WALKING THE TALK? EXAMINING THE PRACTICAL APPLICATION OF MODELS OF SCIENCE COMMUNICATION IN LONG-TERM ECOLOGICAL RESEARCH SITES

by

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Abstract

L. Bartock. Walking the Talk: Examining the Practical Application of Models of Science Communication in Long-Term Ecological Research Sites, 139 pages, 7 tables, 4 figures, 2015.

Science communication research has developed theories about the way science communication operates in practice, but further investigation is needed to understand how well these models describe the practice of science communication on the ground. This thesis explores the relationship between theoretical models of science communication and the practice of science communication in long-term ecological research sites (LTERs). In particular, this exploratory study focuses on the deficit model, the dialogue model, and the participation model. I conducted semi-structured interviews to understand how science communication practitioners' views about their work relate to established models of science communication. In particular, I asked about how they view their roles and responsibilities, how they view their audience(s), and how they view ethical considerations of their work. Results suggested that the dialogue model was the most dominant model. The deficit and participation models also appeared, though less frequently. Many practitioners are aware of the shortcomings of deficit model approaches to science communication, but may not have the resources or experience necessary to engage in the intensive public engagement activities of participation model approaches.

Key words: long-term ecological research, deficit model, dialogue model, participation model, qualitative research

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CHAPTER ONE: INTRODUCTION

Research Question

Kahan (2013) suggests that we begin to take a scientific approach to science communication – that is, systematically researching and testing various science communication practices and hypotheses. In order to generate findings that are useful for communicators, the study of science communication must "transition from *lab models* to *field experiments*," and this thesis seeks to bridge that gap (Kahan, 2013, p. 12). Using qualitative, semi-structured interviews, my research examines if and how science communication practitioners at long-term ecological research sites (LTERs) align with theoretically established models of science communication if at all. How do practitioners perceive themselves in the context of science communication? Do the practitioners fall neatly into categorical models, or do their practices blur the boundaries of established models? Do practitioners use more than one model through the course of their work? Are there other models that have not yet been identified?

This exploratory study seeks to examine the relationship between science communication practitioners' conceptualization of their goals, responsibilities, and strategies and theoretically established models of science communication in order to develop a more realistic description of communication practices. Particularly, in the LTER context, these findings could be helpful in determining what goals or strategies are being forwarded through communication practices across the LTER Network. Because the LTER Network has its own strategic communication plan, this research will bring an interesting comparison between not only science communication literature and practice, but also organizational plan and practice. Furthermore, the LTER Network is "the largest and longest-lived ecological network in the United States" (LTER, 2013). Spatially, the LTER Network spans the contiguous United States and includes Alaska, Tahiti, Puerto Rico, and the Antarctic. LTER Network sites are set up so that they can collect and maintain decades' worth of data for use in long-term experiments, which is a key and unique feature of the research network. As a prodigious producer of ecological data, and because the Network is funded by taxpayer dollars through the National Science Foundation (NSF), the LTER Network has a strong imperative to conduct science communication. In this context, science communication includes a wide variety of activities, such as producing reports on relevant research for policy makers, holding public meetings to explain the findings of a study, or conducting workshops on local environmental issues. For these reasons, the LTER Network makes for an interesting and valuable context in which to conduct this study.

This thesis focuses on the deficit model, the dialogue model, and the participation model. These models were chosen because of their comprehensiveness in describing science communication in a variety of contexts. The deficit model, sometimes called the diffusionist model, operates from the assumption that scientific controversies are a result of a deficit of scientific information among public audiences that must be filled through the process of transmission or translation (Casini & Neresini, 2013; Nisbet & Scheufele, 2009). In contrast, the dialogue model focuses on the importance of contextualizing scientific information for lay audiences, rather than relying on transmission, so that they can better understand the implications of scientific research in their lives (Bucchi, 2008; Nisbet & Scheufele, 2009). The participation model differs from the deficit and dialogue models in that it aims to involve audiences in the co-production of research goals and scientific knowledge so that they share power with scientists, rather than receiving the results of the research process after the fact (Bucchi, 2008; Walker, 2007).

Justification

LTER context

The Long-Term Ecological Research (LTER) Network is one of the most important organizations for scientific research of environmental science. The LTER Network was created in 1980 by the National Science Foundation (NSF) in order to support important long-term research to aid decision makers (LTER, 2013). Because LTER is the largest and longest running ecological research network in the United States, this network has the capacity to study long-term, large-scale ecological phenomena that few other research organizations can claim to do (LTER, 2013). The importance of conducting long-term research in order to advance the field of ecology has been well documented (Callahan, 1984; Franklin et al., 1990; Magnuson, 1990). For example, the HJ Andrews Experimental Forest in Blue River, Oregon has conducted retrospective studies of fire history during the late 1400s and early 1500s. Many other LTER sites, such as Harvard Forest in Massachusetts, Cedar Creek Ecosystem Science Reserve in Minnesota, and Konza Prairie LTER in Kansas, also study the long-term effects of disturbances such as fire on ecosystems.

Because the LTER Network is such a prodigious producer of ecological knowledge, it is actively involved in ensuring that data and information are useful for civil society. In fact, the LTER Network's "mission is to provide the scientific community, policy makers, and society with the knowledge and predictive understanding necessary to conserve, protect, and manage the nation's ecosystems, their biodiversity, and the services they provide" (LTER Network, 2010). In order to address this mission, the Network established a Strategic Communication Plan in 2010 to carefully plan what its goals and objectives for science communication would be. Additionally, because the LTER Network is funded by the National Science Foundation (NSF), the Network has an obligation to make its data and findings available to the taxpayers who fund their work. As with scientific research, communication efforts cannot be undertaken lightly or without careful planning. My research undertakes a critical examination of LTER communication efforts in order better understand them in relationship to the current theoretical understanding of science communication.

The LTER Network provides an interesting context in which to explore the relationship between theory and practice of science communication. Other studies have explored this relationship between science communication theory and practice, but so far no others have focused on the LTER Network and the models selected for this study (Baram-Tsabari & Osborne, 2015; Brossard & Lewenstein, 2009; Casini & Neresini, 2013; Hetland, 2014; Lewenstein & Brossard, 2006; Palmer & Schibeci, 2012; PytlikZillig & Tomkins, 2011; Secko et al., 2013; Verhoeff & Waarlo, 2013). As researchers, we should strive to continually refine the theoretical models that are a part of our literature, particularly in the young field of science communication (Kahan, 2013). By systematically researching and testing science communication practices and hypotheses, we can improve both our science communication practice and the theory that informs it. This study seeks to provide an exploratory foundation to support the testing of communication practices and hypotheses.

This exploratory study seeks to examine the relationship between science communication practitioners' conceptualization of their goals, responsibilities, and strategies and theoretically established models of science communication in order to develop a better description of on-the-ground communication practices. Particularly, in the LTER context, these findings could be helpful in determining what goals or strategies are being forwarded through communication practices across the LTER network. The science communication literature can offer a wealth of understanding to informing LTER practices that could help the Network more effectively construct communication efforts to reach their goals. Because the Network has its own strategic communication plan, this research will bring an interesting comparison between not only science communication literature and practice, but also plan and practice. The mission of the LTER Network is to produce and provide information for natural resource managers across the nation. In order to support this mission, the LTER Network has developed a Strategic and Implementation Plan that covers a host of LTER functions, such as research and information management, as well as a Strategic Communication Plan that focuses exclusively on their communication functions (LTER, 2010; LTER, 2011). These plans outline three goals for communication within the Network:

> "(1) for the LTER Network to become recognized as a leading resource for long-term ecological research by the broader scientific community, decision makers, and the media; (2) to harness the power of long-term ecological research for decision making through two-way exchange between LTER scientists and policy makers, natural resource managers, funders, and the media; and (3) to strengthen communication within the Network and between the Network and the broader scientific community to advance scientific collaboration and innovation" (LTER, 2011).

Individual sites and people working within the Network have also reflectively engaged with the concept of science communication. For example, the Hubbard Brook Ecosystem Study, an LTER based in New Hampshire, has developed the Science Links Program that aims to effectively integrate complex ecosystem science and environmental policy through strategic communication (Driscoll et al., 2011). The Cary Institute of Ecosystem Studies, which collaborates closely with multiple LTERS, hosted a Cary Conference focused on "effective communication of science in environmental controversies," and participants of that conference produced an article synthesizing science communication research and the work of various LTER employees (Groffman et al., 2010). Other LTER employees have also published articles examining case studies of LTER science communication and best practices within those cases (Driscoll et al., 2012). The LTER Network has been studied in the context of information management and cyberinfrastructure, which is primarily for the benefit of sharing data and information between experts, not necessarily public audiences (Baker et al., 2003; Burton & Jackson, 2012; Heemskerk et al., 2003; Jackson & Barbrow, 2013; Karasti et al., 2006). There has been a dearth of research qualitatively examining science communication in a broader, theoretical context, particularly with respect to public communication of science.

Importance of evidence-based science communication

According to Kahan (2013), the impetus for the systematic study of science communication was conflict between scientists and members of the public over the safety of nuclear power in the late 1970s and early 1980s. While scientists attempted to assure the public that nuclear power was indeed safe, and potentially safer than other forms of energy, members of the public were incredibly worried by the use of nuclear power in spite of scientific evidence and opinion that was meant to assuage their fears. Paul Slovic, Daniel Kahneman, Baruch Fischhoff, and other investigators developed the psychometric approach to risk perception in order to better understand the conflict over science and possibly quiet that conflict over nuclear power (Kahan, 2013; Slovic et al., 1986). Today, there is a continued need to understand the relationship and interactions between scientific experts and public audiences, particularly with respect to science with implications for political and social issues, such as the ecological research being conducted at LTERs.

Even though the scientific community has generally come to consensus about the existence and potential causes of climate change, there is still significant dissenting public opinion that blocks progress on climate change policies (Nisbet & Scheufele, 2009). There are many theories as to why the public is much less worried about climate change than scientists. Some would suggest that the root of the dissenting opinion and conflict is the ignorance of a lay audience, and in order to resolve the conflict, the audience must be taught the scientific knowledge necessary to comprehend the matter. Kahan (2013) identifies this line of thinking as the public irrationality thesis, in which the controversy is attributed "to a deficit in public comprehension" (p. 3). The public irrationality thesis has the same underlying assumption as the deficit model of science communication, which has been a dominant view in science communication practices, though there have been efforts to shift away from the deficit model (Besley et al., 2012; Bucchi, 2008; Stilgoe & Wilsdon, 2009).

Though the academic field of science communication is fairly young, the practice of science communication is as old as science itself. Bucchi (2008) points out that as early as the 18^{th} century popular science books were written for public audiences, especially women. However, as science and scientific research developed and specialized as a method of producing knowledge, the need to effectively communicate science also grew. The field of science communication continually seeks to explain the practice of science communication through empirical study and theoretical description. Models of communication seek to describe how communication functions in the real world, and they can inform the design and implementation of communication strategies (Leach et al., 2009).

Though these theoretical models may not be explicitly expressed in the work of science communication practitioners, they give insight into the underlying assumptions and foundation of communication practices. While the deficit, dialogue, and participation models have been the subject of many studies, there has been little exploration of they as they function at a practical level – that is, how these philosophies may guide or underlie activities practitioners engage in with public audiences (Baram‐Tsabari & Osborne, 2015; Brossard & Lewenstein, 2009; Casini & Neresini, 2013; Hetland, 2014; Lewenstein & Brossard, 2006; Palmer & Schibeci, 2012; PytlikZillig & Tomkins, 2011; Secko et al., 2013; Verhoeff & Waarlo, 2013). For example, Casini and Neresini (2013) conducted interviews with science professionals in European research institutions in order to examine how scientists viewed their role with regard to public engagement activities, particularly under the framework of "Science in Society," which consists of science communication and public engagement. The authors found that many of the "Science in Society" activities at the research centers under this study operated from a "deficit-oriented model" (Casini & Neresini, 2013, p. 57). With regard to the deficit, dialogue, and participation models, Casini and Neresini (2013) describe in detail the deficit model and how it is a dominant approach to communication, but the authors do not go into the same detail to describe the dialogue or participation models. Rather, they define these models jointly and in opposition to the "deficit/transmission model" (Casini & Neresini, 2013, p. 56). While this study provides interesting insight into how European scientists conceptualize their work in the context of public engagement, the authors do not fully differentiate between these models. Furthermore, this study focuses on scientists, rather than science communicators, who are not necessarily the same people. In this study, the participants are those that self-identify as science communicators whose primarily responsibility is science communication.

Because the LTER Network is a science research organization, it follows that it should take a scientific approach to its communication efforts (Kahan, 2013). By taking a scientific approach to managing science communication, the LTER Network can not only improve its own communication efforts, but it can also contribute to the important study of science communication. By utilizing the unique context of the LTER Network to critically examine established science communication theories, or to develop new theories, we can expand our evidence-based understanding of science communication.

Role of the researcher

As Charmaz (2006) points out, "grounded theorists' background assumptions and disciplinary perspectives alert them to look for certain possibilities and processes in their data" (p. 16). Because of this, it is important to reflect on the background and experiences I have that influences my collection and analysis of my data. I first learned about LTERs when I worked as a research intern at Harvard Forest through their Research Experience for Undergraduates (REU) program. As an REU intern, I worked closely with a research mentor at the LTER. The project I worked on was focused on the conservation awareness of forest landowners in Massachusetts. Through working on this project, I learned about the daily work and demands of researchers in LTERs. However, through the REU program more broadly, fellow interns and I learned about the LTER Network and its broader visions and goals by attending seminars and listening to various speakers. One experience in particular was formative. I attended a lunchtime conversation with Kathy Fallon Lambert who was influential in shaping the goals and processes of communication in the LTER Network. Kathy spoke extensively about her work in the Science Links program at the Hubbard Brook Research Foundation, where she and her colleagues designed a model that worked to better integrate the research being done at Hubbard Brook and policy decisions at local and national levels. This conversation started me on a path thinking about the role and process of science communication in LTERs.

As I designed a systematic study exploring these broad questions for my thesis, I contacted LTER administrators for their help in recruiting participants. Through my experience working at Harvard Forest, I was expecting to find a clear delineation of who is responsible for communication at which sites, as was my experience. However, recruitment became more complicated than I had first anticipated, and because of this, I had to modify the recruitment script and broaden my search criteria. Though my bias seemed to create an obstacle at first, ultimately the recruitment process itself offered interesting observations about the structure and process of science communication within the LTER Network.

Throughout the process of data collection and analysis, I utilized the constant comparative approach of grounded theory in which observations and analysis are considered and recorded through memoing throughout the process. The "simultaneous involvement in data collection and analysis" is a key component of grounded theory and is intended to allow for the emergence of new theories as the research process continues (Charmaz, 2006, p. 5). Therefore, some of the questioning in my semi-structured interviews changed as I progressed. In particular, in several early interviews I engaged my participants more deeply in conversations about the meaning of the terms "public" and "scientific literacy." However, as my interviewing progressed, I found that these terms in particular, and many of the definitions I asked for more broadly, were not as important as conversations about goals and goal setting. In later interviews, I encouraged deeper conversation about goals and focused less on the public and other definitions than in earlier interviews. During the coding process, these definitions often emerged as codes that were rarely used more than once. More focused questioning could have led to definitions with more commonality, or I could have spent more time examining participants' responses for commonalities. Though these varying definitions could provide an interesting topic for exploration, I made the choice to slightly shift the focus of my interviews as theories emerged from the data.

Literature Review

Though many models of science communication explore various aspects of the process of communication, my thesis focuses on three broad models: the deficit model, the dialogue model, and the participation model. These models were chosen because of their comprehensiveness in describing science communication in a variety of contexts, and also because they have been discussed extensively in science communication literature. Additionally, they can be envisioned on a spectrum of public engagement, which is bidirectional in nature and includes “a broad array of processes that emphasize face-to-face deliberation, problem-solving, and consensus building” (Beierle & Cayford, 2002, p. 1). On this spectrum, the deficit model is at the low end of engagement, the dialogue model is in the middle, and the participation model is at the high end of engagement. Though these models are significantly different, they are not mutually exclusive, nor is one inherently superior to another, as will be explained below.

Deficit model

Nisbet and Scheufele (2009) explain that the deficit model “is defined as a process of transmission,” in which the “prevailing assumption has been that ignorance is at the root of social conflict over science,” and the public is able to overcome their ignorance with effective scientific communication (p. 1767). The deficit model is also sometimes called the diffusionist model or dissemination model (Bucchi, 2008; Hetland, 2014). Through the deficit model, a single, undifferentiated public audience is seen as incapable of understanding science without the intervention of scientists and science communicators. In its earliest forms, this approach was also known as the public understanding of science (PUS) model, which reflects the emphasis placed on the abilities of the public audience to engage with scientific information (Stilgoe & Wilsdon, 2009). The assumptions of the deficit model have been undercut by years of research, and yet the model "still possesses a zombie-like longevity" in science communication practices (Irwin, 2009, p. 8; Nisbet & Scheufele, 2009).

One assumption of the deficit model that has been thoroughly critiqued is its implication that increased scientific literacy leads to increased environmental concern or greater acceptance of policies based in scientific evidence. For example, Kahan et al. (2012) found that cultural worldviews were better predictors of perceived climate change risks than science literacy or numeracy. The authors assessed respondents' science literacy using the National Science Foundation's Science and Engineering Indicators, which are widely accepted standards for measuring basic science comprehension, and utilized mathematical word problems to assess the respondents' numeracy (Kahan et al., 2012). The authors used a variety of questions on a ten point scale ranging from "no risk" to "extreme risk" to assess respondents' perceptions of risk surrounding climate change and nuclear power (Kahan et al., 2012, p. 735). Contrary to the assumptions of the deficit model, members of the public with the highest degrees of science literacy and technical reasoning capacity were not the most concerned about climate change. The authors suggest that their study shows that "public divisions over climate change stem not from incomprehension of science but from a distinctive conflict of interest: between the personal interest individuals have in line with those held by others with whom they share close ties" (p. 732). Kahan et al. (2012) argue that these results support a broader cultural cognition thesis, which argues that individuals tend to perceive and assess risks in ways that cohere with their cultural and social identities.

McCright and Dunlap (2011) find further information to support this alternative in their study of the polarization over climate change in American politics. In their study, McCright and Dunlap (2011) used data from ten Gallup Polls from 2001 and 2010 to longitudinally examine the relationship between political beliefs, party identification, and views on climate change. While liberals and Democrats with higher educational attainment held stronger beliefs about climate change that were in line with scientific consensus, that trend is nonexistent or negative for conservatives and Republicans (McCright & Dunlap, 2011). Rather, McCright and Dunlap (2011) found evidence that conservative white males who self-report a high understanding of global warming are significantly more likely to "endorse denialist views" on climate change than other Americans (p. 1163). The authors suggest that this may be explained by "identity-protective cognition", in which individuals process data in ways that do not challenge their existing beliefs (McCright and Dunlap, 2011, p. 1171). Again, this study challenges the assumptions of the deficit model. Echoing Kahan et al. (2012), McCright and Dunlap (2011) explain that "citizens' political orientations filter [new information and] learning opportunities in ways that magnify [the political] divide" over climate change (p. 1171). The work of Kahan et al. (2012) and McCright and Dunlap (2011) show that there are factors beyond "ignorance," including social, political, and cultural contexts, which influence attitudes toward and perceptions of scientific issues that must be taken into considering when communicating science to nonscientists.

Dialogue model

The dialogue model is characterized by the emphasis of contextualizing research for specific audiences through two-way communication, rather than the one-way approach of the deficit model. Hetland (2014) explores how Norwegian science and technology communication policy has evolved since 1975 under the framework of the deficit model, the dialogue model, and the participation model. After conducting a content analysis of nine Norwegian white papers focusing on science and technology policy, Hetland (2014) outlines five reasons that the dialogue model is used:

> "1) the researchers get corrective feedback and ideas; 2) the users get an opportunity to participate; 3) the research results are more easily accepted by the users and adopted if relevant; 4) both researchers and users enrich their knowledge; and finally 5) the users get a better understanding of certainty and uncertainty when interpreting the results" (p. 11).

Additionally, Trench suggests that under the dialogue model, "science is communicated between scientists and their representatives and other groups, sometimes to find out how science could be more effectively disseminated, sometimes for consultation on specific applications" (Trench, 2008, p. 11). The lay audience is not involved in the process of conducting research or forming research questions but "[has] knowledge and competencies, which enhance and complete those of scientists and specialists" (Bucchi, 2008, p. 68). Essentially, the dialogue model moves beyond the deficit model in terms of public engagement by acknowledging that audiences can relate to scientific information through their own specific contexts, and understanding and utilizing these contexts can be beneficial for science communicators. The utility of public involvement is acknowledged and embraced under the dialogue model.

While the dialogue model acknowledges the importance of cultural and social contexts that the deficit model ignores, it is not without its own limitations. Durodié (2003) argues that the dialogue model "politicis[es] the decision-making process" by over-valuing unsubstantiated claims under the guise of incorporating lay knowledge alongside scientific knowledge (p. 88).

By incorporating public opinion, the dialogue model may give too much credit to unsupported assertions made by non-scientists who become involved in the process. For example, there is some debate over whether fluoridated water is safe for communities to drink, with some groups pushing to have fluoridation stopped in municipal water supplies. However, scientific evidence has overwhelmingly shown that fluoridated water poses significant benefits and is very low risk. By incorporating lay perspectives, such as fears over the negative effects of drinking fluoridated water, communities that benefit from this policy may be disadvantaged. However, Bucchi (2008) has a much different criticism of the dialogue model. Rather than over-valuing lay knowledge, Bucchi (2008) argues that the dialogue model has the same faulty assumption as the deficit model: "[the deficit model], in a forceful way, and [the dialogue model], in a gentler, more pragmatic way, deny lay people any competence for participating in the production of [scientific knowledge]," the type of knowledge which holds the most value (p. 68).

If we assume that the process of scientific discovery is meant to benefit society broadly, then denying non-scientists the opportunity to participate in the scientific process is limiting in two ways (Nabatchi, 2012). Firstly, from an instrumental view, research questions that incorporate the perspectives and needs of stakeholders in a scientific issue will be more relevant and be of greater use to those ultimately using the results of the study. Secondly, from an imperative view, an ethical argument can be made that the public should have the opportunity to participate with and engage in the scientific process being done in their name, particularly if the research is publicly funded. The dialogue model, though acknowledging that the public has the ability to enhance the scientific process, does not allow the public to fully participate in the process of doing science. For example, citizen science projects in which citizens collect data for a research project being conducted in their community may seem to include those lay citizens in the research process. However, these projects often involve citizens after the research questions and methods have been chosen and citizens are not involved in the analysis after data collection is finished. Citizens do nothing more than collect data for researchers, which is not “true” participation (Walker et al., 2006).

Participation model

The participation model differs from the deficit model and the dialogue in that the audience is involved in the scientific process from the beginning, rather than receiving its results at the end. Under the participation model, multiple ways of knowing are valued, and non-scientific audiences are seen more as equal partners than passive vessels, or sources, for information (Brossard & Lewenstein, 2010; Bucchi, 2008; Trench, 2008). Whereas the deficit model focuses on the transmission of knowledge, and whereas the dialogue model focuses on the discussion of the implications of knowledge, the participation model of science communication focuses on the co-production of knowledge by scientific experts and the lay public. Under the participation model of communication, lay knowledge is valued equally as scientific knowledge, and both experts and the public are involved in “setting the aims, shaping the agenda of research” (Bucchi, 2008, p. 69).

Walker (2007) describes the participation model as “[emphasizing] communication interaction as a part of policy making, rather than more conventional ‘inform and educate’ or ‘command and control’ approaches” that exemplify the deficit and dialogue models of communication (p. 102). Furthermore, the participation model “incorporates traditional knowledge (local, indigenous) as well,” the types of non-scientific knowledge that both the deficit and dialogue models are critiqued for undervaluing (Walker, 2007, p. 102). Through the shared power in the bottom-up strategy of the participation model, this model may be able to address some of the shortcomings of both the deficit and dialogue model. For example, the participation model seems to cohere with the cultural cognition thesis as described and supported by Kahan et al. (2012). One way to overcome the gaps created by differing social groups may be engaging scientists and lay stakeholders in joint-learning processes, in which we may be able to facilitate the development of a shared identity on scientific issues, rather than perpetuating adversarial groups (Daniels & Walker, 2001). Furthermore, the participation model empowers the public to be a part of a scientific process from the very beginning in shaping the aims of research, addressing both the instrumental and the imperative motivations for public engagement.

Even though the participation model seems to address the limitations of the deficit and dialogue models, there is still significant criticism for this model, particularly concerning the feasibility of its implementation. Irvin and Stansbury (2004) critically examined their attempts to utilize the participation model of communication by involving the Papillion Creek system community in Omaha, Nebraska in decision-making for watershed management. According to the authors, in spite of "heroic efforts [that] were applied to convene a participatory working group," the organizers of this effort did not significantly attract stakeholders to the public meetings (Irvin & Stansbury, 2004, p. 60). Because of their failure in spite their resource intensive efforts, the authors suggest that the ideals of the participation model of communication, meaning public participation in goal and solution formation, may not be applicable to all decision-making situations. Rather, Irvin and Stansbury (2004) suggest a set of indicators to identify when public participation in decision-making is most worthwhile. They suggest that conditions for public participation are ideal when stakeholders are interested and invested in an issue, and also have the time and resources to participate in engagement activities, such as attending regular meetings (Irvin & Stansbury, 2004). In the absence of these conditions, the authors suggest that participatory communication may not be cost-effective for decision-making.

While these indicators may be prohibitively restrictive in some cases, the failed efforts of Irvin and Stansbury (2004) illustrate that participatory communication requires a significant investment of resources and hinges on public interest. There are a variety of reasons that a participatory approach to communication may fail. In cases where a project is already constrained by time and/or money, participatory communication may not be feasible. If a problem identified by researchers is not salient or recognizable by the community, the public may not feel motivated to be involved. Furthermore, if a participatory process is facilitated by a group that stakeholders distrust, even if the stakeholders are interested in and concerned by the problem, they may not participate because of the poor relationship between the parties (Wondolleck & Yaffee, 2000). For example, many Native American groups are distrustful of federal government operations because of the tumultuous history shared between the two groups. If representatives from the United States Department of Agriculture or the United States Geological Survey wanted to conduct community-based research in Native American territories or reservations, they may not be welcome. Even if the participation model addresses the theoretical or ethical concerns of the deficit model or the dialogue model, this model has very real, practical limitations.

Other models

Though this thesis has focused on the deficit, dialogue, and participation models, these are not the only theoretical models of science communication in the literature. These models were not included in my research because they are not as comprehensive as the deficit, dialogue, and participation models.

The Shannon-Weaver model. One of the earliest conceptualizations of communication came from Shannon and Weaver in “The Mathematical Theory of Communication” (1949). Shannon and Weaver were working for Bell Telephone Labs as engineers shortly after World War II when they developed this model in order to maximize the efficiency of telephone communications by taking a mathematical approach to understanding the field of communication. In doing so, they developed a visualization of the process of communication (Cox, 2013; Fiske, 2010).

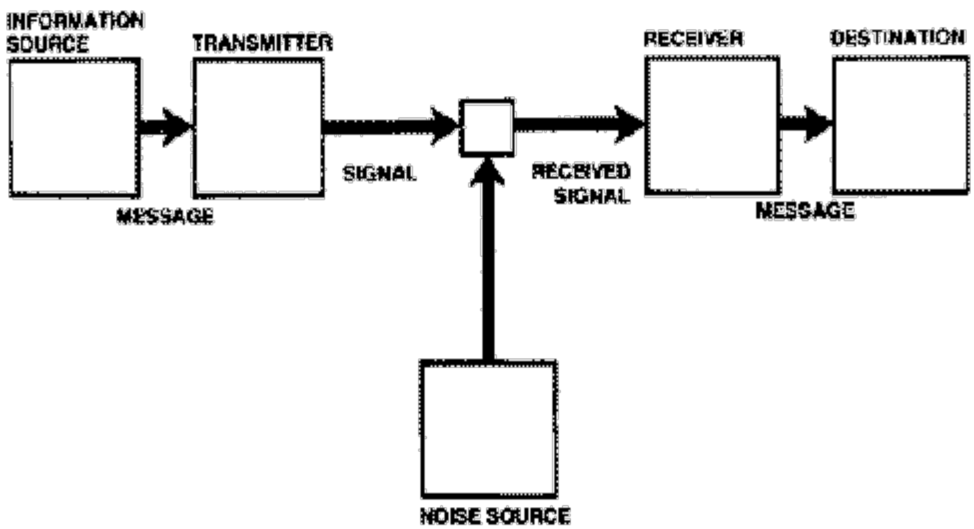


Figure 1.1: The Shannon-Weaver model of communication. Reprinted from *The Mathematical Theory of Communication* (p. 5), by C. E. Shannon and W. Weaver, 1949, Urbana, IL: The University of Illinois Press. Copyright 1949 by The University of Illinois Press.

The Shannon-Weaver model (Figure 1.1) is a relatively simple depiction of the process of communication. The diagram depicts the information source, the transmitter, a noise source, a receiver, and the destination. The transmitter and receiver “[operate] on the message in some way to produce a signal suitable for transmission over the channel,” which is represented by the middle square (Shannon & Weaver, 1949, p. 5). In the original description of this model, the channel is described as a medium through which the signal is transmitted, and examples include "a pair of wires, a coaxial cable," and so on (Shannon & Weaver, 1949, p. 5). Though communication is approached in this highly technical way, the model has been important for the development of the study of communication and has served as a basic model for understanding communication as a process. However, the simplistic nature of the model does not accurately reflect the realities of the process of communication, and using the model as a basis for understanding communication has been problematic (Cox, 2013; Fiske, 2010). For example, though Shannon and Weaver (1949) include a "noise source" in their model, it is depicted as an outside interference that distorts or interrupts the message transmission. In reality, this is a gross oversimplification of how messages may become distorted and removes any internal processes (such as idiosyncratic interpretations of messages) that contribute to miscommunication. Furthermore, communication in the Shannon-Weaver model is displayed as a one-way, linear transmission, whereas, in reality, communication is a cyclical process. Once a message is received, there is usually feedback from the receiver to the send that prompts further back and forth. In this way, this model is also related to the deficit model, because both are models of a one-way transmission of information.

The contextual model. The contextual model, as described by Brossard and Lewenstein (2010), has similarities to the dialogue model and the deficit model, but is somewhat distinct. The contextual model "recognizes the ability of social systems and media representations to either dampen or amplify public concern about specific issues," which is similar to the assumptions of the dialogue model (Brossard & Lewenstein, 2010, p. 14). However, the contextual model is characterized by one-way transmission from scientific experts to a lay pubic, as with the deficit model (Secko et al., 2013). This is still a top down model in which scientific knowledge is prized above other kinds of knowledge and in which the public is uninvolved in the scientific process. For example, a science communication practitioner may focus on contextualizing their message for a particular audience by ensuring that the content is relevant, but the motivation for doing so is ensuring that the message can be transmitted more effectively. Under this model, context is a tool to aid transmission. The contextual model falls somewhere between the deficit model and the dialogue model, because it is still primarily a process of transmission, but it acknowledges that public audiences are not merely passive vessels for information.

The lay expertise model. The lay expertise model is similar to the dialogue and participation models, but is distinct from both (Brossard & Lewenstein, 2010; Secko et al., 2013). What sets this model apart is that it values both scientific knowledge and lay knowledge equally. One criticism of this model is that it may go too far by "privileg[ing] local knowledge over reliable knowledge about the natural world produced by the modern scientific system" (Brossard & Lewenstein, 2010, p. 15). The lay expertise model is similar to the dialogue model in that it emphasizes consultation between scientific experts and lay people, or those with the ability to participate in the scientific processes and those that do not, but lay people are given a distinct power under the lay expertise model. The lay expertise model is intended to empower communities that have historically, or recently, tenuous or unequal relationships with the scientific community, particularly when it comes to issues that are not wholly scientific. In this way, is it similar to the participation model because it "theoretically suggests that lay people should supply questions they want answered, and provide direct input into what they would like to see done" (Secko et al., 2013, p. 69). However, whereas the participation model promotes empowerment of lay people within the scientific process, the lay expertise model suggests that empowerment should come from the validation of non-scientific knowledge through social systems, such as through the sharing of local histories and public dialogue.

Conclusion

Outline of Study

In this research, I examine how three theoretical models of science communication align with the practice of science communication in long-term ecological research sites (LTERs). The deficit, dialogue, and participation models have been thoroughly described in science communication literature, but they have yet to be explored in the LTER context (Baram-Tsabari & Osborne, 2015; Brossard & Lewenstein, 2009; Casini & Neresini, 2013; Hetland, 2014; Lewenstein & Brossard, 2006; Palmer & Schibeci, 2012; PytlikZillig & Tomkins, 2011; Secko et al., 2013; Verhoeff & Waarlo, 2013). The LTER Network is one of the largest ecological research networks in existence, and it is publicly funded. Though other aspects of LTER operation have been studied, science communication has not been fully explored in this context (Baker et al., 2003; Burton & Jackson, 2012; Heemskerk et al., 2003; Jackson & Barbrow, 2013; Karasti et al., 2006). The integration of science communication and LTER research provides a valuable font of contributions to both theory and practice.

Manuscript for publication. In order to address the theoretical side of my research, I produced a manuscript intended for publication as one chapter of my thesis. In this manuscript, I positioned my research within the literature, described my methodology, and outlined my findings. In particular, my findings focused on the lack of distinction between education and communication within the Network, the appearance of the theoretical models of science communication, and countervailing goals found within the Network. The first observation concerning education versus communication originated in the recruitment process of this study and was borne out in conversations asking participants to define and distinguish between science education and communication. In general, there was a lack of distinction between the two fields, which is particularly interesting when considering that they are regarded as distinct disciplines within academia as well as distinct functions within LTER administration. With regard to the appearance of the deficit, dialogue, and participation models within my study, I found that the dialogue model was the most dominant of the models, though all three models were represented within the participants' descriptions of their daily work. I suggest that this may be because the dialogue model represents middle-of-the-road approach to public engagement, requiring a medium level of effort to achieve and produce satisfactory results. My third observation is that through conversations regarding goals with participants, two distinct and countervailing goals emerged: *informing* decision making versus *improving* decision making. An explicit mission of the LTER Network is to provide information for decision making, so it comes as no surprise that somehow being involved in decision making is a focus for many participants. However, some participants expressed a desire to remain objective and neutral so that they could *inform* decisions, whereas some participants expressed a desire to *improve* decisions so that they resulted in environmentally positive outcomes. In this manuscript chapter, I provide evidence for these findings, as well as explain their implications for science communication theory.

White paper for LTER administrators. In order to address the practical side of my research, and also to distill my findings for my study population, I produced a white paper targeted for LTER administrators as another chapter of my thesis. In addition to reviewing the literature, describing the methods of my study, and relating my findings, I also outlined recommendations for the practice of science communication in the LTER Network. These recommendations include creating a shared identity, recommendations specific to each of the three models, and utilizing the adaptive management approach for science communication. The suggestion to work towards creating a shared identity is related to the observations I made about the lack of distinction between education and communication. If the LTER administration wants to ensure that communication is a distinct function as intended by the LTER Network Strategic and Implementation Plan, I suggest the Network invest time and energy into determining how they envision these functions as distinct practices. Then, this identity can be shared by a community of individuals who have been singled out as communicators. For the deficit, dialogue, and participation models of science communication, I describe the advantages and limitations of each model so that the LTER Network may be able to better determine in which scenarios each of these approaches might be most useful. I also outline an adaptive management framework that can be used as a management and learning tool for the Network. By using an adaptive management approach, the LTER Network may be able to refine which models are most appropriate for particular needs, as well as determine which forms of implementation meet their needs. Furthermore, the adaptive management approach can be used to contribute to the study of science communication more broadly.

Contributions to the literature

This study brings together science communication theory and the LTER context in a way that has not been done before. However, beyond filling this gap, this research offers new pathways for science communication research. After observing that the dialogue model is the most dominant model of the three science communication models studied in this project, I suggest that this may be because it moves beyond the limitations of the deficit model, but is not as resource intensive as the participation model. However, this hypothesis should be further explored in subsequent research. For example, future research should explore why science communicators fall into these particular patterns or models that have been described. What motivates a communicator to adopt one approach over another? Furthermore, this research as illuminated a disconnect between theory and practice with regard to education and communication. Why is it that, in practice, education and communication become indistinct? What role does "outreach" play in the gray area between these two fields? Though there have been attempts to reconcile this difference in recent literature, this is an area that should be considered for further exploration (Baram-Tsabari & Osborne, 2015).

CHAPTER TWO: MANUSCRIPT

Abstract

Science communication research has developed theories about the way science communication operates in practice, but further investigation is needed to understand how well these models describe the practice of science communication on the ground. This study explores the relationship between theoretical models of science communication and the practice of science communication in long-term ecological research sites (LTERs). In particular, we focus on the deficit model, the dialogue model, and the participation model. We conducted semi-structured interviews to understand how science communication practitioners' views about their work relate to established models of science communication, how they view their roles and responsibilities, and how they view their audience(s). Results suggested that the dialogue model was the most dominant. The deficit and participation models also appeared, though less frequently. Most practitioners are aware of the shortcomings of deficit model approaches to science communication, but may not have the resources or experience necessary to engage in the intensive public engagement activities of participation model approaches.

Keywords

long-term ecological research, deficit model, dialogue model, participation model, qualitative research

Introduction

Within many social science disciplines, there is an oft-noted gap between theory and practice. Kahan (2013) echoes this concern by suggesting that we begin to take a scientific approach to science communication – that is, systematically researching and testing various science communication practices and hypotheses. Using qualitative, in-depth, semi-structured interviews, we examine how science communication practitioners at long-term ecological research sites (LTERs) think about their job, and whether these perceptions of science communication align with models of science communication established in the literature.

This article focuses on the deficit model, the dialogue model, and the participation model. The deficit model, sometimes called the diffusionist model, operates from the assumption that scientific controversies are a result of a deficit of scientific information among public audiences that must be filled through the process of transmission or translation (Casini &Neresini, 2013; Nisbet & Scheufele, 2009). The dialogue model, by comparison, focuses on the importance of contextualizing scientific information for lay audiences so that they can better understand the implications of scientific research in their lives (Bucchi, 2008; Nisbet & Scheufele, 2009). The participation model aims to involve audiences in the co-production of research goals and scientific knowledge so that they share power with scientists (Bucchi, 2008; Walker, 2007). How well do these models describe the work of science communication practitioners at LTERs? Do practitioners significantly blend or overlap these models? Are there new models that have not yet been described?

In particular, the LTER Network provides an interesting population of communicators to examine because of the network's focus on impactful and diverse communication strategies, such as "boundary-spanning activities" which include "public engagement, decision-relevant synthesis, distillation of results, and science translation and dissemination" (Driscoll et al., 2012, p. 354). Furthermore, the LTER Network has a recently written strategic communication plan, suggesting that science communication is undertaken thoughtfully within this context. Understanding how science communication practitioners at LTERs may offer insight into a diverse range of communication strategies that may or may not be accurately reflected in the established literature. As researchers, we should strive to continually refine the theoretical models that are a part of our literature, particularly in the young field of science communication (Kahan, 2013). This study can elucidate how science communication is practiced in the LTER Network, helping us to better understand what goals and assumptions drive science communication practitioners in the course of their work.

Literature Review

Theoretical context

Though many models of science communication explore various aspects of the process of communication, this article focuses on three broad models: the deficit model, the dialogue model, and the participation model, which are detailed in Table 3.1. These models were chosen because of their comprehensiveness in describing science communication in a variety of contexts, and also because they have been discussed extensively in science communication literature (Baram‑Tsabari & Osborne, 2015; Brossard & Lewenstein, 2010; Casini & Neresini, 2013; Hetland, 2014; Lewenstein & Brossard, 2006; Palmer & Schibeci, 2012; PytlikZillig & Tomkins, 2011; Secko et al., 2013; Verhoeff & Waarlo, 2013). Additionally, these models can be envisioned on a spectrum of public engagement, meaning their use of "a broad array of processes that emphasize face-to- face deliberation, problem-solving, and consensus building" (Beierle & Cayford, 2002, p. 1). The deficit model is at the low end of this engagement spectrum, the dialogue model in the middle, and the participation model at the high. Though these models are significantly different, they are not mutually exclusive, nor is one inherently superior to another. Rather, they represent broad approaches to science communication that can be used to categorize different practices and processes that their own utility.

Theoretical models of science communication seek to describe how communication functions in real world practice, though they are necessarily simplistic and incomplete. Models in general can inform the design and implementation of communication strategies. Though these models may not be explicitly expressed in the work of science communication practitioners, they give insight into the underlying assumptions and foundation of communication practices. While the deficit, dialogue, and participation models have often been the subject of many studies, there has been little exploration of how they function at a practical level (Baram‐Tsabari & Osborne, 2015; Brossard & Lewenstein, 2010; Casini & Neresini, 2013; Hetland, 2014; Lewenstein & Brossard, 2006; Palmer & Schibeci, 2012; PytlikZillig & Tomkins, 2011; Secko et al., 2013; Verhoeff & Waarlo, 2013).

For example, Palmer and Schibeci (2012) examined how science research funding bodies around the world, such as the National Science Foundation and the Australian Research Council Centres of Excellence, espoused different models or approaches to science communication through their research grant application forms and guidelines, research policy documents, and their websites. Based on these sources of information, the authors assigned each of the funding bodies either a professional, deficit, consultative, or deliberative "type." Furthermore, while Palmer and Schebeci's (2012) study examines how funding bodies frame the aims of science communication, it does not explore how science communication practitioners' work aligns or differs from these conceptions. We aim to better understand how well theory can be used to describe the practices of science communicators on the ground.

Deficit model. Nisbet and Scheufele (2009) explain that the deficit model "is defined as a process of transmission," in which the "prevailing assumption has been that ignorance is at the root of social conflict over science," and the public is able to overcome their ignorance with proper scientific communication (p. 1767). The deficit model is also sometimes called the diffusionist model or dissemination model (Bucchi, 2008; Hetland, 2014). Through the deficit model, a single, undifferentiated public audience is seen as incapable of understanding science without the intervention of scientists and science communicators. In its earliest forms, this approach was also known as public understanding of science (PUS), which reflects the emphasis placed on the abilities of the public audience to engage with scientific information (Stilgoe & Wilsdon, 2009). The assumptions of the deficit model have been undercut by years of research and yet the model persists as a dominant paradigm in science communication (Nisbet & Scheufele, 2009).

One assumption of the deficit model that has been thoroughly critiqued is its implication that increased scientific literacy leads to increased environmental concern. Kahan et al. (2012) conducted quantitative survey research in order to assess how participants' measures of scientific literacy and numeracy related to their perception of climate change risks. Contrary to the assumptions of the deficit model, members of the public with the highest degrees of science literacy and technical reasoning capacity were not the most concerned about climate change. The authors suggest that their study shows that "public divisions over climate change stem not from incomprehension of science but from a distinctive conflict of interest: between the personal interest individuals have in line with those held by others with whom they share close ties" (p. 732). Thus, this study challenges the assumption of the deficit model that there is a positive correlation between scientific knowledge and concern about relevant scientific risks. Kahan et al. (2012) argue that these results support the broader cultural cognition thesis, which argues that individuals tend to perceive and assess risks in ways that cohere with their cultural and social identities.

McCright and Dunlap (2011) find further information to support this alternative in their study of the polarization over climate change in American politics. The authors used data from ten Gallup Polls from 2001 and 2010 to examine the relationship between political beliefs, party identification, and views on climate change over time. Findings suggest that liberals and Democrats tend to express more personal concern about climate change than conservatives and Republicans. While this observation may seem obvious for any follower of American politics, what is more interesting is that while liberals and Democrats with higher educational attainment held stronger beliefs about climate change in line with scientific consensus, that trend is nonexistent or negative for conservatives and Republicans (McCright & Dunlap, 2011), challenging the assumptions of the deficit model. Echoing Kahan et al. (2012), McCright and Dunlap (2011) explain that “citizens’ political orientations filter [new information and] learning opportunities in ways that magnify [the political] divide” over climate change (p. 171). The work of Kahan et al. (2012) and McCright and Dunlap (2011) show that there are factors beyond “ignorance” that influence attitudes toward and perceptions of scientific issues that must be taken into considering when communicating science to nonscientists.

Dialogue model. The dialogue model is characterized by the emphasis of contextualizing research for specific audiences through two-way communication, rather than the one-way approach of the deficit model. Hetland (2014) suggests that the dialogue model is used because science communicators get feedback from audiences on their work is received, the research itself is uncontested and relevant to the audience, audiences can better understand the uncertainties of research, and both science communicators and audiences learn more in the process. Additionally, Trench (2008) suggests that under the dialogue model, “science is communicated between scientists and their representatives and other groups, sometimes to find out how science could be more effectively disseminated, sometimes for consultation on specific applications" (p. 11). The lay audience is not involved in the process of conducting research or forming research questions but "[has] knowledge and competencies, which enhance and complete those of scientists and specialists" (Bucchi, 2008, p. 68). Essentially, the dialogue model moves beyond the deficit model in terms of public engagement by acknowledging that audiences can relate to scientific information through their own specific contexts, and understanding and utilizing these contexts can be beneficial for science communicators.

While the dialogue model acknowledges the importance of cultural and social contexts that the deficit model ignores, it is not without its own limitations. Durodié (2003) argues that the dialogue model "politicis[es] the decision-making process" by over-valuing unsubstantiated claims by lay people under the guise of empowering lay knowledge. However, Bucchi (2008) has a much different criticism of the dialogue model. Rather than over-valuing lay knowledge, Bucchi (2008) argues that the dialogue model has the same faulty assumption as the deficit model: both the deficit model and the dialogue model deny lay people the ability to participate in creating scientific knowledge, the type of knowledge which holds the most value (p. 68). If we assume that the process of scientific discovery is meant to benefit society broadly, then denying non-scientists the opportunity to participate the scientific process is limiting in two ways. First, from an instrumental view, research questions that incorporate the perspectives and needs of stakeholders in a scientific issue will be more relevant and be of greater use to those ultimately using the results of the study. Secondly, from an imperative view, an ethical argument can be made that the public should have the opportunity to participate with and engage in the scientific process being done in their name, particularly if the research is publicly funded.

Participation model. The participation model differs from the deficit model and the dialogue in that the audience is involved in the scientific process from the beginning, rather than receiving its results at the end. Under the participation model, multiple ways of knowing are valued, and non-scientific audiences are seen more as equal partners than passive vessels for information (Brossard & Lewenstein, 2010; Bucchi, 2008; Trench, 2008). Whereas the deficit model focuses on the transmission of knowledge, and the dialogue model on discussing of the implications of knowledge, the participation model focuses on the co-production of knowledge involving scientific experts and the lay public. Under the participation model of communication, lay knowledge is valued equally to scientific knowledge, and both experts and the public are involved in "setting the aims, shaping the agenda of research" (Bucchi, 2008, p. 69).

Walker (2007) describes the participation model as "[emphasizing] communication interaction as a part of policy making, rather than more conventional 'inform and educate' or 'command and control' approaches" that exemplify the deficit and dialogue models of communication (p. 102). Furthermore, the participation model "incorporates traditional knowledge (local, indigenous) as well," the types of non-scientific knowledge that both the deficit and dialogue models are critiqued for undervaluing (Walker, 2007, p. 102). Through the shared power in the bottom-up strategy of the participation model, this model may be able to address some of the shortcomings of both the deficit and dialogue model. Furthermore, the participation model seems to align with the cultural cognition thesis as described and supported by Kahan et al. (2012). The cultural cognition thesis "posits that individuals, as a result of a complex of psychological mechanisms, tend to form perceptions of societal risks that cohere with values characteristic of groups with which they identify" (Kahan et al., 2012, p. 732). This suggests that conflicts over scientific issues tend to be more influenced by social and cultural identities than with scientific literacy. By engaging scientists and lay stakeholders in joint-learning processes, as described by Walker (2007), we may be able to facilitate the development of a shared identity, rather than framing adversarial groups, which could reduce conflict over scientific issues. Whereas the dialogue model is focused on contextualizing scientific knowledge for specific audiences, the participation model actively involves audiences in the creation of scientific knowledge, which may allow those audiences to have ownership over the findings of a research process and to more readily accept those findings.

Even though the participation model seems to address the limitations of the deficit and dialogue models, there is still significant criticism for this model, particularly concerning the feasibility of its implementation. Irvin and Stansbury (2004) critically examined their attempts to utilize the participation model of science communication by involving the Papillion Creek system community in Omaha, Nebraska in decision-making for watershed management. According to the authors, in spite of “heroic efforts [that] were applied to convene a participatory working group,” the organizers of this effort did not significantly attract stakeholders to the public meetings intended to engage such stakeholders (Irvin & Stansbury, 2004, p. 60). Because of their failure in spite of the resource intensive efforts of the organizers, the authors suggest that the ideals of the participation model of communication, meaning public participation in goal and solution formation, may not be applicable to all decision-making situations. Rather, Irvin and Stansbury (2004) suggest a set of indicators to identify when public participation in decision-making is most worthwhile. Irvin and Stansbury (2004) suggest that ideal conditions for public participation include when stakeholders can easily attend meetings without extensive travel or missing other obligations, different interest groups can be easily represented, and stakeholders are interested and motivated by the issue.

In the absence of these conditions, the authors suggest that participatory communication may not be cost-effective for decision-making. While these indicators may be prohibitively restrictive, the failed efforts of Irvin and Stansbury (2004) illustrate that participatory communication requires a significant investment of resources and hinges on public interest. In cases where a project is already constrained by time and/or money, participatory communication may not be feasible. Furthermore, if an audience that is perceived to be stakeholder group does not truly feel that they have a stake or interest in an issue, then there may be no grounds to attempt such a resource-intensive communication effort.

***Table 2.1*: Three models of science communication on a spectrum of public engagement**

	Also known as	Degree of public engagement	Goals	Perception of audience	Examples
Deficit	Diffusionist Dissemination	Low	Transmission of scientific information Overcoming ignorance	Homogenous Scientifically illiterate	Magazine or newspaper articles Documentaries
Dialogue	Contextual Consultation	Medium	Contextualizing scientific information Discussing implications of research	Heterogeneous Differing degrees of scientific literacy	Public meetings Educational workshops Classroom activities
Participation	Public engagement Deliberative	High	Co-creating research aims Engaging in democratic decision making	Heterogeneous Have important non-scientific knowledge and expertise	Citizen advisory boards Community-based research

Informed by: Brossard & Lewenstein (2010), Bucchi (2008), Trench (2008)

Science communication literature has developed and explored these theoretical models based on observations from real-life contexts. However, these models should be regularly challenged and evaluated in order to refine our theories. The deficit model has received heavy criticism from science communication researchers, but the current understanding is that it is still the dominant model of science communication (Nisbet & Scheufele, 2009; Palmer and Schebeci, 2012). This study explores how well the practices of science communicators at LTERs align with the deficit, dialogue, and participation models in order to better understand the current usefulness of these models.

Ethical considerations in science communication. Scientists themselves follow ethical standard that was unwritten until described by Robert Merton, an American sociologist (Doubleday, 2009). Merton (1973) argued that the ethos of science consisted of four major values: communalism, or the duty to share information; universalism, or validity for all people, regardless of affiliations; disinterestedness, or detachment of scientists form their work, and organized skepticism, or the tendency toward questioning all claims. This previously unwritten social contract guides the way that scientists engage in the scientific process and judge others who are also engaging in that process. During scientific training, there is often explicit discussion of these norms and the ethics of research, but oftentimes, the ethics of science communication are not as completely discussed.

There has been some explicit discussion of the ethics and norms of science communication. One such example comes from The Department for Innovations, Universities, and Skills (DIUS) in the United Kingdom. In September 2007, DIUS published a "Universal Ethical Code for Scientists" written by Sir David King and his colleagues (Doubleday, 2009). This code describes responsible communication as "listening and informing" (DIUS, 2007). In addition to communicating "scientific evidence, theory or interpretation honestly and accurately," the code also states that scientists should "seek to discuss the issues that science raises for society," as well as "listen to the aspirations and concerns of others" (DIUS, 2007). While this is just one standard for ethics in science communication, it emphasizes that science communicators should be concerned with receiving information just as much as transmitting information.

Practical context

The continued study of models of science communication are particularly important in the context of LTERs, institutions that are actively involved in the production of science-based knowledge and that play a key role in disseminating this knowledge. LTER sites are individual research stations that have a focus on environmental sciences and collect data for long-term projects. The LTER Network is the guiding organization for this group and spans across the continental United States and other territories, as shown in Figure 2.1. Funded by the National Science Foundation, the mission of the LTER Network is "to provide the scientific community, policy makers, and society with the knowledge and predictive understanding necessary to conserve, protect, and manage the nation's ecosystems, their biodiversity, and the services they provide" (LTER, 2010). In order to support this mission, the LTER Network has developed a Strategic and Implementation Plan that covers a host of LTER functions, as well as a Strategic Communication Plan that focuses exclusively on their communication functions (LTER, 2010; LTER, 2011). These plans outline three goals for communication within the Network:

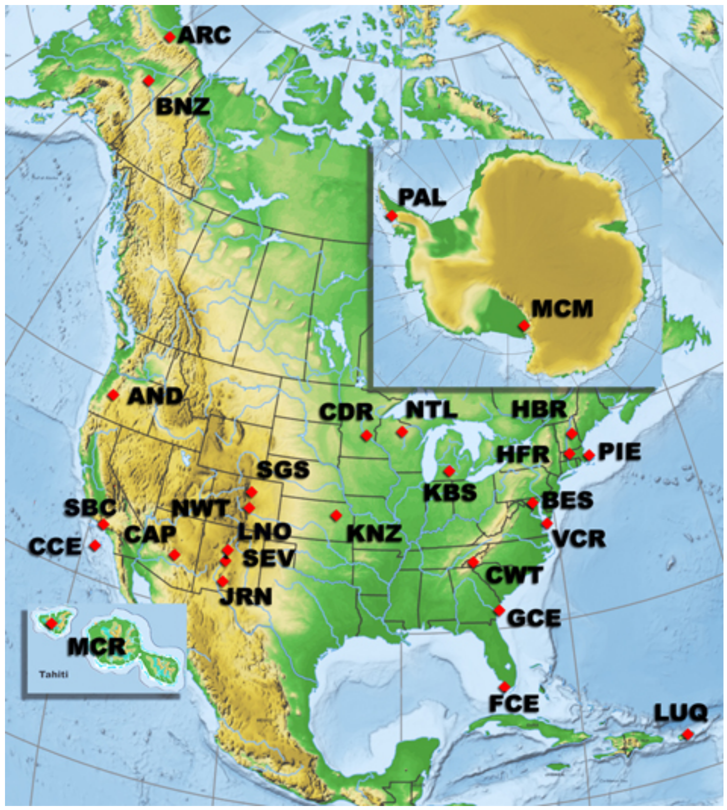
> "(1) for the LTER Network to become recognized as a leading resource for long-term ecological research by the broader scientific community, decision makers, and the media; (2) to harness the power of long-term ecological research for decision making through two-way exchange between LTER scientists and policy makers, natural resource managers, funders, and the media; and (3) to strengthen communication within the

Network and between the Network and the broader scientific community to advance scientific collaboration and innovation" (LTER, 2011).

Individual sites and people working within the Network have also reflectively engaged with the concept of science communication. For example, the Hubbard Brook Ecosystem Study, an LTER based in New Hampshire, has developed the Science Links Program that aims to effectively integrate complex ecosystem science and environmental policy through strategic communication (Driscoll et al., 2011). The Cary Institute of Ecosystem Studies, which is an independent environmental research organization in New York, collaborates closely with multiple LTERs on various research projects, as do many universities and other groups associated with LTER sites. This group hosted a Cary Conference focused on "effective communication of science in environmental controversies," and participants of that conference produced an article synthesizing science communication research and the work of various LTER employees (Groffman et al., 2010). Other LTER employees have also published articles examining case studies of LTER science communication and best practices within those cases, serving as more of an inventory of practices existing within the Network than examining the practices from a theoretical perspective (Driscoll et al., 2012). In a different vein, the LTER Network has been studied in the context of information management and cyberinfrastructure (Baker et al., 2003; Burton & Jackson, 2012; Jackson & Barbrow, 2013; Karasti et al., 2006). These studies have focused on the process of synthesizing data from the wide variety of LTER sites and how to manage data stewardship through the development of cyberinfrastructure.

To date, there has been a dearth of research qualitatively examining science communication in a broader, theoretical context, particularly with respect to public communication of science. Because the LTER Network and its members are engaging thoughtfully and deliberately in the practice of science communication, because LTERs are prodigious producers of ecological knowledge, and because these sites are funded by taxpayer dollars, this context is appropriate for exploring how well science communication practices align with theoretical models of science communication.

***Figure 2.1*: A map of LTER sites**



A map of the LTER Network. The red dots and codes show the location of each of the twenty-six LTER sites. Retrieved from lternet.edu

Research question

I examined if and how LTER science communication practitioners' conceptualization their goals, responsibilities, and strategies align with theoretically established models of science communication, such as the deficit model, the dialogue model, and the participation model. In particular, I asked (1) do the practitioners fall neatly into these categorical models, or do their practices blur the boundaries of established models?; (2) do practitioners use more than one model through the course of their work?; and (3) are there other models that have not yet been identified?

Methods

I conducted semi-structured interviews with individual employees of LTERs who self-identified as science communication practitioners. The interviews lasted 54 minutes on average. During the original recruitment effort, science communication practitioners were defined as anyone affiliated with the LTER with responsibility to communicate, report, or interpret the findings of his/her organization with any other group or organization, excluding K-12 educational programs. This definition was intended to clearly delineate communication and education, as they are two distinct academic fields (Baram-Tsabari & Osborne, 2015). Because I selected a specific and limited population, I employed purposive sampling initially and then expanded using snowball sampling (Singleton & Straights, 2009). Using the LTER Network database, I contacted representatives from each of the twenty-six institutions, as well as communication-specific listservs, to recruit individuals for interviews. However, as recruitment progressed, it was difficult to exclude participants whose work focused on educational programming because of the extensive overlap in responsibilities of many practitioners. Ultimately, any LTER employees who self-identified as playing a role in science communication were included. In total, I conducted sixteen interviews, thirteen with employees of official LTER Network sites and three with employees of a long-term ecological research site outside of this network. I expanded to include a site outside of the network in order to ensure that I had sufficient participants to have a meaningful study, as well as to begin to see if there was any discernable influence from the LTER Network in particular.

The protection of participants' confidentiality was paramount to this study. I worked with the Syracuse University Office of Research Integrity and Protections to gain Institutional Review Board Approval for this study (IRB #14-193). In addition, I received a letter of support for this project from the LTER Network Office. Once my analysis was concluded, I shared a draft of this thesis with my participants to give them the opportunity to review my use of their interviews and ensure their confidentiality was maintained. In this manuscript, the participant's confidentiality is maintained by using confidential labels.

The semi-structured interviews followed five categories of questions: introductory information, LTER network influence, perception of goals, perception of audience(s), and perception of ethical considerations (see Appendix A for full interview protocol). Participants were informed only of my general interest in science communication in the LTER context, and not of my specific interest in theoretical models. Therefore, the categories of questions were designed to probe at the underlying conceptions and self-perceptions of participants, rather than directly engaging participants in conversations about theoretical underpinnings of their work. The "introductory information" section of questions was designed to help the participant ease into the interview, as well as describe in concrete detail what the day-to-day work of their job requires. For example, participants were asked to describe what sort of products they were expected to produce in the course of their work. The "LTER Network influence" section of questions was focused primarily on the participants' familiarity with the 2010 LTER Strategic Communication plan, as well as their interactions with employees of other LTER sites. The "perception of goals" section was designed to explore the underlying assumptions of the participants' goals, which may give insight into beliefs or viewpoints that align with any of the three models of science communication that are the focus of this study. The "perception of audiences" section was established because the perceived role of the audience is one of the differing characteristics for the deficit, dialogue, and participation models. Finally, the "perception of responsibilities/ethics" section covered the underlying assumptions of participants from a different perspective than the "perception of goals" section. For example, the "perceptions of goals" section asked participants to define "science communication," whereas the "perception of responsibilities/ethics" section asked participants to define "science communicator" and explain whether or not that was a term they identified with.

I chose to approach this study from a qualitative perspective in part because of the rich detail afforded by qualitative research, as well as the exploratory nature of this study. In a grounded theory approach, codes are created during the process of data analysis and are refined as the study continues (Charmaz, 2006; Creswell, 2012). Additionally, memos, which are records of general observations and thoughts during various stages of the research process, are kept in order to help the researcher conceptualize, refine, and track emergent ideas. Codes are eventually grouped into concepts and themes that become the basis for new theoretical ideas. Additionally, my analysis followed the constant comparative approach in order to combine the strength of systematic analytic coding with the ability to discover, rather than test, hypotheses (Glaser, 1965). These approaches are ideal for formulating ideas and hypotheses about LTER science communicators that are useful for generating suggestions for practice and future research. Ultimately, this study has utilized research approaches that are optimal for examining in detail the subjects that I have identified.

After transcription, the interviews were coded qualitatively from a grounded theory perspective because these models of science communication are "ideal types" rather than "mutually exclusive categories," and so require flexibility in coding, rather than pre-established categories or codes (Bucchi, 2008; Charmaz, 2006). Codes were created throughout the coding process and grouped into families that had similar themes throughout the process as well. After interviews were coded, each participant was assigned one or more labels to denote the presence of one or more models in their approach to science communication. Labels were determined by holistically examining observations from memos and codes in order to make conclusions about the underlying philosophy(s) of each participant. Figure 2.2 provides a visual representation of this process. Table 2.2 gives examples of how codes were related to the models used in this study.

Figure 2.2: A diagram of the data collection and analysis process.

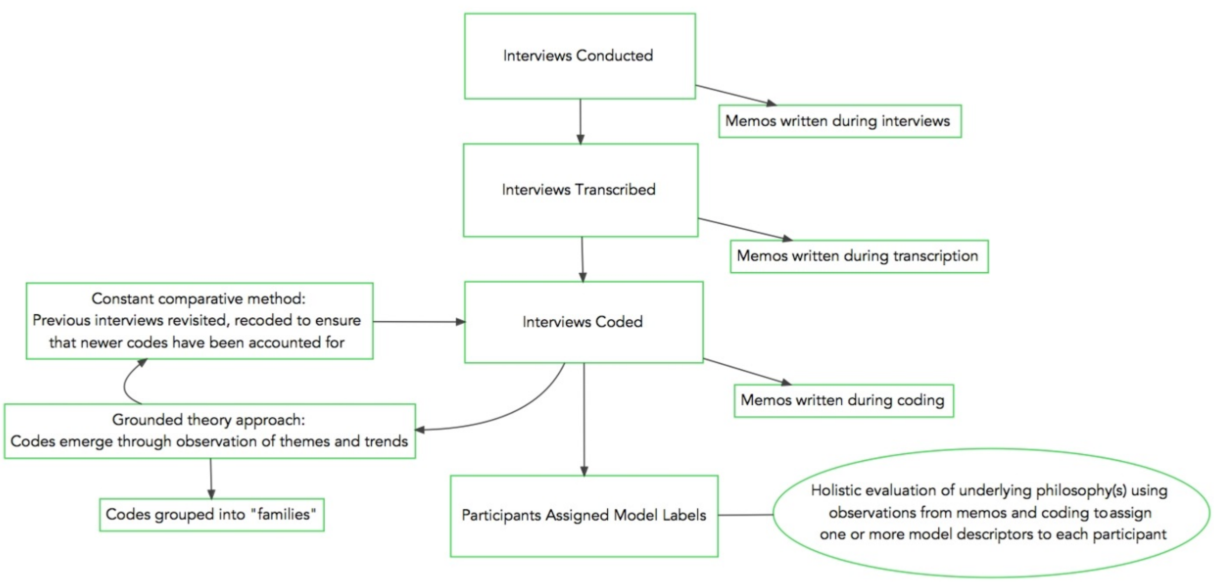


Table 2.2: Codes and their relationship to models of science communication

	Deficit	Dialogue	Participation
Goals	Creating connections Giving content Creating scientific knowledge Translating science	Creating connections Informing decision making Improving decision making	Informing decision making Improving decision making Building public trust

Audiences	K-12 University students Journalists/media/press Public	Decision makers/policy maker K-12 University students	Decision makers/policy maker Stakeholders Relevant professionals
Ethical Considerations	Allowing interpretation Doing good science Scientific objectivity	Right to know information Clearly communicating uncertainty	Maintaining public trust Right to know information Inclusivity
Some codes may be relevant for more than one model. Not all codes are featured in this table.			

Results and Discussion

The definition of science communication

Even before the interview and coding process started, the recruitment process revealed a very interesting trend with regard to science communication. Originally, in our recruitment materials, we defined science communication practitioners as anyone affiliated with the LTER with responsibility to communicate, report, or interpret the findings of his/her organization with any other group or organization, excluding K-12 educational programs. However, the initial email recruitment efforts returned participants who spend a significant amount of time on educational programming or who were unsure of whether or not they met the description of the participants sought. Furthermore, as the recruitment efforts continued, it was difficult to recruit a meaningful number of participants while excluding LTER employees who identified equally as an educator and communicator, or who identified mostly as an educator with some communication responsibilities. During the snowball sampling portion of recruitment, other potential participants were recommended who were actively involved in communication efforts even when that was not a formal component of their job.

We tried to draw a clear distinction between science communication and science education because the aim of this research is to examine models of science communication, rather than science education. However, in this particular context, the lines between the two appear to be very blurred. In the interview, we asked participants to define science communication and draw a distinction between science communication, education, and outreach. Many participants struggled with this question and gave vague answers that generally emphasized the breadth of science communication. For example, these two participants both defined science communication as a broad field and then gave more specific examples of science communication in practice:

> P14: "Science communication, well that's pretty broad... because of course science communication has to include all of the peer reviewed literature… but then of course... it does also include um how we speak to the public… in order to get people to get behind our science."
> P12: "Sci comm is actually... pretty broad field... it overlaps with education and outreach but… basically it's communicating sciences to a variety of audiences."

When asked to define science communication and differentiate it from education or outreach, many participants gave very simple definitions, like these two participants:

> P7: "So I would say that it is explaining current scientific research and findings to non-scientific audiences."
> P9: "So science communication is a way of conveying... scientific principles or scientific research findings to audiences."

In this context, it appears that science communication constitutes a wide array of practices that simply transmit information from scientists and researchers to anyone else. When trying to maintain education and communication as separate functions, this definition is not especially useful.

This observation is particularly interesting when considering the way that the LTER administration treats education and communication – that is, as distinct entities, with separate committees and sections within the LTER Network Strategic and Implementation Plan. Within this plan, education and communication have distinct missions, visions, goals, objectives, and strategies (LTER, 2011). However, when closely examined, what seem like two separate functions of the LTER Network seem to overlap. Consider the visions for both education and communication within the LTER Strategic and Implementation Plan. The education mission states:

> "We will promote and build environmental literacy by providing scientists, policy makers, and society with the long-term knowledge and predictive understanding necessary to conserve, protect, and manage the Earth's ecosystems, their biodiversity, and the services they provide."

The communication mission seems to suggest the same ultimate goal:

> "We will establish a two-way exchange between the LTER science community and decision makers, including the public, and to share information of interest in a timely, consistent, and easily understood manner."

The only substantive difference between these two missions is the education mission focuses on environmental literacy with the intention of informing action, while the communication mission focuses on a vague "two-way exchange." Though "two-way" may suggest that the LTER Network is also interested in receiving feedback, the focus of the mission seems to be to make information available to a few broad audiences, without any language to suggest how the Network plans to receive input. While each mission seems to suggest slightly different audiences, the distinction between "policy makers" and "decision makers" or "society" and "the public" is unclear. The language of the communication mission may suggest that education is not bidirectional in practice; however, the field of science education focused on the importance of a participatory model of learning before the field of science communication did so (Baram-Tzavari & Osborne, 2015). Upon close consideration of these definitions, these missions are not substantively different. If LTER communication practitioners are fully aligned with these missions, it may explain the lack of distinction between education and communication in practice. Though this study has explored participants' familiarity with the 2010 Strategic Communication Plan, further research is needed to understand how the broader LTER missions impact their conceptions of their work.

Participant training and background

The participants I interviewed through the course of this study occupied a wide variety of roles within their institutions and had an even wider variety of backgrounds and experiences. I conducted sixteen interviews with participants at twelve unique sites, which will not be identified in this chapter to protect the confidentiality of my participants. In Table 4.1, I detail the responses participants gave when asked what sort of training prepared them for their role as a communication. The majority of participants had formal scientific training, typically through the completion of a doctoral degree in specific field-related ecological research. Relatively few participants had any formal education or training in communication or related disciplines. Rather, it was not uncommon to hear that participants were "learning on the go" in their roles as science communication practitioners. When asked about what type of training is necessary to do her/his work, on participant observed that this is a limitation in the field of science more broadly:

> P15: "The trickier part is how do you teach? And I think that's one of the really interesting things in the field of science... because we take all these classes in how to be a scientist and very few classes on how to teach science, and yet you can get your PhD, and then go get hired a professor, and you're supposed to be able to develop a class."

This participant pointed to the fact that in the process of being trained as a scientist, PhDs are assumed to be able to teach the subject matter they are mastering. However, what is missing is the parallel observation that PhDs are also expected to be able to communicate their subject matter as well, with little or no training. It could be that these two functions are conflated, as I have discussed in other parts of this thesis. While learning by doing is not an uncommon practice in almost any field, relying too heavily on this strategy is likely to keep science communication practitioners disconnected from the best practices advanced by science communication research. As Nisbet and Scheufele (2009) point out, communication efforts often pay little attention to the wealth of research intended to inform the practice of science communication. If science communication practitioners obtain formal training and education in science communication, they may have a better understanding of communication theories and recommendations that can enhance their efforts. Further research is needed to understand how training impacts the strategies adopted by practitioners, as well as the effectiveness of their work.

***Table 2.3*: Inventory of participant training**

Type of training	*Number of participants*	*Examples*
Scientific training	11	Undergraduate, graduate degrees in environmental sciences; professional experience as a field ecologist
Professional experience in education/interpretation	3	Work experience in an interpretative center; work as a teaching assistant
Experience in journalism/writing	3	Extracurricular writing experience; fiction writing for leisure; writing for local newspaper
Informal communication training	3	Professional development training; attendance at communication workshops
Journalistic/writing training	2	Undergraduate, graduate degrees in journalism/non-fiction writing
Education training	1	Education coursework
Interpretation training	1	Graduate degree in interpretation
Professional experience in outreach	1	Peace Corps volunteer
Social science training	1	Graduate degree in social sciences
Hospitality management training	1	Undergraduate degree in hospitality management

In addition to varied backgrounds, participants in my study also filled a variety of roles within their LTER sites. These roles included principal investigators, project managers, communication officers, and researchers. Some participants were the sole person responsible for communication at their site, while others shared this responsibility and/or were supported by their colleagues. Though I expected to recruit a diverse group of participants, I expected to find some common thread among participants, such as the formal identification as site communicator, but that ultimately did not come through in my interviews. The LTER Network intends to have one person at each LTER site be designated the site communicator. However, almost no participants identified themselves in this way. In my recruitment efforts, I expected to be able to use this designation to identify potential participants at each site, but I could not find any formalized list of site communicators. Why did these site communicators fail to emerge? The intention of having a site communicator could be an administrative effort that was not strictly enforced. Alternatively, it could be that this label became one more label on top of an ever-growing list of labels, rather than a fully realized role. The science communication practitioners in this study often had several different responsibilities in communication, some of which are related to the practice of communication. For example, a principal investigator (PI) is often the point-person for the site he or she is overseeing. This is an inherently communication-intensive role, but a principal investigator has many other demanding responsibilities. Communication may not be the foremost in his or her mind. Or rather, PIs may be focused on intraspecialist communication and not communication with members of the public. Future research is needed to determine how the responsibility of communication is distributed among individuals at LTER sites, as well as what factors influence the adoption of a "communicator" identity. From an administrative or organizational standpoint, having a clear "science communicator" at each site would be beneficial for being able to increase accountability for communication strategies.

Appearance of the models

Because of the qualitative nature of this study, no strict, formal indicators of the deficit, dialogue, and participation models were decided upon before the coding process began. Rather, the first author familiarized herself with the differing ideologies and characteristics of each of the three models and designed interview questions that would allow participants to describe their goals and intentions with regard to science communication, which could reveal ideologies or characteristics that aligned with any or all of the models.

The dialogue model was the most dominant model, as many participants described their work as contextualizing scientific information for particular audiences. Though many participants described a broad, undifferentiated public as one of their audiences, all participants were able to identify specific groups, such as relevant professional groups or decision makers that required their attention. Thus, participants were not necessarily relying on a diffusion of undifferentiated – meaning not specified (tailored?) for a particular audience - facts as their main mode of communication as would be seen under the deficit model. Furthermore, a common theme among participants was the need to "know your audience," meaning that in order to achieve your communication goals, whatever they may be, you must be able to identify the specific needs or values of your audience in order to relate your material to them. For example, when asked about how goals change with respect to different audiences, P9 said:

> "I'm thinking really hard about what they already are thinking about... I try to talk to audience audiences as much as I can. I try to read their newsletters and go to their seminars and things like that... and just have as many informal conservations

> as I can just to figure out what's already in their kind of world, so that I can fit into it."

When asked about his/her expectations for products and programming for her/his LTER, P3 responded:

> "Um I'm much more interested in seeing programming that's based on dialogue and a two-way exchange of knowledge, and so that's the expectation I've made for myself for the programming."

This theme of needing to understand an audience in order to better communicate was apparent in almost all interviews. The underlying motivations for this goal seemed to be largely instrumental. From an instrumental motivation, the need to understand audiences stemmed from a need to effectively communicate and successfully transmit a message of interest to the communicator. This line of thinking is in line with the underlying assumptions of the deficit model, which, though not as prevalent as the dialogue model, was pervasive in participants' comments. There was, at times, overlap of the deficit model and the dialogue model in some participants' comments, demonstrating that practitioners may not strictly align with only one model within different aspects of their daily work, as is showing in Table 2.2. For example, when asked what science communication entails, P2 said:

> "Bring something in that other people can identify with... your farming audience... what are they really concerned about with their changing environment?... and making it relevant to your audience. You know it's a two-way street."

The indication that context matters and that science communication is bidirectional is indicative of the dialogue model. However, in the same response, the same participant, P2 also said:

> "Ignorance is not going to keep you from getting a ticket when the officer pulls you over… Ignorance is not going to stop our global change. And it's high time that we really are able to show people concrete examples of data that can and have been employed to address real hypotheses... that are kind of hidden in... mainstream academic science communications."

Though this participant had expressed a desire to contextualize scientific information for his/her audiences, the motivation for doing so seems to be overcoming scientific ignorance, a defining goal of the deficit model. It was not uncommon for participants to lament the public's ignorance or lack of scientific literacy, or for participants to associate scientific ignorance with conflict over scientific policy. For example, two different participants both gave the specific example of climate change denial as a result of failed science communication. When asked about her/his goals relating to science communication, P15 responded:

> "Most scientists are pretty damn lousy at getting it to the general public. Let's be honest. There is a reason why a huge chunk of our country does not believe in human induced climate change... even though there is a pretty darn big consensus among the world's scientists that human activity has impacted the world climate... but what we don't always communicate that data very well to people."

The other participant, P10, when asked generally about his/her responsibilities relating to science communication, gave an answer with a very similar theme:

> "We have people... who don't believe in climate change but at the same time believe in Bigfoot. So somewhere we have failed this part of the population in getting our message across."

Both of these responses seem to indicate a belief that in effective science communication, scientific facts automatically assimilated and prevent controversy over public issues, as opposed to a cultural cognition perspective. While the deficit model did not seem to be as commonly expressed as the dialogue model, the deficit model seemed to align with a subset of participants' communication strategies. However, some participants explicitly denounced the deficit model. This is particularly interesting because participants were not informed that these models of science communication were the focus of this study. Furthermore, the deficit model was the only science communication model explicitly referred to by name, and it was generally discussed in negative terms. One participant that discussed the limitations of the deficit model explained that she/he had learned about it from a scholar of science communication at a conference focusing on science communication. Only one other participant mentioned the deficit model by name, and she/he did not describe how she/he became familiar with the concept.

The participation model was the least evident of the three models, but there were still participants who expressed goals and strategies that aligned with participatory characteristics. For example, two participants emphasized the importance of engaging with potential audiences at the outset of their work. P5 described gathering potential stakeholders for a meeting at the outset of defining a research project to help shape the research questions and determine what the best uses for the data might be:

> "So it's not a matter of handing information off to them so much as crafting research programs this is kind of essence of our LTER program now, crafting research programs that are very tightly coupled to their needs… So it's not a matter of sort of selling them your wares so much as passing on to them what you've agreed that you're kind of doing collaboratively."

Another participant, P7, described involving stakeholders in deciding how to integrate the research being done into other products and activities that would be useful for those stakeholders:

> "I go to these various science communication groups or these interface groups and we have this discussion. So I say alright so okay I'm doing research on [organism]. Um what should we do with [organism]? … It's been very enjoyable to go to professionals, say here's my topic um what do you think would be effective interface activities?"

Another participant, P3, described a partnership with leading stakeholders in which they co-developed workshops and training sessions for other stakeholders in the community:

> "For example a group of ag professionals... where I've been working with them for about four years now. I co-founded and I'm co-leading a climate change outreach group that many of them are members of. And so that kind of interaction has been very deep you know we do a lot of programming, we write grants together, and very involved and fruitful."

These three participants exhibited the only examples of science communication that could be described as adhering to the participation model. Though the participation model was not widely represented among the comments of the entire participant sample, those participants who did align with the participation model were clearly thoughtfully engaged in public engagement processes and could describe in detail their goals and objectives for participatory communication. These participants may differ from others in that they seemed to be better funded with regard to communication than other participants. For example, the participant who described being involved in co-leading a group with her/his audience said that because of her/his "PIs' ability to secure funds," her/his LTER is able to have dedicated programs for each of their main audiences, which enables them to have deep interactions as described earlier.

Countervailing goals within the Network

Because of the wide variety of backgrounds of science communication practitioners and the wide variety of research focuses in the LTER network, it is not surprising to find that there were a wide variety of goals for communication among participants. These ranged from very instrumental goals such as "recruiting audience" and "demonstrating value of program/site" to more idealistic goals such as "creating positive environmental attitudes" and "improving decision making." Because the LTER mission statement is "to increase understanding of Earth's ecological systems towards providing the scientific community, policy makers, and society with the knowledge and predictive understanding necessary to conserve, protect, and manage Earth's ecosystems, their biodiversity, and the services they provide," it should be no surprise that "informing decision making" was one of the most prevalent goals among participants (LTER Network, 2010). What is particularly interesting, however, is that "*informing* decision making" and "*improving* decision making" emerged as two distinct goals. While some participants made it very clear that they need to maintain their scientific objectivity – meaning their detachment as a researcher – and deliberately try not to influence the decision making process, others made it clear that their goal was to help their audiences make better decisions that would result in positive environmental behaviors or policies.

Informing decision-making. On the one hand, some participants made it clear that their role was to maintain scientific objectivity and simply provide information for audiences to interpret and apply to their own decision-making processes. For example, three of the four most common ethical considerations that were described by participants were "keeping bias out of information" (i.e., accurately reporting scientific results and data), "allowing interpretation" (i.e., giving audiences space to interpret results and data from their own perspective), and "maintaining scientific objectivity" (i.e., adhering to scientific norms of disinterestedness). Participants described similar goals and ethical concerns often said something similar to P8:

> "I think we have a moral or an ethical obligation to make sure that we're not dictating that the information that we gained here should inform one answer… we provide that information to decision makers but we're not telling them what decision to make. I think that is something that we take pretty seriously…"

Improving decision-making. On the other hand, some participants expressed a desire to communicate scientific information so that audiences would make decisions that would result in environmentally positive behaviors or policies. Some participants explicitly expressed a desire to improve decision making, in those terms. In other cases, participants, such as P9, described the improved decisions they wished audiences would make based on their communication efforts:

> "I mean ultimately I would I would want behavior change, right? … I'd like to be able to communicate ecosystem service to people in a way that helps them to want to preserve those ecosystems services."

It is possible that these participants who aimed to improve decisions felt that simply having the additional information from scientifically objective research would result in better decisions because more information always allows for more complete decision making, or because the solutions provided by objective scientific information are self-evident. Further research should investigate how and why these goals diverge within the LTER Network.

Conclusion

The qualitative nature of this research has both strengths and limitations. The rich data collected in interviews can help work towards bridging models and practice. By interviewing science communication practitioners, we are able to understand how these participants frame their work in their own words and to take the conversations in the directions that are most relevant to them, which can allow these participants to describe themes or phenomena that researchers may not have initially been looking for. However, this study is limited by the sample size. Though each of the twenty-six LTER sites has an appointed science communicator, one representative from each site was not obtained. Expanding recruitment efforts in order to be fully representative of this population would strengthen this research by increasing its generalizability.

As evidenced by the difficulties experienced during recruitment for this study, it is not precisely clear who is science communicator at each site within the LTER Network. Though education and communication are given separate attention in the Strategic and Implementation Plan developed in 2011, these functions are not clearly separate in practice. Furthermore, the aims of science communication manifest differently among participants in this study. Though communication is an important function of the LTER Network, it is not clear what that entails. The prevalence of the dialogue model suggests that the majority of science communication practitioners in the LTER Network take a middle-of-the-road approach to science communication, the motivations should be explored further in future research.

This article reveals just how indistinct science communication can become in practice. Though the field of science communication has done its best to define and differentiate science communication, as well as develop descriptive models, these distinctions seem to be missing in the actual practice of science communication. Perhaps the science of science communication is not being effectively communicated to the practitioners who are the subject of study. Most participants in this study had no formal training in science communication, which may explain why distinctions between education and communication were lacking, or why the deficit model, which has been thoroughly criticized, was still pervasive. The study of science communication has yielded useful recommendations that can inform best practices, as well as findings that challenge faulty assumptions. Without having a formal education or training in science communication, science communication practitioners cannot receive the full benefits of this wealth of knowledge.

Future research should explore more deeply how science communication practitioners interface with the theory of science communication. This article has offered a qualitative exploration of the "how" of science communication in LTERs, but future research should more closely examine the "why." Why do these LTER employees end up as science communicators even when some of them have no communication background? Why does the dialogue model approach seem to be dominant among this group? We have offered some explanation for our observations throughout this article, but they must be evaluated. The first step in answering these questions is expanding the number of sites and science communication practitioners included in the sample size of future research. Additionally, a future survey or series of interviews should focus on ascertaining to what degree science communication practitioners reflect the visions and missions of the LTER Strategic Communication Plan and/or the LTER Strategic and Implementation Plan.

CHAPTER THREE: WHITE PAPER FOR THE LTER NETWORK

Executive Summary

The Long-Term Ecological Research (LTER) Network is made up of twenty-six research sites and is one of the most important multi-disciplinary groups conducting environmental science research. This network has the capacity to study long-term, large-scale ecological phenomena that few other research organizations can claim. Additionally, because the LTER Network is funded by taxpayer dollars through the National Science Foundation (NSF), the Network has an obligation to make its data and findings available to the public. Because the LTER Network is such a prodigious producer of ecological knowledge, it is actively involved in ensuring that data and information are useful for civil society. In fact, the LTER Network's "mission is to provide the scientific community, policy makers, and society with the knowledge and predictive understanding necessary to conserve, protect, and manage the nation's ecosystems, their biodiversity, and the services they provide" (LTER Network, 2010). In order to address this mission, the Network established a Strategic Communication Plan in 2010 to carefully plan what its goals and objectives for science communication would be. As with scientific research, communication efforts cannot be undertaken lightly or without careful planning. This white paper reports on a critical examination of LTER communication efforts in order better understand how the underlying philosophy and assumptions of LTER communication align with the current theoretical understanding of science communication. Science communication research can offer valuable insight into and help enhance science communication practices within the LTER Network,

The LTER Network provides a valuable context in which to explore the relationship between theory and practice of science communication. Other studies have explored this relationship between science communication theory and practice, but so far no others have focused on the LTER Network and these models in this report in particular (Baram-Tsabari & Osborne, 2015; Brossard & Lewenstein, 2010; Casini & Neresini, 2013; Hetland, 2014; Lewenstein & Brossard, 2006; Palmer & Schibeci, 2012; PytlikZillig & Tomkins, 2011; Secko et al., 2013; Verhoeff & Waarlo, 2013). As researchers, we should strive to continually refine the theoretical models that are a part of our literature, particularly in the young field of science communication (Kahan, 2013). By systematically researching and testing science communication practices and hypotheses, we, as science communicators, can improve both our science communication practice and the theory that informs it.

In this report, I will distill my findings and recommendations from my investigation of the relationship between the practice of science communication in LTERs and science communication at a theoretical level. In particular, I examined if and how science communication practitioners at LTERs align with theoretically established models of science communication, such as the deficit model, the dialogue model, and the participation model. The deficit model, sometimes called the diffusionist model, operates from the assumption that scientific controversies are a result of a deficit of scientific information among public audiences that must be filled through the process of transmission or translation (Casini &Neresini, 2013; Nisbet & Scheufele, 2009). The dialogue model focuses on the importance of contextualizing scientific information for lay audiences so that they can better understand the implications of scientific research in their lives (Bucchi, 2008; Nisbet & Scheufele, 2009). The participation model aims to involve audiences in the co-production of research goals and scientific knowledge so that they share power with scientists (Bucchi, 2008; Walker, 2007). Do the practitioners fall neatly into these categorical models, or do their practices blur the boundaries of established models? Do practitioners use more than one model through the course of their work? Are there other models that have not yet been identified?

I conducted semi-structured interviews with science communication practitioners across the LTER Network, and qualitatively coded these interviews from a grounded theory perspective. Originally, I defined a science communication practitioner as anyone affiliated with the LTER who has responsibility to communicate, report, or interpret the findings of his/her organization with any other group, excluding K-12 educational programs. However, as I continued to recruit participants, it was increasingly difficult to exclude employees with educational duties, so I ultimately included them as well. In total, thirteen LTER employees participated in this study, as well as three participants who are employed at a non-LTER research station focused on ecological research. This site outside of the network was included in order to ensure that there were sufficient participants to have a meaningful study, as well as to begin to see if there was any discernable influence from the LTER Network in particular. My interviews consisted of questions on participant's training and background, the influence of the LTER Network on their work, how they view their communication goal(s), perceptions of audience(s), and perceptions of responsibilities and/or ethics with respect to their job.

Results and observations

Below, I have provided a snapshot of my results and observations from my study. In the body of my report, I go into much more depth with regard to these findings. Furthermore, in additional chapters of my thesis (available upon request), I expand upon these findings to include other findings not described in this report.

LTER Network influence

- Participants were asked about how they determined the goals and audiences they worked with in their communication capacity, and about their familiarity with the LTER Strategic Communication Plan that was formed in 2010.
    - Most participants were aware that the LTER Strategic Communication Plan existed, but could not describe the plan in detail.
    - For most participants, the Strategic Communication Plan was not a major influence in their planning.
    - On average, participants were largely self-directed in their planning, meaning that there was no formal document or mandates from supervisors that shaped the course of their work.
    - Many participants received guidance or feedback from supervisors or colleagues, but this seemed to be more of a "check-in" than a collaborative planning effort.

Goals

- Participants described at least twenty two different goals for communication
    - Some goals were very instrumental such as "recruiting audience" and "demonstrating value of program/site."
    - Some goals were very idealistic such as "creating positive environmental attitudes" and "improving decision making."

- “*Informing* decision making” and “*improving* decision making” emerged as two distinct goals.

Deficit model

- The deficit model seemed to align with a subset of participants’ communication strategies but was not dominant. This is likely because the deficit model is a “low hanging fruit” strategy that is likely to get very little reward.
- For example, some participants bemoaned the lack of scientific literacy among members of the public and named that literacy deficit as the cause of political inaction on scientific issues, such as climate change.
- However, some participants explicitly denounced the deficit model. This is particularly interesting because the deficit model was the only model mentioned by name, and it was only talked about negatively.

Dialogue model

- The dialogue model was the most dominant model described by this group of participants. This is likely because the dialogue model is a medium-investment, medium-reward strategy.
- Many participants described their work as contextualizing scientific information for particular audiences.
- All participants were able to identify specific groups, such as student groups or particular stakeholder groups, who required their attention.

- A common theme among participants was the need to "know your audience," meaning that, in order to achieve your communication goals, you must be able to identify the specific needs or values of your audience in order to relate your material to them.

Participation model

- The participation model was the least evident of the three models examined in this study, but there were still participants that expressed goals and strategies that aligned with participatory and engaging characteristics. This is likely because the participation model requires a serious investment of resources, such as time and money, in order to fully engage stakeholders in deliberative processes.
- If communication practitioners are going to utilize their limited resources for such activities, then they likely have a strong commitment to the goals and ideals that fall under the participation model.

Recommendations

Based upon my observations through the course of these interviews, I have determined five recommendations for the LTER Network to strengthen its communication efforts. Each of these recommendations requires a different investment of resources, be it funding or the valuable time of LTER employees. One common theme in my interviews was the lack of funding and priority given to communication within the Network, so this investment will require careful thought and consideration from LTER administrators to determine how communication fits within the broader mission of the LTER Network. In the body of this report, I have identified potential partnerships and funding opportunities that could help with this investment.

Recommendation 1: Create a shared identity and training for communicators

- Though communication is an important function of the LTER Network, it is not clear what that entails.
  - As evidenced by the difficulties I experienced in recruitment for this study, it is not precisely clear *who* is the science communicator at each site within the Network.
  - Though education and communication are given separate attention in the Strategic and Implementation Plan developed in 2011, these functions are not clearly separate in practice.
  - Furthermore, the aims of science communication manifest in a wide array of activities for participants, such as writing newsletters, mentoring students, maintaining websites, and holding stakeholder roundtables.
- LTER employees should partake in training and professional development focused on the theoretical concepts explored in this study so that their planning strategies could account for the strengths weaknesses of the different approaches.
- I recommend that LTER administrators invest time into determining precise goals and objectives for science communication that are distinct from education, as seems to be intended in the Strategic and Implementation Plan. In addition, training and support should be given to science communicators to help implement these goals.

Recommendation 2: Understand the strengths and weaknesses of each model

- Each model may provide a useful framework for understanding and strategizing communication at different levels within the LTER Network. Figure 3.1 details the strengths and weaknesses of each of these models for practitioners.

- The deficit model can be useful in some contexts, such as introducing audiences to new or unfamiliar subjects. However, the fundamental assumption of the deficit model – that transmitting scientific information to ignorant audiences smoothes over any related conflict – has been undermined by multiple studies (Bucchi, 2008; Kahan et al., 2012; McCright & Dunlap, 2011; Nisbet & Scheufele, 2009).
- Though the dialogue model suffers from some of the same limitations as the deficit model – like incorrectly assuming that scientific understanding is a panacea for scientific conflict – the increased consideration given to audiences through the dialogue model benefits the Network through increased respect for audiences, as well as improved relationships between audience and researchers, which can aid the flow of information across both groups.
- If the mission of the LTER Network is to provide decision makers with the information and knowledge they need in order to manage and protect the nation's ecosystems, then it makes sense to involve those decision makers, and relevant stakeholders, in the design of research questions. This involvement will ensure that research is targeted to the most needed areas, and will strengthen the relationship between the audiences involved and the Network.

Figure 3.1: Strengths and weaknesses of the deficit, dialogue, and participation models

Strengths and Weakenesses of the Deficit, Dialogue, and Participation Models of Science Communication			
	Examples	Strengths	Weaknesses
Deficit Model	Newsletter Magazine article Documentary	Relatively easy to produce Relatively low investment	Very simplistic Doesn't value other ways of knowing
Dialogue Model	Public meeting Workshop Lecture	More interaction with audiences Discussion of research	Stark separation of experts and lay people Implementation can vary widely
Participation Model	Citizen advisory board Community-based research Stakeholder roundtable	Audiences help shape research questions Increased relationship with audiences	Dependent on audience interest Heavy investment of resources

Recommendation 3: Adopt an adaptive management approach to test effectiveness

- Adaptive management - the systematic testing and adjustment of practice based on observation - offers the Network one possible framework to rigorously test different communication strategies and tactics.
    - By taking a scientific approach to managing science communication, the LTER Network can not only improve its own communication efforts, but it can also contribute to the important study of science communication.
- This scientific approach to management gives the sites of the LTER Network the flexibility to approach their unique challenges in their own way, while providing valuable information on the strengths and weaknesses of the approaches they have implemented.

- I strongly recommend that the LTER Network adopt this approach to communication management in order to critically reflect on its work and provide valuable insight to a broader community.

Future Research

This study has provided an interesting first exploratory investigation of the LTER Network's communication practices, and it has yielded almost as many new questions as observations. While I have investigated how well science communication practitioners' goals and assumptions are described by science communication theory, there are ample opportunities for future research to expand upon my work.

- Future research should focus on understanding *why* science communication practitioners adopt these goals and strategies.
- Though I have conducted in-depth interviews with a variety of self-identified science communication practitioners, it would be useful to expand this study to include other LTER employees who engage in science communication, such as information managers, and to recruit more participants so that additional LTER sites that were not represented in this study can be included.
- A comparative study of the LTER Network and other research organizations, such as the Organization of Biological Field Stations or the National Association of Marine Laboratories, would help us better understand which of my observations are unique to the LTER Network, which mechanisms of science communication are more broadly applicable, and which practices may be the most effective.

Background

The LTER Network is one of the largest-spanning and longest-running research networks in the world, which means that it plays an incredibly important role in furthering our understanding of the natural world. In order for LTER research to have a significant impact, it must be communicated to audiences outside of the Network. To this end, the Network developed the 2010 Strategic Communication Plan, which details its goals and objectives for the LTER mission: "to provide the scientific community, policy makers, and society with the knowledge and predictive understanding necessary to conserve, protect, and manage the nation's ecosystems, their biodiversity, and the services they provide" (LTER, 2010). My research aims to better understand how this mission is accomplished and how those efforts relate to our current theoretical understanding of science communication.

My first exposure to LTERs and the LTER Network was when I worked in the Research Experience for Undergraduates (REU) program at Harvard Forest in the summer of 2012. As an REU student, I learned about the purpose and vision of the LTER Network, including its communication strategy, which led me to become interested in what role the LTER Network plays in science communication more broadly. Several years later, as a graduate student at SUNY College of Environmental Science and Forestry (SUNY-ESF), I designed a study to pursue this topic further – that is, to investigate the relationship between science communication at a theoretical level and the practice of science communication in long-term ecological research sites. Though the three models of science communication that are the subject of this research are well established at a theoretical level, there has been little exploration of these models as they function at a practical level. In particular, the LTER Network provides an interesting population of communicators to examine because of the network's focus on impactful and diverse communication strategies, such as "boundary-spanning activities" which include "public engagement, decision-relevant synthesis, distillation of results, and science translation and dissemination" (Driscoll et al., 2012, p. 354).

Understanding LTER science communication practitioners' work may offer insight into a diverse range of communication strategies that may or may not be accurately reflected in the established social science literature. The LTER Network has been studied in the context of information management and cyberinfrastructure, which is certainly an important component of science communication but is not the focus of this study (Baker et al., 2003; Burton & Jackson, 2012; Heemskerk et al., 2003; Jackson & Barbrow, 2013; Karasti et al., 2006). Because LTER research is publicly funded, the Network is mandated to make its data publicly available, which is the role of information management and cyberinfrastructure in the Network. Some work has been published describing the communication strategies used by different sites within the LTER Network, such as the Science Links program at Hubbard Brook or the Wildlands and Woodlands Initiative at Harvard Forest (Driscoll et al., 2012; Driscoll et al., 2011). However, my research differs by taking an analytical approach to describing the philosophy underlying science communication within LTERs – such as how audiences are involved or understood – rather than simply describing the various approaches that have been taken at various sites. In situating the work of science communication practitioners in an LTER context within the broader context of science communication theory and research, I am able to offer new insights into the underlying theoretical structures that inform communication practices in the LTER network, as well as offer suggestions to improve these practices.

Theoretical models of science communication seek to describe how communication functions in real world practice, though they are necessarily simplistic and incomplete. Because these models have been theoretically defined and empirically tested, their strengths and weaknesses are relatively well understood; thus, these models can inform the design and implementation of communication strategies, which is particularly important for LTER administrators to understand. Though these models may not be explicitly expressed in the work of science communication practitioners, they give insight into the underlying assumptions and foundation of communication practices, which may also influence the outcomes or effectiveness of communication practices. This study has focused on three theoretical models of science communication in particular, which are detailed in Figure 2.1, though other models do exist. The deficit, dialogue, and participation models were chosen because of their comprehensiveness in describing science communication in a variety of contexts, and also because they have been discussed extensively in science communication literature.

Nisbet and Scheufele (2009) explain that the deficit model "is defined as a process of transmission," in which the "prevailing assumption has been that ignorance is at the root of social conflict over science," and the public is able to overcome their ignorance with proper scientific communication (p. 1767). Through the deficit model, a single, undifferentiated public audience is seen as incapable of understanding science without the intervention of scientists and science communicators. In the dialogue model of communication, rather than being ignorant and separate from science, the lay public "[has] knowledge and competencies which enhance and complete those of scientists and specialists" (Bucchi, 2008, p. 68). This dialogue model is characterized by the emphasis of contextualizing research for specific audiences through two-way communication, rather than the one-way approach of the deficit model. The participation model differs from the deficit model and the dialogue in that the audience is involved in the scientific process from the beginning, rather than receiving its results at the end. Under the participation model, multiple ways of knowing are valued, and non-scientific audiences are seen more as equal partners than passive vessels for information. These three models can be envisioned on a sort of spectrum of public engagement. The deficit model sits on one end, characterized by little to no public engagement in the process of communicating or creating scientific knowledge. At the other end of the spectrum is the participation model, in which audiences are highly involved in the development of research questions and aims. Though these models are significantly different, they are not mutually exclusive, nor is one inherently superior to another.

Model	Deficit	Dialogue	Participation
Degree of public engagement	Low	Medium	High
Goals	Transmission of scientific information	Contextualizing scientific information, Discussing implications of research	Co-creating research aims, Engaging in democratic decision making
Perception of audience	Homogeneous, Scientifically illiterate	Heterogeneous, Differing degrees of scientific literacy	Heterogeneous, Have important non-scientific knowledge and expertise
Examples	Magazine or newspaper articles, documentaries	Public meetings, Educational workshops, Classroom activities	Citizen advisory boards, Community-based research

Informed by: Brossard & Lewenstein (2010), Bucchi (2008), Trench (2008)

Figure 3.2: Three models of science communication on a spectrum of public engagement.

Methods

For this study, I conducted semi-structured interviews with employees of the LTER Network who are science communication practitioners. Originally, I defined science communication practitioners as anyone affiliated with the LTER with responsibility to communicate, report, or interpret the findings of his/her organization with any other group or organization, excluding K-12 educational programs. This definition was intended to clearly delineate communication and education, as they are recognized in academic settings as two distinct disciplines. However, as my recruitment progressed, it was difficult to exclude participants whose major work focus was on educational programming because of the extensive overlap in responsibilities of many practitioners. Initially, I recruited participants by email solicitation through a variety of LTER listservs, and then expanded my recruitment through "snowball sampling". Snowball sampling is a technique in which participants who have agreed to be a part of the study suggest other potential participants that may be relevant to the researcher's interest (Singleton & Straits, 2009).

My interviews consisted of five sections of questions that asked about participants' background information, influence of the Network, perception of goal(s), perception of audience(s), and ethical considerations. These questions were designed to shed light on participants' underlying assumptions and frameworks for understanding science communication. After conducting interviews, I coded the interviews qualitatively from a grounded theory perspective (Charmaz, 2006). I chose to approach this study from a qualitative perspective in part because of the rich detail afforded by qualitative research, as well as the exploratory nature of this study. In a grounded theory approach, codes, which are ways of describing and categorizing repeated observations, are created during the process of data analysis and are refined as the study continues. Additionally, memos, which are records of general observations and thoughts during various stages of the research process, are kept in order to help the researcher conceptualize, refine, and track emergent ideas. Codes are eventually grouped into concepts and themes that become the basis for new theoretical ideas. This perspective allows for flexibility during coding and analysis, which is important because these models of science communication are "ideal types" rather than "mutually exclusive categories" (Bucchi, 2008; Charmaz, 2006). Additionally, I have used the constant comparative approach to my analysis, which combines the strength of systematic analytic coding with the ability to discover, rather than test, hypotheses (Glaser, 1965). Because this is an exploratory study of LTER network science communication, I am more interested in developing a clearer understanding of the Network's communication strategies and offering initial insights that can be further explored in the future and can generate suggestions for practice. In order to maintain the confidentiality of my participants, I have used confidential labels when referring to them throughout this report.

Results and observations

In total, I interviewed sixteen participants, thirteen of whom were associated with official LTER sites and three of whom worked at research stations that conducted similar long-term ecological research but are not within the LTER Network. Even when I began recruitment for this study, I was struck by the variety of different types of roles my participants filled. Though each site is intended to have a distinct point person to be a site communicator, this did not come across clearly in my recruitment efforts. Site communicators are intended to be the point person responsible for the communication efforts of the site, as well as any incoming requests or inquiries. My participants were a mix of principle investigators (PIs), researchers who are also responsible for communication, staff whose sole focus was communication, and researchers who simply enjoyed participating in communication efforts. I asked these participants about their understanding of the LTER Strategic Communication plan, and even that was not a common thread among participants. Most participants were aware that the plan existed, though they could not necessarily explain any of the content in their own words, nor was it an influential document when designing their own communication strategies. Some participants were very involved in the design of the plan and very familiar with its content, whereas a few were completely unaware of the plan. For the most part, participants were largely self-directed in their communication planning efforts, though many of them received guidance or input from supervisors or other colleagues. However, it was not uncommon to hear something similar to what P14 said when asked how she/he determines her/his communication goals:

> "I come up with some opportunities that I think we should take advantage of or something that that I would like to spend my time doing. And then I run it by the PI. I say you know, is this something that you, you want me to do. You know, under my education and outreach hat. And they say, yes or no."

It is likely because these communication practitioners are largely self-directed that we see a wide variety of goals and audiences emerge. For example, under the code family "goals," I identified twenty-two distinct codes, which are detailed in Table 2.1. Though some of these differences were subtle or esoteric, each distinct "goal" code was presented differently by the participants. Among the most prevalent goals in the LTER network were "creating connections," "giving content," "informing decision making," and "demonstrating value of program/site." I will focus in detail on these goals.

Table 3.1: **Goals of communication**		
Code	*Rank by frequency*[1]	*Definition*
Creating connections	1 (n=28)	Actively connecting audiences to products of LTER
Giving content	2 (n=16)	Passively providing access to products of LTER
Creating scientific knowledge	3 (n=14)	Effectively communicating facts and discrete information to audiences
Informing decision making	4 (n=13)	Providing information for audiences to interpret and apply to their decision-making processes
Demonstrating value of program/site	4 (n=13)	Showing importance of educational program, workshop, or research of LTER site
Improving decision making	5 (n=11)	Providing information for individual to encourage environmentally positive decisions or policies
Giving context	6 (n=9)	Making discrete pieces of information relevant for audiences through context
Increasing scientific literacy	6 (n=9)	A distinct frame used by participants to describe science communication
Instructor development	6 (n=9)	Preparing educators to communicate about the work done by the LTER site
Creating scientific understanding	7 (n=8)	Effectively communicating the process of discovery and context of research
Translating science	7 (n=8)	A distinct frame used by participants to describe science communication
Creating positive scientific attitudes	8 (n=7)	Engendering trust and positive affect towards science
Creating positive environmental behaviors	8 (n=7)	Encouraging audience to behave in ways that increase environmental quality
Creating positive environmental attitudes	9 (n=6)	Engendering value and positive affect towards the environment
Improving environmental quality	9 (n=6)	Communicating science in order to make a positive impact on the natural world
Increasing/expanding communication efforts	10 (n=5)	Gathering additional resources for programming, or expanding existing programming to additional audiences/topics
Recruiting audience	11 (n=2)	Increasing participation in programs
Creating curiosity	12 (n=1)	Engendering interest in specific projects or the research process more broadly
Influencing policy	12 (n=1)	Providing scientific information in order to encourage a specific policy outcome
Building public trust	12 (n=1)	Engendering trust in the scientific process

		among citizenry
Being the authority	12 (n=1)	Being recognized as a leader and a trusted source of ecological science
[1]The rank is determined by the frequency of the codes relative to other codes. The number of times a code was used across the interviews is "n."		

The "creating connections" code covered goals that were related to building and maintaining relationships within and without the LTER Network. In some cases, audiences described their goals in this exact language, which was how I initially developed this code. For example, when asked to describe her/his main goal, P3 said, "I see the main goal of my work as connecting the research and activities at the [LTER site], our science, with stakeholders who might be interested in and benefit from what we're learning." As I continued to analyze the interview data, I noticed other participants describing similar goals that also fit within the theme of "creating connections." For example, P13, when asked to describe how goals change with respect to different audiences, said, "When it's younger kids it's more focused on just kind of the experience, so getting them outside getting their hands dirty, that kind of a thing." One explanation for the prevalence of the "creating connections" code is that it is a very broad goal that can capture a wide variety of meanings. This breadth could stem from participants having vague, unspecified goals that are best described as creating connections. Further research is needed to clarify the degree of specificity to which participants conceptualize their goals.

"Giving content" was the second most prevalent goal and is used to describe goals that focus on the delivering or providing science information to an audience or multiple audiences. Some participants used this exact language, such as P7 when asked to describe her/his goals: "I'm focused on delivering some scientific content." Most participants stated this goal slightly differently, as in this example from P1: "But it's more you know we serve as conduits of information and stand in front of the audiences and that sort of thing." This differs from "creating connections," because "creating connections" is actively bridging content and audiences, whereas "giving content" is serving as a passive provider. Similarly to "creating connections," "giving content" is an extremely broad way to describe the most basic function of communication, which is likely why it was extremely prevalent. Again, additional research is needed to understand why practitioners described their work in such broad terms as "giving content."

It should be no surprise that "informing decision making" was one of the most prevalent goals among participants because the LTER mission statement is "to increase understanding of Earth's ecological systems towards providing the scientific community, policy makers, and society with the knowledge and predictive understanding necessary to conserve, protect, and manage Earth's ecosystems, their biodiversity, and the services they provide" (LTER Network, 2010). What is particularly interesting, however, is that some participants framed this goal as simply *informing* decision making, whereas others framed their goal as *improving* decision making. While some participants made it very clear that they need to maintain their scientific objectivity and deliberately try not to influence the decision making process, others made it clear that their goal was to help their audiences make better decisions that would result in positive environmental behaviors or policies. For example, when asked about her/his goals for communication, P4 responded:

> "To inform the conversation. So I like to think that I would be doing sort of an objective analysis and provide these information to people and sort of talk about what the pros and cons are."

This participant is focused on *informing* decision making by providing scientifically objective information to enhance the audience's understanding. On the other hand, P9 had this to say when asked about her/his goals:

> "I mean ultimately I would I would want behavior change, right? … I'd like to be able to communicate ecosystem service to people in a way that helps them to want to preserve those ecosystems services."

This participant explicitly wants to *improve* decision making through her/his communication efforts. It is possible that these participants who aimed to improve decisions felt that simply having the additional information from scientifically objective research would result in better decisions because more information always allows for more complete decision making, or because the solutions provided by objective scientific information are self-evident. Future research should explore this distinction further.

Ultimately, the goal of this research is to examine the relationship between the science communication practices within the LTER Network and the theoretical science communication models that exist in the literature. It is important to remember that though each of these models is distinct, there is the possibility "for the simultaneous coexistence of different patterns of communication that may coalesce, depending on specific conditions and on the issues at stake" (Bucchi, 2008, p. 72). This was true for many participants in this study; many participants showed elements of more than one model in their interviews. However, the dialogue model seems to be the most dominant model within this group of participants. Many participants described two-way conversations with their audiences that were focused on contextualizing or framing their research for their intended audience, but did not involve their audiences in the research process or the framing of conversations. For example, P4 said, "We try to engage them and sort of a bidirectional, we're interested in translating it, interpreting the science but we also like to hear how it's received." P5 described their work as the "targeted placement of specific information that um individuals or institutions can put into practice to address their objectives."

While the dialogue model seemed to be the dominant mode of thinking for many participants, the deficit model was also pervasive throughout the participants' comments. This is not necessarily unexpected given that the dialogue model was dominant, because as Bucchi (2008) explains, the deficit model and the dialogue model operate from the same assumption that there is a strict demarcation of scientists and lay people, where scientists are able to participate in the production of valuable scientific information and lay people are not. Under the dialogue model, it is assumed that lay people, or public audiences, have a greater capacity to interact with and understand scientific knowledge. Under the deficit model, lay audiences are denied this capacity. Multiple participants demonstrated alignment with the deficit model by remarking on the public's lack of scientific literacy and its connection to inaction on climate change. For example, when describing her/his responsibilities as a science communicator, P10 complained: "We have people who don't believe in climate change but at the same time believe in Bigfoot. So somewhere we have failed this part of the population in getting our message across." However, there were also participants who expressly spoke out against the deficit model. This is particularly interesting because I did not inform participants that I was interested in these theoretical concepts and because this was the only model called out by name in any interviews. For example, P3 described his/her strategy as "in contrast to the deficit model of science communication where the understanding is if only people knew the facts, if only they knew the science then they would change." P7 described learning about the deficit model and its shortcomings at a conference s/he attended. Having LTER employees be aware of and directly engage with these theoretical concepts could be beneficial for their planning strategies by increasing their understanding of the strengths and weaknesses of the different approaches.

The participation model was not prevalent throughout the LTER Network, but there were a few participants who described goals that aligned with this model. For example, P7 said argued that “you have to spend some time thinking what your audience is and then listening to the audiences... so you learn about well what are they interested in.” Other participants described similar interactions with audiences in which these groups were viewed as partners rather than recipients of LTER products. For example, P5 described a processes in which stakeholders were engaged in deliberative processes to help shape the aims of the research “so it’s not a matter of sort of selling them your wares so much as passing on to them what you’ve agreed that you’re kind of doing collaboratively.” Though the participation model was certainly not widespread throughout the LTER Network, there are already practitioners who are able to implement these strategies in their work.

Because these three models offer different levels of public engagement, it is easy to see how they require different levels of effort. For example, under the deficit model, communication practitioners could write a newsletter once a month and fill their obligations. This type of communication is a relatively low investment of resources such as time and money. Alternatively, under the participation model, designing and implementing deliberative processes to gather stakeholder input require a great deal of time and money, as well as certain expertise. From this point of view, it is understandable why many participants in this study seem to align primarily with the dialogue model. This “middle of the road” approach does not require as much time, effort, or expertise as the participation model, but, in theory, it is able to more thoroughly engage audiences than the deficit model.

Recommendations

Based upon my observations throughout this study, as well as research on the strengths and weaknesses of different theoretical approaches to science communication, I offer a variety of recommendations that the LTER Network can seek to implement. One of the most common limitations for science communication practitioners that came up during these interviews was the limitation due to funding. Communication objectives from the LTER Network Office were often described as "unfunded mandates." Beyond issues of funding, however, another limitation that came across was that communication simply is not perceived to be a high priority throughout the LTER Network. Of course, the primary function of the LTER Network is to conduct ecological research and produce scientific knowledge and information. Because of that, communication is often seen as an afterthought, something that you must do after you've completed your original goal because your funding comes from taxpayers. This prioritization may need to be addressed formally by the LTER Network administration, such as the Network Science Council, in order to determine what is the appropriate role for science communication within the LTER Network's efforts. With that in mind, I can offer suggestions on how to improve communication efforts at different levels that may help address concerns and inconsistencies that I observed in my study.

Creating a shared identity and training

At the outset of my research, the recruitment process offered interesting insight into how science communication is managed within the LTER Network. One of the first places I was directed towards was the LTER Communications Committee, where several LTER employees self-selected to work on communication efforts in the Network broadly. While this group represents people who are clearly dedicated to science communication, it does not represent all people who are doing science communication work. Furthermore, many of my participants are also active in the Education Committee. Initially, I wanted to draw a clear distinction between education and communication during recruitment, and they are treated as distinct functions by the LTER Network as evidenced by their separate committees. However, as I continued to recruit participants and as my interviews progressed, it was nearly impossible to keep education and communication separate. Even these distinct sections in the Strategic and Implementation Plan (2011), with differing matrices of objectives, seem to not be substantively different in their visions. The education vision states:

> "The LTER Network envisions an environmentally literate society in which knowledge based on long-term ecological research is within reach of all citizens and contributes to the development of informed management and decision-making."

The communication vision seems to suggest the same ultimate goal:

> "The LTER Network envisions a future in which long-term ecological research is communicated in a way that improves the scientific basis for decision making."

Both of these visions are focused on getting the scientific research from LTER sites to people outside of the LTER Network to be used in decision-making. With such a hazy distinction between education and communication, it is not hard to see why these functions are so confused in practice. If the LTER Network intends to separate education and communication functions, it must first reexamine what each of those functions entails and then clearly communicate that to those who are employed to serve these functions. In order to address this issue, I suggest that a visioning session or strategy planning meeting involving LTER administrators, principal investigators, and science communication practitioners be held in order to clearly differentiate between the two efforts. More careful thought is needed in order to effectively create goals and objectives for each of these functions. Furthermore, because there are other research organizations that make the same distinction in their own strategic planning, such as the Organization of Biological Field Stations or the National Association of Marine Laboratories, future research could compare how effectively the strategic distinction between education and communication translates into practice, or why these organizations choose to make this distinction in the first place.

In addition to clearly defining the role and function of science communication in the LTER Network, it may also be useful to clearly define who is a science communicator at each site. This can become difficult because in a sense, anyone involved in the scientific process may communicate science in one way or another at any point. Even producing publications, which all researchers are responsible for, is a type of science communication. However, if the LTER Network wants to approach communication efforts strategically, as suggested by the Strategic Communication Plan, it is helpful to have someone that is explicitly overseeing communication operations at each site. Though science communication is rather broad, it would likely be helpful to have a central figure responsible for defining and managing communication functions for each particular site so that each site's individual needs can be met. Through the course of my interviews, I was told that each site is supposed to have an official site communicator, but this information is not publicly available. Simply having a site communicator is only the first step in effectively managing communication efforts at each site. If "site communicator" is just another title with an additional set of responsibilities given to an LTER employee who already has a full workload, then he or she may not have the necessary time, resources, or experience to devote to carefully and strategically approaching communication efforts. For example, one of my participants is employed as both a researcher and communicator at his/her site. Even though P14 is paid equally for both types of work, he/she still "[identifies] mainly as a researcher." For this participant, communication efforts consist mainly of producing a newsletter, mentoring students at the site, and responding to outside inquiries. In all, this is not a proactive communication plan. Rather than actively seeking out opportunities for science communication, this practitioner is simply reacting to requests and doing the minimum required of her/him. This participant is not atypical among the participants I interviewed in this study. In order to have strong communication efforts across the LTER Network, it would help a practitioner to be proactive if she/he has a recognizable, designated position to do the communication work.

Deficit model in the Network

In the results and observations of this report, I noted that the deficit model was pervasive in how participants referred to their communication efforts. Nisbet and Scheufele (2009) also comment on the persistence of the deficit model in spite of mounting evidence that undermines its assumptions. The deficit model assumes that the public's scientific illiteracy leads them to be distrustful of scientists and scientific processes that they do not understand, but that has been shown to be empirically untrue. Yet, Nisbet and Scheufele (2009) cite several analyses that provide evidence against the deficit model, including a 2004 study conducted by the National Science Foundation that "show an almost unrivaled level of public trust, respect, and admiration for science and scientists" (p. 1769). McCright and Dunlap (2011) also demonstrate the moderating effect of political orientation on acceptance of scientific information in their study on conservative white males and climate change denial in the United States. Their work draws on and is supported by the cultural cognition thesis as described by Kahan et al. (2012). The cultural cognition thesis posits that "public divisions over climate change stem not from incomprehension of science but from a distinctive conflict of interest: between the personal interest individuals have in line with those held by others with whom they share close ties" (Kahan et al., 2012, p. 732). Essentially, rather than accepting information that challenges or disproves beliefs related to social or cultural identities, according to the cultural cognition thesis, people are more likely to reject that information so that their identity remains unchallenged and unaffected.

In order to effectively strategize communication efforts within the LTER Network, all those involved in communication, both in the planning and implementation stages, should recognize that this model of thinking has flawed assumptions. When one lacks awareness of the limitations of this model, it can be used ineffectively or inappropriately. Beyond its neglect of cultural and social cognition, the deficit model also prioritizes scientific knowledge over all other types of knowledge, which raises ethical concerns. As Bucchi (2008) states, "Lay knowledge is not an impoverished or quantitatively inferior version of expert knowledge; it is qualitatively different." (p. 60). I suggest that the LTER Network communication philosophy should reflect that the scientific information that it produces, while invaluable, is only one type of knowledge used in the decision making processes it seeks to inform.

I suggest that the deficit model is not likely useful for LTER purposes broadly. The deficit model does not need to be abandoned entirely, because it can be appropriate and effective in cases where there is little at risk for audiences, little motivation for audiences to become involved, and little controversy over the science at hand (Bucchi, 2008). However, the long-term ecological research done within the Network tends to have high public impact, as evidenced by the LTER mission statement. In order to address the appropriate use of the deficit model, I suggest that Network-wide conversations or workshops be held to discuss among communicators the strengths and weakness of this approach in order to identify cases in which the application of this model will benefit the LTER Network goals of science communication.

Dialogue model in the Network

The dialogue model appeared to be the dominant way of approaching science communication for the participants of this study. This makes sense in the context of the types of communication practitioners who work in the LTER Network. Often, these are staff who have responsibilities other than communication and have little to no communication training. In fact, nearly all participants had some sort of specialized training, ranging from journalism to outreach training in the Peace Corps, but very few had formal training within communications. Many had informal training, such as media training workshops provided by the LTER network, but for the most part participants tended to learn on the job. The dialogue model allows for a medium level of effort input into communication with medium sized rewards. In this sense, practitioners can feel like they are doing some kind of concentrated communication effort by targeting relevant groups with information after it has been produced. Essentially, this is a cost effective strategy that only requires practitioners to critically examine for which audiences their information is relevant and understand those audiences well enough to contextualize research for them.

The dialogue model could be very appropriate for the LTER Network given that it does not necessarily require intensive training or vast resources to implement in most cases. In order to improve communication efforts following this model, I suggest that the LTER Network sponsor additional training workshops that provide practitioners the opportunities to gain confidence and competency in working with audiences that they have less experience with. For example, P15 said, “I have colleagues who spend a lot of time in elementary schools… That is not my strength. I don't do well at it." P14, referring to policy makers, said, "Those are the toughest, I think, for me. Although I guess I wanted to go into politics when I was a kid. I became allergic to it when I became a scientist and then I've had to try to temper that feeling." Workshops that focus on how to interact with these specific audiences may help practitioners build practical skills. These workshops could also serve the dual purpose of fostering stronger professional networks and bonds among LTER science communicators if they are led by practitioners with experience and competence working with the targeted audience.

While the dialogue model could be relatively easily formally taken on by the LTER Network and could yield positive results, it is also important to recognize its shortcomings so that it can be used appropriately and thoughtfully. In particular, it must be acknowledged that the audiences being targeted can make valuable contributions to the scientific process. If the intent of the Network is to produce useful scientific information, it may be more helpful to address these audiences at the beginning of the research process rather than the end. Furthermore, the two-way communication that is characteristic of the dialogue model is not always implemented in the same way. Nisbet and Scheufele (2009) warn that each project following the dialogue model "varies by how participants are asked for feedback, how much their feedback matters, and exactly when in the development of a scientific debate consultation occurs" (p. 1770). Essentially, dialogic communication must be undertaken thoughtfully in order to ensure that petitions for audience feedback are well timed and is taken seriously.

Participation model in the Network

Though there were very few participants who demonstrated strategies in line with the participation model, this may be the most effective model for fulfilling the mission of the LTER

Network. The defining characteristic of the participation model is that audiences, also referred to as stakeholders, are involved in the creation of the research questions and goals of a project before the scientific process truly begins. This can be a serious departure for many scientists who are used to creating their own questions and then translating or contextualizing their results for audiences whom they think would be interested. However, by involving audiences such as stakeholders or decision makers from the very beginning, the LTER Network can ensure that the research being conducted, and funded by taxpayers, is relevant to those who need to use that information. When asked what her/his goal for communication is, one participant said, "I would like this organization to be the authority on that so that when something comes up that requires input of scientists they come to us. They don't go to someone else." This sentiment mirrors the LTER Strategic and Implementation Plan communication goal "for the LTER Network to become recognized as a leading resource for long-term ecological research by the broader scientific community, decision makers, and the media" (LTER, 2011, p. 3). If the LTER Network adopts this proactive, participatory approach to communication, then potential audiences will have no reason search elsewhere for scientific information. They will already be involved in the research process within LTER.

In this study, I identified two participants that are already undertaking this kind of work, showing that it is possible to conduct participatory communication in the LTER context. These participants, if they wish to be identified, could offer valuable insight into communicating this way. Additionally, there are other research organizations that the LTER Network could look to for advice and experience in conducting participatory research. The Thriving Earth Exchange (TEX) is a new division of the American Geophysical Union that is focused on building "collaborative relationships between community leaders, scientists and sponsors and helps them design and implement local solutions" (TEX, 2014). Additionally, the University Corporation for Atmospheric Research (UCAR) also has a strong emphasis on developing participatory research through their UCAR Community Programs division. Either of these organizations could provide insight, resources, and/or partnerships to accomplish the goals of participatory communication in an LTER context.

While in theory this strategy will be useful for accomplishing the LTER Network's goals of creating relevant research, it may not be practical in all cases or for all audiences. This type of communication takes a great deal of resources in both the implementation and planning stages, as well as communication practitioners who feel confident in their ability to facilitate collaborative meetings between audiences and researchers. Furthermore, audiences must have a serious interest in the research topic at hand, and the availability and willingness to participate in these kinds of projects. Additional training workshops could be facilitated by the LTER Network in order to help practitioners become competent in these facilitation skills, but that would be yet another added cost to undertaking this kind of work. . A participatory approach to communication would require a serious investment of time, resources, and training in order to accomplish successfully, but it would likely yield research questions and partnerships of great benefit to the LTER mission.

Adaptive management approach

Kahan (2013) suggests taking a scientific approach to science communication – that is, systematically researching and testing various science communication practices and hypotheses. For example, Kahan (2013) emphasizes need to transition science communication research "from *lab models* to *field research*" (p. 12). The LTER Network is ideally suited to undertake this task.

As a research institution, the LTER Network is already engaged in important discovery, including social scientific pursuits. By taking a scientific approach to managing science communication as is advocated through an adaptive management framework, the LTER Network can not only improve its own communication efforts, but it can also contribute to the important study of science communication. Because of this, I strongly suggest that the LTER Network take an adaptive management approach to its science communication work.

Adaptive management has its roots in studies seeking to address management concerns under conditions of uncertainty (Medema et al., 2008). Rather than operating under a technocratic regime that follows one proven path, the adaptive management framework is "centered on a learning model" where management practices have a focus on testing and learning (Medema et al., 2008 p. 2). The adaptive management cycle begins when a challenge is identified. After describing the challenge, goals and concrete objectives are established in order to create a framework for success. Once the challenge and desired outcome are identified, the experimentation process begins. Various potential management solutions are identified, and different adaptive management programs experiment with them in different ways. In some cases, one potential solution is tested, whereas in other cases, a variety of solutions are implemented simultaneously. Adaptive management is already a popular tool among natural resource managers, and its management principles can be applied to any field, including the practice of science communication. In an LTER context, adaptive management can be used to test different communication approaches at different LTER sites. This can allow for useful comparative scientific studies of communication practices. For example, LTER sites may be able to test and share best practices for conducting citizen science, or for better understanding of how to recruit different audiences to participate in outreach programs.

Potential partnerships and opportunities

In order to build a stronger strategic communication program, the LTER Network could invest in additional skill building and relationships with other organizations. The LTER Network already has a formal relationship with the National Socio-Environmental Synthesis Center (SESYNC), which could be expanded upon. SESYNC already invited proposals for workshops and short courses, which are evaluated twice a year. These are critical funding opportunities for skill building workshops, such as how to communicate with policy makers or how to create an instructor development program. Also, because SESYNC has funding opportunities for socio-environmental research, these could provide funding for program evaluation research on LTER communication efforts.

The Thriving Earth Exchange (TEX) is still a fairly new program under the American Geophysical Union (AGU), but its mission is to support community science. This organization not only helps find funding opportunities to support community research, but they also can assist with the design and implementation of community research programs. The practice of community research has many of the same goals as the participation model, namely to have stakeholders share in shaping the aims of research being done in their communities. This expertise may be the most important contribution TEX has to offer. While funding is critically important for these efforts, the expertise that TEX can provide in support of community science is invaluable for LTER researchers and communicators who are unfamiliar with participatory research.

The University Corporation for Atmospheric Research (UCAR) also has a Community Programs division that could serve as a model for how to organize public engagement within the

LTER Network. Additionally, UCAR offers a variety of training programs for science researchers and students, as well as logistical support for a variety of programs. For example, UCAR-NCAR (National Corporation for Atmospheric Research) Communicating Science Program holds an annual media training workshop for scientists called "Science: Becoming the Messenger" that trains participants in how they can identify their audiences and prepare media to target those audiences. Universities that are affiliated with LTER sites may already have connections or partnerships within UCAR that can be further explored. Beyond formal avenues of support, the research programs under the National Center for Atmosphere Research (NCAR) that UCAR supports may provide practical examples of how to integrate communication and research.

Conclusion

In this study, I used semi-structured interviews and qualitative coding to examine how the work of science communication practitioners in LTER sites aligned with three theoretical models of science communication. I found that the dialogue model was the most dominant model among my participants, though the deficit model was pervasive in many of the participants' strategies as well. There are few examples of the participation model among LTER communicators, but they do exist and could provide strong examples for other LTER communication practitioners that are interested in pursuing this type of communication. Each of these models may be useful to inform the strategies for different communication needs. The LTER Network should encourage and support professional development and learning opportunities for science communication practitioners to better understand the theory to inform their practice.

Overall, the LTER Network must establish a more concerted approach to communication across the board. Many LTER employees engage in science communication without considering themselves science communicators. Those who do identify as science communicators take a wide range of approaches that span the spectrum of public engagement. Though a strong Strategic Communication Plan has been built its implementation is not universal. Currently, the communication efforts within the Network are diffuse and individualized. Though it is important for each site to have the autonomy to craft a communication plan that meets its needs, a united effort would likely better meet the overarching mission of the Network. The LTER Network could benefit from a critical reflection on its strategy for science communication and have that become a strong identity for its science communication practitioners.

CHAPTER FOUR: CONCLUSION

This thesis has explored how theoretical models of science communication align with the practice of science communication in long-term ecological research sites (LTERs). I conducted semi-structured interviews with science communication practitioners that were coded from a grounded theory perspective. Because of the qualitative and exploratory nature of this study, a wide variety of observations emerged, many of which require further investigation. The white paper and manuscript chapters of my thesis explored focused results of this study, but there are many other interesting observations that came through in my analysis that were not covered in those chapters. This conclusion chapter discusses other emergent observations that were not given ample consideration in other chapters and considers the broader implications for the theory and practice of science communication.

Strength of methodology

Because of the exploratory nature of this study, a qualitative approach is appropriate. Generally, qualitative studies are process-oriented and generate theory from data (Holloway & Brown, 2012; Weiss, 1995). A qualitative methodology will allow me to examine how science communication theory operates in a specific context. Furthermore, qualitative interviewing in particular allows for the collection of rich, contextual data (Holloway & Brown, 2012; Weiss, 1995). Because of their focus on standardization and replicability, "quantitative studies… do not obtain full reports," whereas qualitative interviews "achieve fuller development of information" with their open, probing structure (Weiss, 1995, pp. 2-3). Grounded theory also provides "a close fit with the data, usefulness, conceptual density, durability over time, modifiability, and explanatory power" in its analysis (Charmaz, 2006, p. 6). Particularly because these models are flexible categories themselves, the flexible but systematic guidelines for data analysis and collection provided by grounded theory are better suited for this analysis than strict quantitative coding. For example, quantitative coding may be more appropriate if we were trying to inventory the training and/or background of science communication practitioners and correlate that information with their job responsibilities. However, this study is more focused on developing exploratory, illustrative findings, rather than broadly generalizable results. Combined with a grounded theory analytical perspective, the qualitative interview methodology followed in this study is useful for examining theoretical models of science communication in a practical context.

Limitations of methodology

Though the qualitative interview approach I have taken is the strongest methodology for my study, it is not without limitations. First and foremost is its limitation in terms of generalizability. In qualitative interview research more broadly, generalizability is usually limited, but confidence in our generalizability can be increased through more complete sampling and corroboration of data through multiple interviews with as many participants as possible (Weiss, 1995). A census of the population would be ideal, however, given time and logistical restrictions, that was not possible for this study (Singleton & Straits, 2009). Instead, I used purposive sampling augmented by snowball sampling to recruit interview participants. I ended the recruitment process once I had exhausted email recruitment and the snowballing method no longer yielded new participants. This method of sampling is non-probabilistic, which is a further weakness, but the limited scope of my population precludes random sampling (Singleton & Straits, 2009).

Implications for theory

One of the aims of this study is to inform the theory of science communication. The findings of this study support the claim that "these models should be conceived as ideal types, rather than as mutually exclusive categories" because although participants tended to be aligned more heavily with one model or another, there were almost no participants that did not show elements of at least two models (Bucchi, 2008, p. 69). Through my interpretation of my participants' descriptions of their work, there did seem to be some overlap across the models. This overlap may be able to be described by other models of science communication that have been described, such as the contextual model and the lay expertise model (Brossard & Lewenstein, 2010; Secko et al., 2013). For example, one participant emphasized the importance of finding common language to contextualize and make her/his information relevant to audiences, but nearly all of her/his attention was focused on writing articles for newsletters and providing digital resources that audiences could search for on the Internet. While I coded this participant as having both elements of the dialogue model and the deficit model, she/he would be best described by the contextual model, which acknowledges the potential influence from social and cultural spheres but is still focused on the process of information transmission. One participant who had significant overlap between the dialogue model and the participation model may be better described by the lay expertise model, which works to empower communities that have imbalanced relationships with the scientific community by engaging in other modes of knowledge production. However, more information about this participant's work is needed to understand the motivations for this type of work.

In order to better describe the relationship and overlap between the deficit model, the contextual model, the dialogue model, the lay expertise model, and the participation model, I suggest that these models be placed on a spectrum of public engagement, as shown in Figure 4.1. This visual concept is similar to Arnstein's (1969) ladder of citizen participation, which describes a hierarchical typology of citizen participation and non-participation in public decision-making. However, the spectrum of public engagement in science communication is not intended to suggest that any model is inherently superior to any other model. Rather, each model has strengths and weaknesses that may be appropriate in different contexts.

***Figure 4.1*: A spectrum of public engagement in science communication**

Low engagement | High engagement

Low effort | High Effort

In addition to representing a spectrum of public engagement, I also suggest that this spectrum represent the increasing level of effort that is associated with communication practices that follow each of these models, as seen in Figure 4.1. For example, deficit model communication, such as producing a newsletter, requires significantly less effort than participation model communication, such as organizing a series of public workshops to gather stakeholder input. This is not necessarily a perfect representation, however. A high quality documentary series with high production value could be considered an example of deficit model communication that is resource and effort intensive. Alternatively, a science communicator could send an electronic survey via email to stakeholders to gather their input, which would require much fewer resources. However, in general, increased public participation tends to require more effort on the part of science communication practitioners in order to be effective. Increased participation may also demand more effort on the part of the audience as well, but I have approached these models from the perspective of a communicator planning their approach. Though there is no exact correlation between level of public engagement and level of effort for communication practitioners, the trend of increased effort for increased participation may represent a barrier for science communication practitioners.

Implications for practice

In addition to expanding theory of science communication, this study also intended to improve our understanding of science communication in practice, particularly in the context of the LTER Network. In the course of these interviews, I found that many science communication practitioners were eager to learn more about science communication and excited about the prospect of my research. Furthermore, some practitioners had already taken it upon themselves to learn more about science communication theory, such as the participants who had learned about the deficit model. Because these practitioners are excited about their work and willing to learn more, there is space for discussion of science communication theory in the LTER Network. Because many of these practitioners have no background or training in communication other than skills they are learning on the job, many of them are unaware of the body of literature that has been developed around their profession. In order to resolve this disconnect between theory and practice, there must be overt conversations about the different models and theories of science communication that engage practitioners in critically reflecting on the assumptions that underlie their communication strategies. For example, through the course of my interviews, I asked participation to define several terms, including "science communication," "the public," and "scientific literacy." Often, participants' definitions were unrefined compared to how these terms are discussed and defined in science communication literature, which is not necessarily unsurprising or unique. Participants within this study, who are experts in their field, could make the same comments about the practitioners or professionals in their field. Less than half of the participants remarked the limitations of the term "public," even though the 2010 Strategic Communication Plan explicitly states that "the 'general public' is … too broad to be useful in developing specific tactics" (LTER, 2010, p. 5). The disconnect between theory and practice needs to be addressed so that practitioners are able to fully benefit from the ever-growing body of research.

Further evidence of the gap between theory and practice comes from the extensive overlap between education and communication that was observed in this study. Even though education and communication are distinct academic disciplines with different roots, and even though education and communication are separate functions within the LTER Strategic and Implementation Plan, there was little to no distinction between the two in practice. This is important because though education and communication are related, they ultimately serve different purposes. In the process of education, established bases of knowledge are transferred and help to shape the way people think, feel, and act. Communication is a shared process of discovery that is much more broad, though the discipline of communication has its roots in social psychology and the study of persuasion (Cox, 2013). Why are these two fields conflated in practice? It could be that science communication and education are lumped together in pursuit of the "broader impacts" requirement from the National Science Foundation (NSF). The broader impact criterion is used to evaluate the contribution of research to education, diversity, and societal benefit broadly in order to help assess the value of research and determine whether or not to fund the research (Holbrook, 2012). Since the addition of the broader impacts criterion in 2005, many researchers looking for funding from NSF have struggled to address this aspect of the application in their proposals. Often, the broad impacts get treated as a check box, or just another requirement that is haphazardly filled. This rush to meet a confusing requirement in any way possible may contribute to the conflation of education and communication. Further research is needed to understand how the broad impacts criterion is perceived by researchers, as how these criteria impact the practice of science communication.

Future research

This study has looked at the "how" of the intersection of theory and practice, but future research should delve into the "why." Possibilities for future research include, but are not limited to:

- How is the responsibility of communication is distributed among individuals at LTER sites?
- What factors influence the adoption of a "communicator" identity?
- How does the "coordination with other networks" function from the LTER Strategic and Implementation Plan manifests in practice?
- What is the larger role of the LTER communication committee impact how science communication practitioners conceptualize their roles and responsibilities?
- When practitioners describe the goals of communication as "creating connections," are there different types of connections that practitioners are making? Do these connections relate to the National Academy of Science's six strands of science learning?
- How do participants think about the specificity of their goals?
- Is there a true distinction between "creating scientific knowledge", "creating scientific understanding", and "giving context" as I have described in my coding process?

- How doe site leaders, or any and all other employees of LTERs, conceptualize and perceive science communication?
- Do science communication practitioners actively differentiate between stakeholders and decision makers, and if so, how?
- How do science communication practitioners in the LTER Network develop their conceptions of the ethics of their work?
- How well do practitioner's descriptions of their work actually depict their work on the ground?
- How does the 2010 Strategic Communication Plan in depth and its recommendations impact the development of communication responsibilities at each LTER site?
- Is there a difference between biophysical science-trained versus non- biophysical science trained communication practitioners?
- What resources, training, or other advantages the exemplars of participatory communication in this study have that enable them to do so?

Throughout this chapter, I have postulated explanations for the observations I made during the course of my study. While these explanations are firmly rooted in the literature and my knowledge of the LTER context for the most part, they are opportunities for further research and verification. Furthermore, though my interviews explored the goals and strategies for science communication in LTERs, I did not fully explore the motivations for adopting these different practices, which is another important question to be explored. Additionally, participants were asked to discuss the definitions of terms they used throughout the interviews. Though this contributed to my interpretation of their assumptions, this particular topic of discussion deserves further investigation and analysis. This exploratory study has provided an interesting first look at science communication in the LTER Network, and has revealed many opportunities to expand our understanding of the intersection of science communication theory and practice in the LTER Network.

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Appendix A - Interview Protocol

[Introduce self and project and thank individual for participating. Review the informed consent form and seek permission to audiotape interview.]

Introductory information

1) How did you come into your role at [insert LTER site]?

2) How long have you worked here? Have you worked at other LTER sites?

a. How would you describe your role within the LTER? For example, what would you say are your main responsibilities?

b. What kind of products are you expected to produce?

c. What sort of training does an individual need to fulfill the job that you do at [LTER site]? How have you obtained this training? (Are there other skills or fluencies that allow you to excel at the job you do?)

3) Does your work overlap with that of other employees at [LTER site]?

a. If so, in what way(s) does it overlap, and with whom?

b. How important is this overlap, if at all?

c. How often do you interact with other employees?

LTER network influence

4) Are you aware of the 2010 LTER Strategic Communication Plan?

a. If so, can you describe it in your own words?

b. Did you have any input in the creation of the communication plan? What was the nature of this input?

c. To what degree does this plan influence your work, if at all?

d. Do you have any particular agreements or disagreements with the content of the communication plan?

5) Do you interact with other LTER communication practitioners?

a. If so, what is the nature of these interactions? For example, where do you interact with these individuals, and about how frequently?

Perception of goal(s)

6) What would you say is the main goal of your work at [LTER site]?

a. Are there other goals?

7) How is this goal (are these goals) set?

a. Do you determine your own goals, or is there another person/group that determines your goals?

8) How would you define “science communication”?

a. How does this differ from “science education”? “Outreach”?

Perception of audience(s)

9) When thinking about your job, how would you describe your audience?

a. Do you have multiple audiences?

b. Are some audiences prioritized over others? If so, what?

10) How do you interact with these audiences?

11) How do your goals change with respect to different audiences?
12) What is the role of scientific literacy in your work?
    a. How often does this term come up?
    b. How does scientific literacy relate to your goals?
    c. How would you define scientific literacy?
    d. How would you describe your audience(s)' degree of scientific literacy?
    e. Are there other types of knowledge that are important to your work?
13) How would you define "the public"?
    a. How would you define "participation"?

Perception of responsibilities/ethics
14) How do ethical considerations fit into your work?
    a. How do you manage these considerations?
15) Are there any general responsibilities, other than those related to your particular job, associated with working at an LTER?
16) What does the term "science communicator" mean to you?
    a. Do you perceive yourself to be a "communicator"?

****Do you have suggestions of who else I should contact?**

Resume

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Education
State University of New York College of Environmental Science and Forestry, Syracuse, NY
M.S. Environmental Science; Focus: Environmental Communication and Participatory Processes
Expected May 2015. 4.0 GPA.

Syracuse University, Syracuse, NY
Certificate of Advanced Study in Conflict Resolution
Expected May 2015.

University of Maryland, Baltimore County, Baltimore, MD
B.S. Environmental Science, B.A. Media and Communication Studies, Minor in Spanish
Received May 2013. 3.61 GPA.

Relevant Experience
SUNY ESF, Graduate Research Assistant — July 2014 – Present
Assisting with the facilitation of a technical advisory panel to investigate the Tully Mudboils by conducting background research, arranging logistical needs, and supporting facilitation

SUNY ESF, Graduate Teaching Assistant — Aug 2013 – May 2014
Assisted with the instruction of 200- and 300-level courses in science communication for up to 50 undergraduate students
Facilitated class discussion and graded assignments such as essays and exams

Harvard Forest, Research Intern — May 2012 – Aug 2012
Conducted social science research pertaining to conservation awareness among landowners through qualitative and quantitative research methods, including interviews and survey research
Presented research findings at a symposium of undergraduate research

Living Classrooms Foundation, Summer Support Staff — June 2010 – Aug 2010
Helped teach ship-based lessons related to the natural history of the Chesapeake Bay and environmental science to groups of ten to fifteen students
Oversaw land-based logistics, such as student safety, meal planning, and campsite organization

Advanced Land and Water, Inc., Technical Intern — June 2009 – Aug 2009
Worked closely with geologists, hydrogeologists, soil scientists, and GIS analysts on environmental consulting projects generally focused on hydrological feasibility evaluations
Collected field data, such as water quality and quantity, and tracked data in GIS databases