerations, audience reach is not guaranteed – especially with social media (Welbourne and Grant, 2016). The rapid pace and algorithm used is unclear and often seems unpredictable regarding determining virality and reach. Most often, algorithms detect varying factors and determine “popular content” based on intrinsic and extrinsic factors. Part of that algorithm follows a “rich get richer” scenario. Thus, already popular content is shown to more users, increasing the already elevated popularity (Zhou et al., 2010). Popularity can be determined by intrinsic factors: the topic discussed, the target audience, the media length, and other stylistic and informational characteristics. External factors can include upload time, the social network of the poster, and the networks of those interacting (Crane and Sornette, 2008; Davenport and Beck, 2001; Figueiredo et al., 2014; Kim et al., 2012).

Science communication cannot occur exclusively on one platform. Support across media channels provides the widest opportunities for visibility and engagement. Crossing media channels between journalistic outlets (e.g. newspapers, magazines, radio, television, and internet sources), developing new media (e.g. blogs, wikis, and vlogs), and interacting on social media networks facilitates the ability to keep abreast of developing conversations (Allgaier et al., 2013). Outreach activities like interacting with reporters and mentioning other scientists on social media helps promote and expand beyond the communicator's bubble of influence. Having multiple online accounts and methods of sharing amplifies the effects of other forms of outreach off-screen. This online "buzz" increases impact and enriches the information exchange between community and audience (Liang et al., 2014).

The development of new tools for science communication and the constant evolution of social media spaces lends itself to a few challenges that have yet to be solved. One is the easy access to scientists (Liang et al., 2014). It is easy to directly contact a scientist in a field by finding their contact information or social media handles and engaging in an open and interactive dialogue. While most of the time this may seem innocuous or based predominantly in curiosity, there is the potential for harm through threats, proposed violence, or even doxing (the practice of exposing personal and private information to the public via social media with the intent of doing harm). Another challenge is the regular repurposing and willful misinterpretation of information, followed by the rapid transmission of the warped information. Information taken out of context can be applied with a twist to appear to support contradictory stances. Further, a typo, an accidental misinterpretation of the data, or an incomplete thought can be reposted and experience a larger impact than the author intended. The virality of science news can polarize perceptions of risk, either creating unnecessary panic or reducing vital concern. Beyond the social issues with social media and science communication, consideration, and changes around mapping academic impact via web presence is necessary. Page rankings on websites like Google Scholar or ResearchGate.com provide one metric, but interactions and impact on social media is more challenging to assess. Tools do exist that attempt to provide meaningful data on the interactions and impact, but they are not consistent in application.

Conclusion

Science communication has undergone an enormous shift with the development and implementation of the internet and social media. Tailoring objectives to use and employ these new technologies allows for an improved experience for the science communicator and the audience. While there is the opportunity for new development through science blogging, the use of Twitter and similar social media sites, and video hosting sites like YouTube, there are still challenges. The dilution of the intended message, misinterpretation of data and engagement in interactive dialogue all require science communicators to adapt and verify their intended message. The development of new media communication tools has allowed the rapid expansion and sharing of ideas. These tools should be leveraged by science communicators to maximize involvement and engagement.

References

Allgaier J., Dunwoody S., Brossard D., Lo Y.-Y., Peters H.P. (2013) Journalism and social media as means of observing the contexts of science. BioScience 63:284-287.

Borgatti S.P., Cross R. (2003) A relational view of information seeking and learning in social networks. Management science 49:432-445.

Bortree D.S., Seltzer T. (2009) Dialogic strategies and outcomes: An analysis of environmental advocacy groups' Facebook profiles. Public relations review 35:317-319.

Brechman J.M., Lee C.-j., Cappella J.N. (2011) Distorting genetic research about cancer: from bench science to press release to published news. Journal of Communication 61:496-513.

Brossard D. (2012) A (brave) new world? Challenges and opportunities for communication about biotechnology in new information environments, Biotechnologie-Kommunikation, Springer. pp. 427-445.

Brossard D. (2013) New media landscapes and the science information consumer. Proceedings of the National Academy of Sciences 110:14096-14101.

Bubela T., Nisbet M.C., Borchelt R., Brunger F., Critchley C., Einsiedel E., Geller G., Gupta A., Hampel J., Hyde-Lay R. (2009) Science communication reconsidered. Nature biotechnology 27:514.

Cacciatore M.A., Anderson A.A., Choi D.-H., Brossard D., Scheufele D.A., Liang X., Ladwig P.J., Xenos M., Dudo A. (2012) Coverage of emerging technologies: A comparison between print and online media. New media & society 14:1039-1059.

Caulfield T., Condit C. (2012) Science and the sources of hype. Public Health Genomics 15:209-217.

Claussen J.E., Cooney P.B., Defilippi J.M., Fox S.G., Glaser S.M., Hawkes E., Hutt C., Jones M.H., Kemp I.M., Lerner A. (2013) Science communication in a digital age: Social media and the American Fisheries Society. Fisheries 38:359-362.

Colson V. (2011) Science blogs as competing channels for the dissemination of science news. Journalism 12:889-902.

Crane R., Sornette D. (2008) Viral, Quality, and Junk Videos on YouTube: Separating Content from Noise in an Information-Rich Environment, AAAI Spring Symposium: Social Information Processing. pp. 18-20.

Davenport T.H., Beck J.C. (2001) The attention economy. Ubiquity 2001:1-es.

Dijkstra A.M., Gutteling J.M. (2012) Communicative aspects of the public-science relationship explored: Results of focus group discussions about biotechnology and genomics. Science Communication 34:363-391.

Du Gay P., du Du Gay P. (1997) Production of culture/cultures of production Sage.

Dudo A., Dunwoody S., Scheufele D.A. (2011) The emergence of nano news: Tracking thematic trends and changes in US newspaper coverage of nanotechnology. Journalism & Mass Communication Quarterly 88:55-75.

Figueiredo F., Almeida J.M., Benevenuto F., Gummadi K.P. (2014) Does content determine information popularity in social media? a case study of youtube videos' content and their popularity, Proceedings of the SIGCHI Conference on Human Factors in Computing Systems. pp. 979-982.

Fiske J. (1986) Television: Polysemy and popularity. Critical Studies in Media Communication 3:391-408.

Fujimura J.H. (1988) The molecular biological bandwagon in cancer research: Where social worlds meet. Social Problems 35:261-283.

Hallahan K. (2010) Public Relations Media SAGE, Thousand Oaks, CA.

Juhasz A. (2009) Learning the five lessons of YouTube: After trying to teach there, I don't believe the hype. Cinema Journal 48:145-150.

Kaplan A.M., Haenlein M. (2010) Users of the world, unite! The challenges and opportunities of Social Media. Business horizons 53:59-68.

Kent M.L. (2013) Using social media dialogically: Public relations role in reviving democracy. Public relations review 39:337-345.

Kim C., Jin M.-H., Kim J., Shin N. (2012) User perception of the quality, value, and utility of user-generated content. Journal of Electronic Commerce Research 13:305.

Lee N.M., VanDyke M.S. (2015) Set it and forget it: The one-way use of social media by government agencies communicating science. Science Communication 37:533-541.

Liang X., Su L.Y.-F., Yeo S.K., Scheufele D.A., Brossard D., Xenos M., Nealey P., Corley E.A. (2014) Building Buzz: (Scientists) Communicating Science in New Media Environments. Journalism & mass communication quarterly 91:772-791.

Lo A.S., Esser M.J., Gordon K.E. (2010) YouTube: a gauge of public perception and awareness surrounding epilepsy. Epilepsy & Behavior 17:541-545.

Nisbet M.C., Scheufele D.A. (2009) What's next for science communication? Promising directions and lingering distractions. American journal of botany 96:1767-1778.

Petersen A. (2009) The ethics of expectations. Monash bioethics review 28:22-33.

Ransohoff D., Ransohoff R. (2001) Sensationalism in the media: when scientists and journalists may be complicit collaborators. Effective clinical practice: ECP 4:185.

Reed M., Keech D. (2018) The ‘Hungry Gap’: Twitter, local press reporting and urban agriculture activism. Renewable Agriculture and Food Systems 33:558-568. DOI: 10.1017/S1742170517000448.

Rybalko S., Seltzer T. (2010) Dialogic communication in 140 characters or less: How Fortune 500 companies engage stakeholders using Twitter. Public relations review 36:336-341.

Tuchman G. (1972) Objectivity as strategic ritual: An examination of newsmen's notions of objectivity. American Journal of sociology 77:660-679.

Wallace H. (2010) Bioscience for life. Who decides what research is done in health and agriculture.

Welbourne D.J., Grant W.J. (2016) Science communication on YouTube: Factors that affect channel and video popularity. Public Understanding of Science 25:706-718.

Wilson J.M. (2009) A history lesson for stem cells. Science 324:727-728.

Wright D.K., Hinson M.D. (2013) An updated examination of social and emerging media use in public relations practice: A longitudinal analysis between 2006 and 2013. Public relations journal 7:1-39.

Yang S.-U., Kang M., Johnson P. (2010) Effects of narratives, openness to dialogic communication, and credibility on engagement in crisis communication through organizational blogs. Communication research 37:473-497.

Zhou R., Khemmarat S., Gao L. (2010) The impact of YouTube recommendation system on video views, Proceedings of the 10th ACM SIGCOMM conference on Internet measurement. pp. 404-410.

CHAPTER 4: Science Communication Case Studies

Introduction

The Doctor of Plant Health Program requires students to complete two internships during their tenure within the program. This requirement expands the student's understanding from what is taught in the classroom through experiences in real-life situations. My first internship was as the Doctor of Plant Health Horticulture Intern at the Denver Botanic Gardens, in Denver, Colorado in the summer of 2018. The second internship position was the Science Communication Intern at the University of Nebraska Panhandle Research and Extension Center in Scottsbluff, Nebraska during the summer of 2019.

Prior to these experiences, I conceptually understood the methodology of science communication through discussions in coursework and previous work experience. I had a grasp of how to speak to and teach different age groups, how to do assessments to ensure goals were met, and what concepts to consider when designing tools to use. The components I lacked included the specific terminology and frameworks laid out in previous sections of this document. This section provides a retrospective view of how these established frameworks applied to the programs I worked with and developed. Applying the identification of intended audience parameters, the methods of engagement, and the goals and objectives of each method allows for a better understanding of how the frameworks of established science communication efforts can be applied, even if the communicator is not aware of the specifics.

Case Study 1: Science Communication in a Public Garden

At Denver Botanic Gardens, visitor demographics span across ages, cultures and scientific literacy skills. With three locations spanning over 24 acres in the Denver metropolitan and outlying areas, the Denver Botanic Gardens serve as a center for public outreach and scientific research specifically surrounding steppe environments.

Because of the diversity of visitor demographics and longevity of operation, Denver Botanic Gardens had already established their intended audience in all their communication. The knowledge level of the target audience ranged from inexperienced through expert, but most of the material developed relied on basic information to bring the inexperienced visitors up to speed and supplement with additional knowledge if necessary. For most writing, Denver Botanic Gardens aimed at a 6th grade education level; an age range that had a basic grasp of scientific terms and was capable of making inferences from information provided. With direct hands-on-science events, like the Science Chats at the Science Pyramid, lessons were geared toward the 2nd grade. Visitors were likely to have basic knowledge of plants but they did not have a full grasp on the scientific terms used. Most of the content I built focused on a few key frames: scientific uncertainty, social development, and public integration (Nisbet and Scheufele, 2009). Scientific uncertainty frames My intent was to present scientific information about how plants and plant health mattered to the audience.

Science Pyramid Science Chats

The first method of engagement I was involved with was the development and updating of Science Chats for the Science Pyramid. The Science Pyramid focused on the ecology and interconnectedness of the flora and fauna of the region. Science Chats were designed to talk about hydrology, entomology, plant physiology and other topics as they applied to the Colorado Steppe environments. I worked specifically with the “Plant Trichomes” chat, a previously designed module that explored the importance and function of plant trichomes. I also developed a “Plant Detective” chat, a module designed to teach the basics of plant health diagnostics.

To ensure appropriate design while building and updating these modules, I had to identify my goals and objectives. Looking back, it was clear what my goals and objectives were, even if I had not specifically written them down. Most of my goals revolved around being affective and content-based, focused on the feelings and attitudes toward specific topics and to further the comprehension and application of those topics (Baram-Tsabari and Lewenstein, 2017; Bell et al., 2012). The affective goal of the “Plant Trichome” chat expected “the participants to develop an awareness of Colorado plant diversity and morphology.” The content related goal was to “foster an understanding in different roles of plant trichomes in the audience members.”

To meet these two goals, I identified objective categories that could help accomplish those goals: predominantly education, engagement and entertainment (Tetro, 2018). Enrichment objectives were not applicable in this frame because the individuals participating were not having information challenged against core values and prompting a reconciliation of ideas. Empathy based objectives were also not useful here as participants were unlikely to take their knowledge and use it to have a profound effect on other individuals.

The primary education objective was that “the participants will understand plants have specialized structures called plant hairs.” By doing this, I met the minimum of the affective goal: an understanding of plant diversity within Colorado. Since I was using plants from within the gardens, visitors were able to make direct connections to these concepts as they continued their visit. The engagement objective strove for “participant engagement with the presenter as they show the leaf hairs under the stereo microscope” and for general two-way communication to occur during the chat. Finally, the entertainment objective was met when “audience members share experiences with the presenter about leaf trichomes and are able to make correlations to plant behaviors.”

Looking back on these goals and objectives, I achieved most of them regularly with the patrons that visited this Science Chat. While some audiences – predominantly extremely young children – were not able to reach the education objective, they completed the engagement and entertainment objectives with ease. Most of the time all three objectives were met, and thus the affective and content goals of this specific chat were completed. Most participants walked away with some new knowledge about plant trichomes and their roles in Colorado plant diversity.

The “Plant Detective” chat, was designed to introduce issues that were commonly found with in-home gardens and house plants. The affective goal set with this chat was “participants will develop an interest in simple plant health related concepts.” My intent was to get individuals to think about why a plant may be respond to several different factors, both abiotic and biotic. The resulting content goal was “audience members will comprehend how different symptoms affect the identification of plant health issues.”

To meet these goals, I again set education, engagement and entertainment objectives. Like the “Plant Trichome” chat, enrichment and empathy weren’t as applicable to this setting. The education objective revolved around “participants will have an understanding of common plant diagnoses they may encounter.” In doing this, I intended to share the basic concepts behind plant diagnosis and a simplified decision tree to eliminate some likely causes. My engagement objective was incredibly similar to that of the previous chat, where “individuals choosing to participate will share their experiences with plant health with the chat host.” Like the previous chat, I hoped to have people make connections between experiences they’ve had and the science behind it. Having a fun, interactive flow chart and puzzle for visitors to work through helped meet the entertainment objective of “have visitors enjoy learning about plant health and simple diagnoses they can do on their own.”

Both of these chats met their objectives and their goals. The “Plant Trichomes” chat was an established chat I updated to better reflect the tools available to volunteers, and the “Plant Detective” chat was a newly established chat. Unfortunately, I didn’t get to do more than a few runs of the “Plant Detective” chat due to timing and availability at the Science Pyramid. However, in the trials I was able to complete with volunteers, the module met my personal goals and objectives and the requirements for Denver Botanic Gardens.

Public Outreach and Communication

Another science communication component of my internship at Denver Botanic Gardens was part of a research collaboration between The Gardens and Colorado State University’s (CSU) Entomology Department. Denver has an isolated population of the invasive Japanese beetle (*Popillia japonica*) that has become established. CSU was testing the release of the parasitic winsome fly (*Istocheta aldrichi*), as an additional method to manage the pest.

My role in this study was to collect the insects from the kairomone trap placed within the garden and act as a public liaison to explain the project. The science communication that happened in this scenario was much less formal than that in the Science Pyramid or in other scenarios, but there was a clear set of goals and objectives to complete in each interaction. Affective and content goals were set, but further goal levels were not as attainable with the speed of interactions. The affective goal for these interactions was “visitors will be supportive of the study.” The content goal consisted of “interested parties remember some information about the Japanese beetle or the parasitoid study by CSU.”

To achieve these goals, I set simple education and enrichment objectives. Engagement, empathy and entertainment goals were not applicable in this context. The education objective was simplified down to “provide information for visitors about the Japanese beetle parasitoid project.” The enrichment objective sought to “expand guest understanding about Japanese beetles and how this research benefits them and their pest management needs.”

These communication opportunities were short and typically begun and lead by the guests. This provided me the flexibility to provide information specific to their interest and tailor the conversation to meet the goals and objectives stated above. Overall, I think most of the conversations met the goals and objectives for these short-form science communications.

‘Plant Health Highlights’ Blog

Finally, the last science communication portion of the internship was digitally based. Short Plant Health Highlights were written bi-weekly for the Denver Botanic Garden’s blog called ‘Digging in the Gardens.’ These were short 500-word articles written at a 6^{th} grade education level with a few descriptive images. The brevity and digital nature of these blog posts lead to reliance on affective and content goals with a focus on education and engagement objectives.

The affective goal was encompassed by “readers will become interested in specific plant health issues faced at the gardens that they may also encounter in their gardens.” The content goal was “readers will retain information about the specific plant health related topics." Both goals were supported by specific education and engagement objectives: "blog visitors will gain knowledge about plant health issues at the gardens" (educational), and "blog visitors will leave comments about their experiences in similar situations" (engagement). All objectives and goals were met, though having a better idea of seasonal issues before they were concerns would have been more ideal to better plan and align releases.

Retrospective on Public Garden Science Communication

In looking back at this internship and applying the goals and objectives to fit the activities, it became clear that I was heavily reliant on affective and content goals with education and engagement objectives. This makes sense, because many of these opportunities were short, unscheduled interactions with a wide variety of guests. Scaling the activities and discussions to the audience's level enabled me to meet the objectives and goals more effectively. However, when designing modules like the science chat or preparing other volunteers to provide information, there is a need to make the information scalable to the level of the person being trained. This allows them to be prepared to engage at a level they are comfortable at and would require a reassessment of goals and objectives to better fit the needs of the volunteers. The ability to adjust to both volunteer and participant knowledge levels are key to interactive and multi-level outreach initiatives.

Case Study 2: Science Communication Through Online Program Development

My second internship was at the University of Nebraska – Lincoln Panhandle Research and Extension Center in Scottsbluff, Nebraska. I worked as the Science Communication Intern developing a foundation for an online science communication project called “Farm Sci-Ed.”

“Farm Sci-Ed” Development

“Farm Sci-Ed” was created to share in-field research and explain the science behind the farming practices being evaluated. “Farm Sci-Ed” was developed to emphasize the importance of agricultural research occurring in western Nebraska through a multi-media strategy using video, audio and written episodes. Over fifty, 30-minute episodes were scripted, recorded and partially edited. Audio, video and guest interviews were coordinated and collected into a library to be used later. A simple filming studio built in the PHREC building and protocols for completion and launch of the program developed.

Since the “Farm Sci-Ed” program was designed to be available online in a few different formats, there was no way to identify one specific audience that would be engaging with the material. It was not designed to be an in-person program or have an in-person component. However, since the individuals who would be interacting with the video would have to have some reason for doing so, it’s acceptable to assume that the knowledge level of the audience member ranges from interested to expert. This material would be unlikely to be randomly selected, so individuals would be expected to have an intentional reason to engage with the material.

The framing that this program would be most likely examined through consisted of social development and scientific impact (Nisbet and Scheufele, 2009). Social development framing examines the science presented in comparison to the needs of the community. Scientific impact framing explores the way science and its presentation has some tangible effect on policy or practice within the community. “Farm Sci-Ed” had to be prepared to handle many of the questions and discussions around the importance of the research being demonstrated.

The application of goals for “Farm Sci-Ed” highlights the intent of the program. “Site visitors will be interested in western Nebraska agricultural research” and “audience viewers will be motivated to seek out further information” were two of the main affective goals set. The content goal was that “audience members will understand the importance of western Nebraska agricultural research.” These goals were in line with the mission of “Farm Sci-Ed” and were achievable through the objectives set.

The objectives for “Farm Sci-Ed” were primarily education, enrichment and entertainment based. The lack of real-time audience feedback and limited engagement opportunities prevented expansion into more complex, bi-directional information sharing objectives. The education objective was probably the most straightforward: “participant viewers will understand the basic need for agricultural science research.” This objective permitted a wide variety of topics to be discussed, but also ensured that conversations within the episodes stayed on target and focused. The enrichment objective revolved around the concept that the “audience will comprehend the effect agricultural research has beyond the technical aspects.” This objective urged me as the show producer to ensure that the impacts discussed in the project expanded beyond research for science’s sake and into the broader community impacts. Finally, the entertainment objective required me to think about how viewers could participate in the show since it was not immediately face-to-face. The objective sought to “provide a space where participants can ask questions and get answers from the hosts through Q and A sessions and comments.” This set the framework for the outline of the project without limiting the topics of the discussions.

Retrospective on Online Science Communication Program Development

This internship was predominantly focused on the development of “Farm Sci-Ed”, thought I did also help in other capacities with audio/visual support for field day events and other major talks given at the center. It highlighted the need for expansion into the digital realm for institutional science communication. One of the main challenges was the learning curves required with digital media development, including video and audio editing programs and live-streaming content. The other main lesson learned from this project was the need to have a very clear, yet adaptable framework and strategy so future expansions do not need to recreate from the beginning every time. Science communication via digital technology contains its own set of challenges, but having clear guidelines assisted in the deployment of this project.

Conclusion

Using the methods discussed previously in this document to create targeted and effective science communication projects becomes a crucial step to success. Had I known and used these techniques when I started any of these projects, I may not have struggled as much as I did to guide and create my final products. As I go forward with my science communication endeavors, the skills and techniques I developed through these internships will provide a sound foundation to continue structuring programming. The year between my internship at Denver Botanic Gardens and “Farm Sci-Ed” development demonstrates my development in level of engagement and understanding within science communication efforts. The work on “Farm Sci-Ed” was more consistent with regard to quality than that at Denver Botanic Gardens.

While I was not cognizant of these specific techniques and methods for developing science communication when I was doing my internships, it’s clear that taking a retrospective approach to review these activities provides insight into how science communication isn’t prescriptive, but it needs to be flexible and adaptable to the situation. The lack of understanding of common frameworks used to plan and organize for events didn’t hamper my ability to create effective communication strategies, though it’s clear that having these structures will improve the quality of development.

Most science communication with a broad audience like both of my internships had will have a limited breadth of goals and outcomes, predominantly due to the diversity in knowledge base of target audiences, previous experiences and other factors. In reflection, “Farm Sci-Ed” could adapt and become more specific to a sub-set of clientele that are at a given knowledge level, enabling more in-depth learning and more intense goals and objectives reflecting the higher engagement possible. Smaller target audiences allow for science communication to be more focused and engaging.

Taking the nuances and specificities that exist within science and communicating them to broad audiences can be challenging. Relying on frameworks that exist , thinking about who is in the audience and wanting to engage with the audience allows for more successful and comprehensive science communication experiences for both the presenter and the audience. The shifting platforms science communication uses requires communicators to have foundations they can build upon so that no matter what the medium they are communicating through; they are able to clearly convey their message.

References

Baram-Tsabari A., Lewenstein B.V. (2017) Science communication training: What are we trying to teach? International Journal of Science Education, Part B 7:285-300.

Bell P., Lewenstein B., Shouse A., Feder M. (2012) Learning Science in Informal Environments: People, Places, and Pursuits. 2009. Washington, DC: Nat Acad Pr. 336p.

Nisbet M.C., Scheufele D.A. (2009) What's next for science communication? Promising directions and lingering distractions. American journal of botany 96:1767-1778.

Tetro J.A. (2018) Learning from History to Increase Positive Public Reception and Social Value Alignment of Evidence-Based Science Communication. Journal of microbiology & biology education 19.

CONCLUSION

Science communication is a cross-disciplinary field combining science disciplines with communication to enable conversations from specialists to non-specialist groups (Baram-Tsabari and Lewenstein, 2017; Bray et al., 2012; Mulder et al., 2008). It may occur within scientific journalism, museum displays, outreach activates, or a vast number of other methods. While covering a wide spectrum of topics, there are limitations to the effectiveness of science communication (Nisbet and Goidel, 2007).

Individual scientists tend to rely on two main models to communicate science: the deficit model and the dialogue model. The deficit model involves the sharing of information from a specialist to a non-specialist through top-down transmission (Bell et al., 2012). The dialogue model focuses on building a relationship between parties and allowing a two-way information sharing conversation (Van der Sanden and Meijman, 2008). Most untrained science communicators rely on the deficit model to transmit information. This predominantly results from feelings of unpreparedness and lack of training.

Scientists are trained to approach concepts with objectivity, basing their knowledge on empirical information (Simis et al., 2016). In contrast, non-experts rely on heuristics to shortcut the process through the conclusions. Approximately half of scientists, when interviewed, view the public as a homogenous group that are not interested in learning from them (Simis et al., 2016). In contrast, “the public” is a diverse collection on individuals with individual knowledge, values, beliefs and world views. This distinction often results in differing interpretations of the same information by different groups. In contrast, a large segment of the population (85%) view science research advancing the frontiers of knowledge as necessary and worthy of support (Nisbet and Scheufele, 2009).

When designing a science communication program, coordinators should clarify the expected goals and objectives. This effort should be accomplished with a clear understanding of the audience's receptiveness to the information. Goals tend to focus on long-term success and is reliant on the development of trusting relationships between communicator and audience. This relationship provides groups for development of improved understanding of the science and increasing science literacy (Baram-Tsabari and Lewenstein, 2017). Objectives are short-term, activity-specific aspirations that are usually focused on the participation of the audiences (Tetro, 2018). Understanding the receptiveness of the audience and the frames they use to process information through provides valuable insight for developing programs. These factors help direct language and teaching tools that can increase the effectiveness of objectives and goals of a science communication program.

With the development of internet based applications, science communication through the media underwent a fundamental shift. Science and media now rely to a greater extend on linked feedback between each other. The media influences public opinion, which in term affects what science studies and the resources available to it (Scheufele, 2014). Because the media is reliant on revenue to stay functioning, stores that "sell" are given space, shortchanging more educational efforts of scientific journalists. This reduces the accuracy and depth of information available (Caulfield and Condit, 2012). This development of hype often leads to misinterpretation or oversimplification of information as it gets passed between parties. Social media has become a common tool for science communication, as the rapid feedback and versatility to share, critique, and assess ideas allows contributions to the general public's understanding of science (Kent, 2013). When science communicators decide to use social media to convey information, a balanced approach to minimize misinformation is crucial (Bubela et al., 2009). Building momentum with regular postings and relying on cross-media channels to expand the reach of the information can increase impact and enrich the exchange.

To explore the changing and diverse methods of science communication, I completed two internships, the first with Denver Botanic Gardens and the second with the University of Nebraska Panhandle Research and Extension Center (PHREC). Both of these institutions allowed me to explore and develop skills in science communication. The internship at Denver Botanic Gardens was focused more on face to face presentations, designed to be flexible and allow for adjustments for length and level of scientific understanding. Building "Farm Sci-Ed," a multimedia science communication strategy at the PHREC developed more online science communication skills. Both experiences reinforced the importance of science communication to me.

Science communication has undergone broad shifts as technology has improved. The trend of shifting from deficit based teaching to dialogue based teaching is important. As a science communicator, it is imperative to set goals and objectives prior to designing and know who your audience is, so they can be met in a way that compliments their knowledge. The constant developments of media delivery influences available tools and provides new avenues to explore for maximized impact. The most important part of science communication though, is that it is not just about the science; it is also about acknowledging and respecting the perspectives of the people being taught.

References

Baram-Tsabari A., Lewenstein B.V. (2017) Science communication training: What are we trying to teach? International Journal of Science Education, Part B 7:285-300.

Bell P., Lewenstein B., Shouse A., Feder M. (2012) Learning Science in Informal Environments: People, Places, and Pursuits. 2009. Washington, DC: Nat Acad Pr. 336p.

Bray B., France B., Gilbert J.K. (2012) Identifying the essential elements of effective science communication: What do the experts say? International Journal of Science Education, Part B 2:23-41.

Bubela T., Nisbet M.C., Borchelt R., Brunger F., Critchley C., Einsiedel E., Geller G., Gupta A., Hampel J., Hyde-Lay R. (2009) Science communication reconsidered. Nature biotechnology 27:514.

Caulfield T., Condit C. (2012) Science and the sources of hype. Public Health Genomics 15:209-217.

Kent M.L. (2013) Using social media dialogically: Public relations role in reviving democracy. Public relations review 39:337-345.

Mulder H.A., Longnecker N., Davis L.S. (2008) The state of science communication programs at universities around the world. Science Communication 30:277-287.

Nisbet M.C., Goidel R.K. (2007) Understanding citizen perceptions of science controversy: bridging the ethnographic—survey research divide. Public Understanding of science 16:421-440.

Nisbet M.C., Scheufele D.A. (2009) What's next for science communication? Promising directions and lingering distractions. American journal of botany 96:1767-1778.

Scheufele D.A. (2014) Science communication as political communication. Proceedings of the National Academy of Sciences 111:13585-13592.

Simis M.J., Madden H., Cacciatore M.A., Yeo S.K. (2016) The lure of rationality: Why does the deficit model persist in science communication? Public Understanding of Science 25:400-414.

Tetro J.A. (2018) Learning from History to Increase Positive Public Reception and Social Value Alignment of Evidence-Based Science Communication. Journal of microbiology & biology education 19.

Van der Sanden M.C., Meijman F.J. (2008) Dialogue guides awareness and understanding of science: an essay on different goals of dialogue leading to different science communication approaches. Public Understanding of Science 17:89-103.