ABSTRACT

Title of Document: THE ROLE OF NEW INFORMATION AND COMMUNICATION TECHNOLOGIES (ICTS) IN INFORMATION AND COMMUNICATION IN SCIENCE. A CONCEPTUAL FRAMEWORK AND EMPIRICAL STUDY

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Problem

This dissertation presents a literature-based framework for communication in science (with the elements partners, purposes, message, and channel), which it then applies in and amends through an empirical study of how geoscientists use two social computing technologies (SCTs), blogging and Twitter (both general use and tweeting from conferences). How are these technologies used and what value do scientists derive from them?

Method

The empirical part used a two-pronged qualitative study, using (1) purposive samples of ~400 blog posts and ~1000 tweets and (2) a purposive sample of 8 geoscientist interviews. Blog posts, tweets, and interviews were coded using the framework, adding new codes as needed. The results were aggregated into 8 geoscientist case studies, and general patterns were derived through cross-case analysis.

Results

A detailed picture of how geoscientists use blogs and twitter emerged, including a number of new functions not served by traditional channels. Some highlights: Geoscientists use SCTs for communication among themselves as well as with the public. Blogs serve persuasion and personal knowledge management; Twitter often amplifies the signal of traditional communications such as journal articles. Blogs include tutorials for peers, reviews of basic science concepts, and book reviews. Twitter includes links to readings, requests for assistance, and discussions of politics and religion. Twitter at conferences provides live coverage of sessions.

Conclusions

Both blogs and Twitter are routine parts of scientists' communication toolbox, blogs for in-depth, well-prepared essays, Twitter for faster and broader interactions. Both have important roles in supporting community building, mentoring, and learning and teaching. The Framework of Communication in Science was a useful tool in studying these two SCTs in this domain. The results should encourage science administrators to facilitate SCT use of scientists in their organization and information providers to search SCT documents as an important source of information.

THE ROLE OF NEW INFORMATION AND COMMUNICATION TECHNOLOGIES (ICTS) IN INFORMATION AND COMMUNICATION IN SCIENCE. A CONCEPTUAL FRAMEWORK AND EMPIRICAL STUDY

By

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1. Introduction

1.1 Overview

Communication is the “essence of science” (Garvey, 1979). Evolving information and communication technologies (ICT), including social computing technologies (SCT) like blogs and microblogs (Twitter), have a major impact on how scientists communicate in ways that are not yet well understood. This dissertation embarks on a systematic study of communication in science, in particular the impact of ICTs, using blogging and microblogging as two examples to be studied empirically using a broad-based framework. How do scientists use these technologies and what value do they derive from them? The approach is as follows:

(1) develop a comprehensive framework to describe information and communication in science: partners, purposes, message, and channel characteristics based on a review and analysis of the literature on communication in science from multiple research traditions dealing with many communication modes and technologies,.

(2) Use the framework to guide the empirical study of two example ICTs used in science, updating the framework in the process to reflect the findings of the research and applying it to other ICTs using the results of descriptive studies published in the literature.

ICTs, including SCTs, are heavily used by scientists, but their use is not well understood or described using existing frameworks or lenses emergent from the various literatures that address communication in science. Frameworks to describe communication in science are found, among other literatures, in library and information science (LIS) studies of scholarly communication; in communication, including English for special purposes and rhetoric studies of scholarly and popular communication; in science and technology studies (STS); and in computer science in studies of computer-supported collaborative work (CSCW) and online communities, Frameworks from each of these disciplines emphasize some aspects of communication, but none are sufficient in describing modern computer-mediated communication (CMC) that can be both popular and scholarly, ephemeral and archival, public and private, and have characteristics of both written and oral communication (Bryant & Pribanic-Smith, 2010; Kent, 2015).

Studying communication in science is important; scientific knowledge is built through the communication of data, methods, and results both formally in publications and releases and informally among scientists. Scientists communicate now more than ever, and much if not most of that communication uses ICTs and is computer-mediated (Trench, 2007; Walsh & Maloney, 2007). Tenopir and King (2000) reviewed studies of how scientists spend their time; scientists devote more than half of their time to communication-related activities such as identifying and accessing documents, reading, attending internal and external meetings, reading and writing e-mail, and writing reports or articles. With so much time spent on communication, any tools or processes that facilitate or improve communication can be beneficial to the scientific enterprise.

Over the last half-century, many ICTs have been introduced within science communication including SCTs. Experts question if or to what extent the many new ICTs significantly change communication in science (Glaser, 2003; Mulligan & Mabe, 2011; Roosendaal & Geurts, 1997), but most agree new ICTs make communication faster, with larger numbers of collaborators, with more communication, and with more international collaboration (Barjak, 2006; Carley & Wendt, 1991; Dumlao & Duke, 2003; Lorigo &

Pellacini, 2007; Reips, 2008; Walsh & Maloney, 2002). Although Roosendaal and Geurts (1997) claim that functions of communication in science are invariable with respect to technology, there are new communication functions that are emerging as a result of the features of new communication media.

ICTs have transformed our world in many ways, yet scholarly scientific communication forms a sociotechnical interaction network in which communication is influenced by technology but defined by the social structures of scientists and their organizations (Kling, McKim, & King, 2003; Lamb, Sawyer, & Kling, 2000). ICTs shape and are shaped by their use, users, and social system of which they are a part (Bijker, 1995; Lievrouw, 2006). Researchers have built a large knowledge base about information and communication in science through a rich history of study of the social structure of science and scholarly communication prior to the widespread availability of ICTs such as e-mail, the internet, and instant messaging. Quite a bit of research has been done to better understand how traditional ICTs such as e-mail, listservs, and electronic journals have been adopted and are used. Less research has been done on how more interactive online technologies like SCTs have been adopted and used in science and little of this research refers to general studies of communication in science or ICTs that support computer-mediated communication (CMC).

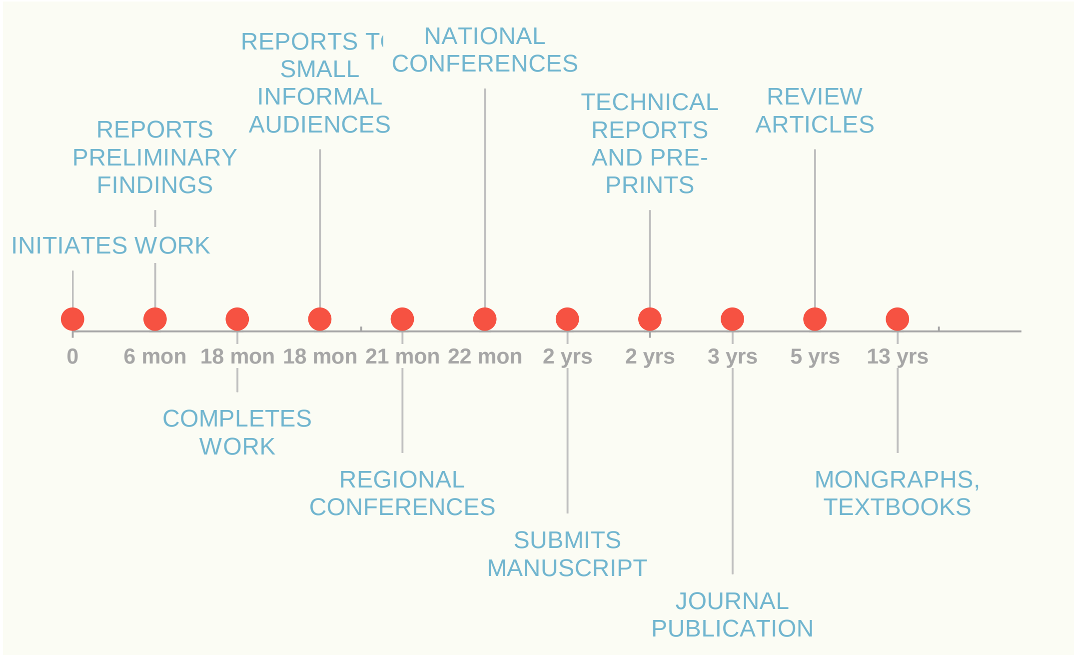

Figure 1 The Garvey and Griffith model of Scholarly Communication in Science (adapted from Garvey & Griffith, 1972)

The Garvey and Griffith model of communication in science (see Figure 1) was developed empirically through studying psychologists and other scientists (Garvey & Griffith, 1967; Garvey & Griffith, 1972). It illustrates how communication moves from informal and detailed through formal and more general. The model has been useful in studies of science communication and in practice in library and information science for retrieval of scientific information in part because it recognizes the value of informal communication. It was developed prior to the introduction of general purpose ICTs (there were, of course, mainframes used for analysis). There have been suggestions of ways to update the Garvey and Griffith model of scholarly communication (e.g., Hurd, 1996) to account for changes to scholarly communication brought by ICTs (e.g., Nentwich, 2003), but these articles stop after considering electronic journals, e-mail, and web pages. The affordances of the new SCTs and the impact they have on the conduct of science warrant study. A more comprehensive framework is needed to make use of the knowledge we have gained through decades of study as well as to situate new technologies.

1.2 Research Questions

The comprehensive framework of communication in science guides the study of SCTs in science to answer the following research questions:

RQ 1. How do scientists use SCTs, specifically blogging and microblogging?

1.1 How do these SCTs fit into the context of scientific work?

1.2 What functions do these SCTs serve?

1.3 What benefits do SCT participants report receiving?

1.4 How do participants and non-participants view these SCTs?

1.5 How do these modes of communication interact among themselves and with traditional modes of communication?

RQ 2. How do these ICTs support data, information, and knowledge creation, seeking, and use in science?

RQ3. Is the framework, based on the literature, suitable for describing communication in science?

1.3 Importance and Contributions

1.3.1 A Comprehensive Framework for Describing and Analyzing Communication in Science

This dissertation is important because it draws from several different bodies of literature and integrates them to build a comprehensive framework; that is, a framework that is comprehensive of the pertinent aspects of communication in science. Studies that draw from only one body of literature will have much narrower interpretive power and implications. Studies that do not draw on the literature and include only descriptive information about a single technology are limited in their utility in that they do not integrate background information on how scientists communicate. Many ICTs used in science faced a period of skepticism and rejection before widespread adoption, but many of these technologies are now so much a part of the fabric of science that it is difficult to imagine doing science without them (see, for example, discussions of electronic journals Tenopir & King, 2000). Descriptive studies that do not account for the reasons ICTs developed as they have may propose changes that will not be accepted, will not perform the necessary functions, and will waste resources. However, we cannot expect short conference contributions, for example, to include full reviews of the vast body of literature describing communication in science. Descriptive studies do have value and these studies can use the framework developed below to situate the new technologies.

This framework can and should continue to develop and form a basis for studying existing and new technologies to have its full impact.

1.3.2 Findings Will be Useful for Various Actors who Aim to Improve Science Communication

1.3.2.1 For Organizations

Scientists are using new ICTs to create, disseminate, retrieve, and use scientific data, information, and knowledge, but there is little institutional support outside of the geosciences. Institutional support might be as simple as hosting and maintaining the technology but might also include recognition of the use of social ICTs to provide outreach or to show the impact of the scientists' work.

There is also little recognition of the role of these tools in *doing* science, instead of just being as a pastime. Some professional societies have made efforts to support the use of new ICTs, but their efforts struggle as society staff often do not understand how the tools can be used and what the society's role should be in supporting their scientist members. Contributions for scientists in organizations and organizations:

- Explain new tools in the context of existing channels and communication methods for greater understanding.
- Help organizations assess the value of the new tools for the purposes they want to achieve and the types of messages they need to convey.
- Guide interactions with staff scientists on social media platforms. For example, identify posts that are disseminating results and further amplify them and identify posts asking for assistance from other scientists in the field and do not amplify them.
- Enable organizations to make the case not to support technologies that do not meet their needs.

1.3.2.2 For scientists

Scientists can use the framework to help decide what tools they might want to trial and also to help in recruiting organizational support and other scientists to their preferred ICTs. The framework provides a language scientists can use to request modifications to the ICTs they need for their work.

1.3.2.3 For Communication Researchers

The actual use of these tools changes continuously as users adapt to them, and adapt them to their work and social processes (MacKenzie & Wajcman, 1999; Rogers, 2003). New ICTs are introduced regularly and existing tools' uses change quickly, so any study of current tools will likely become outdated. Researchers studying how scientists use a new tool can show where the new tool fits into the framework and can use this to build testable hypotheses about the new ICTs. Researchers in one of the referenced areas may find articles cited that come from different research traditions useful.

1.3.2.4 For Communication Tool Designers

The framework will also assist designers in developing new tools or modifying existing tools to address a specific niche in scholarly communication. They may identify new functions they should add to their current tools or gaps where a new tool would be valued.

1.3.2.5 For Librarians

Academic and special librarians who support researchers in science and the social sciences often study scholarly communication in their graduate programs to understand what types of information are needed, where that information can be found, and what methods are most productive in locating that information. Time in these classes is limited, and there are many updates to cover as well. Also, practicing librarians may not understand the utility of these new ICTs to their work. The framework will be useful in structuring learning about communication and information retrieval in science.

Archivists might find the framework useful in deciding if and which traces in new ICTs should be preserved.

1.4 Organization of the dissertation

This dissertation is organized as follows:

Chapter 2 contains the literature review, the development and presentation of the conceptual framework

Chapter 3 applies the framework based on the literature.

Chapter 4 describes the research design and steps taken to increase transferability and validity.

Chapter 5 integrates study of microblogging at conferences with cross-case analysis to answer the research questions.

Chapter 6 discusses the findings of the study and implications.

2. Literature Review and Framework

Drawing on a review of the literature, this chapter develops a framework for analyzing methods / channels / technologies used for communication in science. This framework specifies features, functions, and uses that guide the empirical study of communication transactions that use information and communication technologies (ICTs).

2.0 Framework of Communication in Science. Overview

This section previews the Framework of Communication in Science to provide a map for the organization of the remainder of the chapter in which the details are provided and connections to specific theories and empirical work are made.

A model is a "simplified picture of a part of the real world" (Cobley & Schulz, 2013, p. 7). A theory is a set of concepts and constructs and their relationships (Cobley & Schulz, 2013). Theories may include causal statements, as well, and can be used to explain or understand and make predictions for what is happening. In qualitative research, conceptual frameworks are used to organize findings at various stages of analysis building toward theory development. Here, the term framework is used throughout first as developed through careful analysis of various bodies of literature and then as amplified, refined, and even tested through empirical research. The framework provides variables useful for further research. As the framework becomes stable through application and evaluation, it may be more appropriate to refer to it as a model or theory.

2.0.1 Outline of the Framework of Communication in Science as used in coding

The following table (Table 1) provides an overview of the framework of communication in science.

Table 1 Overview of the Framework of Communication in Science

Section	Name	Subtypes
1	**Features of the Communication Partners**	
1.1	Number of communication partners	• One (interpersonal) • Few (small group) • Many (public) • Unknown
1.2	Individual features of the partners	• Education or sophistication General public ○ Interested public ○ General science ○ Same • Experience and training (communication specific) • Demographics • Cognitive dispositions • Social-personal dispositions • Communicative dispositions • Relational dispositions
1.3	Match and relationship of communication partners	• Match in education/sophistication

Table 1. Overview of the Framework of Communication in Science, continued

2	**Purpose of the communication activity**	
2.1	Dissemination	
2.2	Preservation	
2.3	Certification	
2.4	Discourse	
2.5	Societal Benefit	
2.6	Identity	
2.7	Rewards	
2.8	Learning/teaching	• Advice • How a tool works
2.9	Persuasion	
2.10	Evaluation or Opinion	
2.11	Coordination	
2.12	Social	• Be part of a group • Request comments/interaction • Identity
2.13	Entertainment	• Humor
3	**Features of the message**	
3.1	Topic	
3.2	Type of Content	• Data • Methods/algorithms/workflows • Analysis • Theoretical/philosophical • Opinion/evaluation • Results • Memoir/confessional/biographical
3.3	Register	
3.4	Language	
3.5	Structure	• None to well-structured or highly organized
3.6	Persistence	• None to archived
3.7	Review or Quality Control	

Table 1. Overview of the Framework of Communication in Science, continued

4	**Communication channel**			
Layer 1	Physical layer and basic transmission protocols	Face-to-face Print Technologically mediated (radio, telephone, internet)	Copresence Visibility Audibility Cotemporality Simultaneity Sequentiality Reviewability Revisability Coherence Hyperlinking	
Layer 2	Means of expression and advanced functions of software		Non-linguistic	Linguistic
		Auditory	Sounds Instrumental music	Spoken word
		Visual	Images/pictures Models Still Moving	Text
			Icons Pictograms Sign Language	
		Tactile	Models	Braille
		Other senses (smell, taste, proprioception)	Typically only applicable in virtual reality settings	
		Audiovisual, Multimedia/hypermedia	Combining multiple means of expression.	
Layer 3	Conventions and etiquette			

2.0.2 Introduction to the Framework of Communication in Science

General communication research served as a foundation for the framework. Modifications and elaborations address science contexts, settings, communicators, and messages based on research from sociology of science, the culture of science (from science and technology studies), scientific information (from library and information science), and other fields.

Over the course of the 20th century, communication science developed as a field of study separate from psychology, sociology, and other social sciences with its own theories and models. The first applications were to mass communication, with the study of intrapersonal, interpersonal, small group, and public communication developing mid-century (Bryant & Pribanic-Smith, 2010; Verderber, Verderber, & Sellnow, 2014). Early models of communication such as Shannon's (1963) use a linear flow from communicator through a channel to a recipient. Noise is introduced at each step and the entire process happens within a system within a context. Current views of communication appreciate

- Communication is not linear; rather, it is an interactive ongoing process (Knapp & Daly, 2011)
- Context is social, environmental, historical, psychological, and cultural (Knapp & Daly, 2011; Verderber et al., 2014)
- Settings can be intrapersonal, interpersonal, small group, public, or mass (Verderber et al., 2014)
- Participants are active; personality, demographic, and behavioral factors matter (Daly, 2011).

Further, it should be noted that the divisions of the framework are not independent. Studies have shown, for example, that demographic features of the communication partners impact the motives and purposes of the communication (R. B. Rubin, Perse, & Barbato, 1988). Similarly, register, genre, and channel are closely linked (Biber & Conrad, 2009; Jaworski, 1999; Swales, 2004; Ventola, 2002).

The major divisions of the Framework of Communication in Science to some extent reflect Lasswell's

> "*who* says *what* to *whom* through *what channel* and with *what effect*" (1948, cited in Nabi & Oliver, 2010, p. 256)

That is, divisions cover aspects related to the communication partners, their roles, and their relationships (2.1); the purpose, motives, and goals in communicating (2.2); the features of the message (2.3); and features of the channel (2.4).

2.1 Features of the Communication Partners

According to Rogers and Kincaid (1981), communication is "a process in which the participants create and share information with one another in order to reach a mutual understanding." Communication is based on a relationship (Schramm, 1971). Features and relationships of the communication partners or, as appropriate, the imagined audience (Litt, 2012) are of primary interest. According to Soergel (1985) the most salient features are

- audience size or number of communication partners (elsewhere setting; i.e., if intrapersonal, interpersonal, public, mass communication, or unknown, (Verderber et al., 2014))
- demographic, cultural, personality and other individual characteristics of the participants (Daly, 2011)
- match and relationship among or between communication partners (Herring, 2002). Many types of relationships among communication partners have been studied (e.g., parent-child, husband-wife, doctor-patient), but this dissertation concerns only those that include a scientist as one of the partners.

In SCTs the potential audience can be anyone with access to the web site with appropriate permissions, but the communicator imagines or develops a conception of the audience based on cues from the medium and the context of the communication activity (Jakobson, 1960; Litt, 2012; Marwick & boyd, 2011). Communicators chose how to represent themselves, the styles, cultural referents, vocabulary, and topics they use based on their view of the audience or communication partners (Marwick & boyd, 2011).

2.1.1 Audience Size or Number of Communication Partners

Communication varies if it is one-to-one, one-to-few, or one-to-many. Traditional communication research has sub-fields to study intrapersonal, interpersonal (generally one-to-one), small group (generally three to twenty), public (more than twenty) and mass media (large audiences mediated by mass media) (Verderber et al., 2014).

In one-to-one communication it may be easier to come to a mutual understanding (Rogers & Kincaid, 1981) or common ground (Clarke & Brennan, 1993), particularly if the communication partners are similar or have a similar background (Rogers, 2003,see match of communication partners below).

In online communication, the audience size is potentially in the millions, but participants often treat the audience as bounded; that is, they have an imagined audience for their communication that they determine based on the context and the cues the technology provides (Litt, 2012; Marwick & boyd, 2011).

2.1.2 Individual Features of the Communication Partners

Psychologists have long studied individual differences and personality. Many of these traits have been studied by communication scholars to determine their impact on interpersonal communication. Daly (2011) groups these traits into

- demographic traits
- cognitive dispositions
- social-personal dispositions
- communicative dispositions
- and relational dispositions (see Table 2)

Table 2 Example Features of the Communication Partners (Daly, 2011)

Category	Examples
Demographic	Sex Gender Age Race Ethnicity Culture (which has many variables and classifications) Socioeconomic variables Education Epidemiological status
Cognitive Dispositions	Locus of control Cognitive complexity Authoritarianism Emotional intelligence
Social-personal Dispositions	Loneliness Depression Self-esteem Narcissism Humor Machiavellianism Empathy Self-monitoring
Communicative Dispositions	Argumentativeness Communication Apprehension Conflict Communicative and social competence and skill
Relational Dispositions	Attachment Rejection sensitivity

Communication participants interpret messages based on the context of the communication, their knowledge, and various symbols, among other things (Schramm, 1971).

In science communication in particular, known, perceived, or expected knowledge or education of the communication partners is one of the most frequently discussed individual features. This aspect of the audience is typically divided into categories:

- Members and participants in the specific research area who share background knowledge, expertise, and experience (Collins, 1985a; Crane, 1972; Fleck, 1979/1935; Kuhn, 1996). Luzón (2013) calls this "intraspecialist level."
- Other scientists in the general research area with significant commonalities in research area, but without the specific expertise and experience of direct participants (Paul, 2004). Luzón (2013) calls this "interspecialist level."
- Scientists and non-scientists who have some college-level scientific training and who are interested in science (Kyvik, 2005). Alternatively, practitioners in an applied area of that science who have strong experiential knowledge, but who may have had less formal science education (Fleck, 1979/1935; Wynne, 1995). The most common example of this category is farmers in the area of animal husbandry.
- Non-scientists who have an interest in science (Kyvik, 2005).
- Non-scientists who are not interested in science and who may be distrustful of scientists or some scientific ideas (Merton, 1973b).

When scientists communicate with members and participants in the specific research area who share background knowledge, expertise, and experience, they leave out some details that are fundamental and do not cite works that have become "generic" to the field (Garfield, 1979) or that are part of the context or fabric of the field (Fahnestock, 1986; McCain, 2011; Merton, 1988). In the subdisciplinary areas, there are standardized methods and training as well as specialized language in common (Paul, 2004) so certain details can be omitted. Non-specialist readers may have physical access to a text but may not be able to use it (Hine, 2002).

Experience and training are individual features that have been studied in the context of public communication of science. The training of the scientist in communication can be as important as the perceived education or sophistication of the communication partner. In studies of how scientists communicate with the media, Dunwoody, Brossard, and Dudo (2009) found that scientists were more likely to communicate with the media if they received formal communication training.

Walther (2011) describes how experience with the communication channel changes user’s view of its features and affordances. In channel expansion theory, user’s experience with the channel, their partner, the topic, and the organizational context all impact perception of the communication and satisfaction with it.

2.1.3 Match of and Relationship among or between Communication Partners

In addition to the characteristics of the individual communication partners, the match between communication partners based on similarity in their characteristics is important. If both partners have equal experience levels and knowledge of the topic area the communication will be different than if they have unequal experience or knowledge. Match can be inferred from knowing the characteristics of both partners.

Even if the partners are well matched in terms of experience and knowledge of the topic, they may be philosophically, politically, or ideologically very far apart. This can lead to intentional or unintentional misunderstandings and communication breaks (Collins, 1985b). Likewise, Herring (2002) points out that differences in gender, race, age, and other demographic and cultural variables result in different communication styles and may require more effort for mutual understanding. Older research in face-to-face communication found that situational variables such as match in sex, race, and age affect how information is communicated, received, and valued (reviewed in Sproull & Kiesler, 1986).

Communication partners may be in a relationship, such as long-term collaboration partners, boss-employee, advisor-advisee, parent-child, friends, reviewer-author, and so forth with shared background knowledge (Biber & Conrad, 2009; Menzel, 1966b). Collaboration partners might work together closely but have different but complementary education levels, experiences, and disciplines (Kouzes, 2000). Such relationships cannot be inferred from knowing the characteristics of each partner but rather must be ascertained for each pair of persons.

Another aspect of match is the status. Linguists describe the difference in speaking with an authority figure and a peer (see also tenor in discussions of register below, Swales, 1990).

Experience communicating with a particular partner can increase the user's sense of the richness of the communication channel (Carlson & Zmud, 1994 cited in Walther, 2011) and the ease with which they can convey social information. As an example, Luzón (2013) found that experienced science bloggers use specific techniques to tailor their posts to a general audience:

- Explanation of terms and concepts (definitions, elaboration of terms)
- Paraphrases/reformulations
- Comparisons/metaphors

- Examples from daily life
- Links
- Visuals conveying information (p. 437).

2.2 Purpose of the communication activity

The purpose or function of the communication activity has to do with the intended goal or result and the motives of the participants. In communications theory, Uses and Gratifications describes how individuals select media or interpersonal channel based on their “social, psychological, and biological needs and assess[ment] of functional alternatives” to provide the gratifications they need (Nabi & Oliver, 2010, p. 261). Nabi and Oliver (2010) provide the following categories of gratification needs based on their review of the mass effects media research:

- Diversion (entertainment)
- Personal relationships
- Personal identity
- Surveillance (e.g., news gathering) (p. 261)

Applications of uses and gratifications theory to interactive media including SCTs have generally found the same needs, adding “pastime” to diversion, “information-seeking” to surveillance, and “form connections” to personal relationships (Chen, 2011; Sundar & Limperos, 2013).

In general communication theory, Rubin, Perse, and Barbato (1988) studied motivations for communication. They found the following general categories

- pleasure,
- affection,

- inclusion,
- escape,
- relaxation,
- and control.

Hypothesized motives like convenience and habit were not supported in their validation, but seem reasonable.

The science communication literature lists additional purposes including:

- dissemination
- validation and certification of content
- preservation
- learning, teaching, or assessment
- persuasion
- evaluation or opinion

2.2.1 Dissemination

A primary purpose of communication in science is to disseminate the results of research and to enable awareness in the scientific community (Roosendaal & Geurts, 1997). In linguistic terms, this includes the purposes of informing, explaining, and expositing (Biber & Conrad, 2009).

This is required by funding bodies and organizations, but more importantly, it enables scientists to contribute to the body of knowledge, get feedback, to benefit society or facilitate application of their work, and to increase their visibility among their peers, their management, the public, and funding bodies (Rowley-Jolivet, 1999). In communications literature, particularly in science communication literature, *dissemination*, can imply a one-way transmission of information (Trench, 2008). It is used alongside discussions of the *deficit model*; that is, lack of support for science is due to a lack of knowledge, so educating the public about science will change opinion (Sturgis & Allum, 2004). Here, I use dissemination in the sense of wide distribution.

2.2.2 Preservation

Communicating the results of scientific work, whether sharing data or publishing a formal report in a scientific journal, is useful to assure the continuing availability of the contribution. Traditionally, the peer-reviewed article is the archive for the scientific work (Bowker, 2000; Roosendaal & Geurts, 1997). Until support of data archiving and curation is ubiquitous, publishing the results of scientific work might be the best way to ensure the work is preserved for future researchers (Pikas, 2007). See also the discussion of the persistence of the content below in section 2.3.6.

2.2.3 Validation or Certification of Content

Researchers who study scholarly communication in science, particularly those who study peer review processes, describe a certification, registration, and even legitimization value of publication (Borgman, 2007; Nentwich, 2003; Roosendaal & Geurts, 1997; Zuckerman & Merton, 1971). That is, the knowledge assertions in the scholarly work receive an *imprimatur* by going through the peer review and publication process (Zuckerman & Merton, 1971). The publication process and the reputation of the publication venue lend authority to the assertions communicated and enable other scientists to trust and use the information communicated without having to replicate the experiment themselves (Shapin, 1995).

One of the reasons scientific journals were first started was to register new ideas in order to establish *priority* (Polanyi, 2000; Zuckerman & Merton, 1971) or add a "time stamp" (Nentwich, 2003). Priority, or being the first or the most prominent early reporter of a new idea in science yields more citations and greater rewards. It can even lead to the concept being named for the scientist (Merton, 1973a). Scientists might choose to communicate their ideas outside of science to a popular audience to reinforce their priority as the originator of the idea (Paul, 2004).

Patents are an official, legal way to certify scientific information. Patents provide exclusive use of a novel, non-obvious invention for a fixed period of time in return for disclosure. In the first step of the patenting process laboratory notebooks are signed and witnessed to certify the work (Shankar, 2007). Next, ideas are communicated in disclosures to establish priority. Finally, patents are applied for and granted. Universities and scientists choose to patent inventions to make their transfer to industry more attractive, to make them available to commercial partners, and to speed the transfer (Kleinman, 1998; Larsen, 2011).

2.2.4 Discourse or Contributing to the Conversation

Formal scholarly communication can be seen as discourse. Scientists read the publications of others, cite them, and then build upon them with their own work (Nentwich, 2003). Later other scientists will do the same with their work. Publication venue decisions are made in part to reach the desired audience to facilitate this conversation. In more immediate communication channels (described below) the discourse may be a spoken conversation.

2.2.5 Societal Benefit or Applications

Kleinman (1998) describes how, in some biomedical fields, discoveries must be communicated in patents to attract the attention of organizations that can invest the time and money required to move the innovation into clinical or practical use. The university cannot produce the end product and companies will not invest in moving an innovation into production unless they have the first mover advantage that a patent secures for them.

More generally, scientists ensure their work is available to wider audiences by writing reviews that appear in more general scientific journals, by writing textbooks, by writing popular science books and articles, and by discussing their work with the media (Paul, 2004). Scientists frequently communicate with journalists and enjoy doing so (Peters et al., 2008) and many scientists communicate outside of their fields using blogs (Pew Research Center, 2015; Pikas, 2008b). These posts can then be a boundary object that can link interested public to the results of scientific work (Shanahan, 2011).

2.2.6 Identity

Scientists disseminate their work to establish their research identities and assert their expertise (Polanyi, 2000). Many scientists create websites and other online media to establish and maintain their identities (Lamb & Davidson, 2005). They also ask questions in intellectual discussions to establish identity (Tracy & Naughton, 1994).

Establishing research identity is a purpose of disseminating a scientist's work, but social identity can be constructed in social media through selectively revealing information about oneself and by linking to others (Schmidt, 2007).

2.2.7 Rewards

Rewards can be extrinsic such as status or pay or intrinsic such as satisfaction and feeling valued (Dunwoody et al., 2009). In practical terms, scientists are evaluated for recruitment, promotion, tenure, and salary on the quality and quantity of their formal scholarly communication record as well as the prestige of the publication venues (Borgman & Furner, 2002; Latour & Woolgar, 1986). Measures are sometimes oblique, such as using the journal impact factor of the publication venues to judge the work of an individual (Glanzel & Moed, 2002). Grants are awarded to scientists with a strong publication history. Dunwoody, Brossard, and Dudo (2009) also mention intrinsic rewards scientists get from communicating with the media.

2.2.8 Learning, teaching, or assessment

Scientists also communicate to teach. Within the lab they transfer tacit knowledge through demonstration and discussion (Collins, 1985a; McCain, 1991;

Shapin, 1995). Scientists travel to present to other scientists and to talk at symposia and colloquia (Walsh & Bayma, 1996a). This informal learning is combined with formal teaching and learning in classes (Hara, Solomon, Kim, & Sonnenwald, 2003).

Microbiology protocols provide recipes and instructions for completing specific tasks in the laboratory (Lynch, 2002). These are examples of instructions.

2.2.9 Persuasion

Scientists frequently communicate to persuade or to create or change beliefs, attitudes, or behaviors (Latour & Woolgar, 1986; Penrose & Katz, 1998).They write grant proposals to persuade funding bodies to support their work; they act as government advisors to influence regulations; and they serve as expert witnesses in court (Gieryn, Bevins, & Zehr, 1985) and in the media (Jasanoff, 1987).

In formal scientific communication, scientists persuade through detailed transparent account of research and analysis methods, as well as through elements of presentation and style (Penrose & Katz, 1998; Swales, 1990). Whereas journal article argumentation may be based on facts and transparency, conference presentations can call on emotions and excitement over the potential of new results (Penrose & Katz, 1998). Public communication often draws on novelty, curiosity, and excitement to persuade (Fahnestock, 1986).

2.2.10 Evaluation or Opinion

Scientists communicate to evaluate or provide an opinion. For example, in peer review, reviewers communicate the perceived value of the article to the editors as well as communicating an evaluation of the quality and novelty of the work (Weller, 2001). As managers, scientists must evaluate their staff members. More recently, some scientists have blogged or tweeted opinions and evaluations of scientific meetings or articles (Neylon & Wu, 2009; Priem & Costello, 2010).

2.2.11 Coordination

Lamb and Davidson (2005) call ICTs that are used to "facilitate the work of researchers, particularly those separated in time or space," coordination ICTs. More generally, Vetere, Smith and Gibbs (2009) discuss instrumental purposes of communicating such as coordinating work. There has been a great deal of research done on how scientists communicate to coordinate work whether the collaboration partners are geographically distributed or co-located and which communication channel features are needed (see Section 2.4) (Carley & Wendt, 1991; Kraut, Egido, & Galegher, 1990; Sonnenwald, 2007; Walsh, Kucker, Maloney, & Gabbay, 2000). Studies of collaboratories centered on the use of shared instruments found that instant messaging and other synchronous tools are used to control the devices, evaluate the data as it is produced, and to discuss experimental design or methods (Birnholtz, Finholt, Horn, & Bae, 2005).

2.2.12 Social

A primary use of communication is for social purposes such as getting to know one another, establishing common ground (Clarke & Brennan, 1993), establishing or maintaining group membership (also referred to as inclusion R. B. Rubin et al., 1988), and connecting, forming, displaying, and strengthening social bonds (Tufekci, 2011), observing politeness and adherence to social norms (Schneider, 1988, cited in Vetere et al., 2009), and displaying presence or awareness information (Nardi, Whittaker, & Bradner, 2000).

In a study of e-mail discussion lists, Rojo and Ragsdale (1997) found that participants use the discussion list to build and maintain social contacts but that this mode was fairly uncommon in the large discussion lists they studied. However, in Carley and Wendt's study of discussion lists as part of a distributed research group, they found that social messages made up 20% of the total (1991, cited in Rojo & Ragsdale, 1997).

In oral communication and social media, which share many aspects of oral communication, much of the communication is phatic; that is, it is not primarily informational, rather it is used for social purposes such as establishing rapport and maintaining relationships and for purposes related to establishing and maintaining the communication channel (Vetere et al., 2009) or place in the social network (Miller, 2008).

Scientists also communicate to establish group membership and participate in informal groups researching the same topic, using the same data, or using the same research or analysis methods (Crane, 1972; Postmes, Spears, & Lea, 2000; Wenger, 1998). In linguistics research, these groups are called discourse communities.

> Use of the term 'discourse community' testifies to the increasingly common assumption that discourse operates within conventions defined by communities, be they academic disciplines or social groups. The pedagogies associated with writing across the curriculum and academic English now use the notion of 'discourse communities' to signify a cluster of ideas: that language use in a group is a form of social behavior, that discourse is a means of maintaining and extending the group's knowledge and of initiating new members into the group, and that discourse is epistemic or constitutive of the group's knowledge.(Herzberg, 1986, p. 1, quoted in Swales, 1990, p. 21)

According to Swales (1990) a discourse community has agreed upon goals, intercommunication among members, uses specific genres, has specific terms or jargon, and has a threshold level of expertise and knowledge. Individuals show community membership in their choice of language use in communication.

2.2.13 Entertainment

Some scientists write blogs because they enjoy doing so or because they like to entertain and provide humor (Pikas, 2008b). Scientists also write humorous columns and intriguing puzzles to entertain audiences (see for example Martin Gardner's *Mathematical Games* column in *Scientific American* and the chemistry Sudoku found in *Chemical & Engineering News*).

2.3 Features of the message or content

There are many dimensions that can be used to describe the content being communicated. Of these,

1. topic,
2. type of content,
3. register,
4. language,
5. structure,
6. persistence, and
7. review or quality control

are selected as framework elements as they are discussed most frequently in the science communication literature.

2.3.1 Topic

A primary defining feature of a message is its topic or subject. In science, it is also the subject area context in which the message occurs. That is, the topic might be a description of how to solve an equation, but this will be different if the communication partners are mathematicians or applied physicists. Mathematicians in pure math might describe analytical solutions whereas applied scientists might describe algorithms for computing an approximation.

2.3.2 Type of content

Traditionally, in print text, media researchers use the term *genre* to refer to a class or category of communication. The term can be used more broadly to encompass message structure, content, purpose, and context (Kjellberg, 2009). Genres are situated in the disciplinary community and can be dynamic (Berkenkotter & Huckin, 1995). Some genres of communication used in science research circles are less apparent to outsiders. Swales (2004) calls these – such as recommendation letters, evaluations, and examiner discussions – occluded genres. He also notes that various genres appear in an expected order or *chain* and calls the collection of genres common to a group a genre network (Swales, 2004).

The term “treatment” is related concept used when describing research articles. It is used to differentiate theoretical articles, from review and application articles (Swales, 2004).

Although there are many listings of scientific and scholarly genres, treatments, and types, in the framework I highlight very coarse-grained categories:

- data or observations,
- instructions or descriptions,
- analysis or narrative,
- theory.

2.3.2.1 **Data**

Even within the category of data, there are different levels. A good example of this distinction is NASA's data processing levels (see Table 3). Some data are the direct output of instruments and consist of varying voltage levels, zeros and ones, or pixel values. Some data are cleaned, corrected, geo-referenced, or calibrated using various algorithms. These data are also called 'derived' data (Griffiths, 2009). Output of models or simulations is also considered data by some scientists although a distinction exists in the Earth sensing community.

Table 3 NASA Data Processing Levels

Data Processing Level Definitions	
Processing Level	**Definition**
Level 0	Reconstructed, unprocessed data at full resolution; all communications artifacts have been removed
Level 1	Level 0 data that has been time-referenced and annotated with ancillary information, including radiometric and geometric calibration coefficients, and geolocation information
Level 2	Derived geophysical variables at the same resolution and location as the Level 1 data
Level 3	Variables mapped on uniform space-time grids, usually with some completeness and consistency
Level 4	Model output or results from analyses of lower level data
Example of data processing levels. From: http://outreacheos.nasa.gov/EOSDIS_CD-03/docs/proc_levels.htm (accessed June 16, 2010)	

Data that are meant to be shared (Bowker, 2000) often have metadata attached to describe the circumstances surrounding the gathering of the data, the responsible party, and sometimes provenance and how the data have been used (e.g., citations in the literature Hine, 2006; Zimmerman, 2008) .

2.3.2.2 Methods, algorithms, workflows, protocols, procedures

Methods, algorithms, workflows, protocols, and procedures are the compilations of steps taken in collecting, analyzing, or presenting data (Lynch, 2002). In the past, this knowledge was transferred through apprenticeship in the laboratory (Shapin, 1995). More recently, workflows, workflow patterns, and protocols have also been shared in print and online particularly in molecular biology. The number of venues to share protocols and workflows has increased dramatically (Lynch, 2002). Some of these are curated collections formally published by a major publishing house (e.g. *Springer Protocols, Cold Spring Harbor Protocols*) while others might be included in patents or only local practices shared within an organization (Lynch, 2002). Protocols provide detailed steps, but still require background knowledge and experience to interpret.

The above examples of protocols were recorded in text by the scientists who are skilled in the technique. There are also mechanically recorded or electronically captured protocols that are shared in science. For example there are social networking sites that facilitate the sharing of workflows that are written in standard programming languages and can be enacted directly through the site (e.g. myExperiment, Goble et al., 2010). Workflows link modules of computer code that automate steps to obtain data, clean it, analyze it, and produce results. There are also video protocols that show detailed views of the steps required in an experiment (Pasquali, 2007).

2.3.2.3 **Analysis, expository/narrative, with synthesis**

This type of information tells a story using assorted rhetorical devices to provide context, convey meaning, and make knowledge claims (Hyland & Salager-Meyer, 2008). Traditionally, the most important way to communicate science has been through journal articles (Garvey, 1979; Tenopir & King, 2000). Authors place the new work in context using citations (Nicolaisen, 2007) and provide a narrative explanation of what work was done and what impact that work has. Journal articles are typically submitted after the work is complete and provide enough information to help the reader trust the results. Journal articles can stand independently and often appear months if not years after the empirical work is complete (Garvey, 1979).

Other expository writing includes conference papers and book chapters. While the rhetorical approaches in these might differ, they each present descriptions of scientific work.

In many areas of science, review articles or systematic reviews are used to summarize a body of work including journal articles and conference papers. Reviews typically appear after multiple journal articles exist in the area. Meta-analyses may include re-analysis of the original data aggregated across multiple sources (Blake & Pratt, 2006a; Blake & Pratt, 2006b).

2.3.2.4 **Theoretical or Philosophical**

In some areas of science, communications may be more theoretical or philosophical; that is, they may advance science through logical argument instead of through reporting of empirical work (Walsh & Bayma, 1996b).

2.3.2.5 **Opinion or Evaluation**

Scientists communicate to provide an opinion or evaluation of texts, equipment, processes, and people as in book reviews, peer review reports, grant reviews, and staff or employee evaluations. Peer review reports evaluate a submitted article on accuracy, systematic importance, and intrinsic interest of the subject matter, among other things (Polanyi, 2000). Some systematic reviews evaluate previous studies and synthesize a recommendation or best practice (Blake & Pratt, 2006a). See section 2.3.7 for a discussion of review or quality control as a feature of the message.

2.3.3 Register

Register is a linguistic term used to describe a variety of language that combines aspects of style, tone, tenor and sometimes genre (Biber & Conrad, 2009; Swales, 1990). It is related to the situation and the purposes for which the communication is used (Biber & Conrad, 2009). Register can vary by channel; that is, spoken registers are different from written ones.

Registers can be viewed more or less granularly (academic prose vs research article in geosciences) (Swales, 1990). A common use of *register* is to describe formality. For example in informal spoken language *have to* might be shortened to *hafta* or *got to* to *gotta* (Biber & Conrad, 2009). Another example is the difference in register used by medical professionals as compared to that used by health consumers. Other examples of register are prayer, legalese, and baby talk (Jaworski, 1999).

2.3.4 Language

The most prominent language for communication in science is currently English, but in the past Latin, German (particularly for geosciences and chemistry), French, Japanese, and Russian were more common (Swales, 1990; Swales, 2004). The number of Chinese language journals is rapidly increasing. Still, regional conferences and journals are often in the native language for the area, or if not a native language, then the ex-colonial international language (Swales, 1990).

2.3.5 Structure

Message content varies along a continuum from well-structured to free text and from organized to unorganized. The information might be structured for human or machine consumption. As mentioned above, journal articles have a set structure that facilitates information use by readers (Bishop, 1999). Text may also be marked up semantically to link to definitions, structures, databases and so on (Shotton, Portwin, Klyne, & Miles, 2009). Conversely, a text or a message might consist of a stream of characters or sounds with little discernable internal structure.

2.3.6 Persistence

A feature of communication is its expected persistence; that is, if the communication message will become part of the permanent record, preserved over a long period, or at the other end of the continuum, if the message is ephemeral and no longer exists after its utterance. This idea of persistence can be described as an affordance of the medium or channel; that is, if the channel is such that a message "remains accessible in the same form as the original display after the actor has finished his or her presentation" (Treem & Leonardi, 2012, p. 18). That is discussed in Section 2.4.2. As a feature of the message or content, persistence includes the various steps scientists might take to craft their message or present their content so that is retrievable and useable in the long term. For example, they might expend more effort to carefully describe methods or to assign the proper metadata. They might write more thorough comments in analysis code or cite sources for methods.

One scientist may communicate with another in person or via telephone to keep the communication "off the record" or unavailable to be forwarded or as part of the files that are kept on the computer.

In the case of data, scientists make "back of the envelope" calculations or observations or share trial runs on their instruments to check results. Scientists also run very expensive experiments from which a portion of the science data is to be preserved indefinitely (National Space Science Data Center, 2007). The big science activities and the trial runs of instruments are two extremes on a continuum. There are many smaller science projects for which the preservation of the data is not assured, but may be important (Heidorn, 2008).

Preservation can be an active process, requiring careful pre-planning and addition of metadata early in the planning process, and migration of the file format later (Borgman, 2007). Publication in a peer-reviewed journal facilitates long term preservation because there is an established infrastructure and policies, whereas preservation of and continuing access to "gray literature" like departmental reports, is often not assured (Wood, 1984).

2.3.7 Review or Quality Control

The extent to which the communication is reviewed, edited, or curated prior to or after transmission is an important feature of communication in science (Ziman, 1968). The primary form of review is peer-review. Harley and Krzys Acord (2011) identify these types of peer review:

- Developmental
- Pre-publication
- Publication-based peer review (other sources call this pre-publication peer review)
- Post-publication peer review
- Peer review of data and other scholarly products
- Institutional peer review in tenure and promotion cases
- Peer review for grants/funding
- Cumulative peer review (p. 2-3)

Contributions to the literature might not be reviewed at all, might be reviewed and accepted by an editor only, or might be reviewed by both editors and a panel of three to five peer reviewers prior to acceptance and publication (Weller, 2001; Zuckerman & Merton, 1971).

Review criteria typically include

- selection of the appropriate methods,
- validity,

- reliability of the results,
- presentation and documentation of the work,
- novelty,
- importance to the field,
- and appropriateness to the venue (Borgman, 2007; Nentwich, 2003).

In the case of big-science efforts, such as super colliders, there might be significant internal review within the project team before the work is communicated externally to publishers or the press (Traweek, 1988). Resulting data might be curated to ensure that they adhere to metadata and format standards (Griffiths, 2009). At this writing, the peer review of data is becoming an important issue. Review might consist of checking that the metadata has been applied appropriately or might involve a careful review of the data points, the experimental method, or the preparation process (Parsons, Duerr, & Minster, 2010).

In the case of work performed in government laboratories or by universities or private contractors for the government, there might be extensive reviews prior to release or publication in an unlimited venue. These reviews check for classified, sensitive, or export-controlled information. Likewise, companies review communications by employees for proprietary or competitive information and to determine if there is an intellectual property claim.

Communications also receive reviews after publication. Explicit reviews include book reviews, systematic reviews, and comments on the article web site or within social media (Neylon & Wu, 2009).

The citations an article receives (Zuckerman & Merton, 1971) and discussion in popular media also provide reviews. Section 2.2.10 above discusses evaluation or opinion as a purpose for the communication activity.

2.4 Features and affordances of the communication channel or medium

Some of the earliest mentions of channel were by Nyquist (1924, 1928, cited in Shannon, 1948), Hartley (1928, cited in Shannon, 1948), and Shannon (1948). The channel, for them, was the medium used to transmit the signal from transmitter to receiver whether wires, radio frequency radiation in air, or beams of light. The term is still used in that sense as in a general communications textbook: "the route traveled by the message and the means of transportation" (Verderber et al., 2014, p. 11), but new connotations have been added. In some works, channel is used synonymously with source (Lin & Garvey, 1972; Menzel, 1966a) or with format (Menzel, 1968). New features are needed to account for the encoding and uses as well as the physical layer. Accordingly, the framework of communication in science uses three layers each of which has multiple dimensions (see Table 4 for an overview). The following sections provide definitions, details, and examples from the literatures.

Table 4 Overview of Channel Dimensions (layer 2 based on Soergel, 2015)

<table>
<tr><td rowspan="3">Layer 1</td><td rowspan="3">Physical layer and basic transmission protocols</td><td>Face-to-face</td><td rowspan="3" colspan="2">Copresence
Visibility
Audibility
Cotemporality
Simultaneity
Sequentiality
Reviewability
Revisability
Coherence
Hyperlinking</td></tr>
<tr><td>Print</td></tr>
<tr><td>Technologically mediated (radio, telephone, internet)</td></tr>
<tr><td rowspan="8">Layer 2</td><td rowspan="8">Means of expression and advanced functions of software</td><td></td><td>Non-linguistic</td><td>Linguistic</td></tr>
<tr><td>Auditory</td><td>Sounds
Instrumental music</td><td>Spoken word</td></tr>
<tr><td rowspan="2">Visual</td><td>Images/pictures
Models
Still
Moving</td><td>Text</td></tr>
<tr><td colspan="2">Icons
Pictograms
Sign Language</td></tr>
<tr><td>Tactile</td><td>Models</td><td>Braille</td></tr>
<tr><td>Other senses (smell, taste, proprioception)</td><td colspan="2">Typically only applicable in virtual reality settings</td></tr>
<tr><td>Audiovisual, Multimedia/hypermedia</td><td colspan="2">Combining multiple means of expression.</td></tr>
<tr><td></td><td colspan="2"></td></tr>
<tr><td>Layer 3</td><td colspan="2">Conventions and etiquette</td><td colspan="2"></td></tr>
</table>

Each channel has technical features that affect how science communication is accomplished through it; the software or applications used in CMC have different affordances and technical features that support or at least allow various uses (Sundar & Limperos, 2013). Yet it is insufficient to look only at the physical and software features because different individuals, small groups, and communities understand and use the features differently and are able to do different things with them (Fulk, 1993;

Treem & Leonardi, 2012). Within CMC, there are technical features and affordances associated with the software. Finally, for each of these physical layers, there are conventions that have developed that shape the communication.

Herring (2002) describes the combination of the technical features of a CMC channel with the social and cultural practices *mode*. In more recent literature, the term *affordance* is preferred to describe the perceived uses a feature might afford (Treem & Leonardi, 2012). Like *mode*, it combines technical features with social practices. As Treem and Leonardi (2012) point out,

> Scholars who study the relationship between new technologies and social practices have found great utility in the affordance concept because it helps to explain why, in some cases, people use the same technology differently and why, in other cases, people put the same technology to similar uses and change their communication and work practices in equivalent ways. (p.5)

Using the concept *affordance* mitigates the technological determinism implied by CMC theories that attempt to explain user behaviors by system software and hardware technological features alone (Walther, 2011). Technological features in ICTs are equivocal, that is, they "can be interpreted in multiple and perhaps conflicting ways" (Fulk, 1993). It is clear that in CMC and particularly in SCTs, users experience different affordances for the same technological features; moreover, groups together make meaning of various features.

Examination of communication in a system is a snapshot in time as users adopt and adapt features. Rogers (2003) model of diffusion of innovations for communication technologies describes how features will be adopted when they are successfully modelled, they are trialable, and for interactive features, when there are enough other potential communication partners. Likewise, in the social shaping of technology literature, users mold the development of technology through their choices and actions (Lievrouw, 2006; MacKenzie & Wajcman, 1999)

Affordances and constraints of the communication channel cause the communicators to alter their messages (Herring, 2002; Walther, 2011). For example, in channels in which the addresser is unable to control the recipients of the message such as broadcast media like microblogging, users have adopted the convention of adding @ symbols to direct messages to the appropriate recipients (Honeycutt & Herring, 2009). This symbol was not originally decoded by the software, but helps to create a threaded conversation.

Several channels may be needed to communicate a message and they may be combined in parallel or as a “pipe” in several different sequences (Menzel, 1966b; Menzel, 1968). Chin, Myers, and Hoyt (2002) report that hyper-connected scientists communicate multi-modally; that is, via multiple channels, either channel switching as appropriate to the task or using channels simultaneously to transmit different types of messages.

The remainder of this section groups channels by the physical layer, and reviews the literature on the ways the features and affordances of the various channels change communication in science. The actual uses and the conventions are discussed where appropriate within each channel.

Note: In this literature review, channel characteristics are noted as they appear in the literature, i.e., for a particular physical channel, even if they apply more broadly beyond the context in which they are formulated. In the framework discussed in Section 1.1, all channel characteristics are integrated into one coherent scheme.

2.4.1 Face-to-Face Communication

General aspects. Face-to-face or in-person communication has been considered the gold standard (Kraut et al., 1990) for studying CMC. Face-to-face communication can provide context to the communication and immediate feedback. Things like tone, volume, inflection, speed, and non-verbal cues such as gestures, eye contact, and posture help convey the message (Argyle, 1972; Kiesler, Siegel, & McGuire, 1984). Participants are more able to tailor the messages to the individual recipients and feedback is immediate (Walther, 2011).

In Science. Walsh and Bayma (1996b) reported that there were barriers to learning for scientists at small institutions because access to the papers is not enough. A theoretical physicist explained,

> "It's different to see a paper and to be there. If you are at the big institutions you have access to the oral information, seminars, you can talk to the person. That's still lacking… At the big institutions… you can get help sorting through it."

In mathematics, in particular, face-to-face communication is important, "mathematical knowledge is transmitted orally and informally, through an enculturation process" and not through the very formal, abstract literature (Sheehan, 1990, cited in Walsh & Bayma, 1996b).

Wuest (1965, cited in Menzel, 1966a) found that senior chemists and metallurgists rated personal communication outside the university higher than junior personnel as a source for keeping abreast of new topics. Bernard, Shilling and Tyson (1964, cited in Menzel, 1966a) surveyed bioscientists who reported that informal discussions were important sources for new ideas. They also found that discussions with visiting scientists were very profitable to scientists who were alone in their specialties at their workplace.

STS studies describe aspects of communication channels. For example, Polanyi (2000), Shapin (1995), and Menzel (1968) each describe the *transfer of tacit knowledge* through hands-on experience and physical presence. This includes detailed *how-to* information and the "fruits of experience." McCain (1991) describes methods to acquire new methods in genetic research. Her informants found that visiting a lab to learn hands-on was the method most likely to be successful.

Conferences, as group and individual face-to-face meetings, offer many opportunities for scientists to catch up and reestablish ties with members of their invisible college and to meet members of other social circles within the same larger field. Presenters are the focus of communication at meetings and become centers of contact networks established through discussion of presented results (Garvey, Lin, Nelson, & Tomita, 1970; Garvey, Tomita, Lin, & Nelson, 1972). Garvey et al (1970) found that many scientists named informal, face-to-face discussions at conferences as the source of the most important information obtained at the conference.

2.4.1.1 **Means of Expression**

The second layer of channel encompasses the linguistic and non-linguistic features found in auditory, visual, tactile, and multimedia or hypermedia channels. In face-to-face communication non-linguistic auditory communication may include, for example, a cough, throat clearing or whistle. Linguistic auditory communication is spoken word, such as oration or in conversation. Non-linguistic visual communication includes gestures as well as things like blushing. Linguistic visual communication in face to face conversation can include sign language, for example.

2.4.1.2 **Conventions**

The conventions of face-to-face communication are related to the genre (2.3.2) and register (2.3.3) and the situation in which the communication occurs (Biber & Conrad, 2009). Formal speech using second person may be used in presenting scientific results to an audience. Informal colloquialisms may be used within a research team or in a lab while conducting or troubleshooting an experiment (an example is transcribed in Lynch, 1982). Presentations at lab or research group meetings fall in between (Swales, 2004).

There has been some research into how scientists use language in conferences in comparison both to everyday speech and to written formal communication. Dubois studied short biomedical research presentations in the late 1970s (cited in Swales, 1990). She found speakers provided more information on missteps and false starts in the research process, provided more informal commentary, used less precise numeric values, used narrative rather than an expository, and were more likely to use past tense (Dubois 1980, 1982, 1985 cited in Swales, 1990). In a later review, Swales (2004) lists more questions, more reflexive speech, and fillers in conference oral presentations.

2.4.2 Features of Mediated Channels

In General. A channel is *mediated* if an interactive two-way or multi-way technology such as audio and video telephone, e-mail, or chat, intervenes between the communication partners. Earliest studies compare – often limited – mediated channels to face-to-face communication and examined how missing social cues negatively impacted establishing common ground, conveying status, and providing non-verbal information previously provided through eye contact, gestures, and posture among other cues (Argyle, 1972; Kiesler et al., 1984).

Clark & Brennan (1993) describe these features of CMC channels:

- **Copresen**ce refers to actually being in the same place at the same time.
- Visibility means that the conversation partners can see each other including gestures and facial expressions.
- Audibility means that the conversation partners can hear each other and the tone of voice.
- Cotemporality means that the messages from one person in the conversation to another are received immediately.
- Simultaneity means that both parties can send and receive at exactly the same time.
- Sequentiality refers more to recorded channels. It means that turns by each partner do not get out of order.
- Reviewability enables conversation partners to look at what has been said.
- Revisability enables conversation partners to correct or change what they have said.

In the years since, the rise of SCTs has led researchers to add

- **Coherenc**e, the ability of the channel to support "sustained, topic-focused, person-to-person exchanges" (Herring, 1999; Honeycutt & Herring, 2009, p. 2)
- Hyperlinki**ng,** the ability of the channel to support linking from the communication utterance or contribution to others.

In contrast to most CMC researchers, researchers studying media effects compare digital media to traditional mass media (print newspapers, television news). Sundar (2008, cited in Sundar & Limperos, 2013) proposes four broad classes of technological affordances in digital media which reflect the comparison to one-way, broadcast media:

- modality (text, audio, video);
- agency (content creation and filtering);
- interactivity (user being able to make real-time changes to the content);
- and navigability (user being able to move through the site).

Modality is treated here as an aspect of the channel. Interactivity incorporates aspects of revisability. Navigability is related to hyperlinking.

The *richness* of a communication channel refers to the number of features it has, or the number of cues it carries from the sender to the receiver. In the presence or absence of any combination of these features, the conversation partners must alter their messages from how they would have been conveyed face-to-face to be understood. Media richness theory (Daft & Lengel, 1986) states that

- the number of cues,
- the immediacy of the feedback,
- the ability to use natural language (i.e., instead of the strict formal language of a business letter),
- and the ability to personalize the message

make communication more efficient when the task is equivocal. Later research found this not to be supported; that is, use of less rich channels was slower, but did not lower performance (Dennis & Kinney, 1998).

Social identity theory and the refinement SIDE (Social Identity model of Deindividuation Effects), proposed an explanation for communication success in less rich channels. Where social cues are scarce, individuation (the ability to "form impressions of [people] as idiosyncratic individuals") is difficult, so users are attributed the characteristics of their social identity or group (Tanis & Postmes, 2003).

In the years since this research was conducted, as CMC is no longer foreign and new, it has become less and less appropriate to judge CMC by comparing it to face-to-face. The results of short term experiments with new users of artificially constrained systems are less powerful when applied to current systems that are heavily used and have grown and adapted to users' communication needs and styles (Walther, 2011). Moreover, as Hine (2000) points out when reviewing the literature dealing with reduced social cues in CMC, the original studies tested specific office-type tasks over a short time period in an artificial setting. Social use of CMC provides a "rich and complex social experience" (p. 16) which can be valuable in building and maintaining relationships.

According to channel expansion theory, experienced users of a channel and those communicating with familiar partners will find other ways to convey social cues absent the traditional (Walther, 2011). Social information processing theory of CMC states that users adapt to lack of cues and use the remaining cues to conduct interpersonal communication but that the communication may be slower because of this adaptation process (Walther, 1992; Walther, 2011).

In general, when studying CMC there are basic features build into the technology, but, there are important differences in how the features are used, the means of expression, and the conventions and etiquette employed.

In Science. The early *general* studies of CMC seem to dwell on the negative aspects such as the lack of individuation and lack of social cues. The early studies of CMC *in science* conversely emphasized the ability to span time zones and the speed of communication when compared to print channels. Some articles suggested a lack of social cues would make the formation of new ties *more* likely due to lack of inhibition from status and familiarity cues and the ease of contacting large groups simultaneously (Carley & Wendt, 1991). Carley and Wendt (1991) studied whether e-mail replaced or enhanced other modes of communication in a large research group and found that it enhanced and was used more for secondary and coordination information than presenting new scientific ideas.

2.4.2.1 **Means of Expression**

Often mediated channels provide both linguistic and non-linguistic visual communication as the primary means of communication. Auditory communication is available in other CMC channels.

Videos are sometimes used for formal and informal science communication and teaching (Kousha, Thelwall, & Abdoli, 2012). The new trend of videos of experimental protocols and methods seeks to substitute for in-person demonstrations by adding visibility, audibility, and reviewability (Pasquali, 2007) but cannot provide manual dexterity or information from other senses such as feeling and smelling.

For text-based or visual online communication, the encoding is an important aspect of the channel. For example, an image of a chemical spectrum in a pdf is not machine-readable and does not facilitate re-analysis (Murray-Rust, 2008). In astronomy, including a VO table facilitates transferring the data to an analysis program (Ochsenbein et al., 2009).

2.4.2.2 **Conventions**

Early CMC researchers initially found that a lack of social cues caused communication partners to make assumptions based on perceived or attributed social identity (Sproull & Kiesler, 1986; Tanis & Postmes, 2003; Walther, 2011). Subsequent studies showed that users and groups of users quickly developed conventions and other ways to establish identity absent some face-to-face cues (Walther, 2011). Online community researchers studied impact of having avatars, using emoticons, and what fields were more useful in a profile; but in many cases experience with the channel made linguistic clues sufficient (Walther, 2011).

On social media platforms, conventions quickly form around the language to use, how to refer to objects and other people, and if and how to link (Schmidt, 2007). For example, in Twitter, user names are preceded with an @ symbol to refer to other

Twitter users unless the author is specifically trying to not bring attention to the other user (Tufekci, 2014).

2.4.3 Print Communication

For many years, print communication was primary in discussions of formal science communication and was important, too, for informal science communication. Journals were available only in print editions received in the mail, routed through labs, or on display or shelved in the library. Pre-prints and communications with authors requesting reviews, additional information, or to collaborate came through letters in the mail. Collaboration processes spanned geographical and time zone differences at the expense of elapsed time (Sproull & Kiesler, 1986).

2.4.3.1 **Means of Expression**

Print communication is visual and can be linguistic or not, often including text and images. Images may be actual photographs of experimental equipment or the field site, but also include the visualization of the results of analysis and similar.

2.4.3.2 **Conventions**

Conventions used in print communication are very dependent on the purpose, type or genre, and the register. There are standard conventions when writing a business letter such as adding the date, an inside address, greeting, and then finishing with a closing and signature. Likewise, research articles use formal language, often in third person.

2.5 Comparison to Other Models and Frameworks

Many early models of communication address only the channel and the transmission aspects of communication (Cobley & Schulz, 2013). For example, Shannon's (1948) model shows encoding, transmission, and decoding with feedback and noise in the channel. It does not describe any details about the participants in the communication and their characteristics that impact how they encode or decode the message or how they understand it or make use of it. It also does not address the purposes of the communication.

Since 1948, tens or even hundreds of communication theories have been introduced with varying success. The influence of psychology and constructivism has led to cognitive theories that address how participants co-construct and make meaning of communication activities. These theories address individual characteristics of the participants that were missing in earlier theories, but by doing so, they may omit detailed treatment of the channel.

More recently, Herring (2007) developed a faceted framework of CMC. This framework primarily addresses text communication through ICTs, emphasizing language and language use. Her framework has two major components: medium factors and situation factors (see summary in Table 5).

Table 5 Summary of Herring's Faceted Classification (2007)

Medium Factors	**Situation Factors**
M1 Synchronicity	S1 Participation factors
M2 Message transmission	S2 Participant characteristics
M3 Persistence	S3 Purpose
M4 Size of message buffer	S4 Topic or theme
M5 Channels of communication	S5 Tone
M6 Anonymous messaging	S6 Activity
M7 Private messaging	S7 Norms
M8 Filtering	S8 Code
M9 Quoting	
M10 Message format	

3. Literature-based Application of the Framework

This chapter applies the framework to example ICTs based on the literature. It includes discussion of

1. journals,
2. conferences,
3. e-mail discussion lists,
4. the two newer SCTs that will I studied empirically,
    5. blogs
    6. microblogs.

3.1 Scientific Journal Articles

The scientific journal has been around in some form since the seventeenth century (Zuckerman & Merton, 1971), but its importance grew dramatically throughout the 20th century (Price,1986). The journal article is considered the gold standard for reporting completed work (Latour & Woolgar, 1986). The journal article is typically produced at the completion of a project or of a substantial stage of a project and it reports new findings. The traditional format in most areas of science is as follows (Mullins, Snizek, & Oehler, 1988):

- Introduction and literature review. It presents the current work. Places the work in context of other articles, provides the appropriate background, and indicates what purpose the work is to serve; that is, to show that there is a need or a gap in the literature that this work will address (Swales, 2004). In some areas of computer science this comes later and is called “related work.”

- Research methods. This presentation is generally enough to allow the sophisticated reader to make judgments about the quality of the work and the appropriateness of the methods but not necessarily enough to reproduce each step in the process (Mullins et al., 1988; Shapin, 1995).
- Results. The results section presents selected and summarized data and the end product of the analyses. It likely contains graphs, tables, and other representations of the data as well as text. (Penrose & Katz, 1998)
- Discussion. The discussion reiterates the results and contrasts them with what was previously shown in the literature, emphasizing the contribution of the work. Larger theoretical implications and suggestions for follow-on studies are often included (Swales, 2004).

3.1.1 Communication Partners

Journal articles are typically written for other specialists in the field with the amount of specialization required varying from general for large general science journals (e.g., *Nature*, *Science*, *PNAS*) to very specialized for low circulation society journals (Mullins et al., 1988). The audience, therefore, varies from a large general scientific audience possibly in the millions to a small group of very specialized scientists in a particular research areas. The match between the author and the potential readers may be quite close and this is demonstrated in the amount of detail provided in the methods section and in the literature review where key studies are referenced but there is some obliteration by incorporation (McCain, 2011).

3.1.2 Purpose

The purposes of journal articles span the majority of those in the framework; however, some are explicit whereas others are implicit or almost side effects of the social nature of science. The primary purpose of the journal article is to disseminate and archive the results of scientific work and to make them available to members of the research community for others to build on and use. The collection of scientific articles that refer to each other with citations form a discourse on a topic (Nentwich, 2003).

As part of this dissemination process, journal articles preserve the results of the research work in a format that is archived and can be retrieved (Borgman, 2007). The inclusion of the article in a peer-reviewed journal with some reputation provides validation and certification of results.

Since articles are typically directed towards members of a research community, societal benefit is indirect. In the controversy surrounding the NIH policy requiring federally funded research to be archived in PubMed Central within 12 months of publication, the argument has been made that this access to scholarly journal articles is needed for societal benefit. For example, parents with sick children can read the scientific articles to better understand treatment options. This does happen, but it is not typical (Wynne, 1995).

The collection of journal articles written by a scientist over time forms part of her identity as a researcher and a member of the community. Rewards such as promotion and grants are often tied to the scientist's journal article publication record (Harley & Krzys Acord, 2011; Mulligan & Mabe, 2011).

Journal publication is also a way to validate and certify the work and to establish priority (Roosendaal & Geurts, 1997).Some articles provide tutorials, and many articles are assigned as class readings. Scientists read journal articles to update themselves on advances in their field.

Part of the discussion in a journal article is aimed at persuading the reader first that the research is both needed and important and then that the results have certain implications supported by a theory (Collins, 1985a). Latour and Woolgar (1986) describe the rhetorical methods scientists use to modify assertions they make in scientific articles.

3.1.3 Message Features

The research article is a genre of communication, but also has subordinate genres. The introduction, methods, results, and discussion sections each can be considered sub-genres with different treatments of the subject matter (Swales, 2004). The type of content can vary quite a bit, often including methodology, . analysis, theoretical, or evaluation. In some fields, data are provided in a supplement.

Persistence is a key part of journal publishing. Publishers agree to preserve the print and electronic formats indefinitely or contract with external vendors for a preservation service.

Scientific journals are generally peer-reviewed, but the rigor of the peer review varies widely. At minimum, the editorial staff reviews submissions. In many cases, after the editorial staff has reviewed the submission, it will be sent to three to five reviewers, and their input will be reviewed by an editor and edits will be requested before acceptance is granted.

3.1.4 Communication Channel

Whether printed or electronic, scientific journals are mediated by technology. They are not revisable and are not only asynchronous, but typically display a long lag between authoring and becoming accessible. They are assigned a publication date which establishes sequentiality. Table 6 summarizes how the framework describes journal communication in general. Some online journal platforms that host journals have incorporated hyperlinking, videos (as abstracts or as data), and interactive features such as graphs. In some cases journals are available on these full-featured platforms as well as on third-party aggregators that may include only the text or the text and some static pictures of the data tables and graphs.

Table 6 Framework applied to journal articles

1 Partners	*Number:* Many *Education/Sophistication:* Same; General Science *Match:* Same
2 Purpose	Dissemination (All); Certification; Preservation; Discourse; Identity; Rewards; Learning/Teaching; Persuasion
3 Message	*Topic:* Science content; Research Methods; Pedagogy *Type:* Data; Methods; Analysis; Results; Theoretical/philosophical *Register:* Formal *Structure:* Stable established internal structure *Persistence:* Archival *Review or Quality Control:* Yes – rigor varies
4 Channel	*Physical:* Print or Mediated Sequentiality; Reviewability; Coherence; Hyperlinking *Expression:* linguistic and non-linguistic; visual; *Conventions:* Attribution/citation; Omission of false starts and missteps; Passive voice…

3.2 Conferences

Conferences are traditionally the first way the results of new work are communicated outside of a research group (Garvey et al., 1970; Rowley-Jolivet, 2002). Journal articles are polished and sometimes simplified descriptions of completed work (Knorr & Knorr, 1978; Latour & Woolgar, 1986); communication within the lab is informal and contingent (Lynch, 1982). Conference presentations are somewhere in the middle; they are oral and provide more details of the work but are still practiced and somewhat formalized as compared to laboratory talk (Rowley-Jolivet, 2002). Conferences are constituted from several related genres or types of communication (Ventola, 2002). In addition to oral presentations, there are posters and proceedings papers. There are also informal conversations in the hallway and at social events.

The availability and formality of published proceedings vary by discipline. In computer and information science, the papers are peer-reviewed and archived. In geosciences, the abstracts are listed in a book or on a web page, but there often is no published paper. Peer review can be light or non-existent or can be similar to what is found in journals. Conferences can be small because they draw only from a regional area or narrow topic or can include tens of thousands of participants.

3.2.1 Communication Partners

Presentations. The sessions that include paper and panel presentations have an audience from ten to at most a few hundred scientists who are likely to be in the same research area as the presenter. Plenary sessions may draw large more general audience, particularly for large conferences who draw external speakers (Ventola, 2002).

Social Events. At conferences there are also many one-on-one conversations or few-to-few conversations at poster sessions, during breaks, and at receptions. In addition to other scientists in the field, these events may be sponsored by vendors or may include representatives of funders who are available for inquiry regarding the year's priorities and levels (Rowley-Jolivet, 1999).

Proceedings. Distribution of published proceedings may be large if they are contained in a larger society digital library. Actual readers and the interested audience is similar to journal articles for conferences with significant peer review.

3.2.2 Purpose

The primary purpose of presenting at a conference is disseminating early results of scientific work, but a main purpose of attending conferences is to learn and to keep up in the field and to communicate with like-minded researchers. Conferences are ideal places to discuss the research and to get immediate feedback or solutions to problems (Rowley-Jolivet, 2002). Presenting at conferences can be persuasive to gain allies in using a set of methods or theoretical framework among the *core set* of interested scientists (Collins, 1985b). Conference attendance is also social because it provides an opportunity to meet colleagues who work far away and to establish relationships that can grow into research collaborations (Rowley-Jolivet, 2002).

3.2.3 Message Features

Presentations. The type of content varies. The treatment may be analytical, theoretical, or procedural (Rowley-Jolivet, 2002). Conference presentations typically have the same internal structure as journal articles for the primary content (Ventola, 2002). The primary content is contextualized by introductions, thanks, and question and answer periods (Ventola, 2002). The register of conference presentations tends to be formal. Conference presentations provide more descriptions of false starts, missteps, and other problems than do journal articles (Rowley-Jolivet, 2002).

Social Events. Conversation at social events includes informal discussions of the scientific content of the conference, but also social topics catching up with personal events over the year. Representatives of vendors of laboratory supplies and equipment may be present to provide information and contact information. Likewise, funder representatives may be present to answer questions on research priorities and funding levels (Rowley-Jolivet, 1999).

Proceedings. Most communications at conferences are ephemeral and do not last beyond the meeting. The exception is in some fields like computer science, information science, and optics that publish proceedings that are archived and preserved. Likewise, quality control varies widely. In some fields like computer science and information science, the review process is similar to that of a journal whereas in other fields such as the geosciences, there is little or no peer review.

3.2.4 Communication Channel

Conference communication happens through at least three different channels: published proceedings (see Table 7), oral presentations (see Table 8), and informal hallway conversations (see Table 9).

Table 7 Framework applied to conferences (proceedings)

1 Partners	*Number:* Many *Education/Sophistication:* Same; General Science *Match:* Same
2 Purpose	Dissemination (All – societal benefit and rewards may be less than journal articles depending on the discipline); Learning/Teaching; Persuasion
3 Message	*Topic:* Science content; Science Education; Science Communication *Type:* Data; Methods; Analysis; Results; Theoretical/philosophical *Register:* Formal *Structure:* Typically as a journal article *Persistence:* varies by discipline and conference host *Review or Quality Control:* sometimes
4 Channel	*Physical:* Print or Mediated; Sequentiality; Reviewability; Coherence; Hyperlinking *Expression:* linguistic or non-linguistic; visual *Conventions:*

Table 8 Framework applied to conferences (presentations and panels)

1 Partners	*Number:* multiple but limited (~10-1000) *Education/Sophistication:* Same; General Science *Match:* Same
2 Purpose	Dissemination (Discourse; Identity); Learning/Teaching; Persuasion; Evaluation/Opinion; Coordination; Social
3 Message	*Topic:* Science content; Science Education; Science Communication *Type:* Data; Methods; Analysis; Results; Theoretical/philosophical *Register:* Less formal, but not completely informal *Structure:* Often a standard pattern *Persistence:* Ephemeral *Review or Quality Control:* Limited
4 Channel	*Physical:* Face-to-face; Co-presence; Visibility; Audibility; Cotemporality; Sequentiality; Coherence *Expression:* Linguistic or Non-linguistic; Audiovisual *Conventions:* Thanks; Introduction; Humor; More details

Table 9 Framework applied to conferences (informal conversations)

1 Partners	*Number:* Single to Few *Education/Sophistication:* Same; General Science *Match:* Same
2 Purpose	Dissemination (Discourse; Identity); Learning/Teaching; Persuasion; Social; Coordination
3 Message	*Topic:* Science content; Science Education; Science Communication Social; or any other *Type:* Data; Methods; Analysis; Results; Theoretical/philosophical *Register:* Informal *Structure:* None *Persistence:* Ephemeral *Review or Quality Control:* None
4 Channel	*Physical:* Face-to-face; Co-presence; Visibility; Audibility; Cotemporality; Simultaneity; Sequentiality; Coherence *Expression:* Linguistic or Non-linguistic; Audiovisual *Conventions:*

3.3 E-mail discussion lists (Listservs)

E-mail discussion lists date back at least to the mid-1980s, when email became prevalent in large companies and research institutions. Scientists have been using lists since the beginning (Rojo & Ragsdale, 1997). Walsh and Bayma (1996a), Talja, Savolainen, and Maula (2004), and Matzat (2004) found that discussion lists worked well to broadcast a request for a citation or information and receive numerous quick and helpful answers. Hine (2007) found that biological taxonomists and researchers in systematics used their mailing list for to discuss controversies as well as for job and other announcements. Talja et al. (2004) found that biologists and nursing science researchers had little patience with "conversing" on discussion lists—they viewed the list only as a place for the transmission of information, not as a place for social contact.

3.3.1 Communication Partners

List membership might be small if it is set up for a specific project, but typically list membership is hundreds to thousands of members. Many lists are set up for communication within a research area or among members with similar research interests or using the same tool, code, or instrument, so the education and sophistication of the communication partners is high and the match can be fairly close.

3.3.2 Purpose

E-mail lists may be used to disseminate preprints, as well as announcements of calls for papers or of upcoming conferences. For many mailing lists, discourse is the primary purpose. Contributing to lists and helping others may support identity formation and enhancement of reputation as found in studies of other professionals (e.g., Wasko & Faraj, 2005).

There are many examples of mailing lists being used to seek specific information and being used for learning or teaching. Heated discussions of controversies on mailing lists are intended to be persuasive, but might not convince any of the active or peripheral participants. Matzat (2004) found that mailing lists were useful for establishing social contacts among scholarly users.

3.3.3 Message

Any type of content may be shared such as announcements of the availability of new datasets (but probably not the datasets themselves), information or instruction on methods or algorithms, analysis, theoretical or philosophical discussions, and opinions. There is no structure within posts, but there might be threaded structure when the archive of posts is viewed as a whole. Typically there are mailing list archives that provide some persistence for the content. In a few cases there is some quality control such as a moderator or group of moderators evaluating all messages before they are distributed to the list.

3.3.4 Communication Channel

The mediated channel does not support simultaneous communication and may not even support cotemporality if members of the list are on digest mode or if moderator approval is required (Herring, 2002). Mailing lists do support sequentiality and reviewability.

Table 10 Framework Applied to E-mail Lists

1 Partners	*Number:* hundreds to thousands *Education/Sophistication:* Same *Match:* Same
2 Purpose	Dissemination (Discourse; Identity); Learning/Teaching; Persuasion; Social; Coordination
3 Message	*Topic:* Research Methods; Funding; *Type:* Data (announcements of); Methods; Analysis; Results; Theoretical/philosophical ; Questions and Answers *Register:* Less formal *Structure:* Threads and topic archives but not within messages *Persistence:* Archived *Review or Quality Control:* some lists may have moderators who take more active roles
4 Channel	*Physical:* Mediated; Sequentiality; Reviewability ;Coherence; Hyperlinking Expression; Visual; Linguistic *Conventions:* Quote original message;

3.4 Selected New ICTs that support communication in science

The past decade has brought the introduction, diffusion, and adoption of new SCTs in science. SCTs facilitate content creation and sharing on the web. Examples include social networking tools like Facebook and LinkedIn, social bookmarking tools like Delicious, blogging tools like WordPress, microblogging tools like Twitter, wiki tools like MediaWiki, question and answer sites like Stack Overflow, and social version control systems like Git/Git Hub. In addition to specialized tools, other Web-based or Web-connected ICTs have added social features such as commenting, tagging, voting, and re-sharing.Scientists have adopted these new tools for communicating in science (see summary in Table 11)

Mark Ware Consulting (2008) surveyed *authors, editors, and reviewers of scholarly journals* and found

- 13% read blogs regularly and 3% have a blog;
- 11% contribute to a work-related wiki;
- 7% use social bookmarking.
- Participation was higher among scientists under the age of 36 and among physical scientists and engineers.

A survey of about 1300 *academic researchers in the United Kingdom* (Proctor, Williams, & Stewart, 2010) found

- About 12% were frequent users of at least one of the Web 2.0 technologies. Almost half were occasional users.
- A combined 16% write a blog occasionally or frequently and 23% comment on blogs either occasionally or frequently.

Priem, Costello, and Dzuba (2011) searched *faculty listings at five universities* and searched for those scholars on Twitter.

- Only 2.5% were active on Twitter.
- On average the scholars tweeted five times per week and 30% of those tweets were scholarly.

In 2014, *Nature surveyed their authors and lists of researchers from Web of Science and Palgrave McMillan* (n=3,579) and found (Nature Publishing Group, 2014; Van Noorden, 2014).

- 13% of the STEM researchers visit Twitter regularly and another 72% are aware of Twitter but do not visit regularly.
- Of earth and environmental science researchers, 17% visit regularly and another 72% are aware of Twitter but do not visit regularly.

- Of the regular earth and environmental science Twitter users, the majority (78%) do at least occasionally post about their work

Pew Research Center and the American Association for the Advancement of Science (AAAS) conducted a study of *how American scientists communicate with the public*, n = 3,748 (Pew Research Center, 2015).

- Most scientists read journals and attend professional meetings to stay up to date, but many also use social media (all scientists % | geoscientists %)
- 47% reported using social media to discuss or follow science
- 24% have ever blogged about science and research.
- 32% | 38%belong to a listserv
- 19% | 23%, follow blogs,
- 12% | 12% follow experts on social media
- | 20% write blog posts about their research area.

Table 11 Summary of Scientists Use of Blogs and Twitter

Year	Media	Sample	Result	Reference
2008	Blogs	Authors, editors, reviewers of scholarly journals	3% have a blog 13% read blogs regularly	(Mark Ware Consulting, 2008)
2010	Blogs	British researchers	16% blog occasionally or frequently 23% comment on blogs occasionally or frequently	(Proctor et al., 2010)
2011	Twitter	American and British researchers listed on departmental pages	2.5% are active on Twitter	(Priem et al., 2011)
2014	Blogs Twitter	Nature, Palgrave McMillan authors, list from Web of Science	13% STEM researchers visit Twitter regularly 17% Earth and Environmental Science Researchers visit Twitter regularly	(Van Noorden, 2014)
2015	Blogs	American scientists	24% have blogged about science 19% follow blogs	(Pew Research Center, 2015)

The following sections provide an overview of the literature on two of the most widely adopted of the new social types of SCTs that are currently used in science and by scientists: blogs and microblogs.

3.5 Blogs

Although blogs have been around since the mid-1990s, they became widely used in science only after about 2004-2006. A blog is defined by its format:

collections of discrete or independent posts arranged in reverse-chronological order. Each post has a stable URL, can be assigned keywords or tags, and can be commented upon. A blog usually has one author but may have several. Individual blog posts almost always have a single author.

Early studies of blogs in general found that they were used as filters for news information, as personal journals, and as a communication tool within project teams (Herring, Scheidt, Bonus, & Wright, 2004). Individual blog posts, even within the same blog, vary dramatically in content, length, and structure from collections of links to long scholarly essays with subsections, diagrams, and references.

Pikas (2008b) found that scientists use their blogs to review papers, discuss their lives as scientists, provide basic overviews of science topics, discuss controversial topics, and post information about hobbies and other personal topics. More recent studies of blogs written by academics classify them as their own genre of academic writing that requires a different voice than other scholarly writing (Kirkup, 2010). In two small case studies, Puschmann (2014) found that one blogger used her blog to communicate with her peers on issues in her field using more technical language. Another blogger directed his communication more to the interested public covering a broader variety of issues and using less technical language.

In contrast to early expectations that the blogs would be used to disseminate scientists' own work, Shema and Bar-Ilan (2014) found most blog posts they studied critiqued peer-reviewed journal articles in health topics, discussing other scientists' work, not the author's, and were posted to further disseminate the work for societal benefit and applications.

3.5.1 Communication Partners

The definition of communication partners in science blogs is complicated in that the intended or imagined audience is often not the same as the audience observed through review of server logs or comments (boyd, 2006; Litt, 2012; Marwick & boyd, 2011). For example, Pikas (2008b) found that many of the scientists initially intended to communicate with the public, but more frequently communicated with graduate students in their field or with other scientists in adjacent fields, thus did not follow their own intent. Baumer, Sueyoshi, and Tomlinson (2008) found blog readers were thoughtful commenters and felt “a part” of the blog through interacting with it. They found that this type of interaction and community around the blog and the blogger’s awareness of it changed identity presentation and other communication features.

The potential number of communication partners can be the population of the Internet; the technology supports communication with many partners, at any level of education, and any match with the blogger. However, few science blogs have more than a few hundred readers. The blogger’s purpose might be to disseminate scientific information to a large, less educated public, but the actual reach of the blog might be to a select few colleagues who are highly educated. Nevertheless,.

3.5.2 Purpose

Scientists typically do not use blogs to disseminate unpublished research results, but they may link to published reports and they disseminate scientific information from their own knowledge, experience, or readings in science (Pikas, 2008b). Blogs are interactive and encourage commenting and discourse across blogs through links between post and automatic trackbacks (Pikas, 2008a). Bloggers may be rewarded through increased visibility. Blogs also serve as a public outreach mechanism for individual scientists, scientific societies, and scientific organizations such as research labs. Scientists learn through writing and also while teaching through posting (Fiedler, 2003; Paquet, 2002; Pikas, 2008b).

Posts about controversial issues in public policy and science such as climate change and vaccination are intended to persuade both policy makers and members of the public.

Bloggers both on networks and on independent sites describe feeling like they are part of a community (Pikas, 2008b). Social aspects are revealed through posts about the blogger's personal and professional life and the thoughtful comments on these posts. Scientists also report blogging to entertain, particularly when they post weird science posts or puzzles.

3.5.3 Message

There are blogs by scientists on just about every area of science. The content includes data very rarely but may include workflows, methods, or instructions, particularly in areas of science like bioinformatics where instructions for using statistical software and data sources are often shared on blogs.

Science bloggers often post evaluations of papers, books, or scientific discoveries on their blogs. ResearchBlogging.org is an aggregator of blog posts discussing peer-reviewed literature (Batts, Anthis, & Smith, 2008).

3.5.4 Communication Channel

The blog is a computer-mediated channel that exhibits the characteristics of sequentiality, reviewability, and revisability. Posts are time-and-date-stamped and are typically displayed in reverse chronological order. The owner of the blog can change the dates on posts, but typically the system date is maintained. Both the blogger and the commenter on blogs can review their posts, but typically only the blogger can edit comments. Many blogs contain images and some contain videos. See 3.5for a summary of how the framework applies to blogs as described in the literature.

Table 12 Framework applied to blogs based on the literature

1 Partners	*Number:* Many *Education/Sophistication:* Same; General Science; Interested Public *Match:* Either/Any
2 Purpose	Dissemination (Discourse; Societal benefit or application; Identity; Amplification); Learning/Teaching; Persuasion; Evaluation/Opinion; Social (All); Entertainment
3 Message	*Topic:* Science content; Science Education; Science Communication; Funding; Life in Science; Job Searching; News, Commentary, etc. *Type:* Methods; Analysis; Results; Memoir/Confessional/Biographical; Theoretical/Philosophical *Register:* Any *Structure:* HTML/CSS tags but no internal document structure *Persistence:* Typically persistent *Review or Quality Control:* Rarely for personal blogs
4 Channel	*Physical:* Mediated; Sequentiality; Reviewability; Revisability; Coherence; Hyperlinking *Expression:* Multimedia Convention: Linking to attribute sources

3.6 Microblogs (Twitter)

Microblogging, such as what is done on twitter.com, has not been around as long as blogging, but has developed some interesting uses in science, particularly when used in conjunction with scientific meetings. Users share information in posts limited to 140 characters. They follow other users, viewing their posts in a timeline view, and can mark posts as favorites, reply to them, or reshare them. Although the original design of the site indicated its use is to broadcast status updates ("What are you doing?"), even early studies found that uses included asking questions, getting information, and having conversations (Efron & Winget, 2010; Honeycutt & Herring, 2009; Johnson & Yang, 2009; Mischaud, 2007). So in some of the uses of microblogs are similar to some uses of email listservs.

Conventions have developed to include use of hashtags (#word) to assign subject tags or to include the post in a collection on a topic, the letters *RT* prior to repeating (or re-tweeting) someone's message, and the "at" symbol (@) with a user name to mention another user or send a public message to another user (Levy, 2009). The site has been updated to show conversations built through @ and RT messages. More recently *MT* has been used to indicate a modified re-tweet. Direct messages are generally sent between two users and are not available to other users.[1]

Many scientists maintain Twitter accounts and use them at meetings. Ebner and Reinhardt (2009) found these uses of Twitter at the conference they studied:

[1] Twitter announced group direct (private) messaging in April 2015.

- exchanging resources (hyperlinks, pictures, videos, ...),
- documenting conference activities (posters, slides, notes, ...),
- providing conference announcements,
- giving feedback or asking conference committees questions,
- arranging meetings,
- discussing with people who are participating only online,
- commenting on talks (paraphrased from pp. 6-7)

Scientists also use Twitter to comment on articles; post links to articles they come across in their work. (Priem and Costello,(2010)) . Scientists also discuss articles that have been mentioned in news or blogs. Other uses include building a social network, communicating about research projects, and sharing knowledge (Darling, Shiffman, Côté, & Drew, 2013; Puschmann, 2014). Pepe and Mayernik (2012) suggest microblogging can be modified to help gather and document context in field work data collection.

3.6.1 Communication Partners

With the exception of direct messages and locked accounts, Twitter postings are available for anyone to read. The actual number of readers depends on the number of followers (people who elect to have another user's tweets appear in their timeline) or the number of readers retrieving tweets with a given hashtag; typically there are hundreds to thousands. Honeycutt and Herring (2009) studied conversational exchanges on Twitter and found 2 - 10 participants over the course of an hour.

The readers can be at any level of education or sophistication and may or may not match the author in either education or ideology.

3.6.2 Purpose

Scientists use Twitter to have discussions with their colleagues, their librarians, writers, and friends online. They use it to bring attention to information posted elsewhere. Scientists tweet to share scientific content outside of the research specialty and to engage with the public as well as with other scientists. Keeping up with tweets is social and provides entertainment. See also the introduction to Section 3.6.

3.6.3 Message

Any topic is fair game for tweeting, but there is not enough room for in-depth philosophical discussions. Tweets often point to blog posts or articles where there is more room for nuanced arguments. Exceptions to this include Sean Carroll's explanation of aspects of quantum mechanics in groups of three tweets (for example:

> (1/3) Quantum mechanics says that what you can observe is much less than what really exists. E.g. we observe positions of particles. #qm http://twittercom/#!/seanmcarroll/status/76026233489592321,
>
> (2/3) But what really exists is the wave function: an amplitude for every possible particle position you could potentially observe. #qm http://twittercom/#!/seanmcarroll/status/76026601778839554,
>
> (3/3) The amplitude squared is the probability of observing an outcome. When you're not observing, all amplitudes actually exist. #qm http://twittercom/#!/seanmcarroll/status/76026799024373760),

and the effort to host journal clubs on Twitter (Grant, 2011). Tweets about journal articles and conferences often express opinions.

Communication on Twitter is not intended to be persistent. Tweets are notoriously ephemeral unless a third-party tool is used to extract and save them.

Although the site search has now been extended back to the beginning of the service, the API and other tools retrieve only the previous two weeks' posts.

3.6.4 Communication Channel

Twitter is a mediated channel that exhibits cotemporality, sequentiality, and reviewability. Coherence of conversations and exchanges is often lacking in Twitter; that is, tweets are addressed to individual or groups of communication partners, but other tweets are posted in between elements of the exchange and the thread can easily be lost in interleaved conversations (Honeycutt & Herring, 2009). Pictures and videos (or animated GIFs) are often attached to tweets. See Table 13 for a summary of how the framework is applied to microblogs as described in the literature.

Table 13 Framework applied to microblogs as described in the literature

1 Partners	*Number:* Many *Education/Sophistication:* Same; General Science; Interested Public; General Public *Match:* Either (in Education/Sophistication or Ideologically)
2 Purpose	Dissemination (Discourse; Societal benefit/Application; Identity); Learning/Teaching; Persuasion; Evaluation/Opinion; Coordination; Social (All); Entertainment
3 Message	*Topic:* Science content; Science Education; Science Communication; Life in Science; Job Hunting, News, etc. *Type:* Methods; Analysis; Results; Memoir/Confessional/Biographical; Theoretical/Philosophical; Questions and Answers *Register:* Typically informal, but not always *Structure:* Fields but no internal structure *Persistence:* Not guaranteed unless captured and saved elsewhere *Review or Quality Control:* No
4 Channel	*Physical:* Mediated; Cotemporality; Simultaneity; Sequentiality; Reviewability; Hyperlinking *Expression:* Multimedia *Conventions:* MT; RT; @; subtweet; .@; via or h/t

4. Methods

The framework laid out in Chapter 2 and applied in Chapter 3 emerged from broad reading in various related literatures, few of which specifically mention the impact of ICTs or the role of newer web-based tools in communication in science. Empirical work is required to assess, further explore, and expand or modify the framework, and to demonstrate its utility in describing the newer ICTs, especially SCTs. This dissertation aims to understand how geoscientists make meaning of the selected SCTs and how these tools fit into their scientific work. Multiple embedded case studies serve to better understand the communication features and functions; information and communication needs, uses and tools in science; and the interactions of these features, needs, and tools within these new SCTs. The case studies focused on blog and Twitter use in the geosciences with a view to considering the possibility of generalizing the insights gained to other sciences.

This section describes the overall research design, the cases, methods of data collection and analysis, ethical considerations, and methods that will be used to increase transferability, trustworthiness, and counter threats to validity

4.1 Research Design

The empirical part of this dissertation takes a pragmatic approach focusing on the problems and experiences of science communication and practical improvements that might be made (Creswell, 2002; Feilzer, 2010; Patton, 2002). The methods are selected to illuminate the research subject and to continue to build a real-world framework for describing communication in science. A pragmatic approach is not dogmatic in treating all knowledge as socially constructed or post-positivist in its treatment of representations of reality. Instead, it focuses on the utility of the outcomes of the research and selecting the best methods to answer the research questions (Feilzer, 2010). In a pragmatic approach, it is acceptable to treat knowledge as socially constructed while also looking for regularities across populations that can be used to make predictions or to inform system design.

The multiple (embedded) case study method (Yin, 2003) is used to analyze more than one unit of analysis (embedded) and in more than one case (multiple). That is, both the individual scientists and the technologies are focuses of analysis. The case studies were replicated for multiple scientists to better understand the variations in experiences, the complexities, and for greater transferability.

Embedded case studies of both technologies and their users; that is, online observed behavior and produced content as well as participants' experiences, is also called connective ethnography (Hine, 2007). Connective ethnography supports using multiple traces, online and offline, to view and make meaning of the communication using the framework. It focuses on the individual aspects as well as those held in common and facilitates a holistic view of online and offline communication (Hallett & Barber, 2014). As Hine (2007) states, "looking at the construction of boundaries and the ways in which different forms of communication are used to contextualize one another" (p. 619). The case studies combine analysis of online and offline communication to situate and contextualize the communication activities and the tool features and to emphasize the contiguity of online communication with work done offline (Beaulieu, 2010).

The study examines the content, structure, and interactions of messages; the expectations, perceptions, and reactions of contributors and participants; the interaction of the use of blogs and microblogs with other ways of doing scientific work; and the context of use and the distributed knowledge production (Beaulieu, 2010).

4.2 Selection and Background of Cases

The two macro cases (Patton, 2002) are blogging and microblogging (Twitter). Each case includes nested or embedded case studies of how individual scientists make sense of blogs and Twitter, respectively, and how Twitter is used at conferences.

4.2.1 Selection of Geosciences as the Study Context

Geosciences is a diverse discipline covering all aspects of the surface, interior, and atmosphere of the earth and other planets, and their interactions (Gould, Pearce, & Research Libraries Group. Program for Research Information Management, 1991). Subtopics include geology, geophysics, seismology, volcanology, paleontology, petroleum geology, oceanography, hydrology, atmospheric physics, meteorology, climatology, solar physics, and planetary science. This discipline was selected because many in it use the new SCTs (Jefferson, Hannula, Campbell, & Franks, 2010; Welland, 2010), the prominent professional societies in the discipline support the use of these tools, and the community welcomes discussion on the use of these tools.

4.2.1.1 **Scholarly communication in Geosciences**

Much of the library and information science literature describing scholarly communication and information retrieval in the geosciences refers primarily to geology. Geology information is complicated by the prominence and importance of gray literature; that is, reports, pamphlets, dissertations, unpublished conference or workshop proceedings, government documents, and other materials used to disseminate scientific information that is not available through formal channels and easily findable (Bichteler, 1991). Geological surveys from local, state, regional, and national organizations have been difficult to locate, and libraries that have tried to actively collect these resources have found it very difficult. In geology, in particular, older local works remain of interest as they are useful sources of maps and illustrations. Digitization efforts in local collections have made some of these resources available more broadly, but online collections are far from comprehensive.

In other areas of the geosciences, such as planetary science, scientists may use telescope data and data from robotic space missions such as the probes sent to Saturn and Mercury. These data are stored in large repositories maintained by the mission funder (primarily ESA or NASA) and are released in large collections for anyone to access. Journal articles, book chapters, and monographs are common ways to disseminate research results.

The importance of modeling and simulation in meteorology, climatology, atmospheric sciences, and other areas of geoscience has introduced some aspects of "computer culture" to the geosciences (Sundberg, 2010). For example, simulation software is now available off the shelf instead of being developed locally.

Generally, conferences are not considered archival in the geosciences. Submissions are lightly reviewed for relevance and to select the most interesting for panel presentations. The acceptance rate is near 100%. Some conferences such as the

AGU Fall Meeting do not require full papers and make only the submitted abstracts available in a bound volume of the member newsletter and online. Other conferences like IAU do require papers, but may or may not publish official proceedings. Information shared at conferences is then incorporated into journal articles.

4.2.1.2 **Tradition of Public Communication**

The geosciences have a tradition of communicating with the public. In geology, citizen scientists and amateur enthusiasts collect rocks, visit outcroppings, and use guidebooks prepared by local geologists to enjoy field trips. Some meteorologists working for the government, broadcast and print media channels, and often now private corporations communicate weather forecasts with additional science information regarding models and certainty.

Meteorologists, seismologists, and hydrologists communicate with the public to convey warnings of natural hazards such as hurricanes, tornados, earthquakes, and floods. These hazards can pose tremendous safety and economic risks, so a great deal of research has been done on how to best communicate hazardous conditions such that appropriate protective and preventive actions can be taken.

Conversely, some areas of geosciences with strong funding ties to the mining and petroleum industries have different expectations for public communication. Public communication is needed to gain government approval for and citizen acceptance of resource extraction methods and locations particularly in environmentally sensitive areas, but messages are more advertising than scientific.

While not emphasized in this research, the communication of climate change is a popular area of research in social studies of science and public communication of science (Moser, 2010). Complications in communicating climate change stem in part from the reliance on complex models, the political and economic opposition, the interdisciplinarity required, and the geographic and time scales of the issue (Nisbet, 2014).

4.2.1.3 **Broad Adoption of Social Media within Geosciences**

Many geoscientists use SCTs to communicate about their science (Jefferson et al., 2010; Welland, 2010). As described above in Section 3.4, geoscientists use SCTs more frequently than do scientists in general.

4.2.1.4 **Institutional Support for SCTs**

There is broad institutional support for public communication of results because of funder requirements and support from two leading professional societies. The American Geophysical Union (AGU), Geological Society of America (GSA), and European Geophysical Union (EGU), provide support for SCTs in the form of hosting blogs, providing communication venues to discuss the use of SCTs, and by using microblogging to support their communities.

Also, an advocacy and enthusiast group, the Planetary Society, hosts several blogs, has a podcast, has Twitter accounts, and participates on other SCTs. A staff geoscientist of the society attends and reports from many professional meetings and encourages geoscientists to cover meetings and to guest post on her blog.

NASA, the major funder of planetary science research as well as space-based Earth science research, is very supportive of the use of SCTs to communicate science. Many different offices and programs within NASA have Twitter accounts and blogs and the agency has hosted tweet-ups and other social media gatherings to encourage communication through these channels. NASA also provides some media passes to bloggers and tweeters to get special access at launches and press conferences.

4.3 Data Collection

Data for this study consists of interviews with geoscientists who blog and/or tweet and of tweets an blog posts. For each case study, the data collection consisted of

- selection of study participants and semi-structured interviews with participants (bloggers and microbloggers);
- selection of an appropriate sample of content (tweets, blog posts) and retrieval of the content, the interactions (comments or @ messages), the links;
- observation by the researcher who blogs and tweets in this community (notes, screenshots, and bookmarks) as appropriate (participant observation, (Yin, 2003).

4.3.1 Sample Selection

There are three samples in the study:

1) The sample of geoscientists who blog and/or tweet (the participants)
2) The sample of tweets
3) The sample of blog posts

The participants were selected purposively to maximize variation in their role in the community, level of participation, and type of participation (Maxwell, 2005; Patton, 2002).

In previous studies of SCTs, it has been difficult to draw a boundary around a community to study when relying on the poor recall provided by the sites' keyword searches of free text profiles and content to identify practicing scientists. Some geoscientists do not link to their professional identities in their profiles and many members of the interested public and citizen scientists also communicate geoscience topics in these SCTs. Keyword and profile searches return many marginally relevant users while missing potentially very informative participants who may be known to other geoscientists but do not identify with the selected keywords.

Selecting the three samples was an intertwined and somewhat iterative process. As a starting point to develop a sample of tweets and a pool of potential participants I used a very large international conference, the American Geophysical Union Fall Meetings 2010-2012. This conference is comprehensive of all areas of the geosciences and is very well attended; however, limiting to conference attendees may miss potential participants at small colleges and industrial settings that cannot afford to attend. As described in more detail in Section 4.3.2, I retrieved tweets using the conference hashtag to obtain tweet collection A. From that collection, I identified individual users (i.e., not organizational accounts) who used the hashtag frequently. From this, I purposefully selected seven who represented a diversity in research interest, age, and geography. I favored scientists who maintain blogs. At each interview, I asked the participant to suggest other geoscientists I should interview. This yielded one additional participant who tweets rarely and does not maintain a blog for a total of eight interview participants.

I then compiled tweet collection B consisting of tweets from the participants and a collection of blog posts from the participants' blogs.

For each of the tweet collections, I browsed the entire collection and created separate random samples as follows: using the rand() function in Excel, I assigned each item a number between 0 and 1, I copied the values only into a separate column, sorted on the random number, and selected the first 50. I coded the items in this collection using the codes discussed in Chapter 2. If a selected tweet seemed to be in the middle of a conversation, I reviewed adjacent tweets; if they provided additional information, I added them to the sample and coded them.

When interview participants or conference tweets introduced a new topic or good example of a phenomenon of interest, I searched and browsed the Twitter timeline to locate the original tweets, coded them, and added them to the collection. I also added tweets favorited in my participant observation.

Table 14 provides a count of content retrieved, stored in the analysis tool, and coded. Note that some individual tweets retrieved because they were referenced in the interview or in other tweets were not stored and counted but may be quoted in the dissertation.

Table 14 Data Summary

(+ indicates multiple tweet sources or multiple blogs)

Data	Tweeters	Tweets	Coded	%
Twitter #agu10, #agu2010	860	2981+129	262	8
Twitter #agu11, #agu2011	907	3603	203	6
Twitter #agu12, #aug2012	1276	6207	573	9

Data	Participants	Blog posts	Coded	%
Interviews	8		8	100
Participants’ blogs	4			
Participant AJ		184 +189	33	9
Participant BR		778	197	25
Participant CB		234 + 719	52	5
Participant CR		750 + 149	138	15
Guest posts	3	6	6	100

4.3.2 Content Retrieval

This section describes technique used to create a collection of local copies of blog posts and tweets for analysis. Upon retrieval, the local copies were imported into MaxQDA, a tool for computer-assisted qualitative data analysis.

4.3.2.1 **Blogs**

The blogs used either WordPress or Blogger software and had standard archive layouts. Each post has its own page, but for some blogs it was possible to get the full text of blog posts from archive pages that listed as many as ten individual posts. I used a combination of software tools to compile a collection of blog pages as follows:

1. Visited site to identify archive URL style (e.g., http://<theirurl>/page/2/), and to ascertain if the archive pages were sufficient or if all pages needed to be visited.
2. In Excel, created a list of archive page URLs by filling down from the pattern.
3. Using the R programming language, imported the list of URLs and used a script to retrieve the content from each page.

4. If the archive pages were not sufficient, I used an R script to retrieve them, and extract the individual post URLs. I then repeated the script to retrieve individual post files.
5. I used Beautiful Soup, a Python package for parsing HTML and XML documents, to parse each post (posts are HTML files) to retrieve the post's title, URL, date, author (for the blog with multiple authors), and text.
6. In Excel, added columns for group ID and a post title (without spaces) as needed for import into MaxQDA. I also made edits to repair encoding errors (e.g., I\u2019m was corrected to I'm).
7. Imported into MaxQDA with each post appearing as a document in the folder for the participant, with the parts of the post tagged.

R and Python scripts are archived at https://githubcom/cpikas/blogs-data .

4.3.2.2 Twitter

Dealing with Twitter entails considerable complexity, particularly since over the course of gathering data access to tweets changed. Specifically, the API changed so that third-party service had limited capability (1) to access older tweets and (2) to download and store any tweets.

In 2010, I captured the tweets using a service called TwapperKeeper (http://twapperkeepercom/index.html) that allowed me to archive all of the public tweets with the hashtag #agu10 and created a summary of number of posts, number of unique participants, top URLs shared, etc. Data for each tweet included

- Twitter client used,
- full date time stamp, and

- geocode.

For #AGU2010-tagged[2] and all 2011 and 2012 tweets, I copied the tweet text, time stamp, and user from the Twitter search results for the hashtags. I then used OpenRefine, a standalone open source desktop application for data cleanup and transformation to other formats, to create an Excel spreadsheet with the following columns:

- Name, the full name provided by the user in their profile
- User Name (account), User Name is the @handle used to refer to an account or a person
- Date, to the day (not hour, minute, seconds, as available through the API for recent tweets)
- Text,
- First @, the user names the tweet references
- Second @....
- Tenth @.

Up to ten referenced names were included but it is more typical to see one or two if it is a conversation among those parties. A long list might be used to share who is at a meet up or suggest readers follow new people.

For some years, the AGU published a summary article "meeting in numbers" in their member magazine *EOS*, or on their meetings website. The numbers of tweets

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[2] #agu10 were retrieved using TwapperKeeper. To be comprehensive, both #agu10 and #agu2010 were used as some participants did not follow instructions to use the official tag.

listed on their site is much larger than what can be retrieved through the Twitter website. For example, the Twitter website showed over 3,000 tweets for #AGU11 whereas the AGU reported over 8,000 tweets (http://fallmeetingagu.org/2012/general-information/2011-fall-meeting-highlights/).

Tweets that were looked up and retrieved in response to an interview comment or blog post were copied from the Twitter page in most cases. In some cases, the tweets appeared as embedded collections in blog posts so I saved them instead by printing the screen to PDF.

4.3.3 Interviews

The interviews were semi-structured, responsive interviews (H. J. Rubin & Rubin, 2005). This means that while there was an interview guide (see Appendix 1), the flow of the interview depended on the participant's responses, and I was able to follow up on interesting threads. Interviews were conducted by telephone and in-person in the Fall of 2013 and Spring of 2014 and lasted between 30 and 60 minutes. They were recorded and transcribed; I used hand written notes and memos to record observations and initial analysis. For one interview the recording had problems and not all data could be recovered.

4.3.4 Participant Observation

As a member of a science blogging collective, past regular attendee of a conference on social media in science attended by geoscientists, and a science librarian who works with planetary scientists, I am a participant, to some extent, in this community. As common sense and Hine (2000) suggest, I have been transparent on my blog and on Twitter about my research interests in addition to following the requirements of the Institutional Review Board. This participant role facilitates data collection through observation. Observation is particularly useful in online ethnography to understand how conversations develop instead of just reading completed transcripts (Garcia, Standlee, Bechkoff, & Yan Cui, 2009).

Participant observation, therefore, included following the blogs and relevant hashtags on Twitter and monitoring the addition of new information, the discussions that occurred, and the comments made by third parties. I used field notes, screen captures, and memos to document and explore the observations and to make them available for coding.

4.3.5 Summary of data collection methods

This section related the data collection methods to the specific questions and research questions they address. The table below has an additional column for summaries and memos. This column describes the writing practices that spanned data collection and analysis. Writing can be a “method of inquiry” (Richardson, 2003) and it was used to examine and explore the data and findings.

Table 15 Summary of Data Collection Methods and Specific Questions Addressed

Interviews	Content Analysis	Observation	Summaries and Memos
Who is the participant?			
How do they perceive the features of the SCT? How do they make choices regarding contribution of content?	What communication functions are observed? What styles of communication are used?	What features are supported? What implicit assumptions are coded into ICT design?	What features are available to these participants?
How does this SCT fit into other communication practices and doing science?	What work practices are mentioned?	What science is done in this SCT? What traces of scientific work are observed?	How does this site fit in to their work?
What information needs does this SCT fill?	What types of content are contributed and why?	What types of information can be found?	
Reported value of the SCT? Why do they participate?			What is the perceived value of this SCT to these participants?
How is site content used elsewhere?	What is said about the SCT elsewhere online? What interactions are there among the two SCTs?	What are the interactions among participants? What interactions are there among the two SCTs?	

4.4 Data Analysis

I used directed qualitative content analysis to assess which framework elements or communication functions are served by the SCT and to answer the research questions (Hsieh & Shannon, 2005; White & Marsh, 2006). Directed content analysis is appropriate when there is existing theory or prior research to, as Hsieh and Shannon say, “validate or extend conceptually a theoretical framework or theory” (2005, p. 1281). In this case, the existing framework is drawn from analysis of the literature and presented in Chapter 2. The framework as shown in Table 1 was used as the initial coding scheme. New codes were added to capture emergent themes.

Content includes themes, features, links, and exchanges (Herring, 2010). The primary unit of analysis is the entire blog post or tweet. All applicable purposes or types of data were coded. Interview passages from a few words to several sentences were coded. Many tweets were pointers to blog posts or other texts; such tweets were coded only for their own content, not for the content of the linked document. For example, a tweet is not peer-reviewed, the linked article is. In some cases, when multiple tweets formed a conversation, I coded all of the tweets individually but with the same tags so a search would retrieve them together. Some I copied into a memo for further annotation.

The blog and Twitter data retrieved as described in Section 4.3.2 were loaded into MaxQDA for management purposes and sampled as described in Section 4.3.1. The selected posts and tweets were coded using the framework elements developed through the literature review and described in Chapter 2. Code memos and memos on content were created within MaxQDA to improve the consistency of how codes were applied and to mark passages for review.

After each interview, I wrote a memo to serve as a contact summary sheet (Miles & Huberman, 1994), to summarize what was learned, and note changes to be made in future interviews. I then read the memos, transcripts, meeting tweets, and blog posts codes together to form a clearer picture of that participant's experience. I prepared individual case studies evaluating all of the evidence relating to one participant and providing a summary of how that ICT mediates scientific communication for this participant (example follows with remainder in Appendix 3).

Cross-case analysis serves to increase transferability of the findings from the study of the selected ICTs to other new ICTs (Miles & Huberman, 1994). Cross-case analysis served to highlight the differences between CMC supported by ICTs and face-to-face communication or communication through printed text as well as to learn of variations across multiple ICTs within CMC (Hine, 2000).

Cross-case analysis involved comparison and questioning of the experiences of individual participants as reported in the individual case studies to identify and define common themes. These were then compared to the categories that emerged from the literature to highlight differences and similarities.

4.5 Ethical Considerations

Participation in and research on the ICTs was done in a way consistent with the terms of use and the explicit and implicit norms of the site (Ess & AoIR ethics working committee, 2002) following a protocol approved by the IRB. Balancing participant privacy with providing evidence for assertions is complicated in research on ICTs. Contributions made online and captured in content analysis are difficult if not impossible to anonymize, particularly for other participants in the community, as they will be familiar with the words as well as the style of communication. I intended to follow the lead set by Efimova (2009) and treat contributions to open ICTs as public speech while protecting the privacy of interview participants; however, it became clear that individual case studies would be very useful in exploring the research questions, and these case studies would be very difficult to anonymize.

All participants in interviews were asked for permission to quote them and also to quote their contributions to the ICT as part of the informed consent process. Later, I re-contacted all participants and provided a very rough draft of their case study and requested permission to use their real name and write up the results this way. All approved this request. One provided a correction to the case study draft text.

Attributing the interview quotes to participants by their full name is very unusual in qualitative research for several reasons. Some participants may be less likely to participate at all or if they participate, they might be less likely to share sensitive or negative information. For some research topics, attributing quotes could lead to embarrassment or awkwardness at work or with friends. For this dissertation, respondents all used their real names instead of pseudonyms online. Further, their employers were all aware of their blogs and Twitter accounts.

For participants who were not interviewed (e.g., Twitter users who use a meeting hashtag), attribution of quotes from the ICT is unlikely to cause harm to the participants as the information has already been shared with an unknown audience.

As mentioned above, I have a Twitter profile that identifies me as a doctoral student. My professional blog is findable by searching for my name and it describes my research. Only Twitter content that is publicly accessible was used for the study.

The data will be maintained on multiple computers and on the web, in password protected locations. Offline information will be locked in file cabinets in the researcher's office. Interview participants signed informed consent forms prior to participating in the interview.

4.6 Validity

This section describes steps taken to ensure the trustworthiness of the results.

4.6.1 Prolonged engagement

I used prolonged engagement and persistent observation (Guba, 1981) through extended presence in the research milieu and continuing interaction with research participants. Typically this has been done in laboratory studies by going to the lab and observing and participating in laboratory life to understand the construction of new knowledge (Knorr-Cetina, 1995). In the cases here, I am specifically interested in knowledge production and sharing online, so the location is not a lab but an online space and the *field* of research is defined by co-presence, not co-location (Beaulieu, 2010; Garcia et al., 2009). I have been monitoring these sites for some time and have an ongoing relationship with some of the participants. I continued to monitor these sites throughout the analysis and writing periods. I kept a journal of observations to document and explore the interactions over the course of the study (Guba, 1981).

4.6.2 Triangulation

Triangulation occurs when "a variety of data sources, different investigators, different perspectives (theories), and different methods are pitted against one another in order to cross-check data and interpretations" (Guba, 1981). Multiple sources of evidence and triangulation (Yin, 2003) among the sources were used to verify and validate findings and to counter the weaknesses of any of the individual methods (Maxwell, 2005).

4.6.3 Addressing threats to validity occurring in online research

When the site of knowledge production is online and it is there that people communicate, participants actively think through their responses and share that reflexive process. In other words, participants in this study are likely to be thoughtful about their tool choice and are likely to share these thoughts in text on their blogs or in other social settings online. Participants tweeted about the interviews and their participation in them. This collection of time and location-distributed responses can form an extended group interview or focus group.

This approach – accepting online commentary about the interview process – is discouraged by Kazmer and Xie (2008) as an unfortunate occurrence that introduces additional bias because participants will know the research questions in advance and how others have responded to the questions. All of the participants and the researchers are biased and offer subjective answers to interview questions but the concern is that they do not represent their own subjectivities but those of the blog they read. For the purposes of this research, however, the social interaction of the ICT is central. We should expect interview participants know each other because the tools encourage communication and because of the selection process.

4.6.4 Addressing other threats to validity

Three remaining threats to validity are personal biases, biases related to using real names, and limitations due to only interviewing eight participants and coding a small percentage of conference tweets.

I am a blogger and have used Twitter for many years. I have spoken at conferences and written about the value of blogs for knowledge management and informal communication among scientists. This has the potential to blind me to negative or contrary evidence. What if blogs and Twitter are a waste of time when scientists could be writing for publication? To mitigate this, I wrote several memos examining my biases. I questioned my findings and looked for contrary evidence. I did not interview scientists who are opposed to the use of SCTs or who have tried them but found them not to be useful. In informal discussions with scientists who do not use SCTs, I found that they had not tried them and misunderstood how they worked or were unaware of their uses. Still, it is a limitation that their views are not incorporated.

Similarly, there are limitations to the transferability stemming from the low number of scientists I interviewed. I chose to interview fewer, but retrieve and code much more of their content. Another study might interview twenty scientists but only retrieve a year of content. I believe that the detailed examination of their work and their attitudes over time is more useful in answering the research questions.

4.7 Example Individual Case Study: Anne Jefferson (AJ)

The first version of each case study or case report was developed by grouping blog posts, tweets, and interview passages according to communication functions and content types that emerged from the data for this case (an individual scientist) in order to achieve a better understanding of how each individual on their own makes sense of these things and uses and values them. These original case studies preserve each scientist's own context and reflects their way of thinking. This step of data analysis was informed by the framework: The grouping of blog posts and tweets was aided by coding using the framework but many of the functions that emerged were at a finer level of detail. Analyzing the functions across the seven cases yielded a common schema that served to produce a second version of each case study organized using this common schema. The reorganized case studies are summarized in Table 17.

After a general introduction, this section presents first the original case study and then the reorganized case study.

General introduction

AJ is a tenure track hydrologist at a large Midwestern university. She studies groundwater-surface water interactions, geomorphology, and impacts of climate change. She is a prominent blogger and an early adopter of Twitter. She describes the benefits she receives from using SCTs in a 2012 blog post:

- A collegial atmosphere with more diverse scientists and interested citizens than I see in real life
- Knowledge of a wider breadth of current events in science than I would get from reading journals
- Practice writing for a variety of audiences (blogging has undoubtedly made me a better writer)
- Spill-over knowledge into my teaching
- More visibility than your average assistant professor (media interviews, book reviews, attention from my scientific societies)
- Quick answers to questions either scientific or pedagogical ("crowd-sourcing") (http://all-geo.org/jefferson/how-i-use-new-media/ retrieved 11/1/2014)

Beyond these she has listed, she mentioned new collaborations and new students as benefits of her use of SCTs, especially her blogs.

4.7.1 AJ original case study

4.7.1.1 Blogging

AJ has been blogging at *Highly Allochthonous* as a regular contributor (co-blogger) since 2009. *Highly Allochthonous* was original set-up by Chris Rowan (CR) who also continues to blog there (see Appendix 3.6). Before 2009, she guest blogged from time to time. She considers this to be her primary blog but she has also maintained a lab blog since May 2008. AJ often blogs about her science, using her technical background to explain flooding events that are in the news and translating new research for more popular interest.

*4.7.1.1.1 Blog Functional Categories. Primary Blog (*Highly Allochthonous)

Public Communication

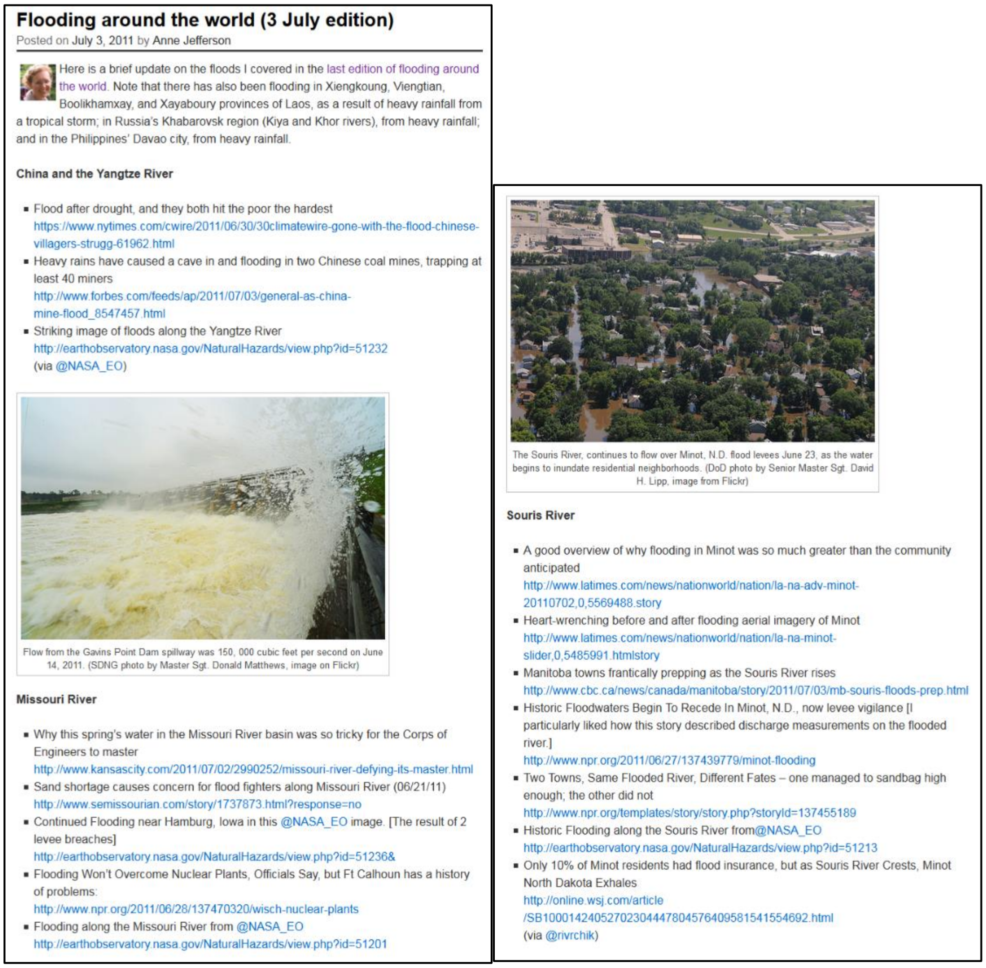
Many posts on her primary blog are geared toward communicating science to the interested public. Theses posts come in several different types.

Science Basic Concepts

In these posts, AJ writes about and explains a scientific concept for the general reader. Some of these posts cite scientific articles. Some have pictures and diagrams. For example, in her post *When a tree falls in a stream, there's always something around to make use of it* (http://all-geo.org/highlyallochthonous/2011/06/when-a-tree-falls-in-a-stream-theres-always-something-around-to-make-use-of-it, retrieved 7/4/2014), she defines and describes what allochthonous means in hydrology.

Discussion of current news related to hydrology

AJ uses her understanding of the highly technical aspects of hydrology to explain hazards and causes from large storms, spills, and flood. Posts in this category include a series inventorying current flooding events around the world with maps and some analysis on economic and humanitarian impacts (see example in Figure 4). Other examples are her posts describing why slow moving hurricanes are more dangerous because of the flooding and how a 2014 West Virginia chemical spill ended up impacting a stream and the local water supply.



Flooding around the world (3 July edition)
Posted on July 3, 2011 by Anne Jefferson

Here is a brief update on the floods I covered in the last edition of flooding around the world. Note that there has also been flooding in Xiengkoung, Viengtian, Boolikhamxay, and Xayaboury provinces of Laos, as a result of heavy rainfall from a tropical storm; in Russia's Khabarovsk region (Kiya and Khor rivers), from heavy rainfall; and in the Philippines' Davao city, from heavy rainfall.

China and the Yangtze River

- Flood after drought, and they both hit the poor the hardest https://www.nytimes.com/cwire/2011/06/30/30climatewire-gone-with-the-flood-chinese-villagers-strugg-61962.html
- Heavy rains have caused a cave in and flooding in two Chinese coal mines, trapping at least 40 miners http://www.forbes.com/feeds/ap/2011/07/03/general-as-china-mine-flood_8547457.html
- Striking image of floods along the Yangtze River http://earthobservatory.nasa.gov/NaturalHazards/view.php?id=51232 (via @NASA_EO)

Flow from the Gavins Point Dam spillway was 150, 000 cubic feet per second on June 14, 2011. (SDNG photo by Master Sgt. Donald Matthews, image on Flickr)

Missouri River

- Why this spring's water in the Missouri River basin was so tricky for the Corps of Engineers to master http://www.kansascity.com/2011/07/02/2990252/missouri-river-defying-its-master.html
- Sand shortage causes concern for flood fighters along Missouri River (06/21/11) http://www.semissourian.com/story/1737873.html?response=no
- Continued Flooding near Hamburg, Iowa in this @NASA_EO image. [The result of 2 levee breaches] http://earthobservatory.nasa.gov/NaturalHazards/view.php?id=51236&
- Flooding Won't Overcome Nuclear Plants, Officials Say, but Ft Calhoun has a history of problems: http://www.npr.org/2011/06/28/137470320/wisch-nuclear-plants
- Flooding along the Missouri River from @NASA_EO http://earthobservatory.nasa.gov/NaturalHazards/view.php?id=51201

The Souris River, continues to flow over Minot, N.D. flood levees June 23, as the water begins to inundate residential neighborhoods. (DoD photo by Senior Master Sgt. David H. Lipp, image from Flickr)

Souris River

- A good overview of why flooding in Minot was so much greater than the community anticipated http://www.latimes.com/news/nationworld/nation/la-na-adv-minot-20110702,0,5569488.story
- Heart-wrenching before and after flooding aerial imagery of Minot http://www.latimes.com/news/nationworld/nation/la-na-minot-slider,0,5485991.htmlstory
- Manitoba towns frantically prepping as the Souris River rises http://www.cbc.ca/news/canada/manitoba/story/2011/07/03/mb-souris-floods-prep.html
- Historic Floodwaters Begin To Recede In Minot, N.D., now levee vigilance [I particularly liked how this story described discharge measurements on the flooded river.] http://www.npr.org/2011/06/27/137439779/minot-flooding
- Two Towns, Same Flooded River, Different Fates – one managed to sandbag high enough; the other did not http://www.npr.org/templates/story/story.php?storyId=137455189
- Historic Flooding along the Souris River from@NASA_EO http://earthobservatory.nasa.gov/NaturalHazards/view.php?id=51213
- Only 10% of Minot residents had flood insurance, but as Souris River Crests, Minot North Dakota Exhales http://online.wsj.com/article/SB10001424052702304447804576409581541554692.html (via @rivrchik)

Figure 2 Example of Flooding Around the World series
(http://all-geo.org/highlyallochthonous/2011/07/flooding-around-the-world-4/ retrieved 7/14/2014)

Historical Essays

These posts are thoughtful essays that review science and also the impact of various phenomena on society. For example, in “Where rocks, water, and history intertwine” (http://all-geo.org/highlyallochthonous/2009/06/where-rocks-water-and-history-intertwine/ retrieved 11/2/2014) she discusses a rock outcropping that had been used as a ford across the Catawba river and a canal built in the early 1800s that lets boats bypass the rocky area. The post includes images.

1 Participants: Audience	Number: Many Education/Sophistication: Interested public; General Science; Students Match: Not matching
2 Purpose	Dissemination (Societal Benefit); Learning/Teaching
3 Message	Topic: Hydrology; Geomorphology Type (Medium): Text; Images; Video; Type (Genre): Results; Theoretical/philosophical

Doing Science

The next most frequent category of posts on AJ's primary blog includes posts on doing science and scientific work. These include posts on conferences, setting up her lab, field work and field equipment, diversity in science, and science communication. She mentors young students and also values communicating with the public. She shares details about moving to a new university and starting up a lab complete with pictures and descriptions of the lab equipment. In older posts, she often covered her field work and necessary equipment and methods for studying streams, for example.

Bibliography or Collections of Articles

From time to time, AJ posts an annotated list of journal articles she is reading for her work. The annotations include summaries and put the article in context of her research interests and research results.

1 Participants: Audience	Number: Many Education/Sophistication: Same; Match: Same;
2 Purpose	Dissemination (Discourse; Identity; Amplification); Personal Knowledge Management; Filter; Opinion/Evaluation
3 Message	Topic: Hydrology; Analysis Methods Type (Medium): Text Type (Genre): Bibliography/Collection; Pointer

Science communication

These posts discuss both communication by scientists (particularly in social media) and communication by journalists and professional science communicators.

Conference reports

Her conference reports tend to be of two different types. In some more recent posts she and her co-blogger post together brief reviews and snippets. Earlier reports were extended essays expanding on the technical information she presented at the conference (see: http://all-geo.org/highlyallochthonous/2010/11/what-do-you-mean-by-hydrogeomorphic-processes-some-thoughts-following-my-gsa-session-on-the-topic/ retrieved 7/4/2014)

1 Participants: Audience	Number: Many Education/Sophistication: Same or Similar; Students; Match: Matching
2 Purpose	Dissemination (Societal Benefit); Learning/Teaching; Social (Group)
3 Message	Topic: Geosciences; Academic Work; Scholarly Communication; Type (Medium): Text; Images; Type (Genre): Biographical; Observations; Analysis; Results; Theoretical/Philosophical

Social - Geoscience Community Building

AJ links to other geoscience blogs and with her co-blogger, helps support new geoscientist bloggers by hosting their posts. She also often participates in memes and did participate in the *Accretionary Wedge* blog carnival when it was active.

1 Participants: Audience	Number: Many Education/Sophistication: Same, Other Geoscientists Match: Same
2 Purpose	Social(Identity; Group membership)
3 Message	Topic: Geosciences; Fieldwork; Scientist Careers Type (Medium): Text; Images Type (Genre): Pointer; News/announcement

Advice to new scientists or students or teachers (Teaching and Mentoring)

These posts provide advice on how to teach and how to study hydrology. One example is *Show me the data!* (http://all-geo.org/highlyallochthonous/2011/10/show-me-the-data/ retrieved 7/4/2014). This post urges students to bring data to advisors early and often. A second example describes to teachers how they can use rock cubes in a lab to learn about hydrogeology (http://all-geo.org/highlyallochthonous/2010/10/using-rock-cubes-to-learn-about-hydrogeology/ retrieved 7/4/2014).

1 Participants: Audience	Number: Many Education/Sophistication: Students; Same Match: Either
2 Purpose	Learning/Teaching
3 Message	Topic: Hydrology; Geomorphology; Study Skills; Teaching Geosciences Type (Medium): Text; Images; Type (Genre): Theoretical/philosophical; Observation; Pointer; Biographical

Images (Entertainment)

In addition to using images to illustrate and explain on historical and basic concepts posts, AJ posts images from her fieldwork and from vacations and trips she has taken. Her posts in this category are rarely annotated or serving didactic purpose.

1 Participants: Audience	Number: Many Education/Sophistication: General
2 Purpose	Entertainment; Social(Identity)
3 Message	Topic: Nature; Travel Type (Medium): Image Type (Genre): Observation; Data(Image)

4.7.1.1.2 Functional Categories in her Lab and Teaching Blog

AJ originally started her lab blog as a place to gather media and news to illustrate points for her lectures. She also used it as a more dynamic part of her lab web site to discuss lab activities, awards, and publications. She has gotten feedback from other hydrologists that the blog has been a useful resource for them in finding media for their courses. Additionally, the blog has served as a recruiting tool for new graduate students.

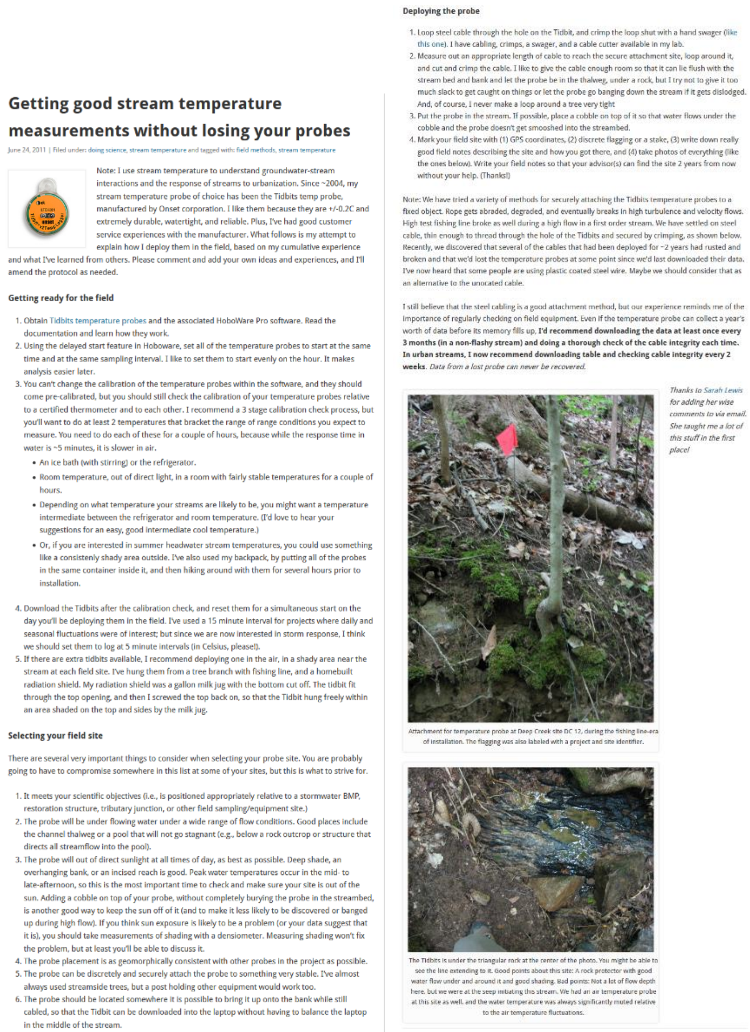
Filter (Pointer to Educational Materials)

Filters the literature, creating bibliographies of interesting articles for use in her classes. Points to videos, news stories, events that provide useful teaching cases for her classes.

1 Participants: Audience	Number: Many Education/Sophistication: Students; Same
Purpose	Filter; Learning/Teaching; Preservation; Evaluation/Opinion; Personal knowledge management
Message	Type (Genre): Pointer; Bibliography/collection

How to Take Measurements (Doing Science)

Several posts are tutorials on research methods and equipment in hydrology. Shows a detailed post on selection, setup, and installation of stream temperature modelling equipment.



Getting good stream temperature measurements without losing your probes

June 24, 2011 | Filed under: doing science, stream temperature and tagged with: field methods, stream temperature

Note: I use stream temperature to understand groundwater-stream interactions and the response of streams to urbanization. Since ~2004, my stream temperature probe of choice has been the Tidbits temp probe, manufactured by Onset corporation. I like them because they are +/-0.2C and extremely durable, watertight, and reliable. Plus, I've had good customer service experiences with the manufacturer. What follows is my attempt to explain how I deploy them in the field, based on my cumulative experience and what I've learned from others. Please comment and add your own ideas and experiences, and I'll amend the protocol as needed.

Getting ready for the field

1. Obtain Tidbits temperature probes and the associated HoboWare Pro software. Read the documentation and learn how they work.
2. Using the delayed start feature in Hoboware, set all of the temperature probes to start at the same time and at the same sampling interval. I like to set them to start evenly on the hour. It makes analysis easier later.
3. You can't change the calibration of the temperature probes within the software, and they should come pre-calibrated, but you should still check the calibration of your temperature probes relative to a certified thermometer and to each other. I recommend a 3 stage calibration check process, but you'll want to do at least 2 temperatures that bracket the range of range conditions you expect to measure. You need to do each of these for a couple of hours, because while the response time in water is ~5 minutes, it is slower in air.
   - An ice bath (with stirring) or the refrigerator.
   - Room temperature, out of direct light, in a room with fairly stable temperatures for a couple of hours.
   - Depending on what temperature your streams are likely to be, you might want a temperature intermediate between the refrigerator and room temperature. (I'd love to hear your suggestions for an easy, good intermediate cool temperature.)
   - Or, if you are interested in summer headwater stream temperatures, you could use something like a consistenly shady area outside. I've also used my backpack, by putting all of the probes in the same container inside it, and then hiking around with them for several hours prior to installation.
4. Download the Tidbits after the calibration check, and reset them for a simultaneous start on the day you'll be deploying them in the field. I've used a 15 minute interval for projects where daily and seasonal fluctuations were of interest; but since we are now interested in storm response, I think we should set them to log at 5 minute intervals (in Celsius, please!).
5. If there are extra tidbits available, I recommend deploying one in the air, in a shady area near the stream at each field site. I've hung them from a tree branch with fishing line, and a homebuilt radiation shield. My radiation shield was a gallon milk jug with the bottom cut off. The tidbit fit through the top opening, and then I screwed the top back on, so that the Tidbit hung freely within an area shaded on the top and sides by the milk jug.

Selecting your field site

There are several very important things to consider when selecting your probe site. You are probably going to have to compromise somewhere in this list at some of your sites, but this is what to strive for.

1. It meets your scientific objectives (i.e., is positioned appropriately relative to a stormwater BMP, restoration structure, tributary junction, or other field sampling/equipment site.)
2. The probe will be under flowing water under a wide range of flow conditions. Good places include the channel thalweg or a pool that will not go stagnant (e.g., below a rock outcrop or structure that directs all streamflow into the pool).
3. The probe will out of direct sunlight at all times of day, as best as possible. Deep shade, an overhanging bank, or an incised reach is good. Peak water temperatures occur in the mid- to late-afternoon, so this is the most important time to check and make sure your site is out of the sun. Adding a cobble on top of your probe, without completely burying the probe in the streambed, is another good way to keep the sun off of it (and to make it less likely to be discovered or banged up during high flow). If you think sun exposure is likely to be a problem (or your data suggest that it is), you should take measurements of shading with a densiometer. Measuring shading won't fix the problem, but at least you'll be able to discuss it.
4. The probe placement is as geomorphically consistent with other probes in the project as possible.
5. The probe can be discretely and securely attach the probe to something very stable. I've almost always used streamside trees, but a post holding other equipment would work too.
6. The probe should be located somewhere it is possible to bring it up onto the bank while still cabled, so that the Tidbit can be downloaded into the laptop without having to balance the laptop in the middle of the stream.

Deploying the probe

1. Loop steel cable through the hole on the Tidbit, and crimp the loop shut with a hand swager (like this one). I have cabling, crimps, a swager, and a cable cutter available in my lab.
2. Measure out an appropriate length of cable to reach the secure attachment site, loop around it, and cut and crimp the cable. I like to give the cable enough room so that it can lie flush with the stream bed and bank and let the probe be in the thalweg, under a rock, but I try not to give it too much slack to get caught on things or let the probe go banging down the stream if it gets dislodged. And, of course, I never make a loop around a tree very tight
3. Put the probe in the stream. If possible, place a cobble on top of it so that water flows under the cobble and the probe doesn't get smooshed into the streambed.
4. Mark your field site with (1) GPS coordinates, (2) discrete flagging or a stake, (3) write down really good field notes describing the site and how you got there, and (4) take photos of everything (like the ones below). Write your field notes so that your advisor(s) can find the site 2 years from now without your help. (Thanks!)

Note: We have tried a variety of methods for securely attaching the Tidbits temperature probes to a fixed object. Rope gets abraded, degraded, and eventually breaks in high turbulence and velocity flows. High test fishing line broke as well during a high flow in a first order stream. We have settled on steel cable, thin enough to thread through the hole of the Tidbits and secured by crimping, as shown below. Recently, we discovered that several of the cables that had been deployed for ~2 years had rusted and broken and that we'd lost the temperature probes at some point since we'd last downloaded their data. I've now heard that some people are using plastic coated steel wire. Maybe we should consider that as an alternative to the unocated cable.

I still believe that the steel cabling is a good attachment method, but our experience reminds me of the importance of regularly checking on field equipment. Even if the temperature probe can collect a year's worth of data before its memory fills up, **I'd recommend downloading the data at least once every 3 months (in a non-flashy stream) and doing a thorough check of the cable integrity each time. In urban streams, I now recommend downloading table and checking cable integrity every 2 weeks**. *Data from a lost probe can never be recovered.*

Thanks to Sarah Lewis for adding her wise comments to via email. She taught me a lot of this stuff in the first place!

Attachment for temperature probe at Deep Creek site DC 12, during the fishing line-era of installation. The flagging was also labeled with a project and site identifier.

The Tidbits is under the triangular rock at the center of the photo. You might be able to see the line extending to it. Good points about this site: A rock protector with good water flow under and around it and good shading. Bad points: Not a lot of flow depth here, but we were at the seep initiating this stream. We had an air temperature probe at this site as well, and the water temperature was always significantly muted relative to the air temperature fluctuations.

Figure 3 Example Scientific Method Tutorial Post
(http://all-geo.org/jefferson/getting-good-stream-temperature-measurements-without-losing-your-probes/ retrieved 4/22/2015)

1 Participants: Audience	Students; Same
2 Purpose	Dissemination(Identity); Coordination
3 Message	Type: Pointer; Observation; Data; Methods; Results

News/Announcements

These posts are lightly annotated announcements of news related to lab members and lab activities:

- Abstracts and papers that have been accepted for publication
- Professional events for lab members (defenses, jobs, etc).
- Open positions/recruits new students

1 Participants: Audience	Number: Many Education/Sophistication: Students; Same
2 Purpose	Dissemination(Amplify; Identity)
3 Message	Topic: Lab management; Scholarly Communication; Employment Type (Medium): Text Type (Genre): Results; News/announcement; Pointer

4.7.1.2 **Tweeting**

AJ does not tweet too much from conferences because she is too busy going to meetings, catching up with colleagues, and mentoring students. She also reports that she doesn't want to have her head down to her phone instead of paying attention and it's too difficult to translate talks to 140 characters. She may tweet local events where no one else is tweeting.

There were 14 conference tweets 14 from 2012 even though she didn't attend. There were 40 conference tweets in the set all together but most are about meeting submission deadlines, returning from the conference, and pointing to blog post conference reports. Some of these tweets were announcing blog posts from her co-blogger (there is a script to automatically announce any new posts, not just her own).

Examples:

```
I now *have* all the data for my #AGU10 talk. Now I just need to
analyze it make it pretty and turn it into my talk. Still
progress. #fb
```

`Back from #AGU11, today = #gradingjail. The end of the semester cometh, whether I am ready or not.`

4.7.2 AJ reorganized case study

4.7.2.1 **Blogging**

AJ has been blogging at *Highly Allochthonous* as a regular contributor (co-blogger) since 2009. *Highly Allochthonous* was originally set-up by Chris Rowan (CR) who also continues to blog there (see Section A3.6). Before 2009, she guest blogged from time to time. She considers this to be her primary blog but she has also maintained a lab blog since May 2008. AJ originally started her lab blog as a place to gather media and news to illustrate points for her lectures. She also used it as a more dynamic part of her lab web site to discuss lab activities, awards, and publications. She has gotten feedback from other hydrologists that the blog has been a useful resource for them in finding media for their courses. Additionally, the blog has served as a recruiting tool for new graduate students.

AJ often blogs about her science, using her technical background to explain flooding events that are in the news and translating new research for more popular interest.

An analysis of AJ's blog posts showed the following content categories and communication purposes, organized using the unified schema of content types and communication functions.

1 Science (for scientists)	
1.1 Pointing to readings	From time to time, AJ posts an annotated list of journal articles she is reading for her work. The annotations include summaries and put the article in context of her research interests and research results. Some of these posts fall into the “Anne’s Picks of the [month] Literature” series. For example, in one post she reviewed a few articles on “humans as agents of hydrologic change” (http://all-geo.org/highlyallochthonous/2010/07/annes-picks-of-the-june-literature-humans-as-agents-of-hydrologic-change/) At times, AJ has posted a weekly round-up of her tweets.
1.2 Discussing scientific topics	Most of the discussion in recent years happens on Twitter instead of her blog, but on some posts there is a lot of back and forth discussion in the comments.
1.3 Tutorials for peers	Several posts are tutorials on research methods and equipment in hydrology. Figure 3 shows a detailed post on selection, setup, and installation of stream temperature modelling equipment.
2 Doing Science	The next most frequent category of posts on AJ’s primary blog includes posts on doing science and scientific work. These include posts on conferences, setting up her lab, field work and field equipment, diversity in science, and scholarly science communication. She mentors young students and also values communicating with the public. She shares details about moving to a new university and starting up a lab complete with pictures and descriptions of the lab equipment. In older posts, she often covered her field work and necessary equipment and methods for studying streams, for example.
2.1 Reporting from field work	Field work is discussed frequently; however, most of the posts are retrospective, describing methods and measurements as well as showing pictures of the sites. Data are not shared.
2.2 Reporting lab work	Not observed

2.3 Analyzing	Not observed
2.4 Requesting assistance	Not observed
2.5 Building science community	AJ links to other geoscience blogs and, with her co-blogger, helps support new geoscientist bloggers by hosting their posts. She also often participates in memes and did participate in the *Accretionary Wedge* blog carnival when it was active.(A meme is a topic or question on which many people create post in the same time frame; it may have been started by someone who encouraged others to participate. A blog carnival is a collection of posts written in response to a request from the carnival leader who then curates and annotates the posts and creates a summary.) In addition to these, she often posts about women and underrepresented minorities in the profession. She summarizes and provides opinion on news regarding unfair treatment.

3 Conference-specific

3.1 Covering a session live	Not observed
3.2 Color commentary	Not observed
3.3 From away from the conference	Not observed
3.4 Summarizing a conference	Her conference reports tend to be of two different types. In some more recent posts she and her co-blogger post together brief reviews and snippets. Earlier reports were extended essays expanding on the technical information she presented at the conference (see: http://all-geo.org/highlyallochthonous/2010/11/what-do-you-mean-by-hydrogeomorphic-processes-some-thoughts-following-my-gsa-session-on-the-topic/ retrieved 7/4/2014)

4 Science News/ Announcements	These posts are lightly annotated announcements of news related to lab members and lab activities.
4.1 Announcing job openings	Lists professor, graduate student, and undergraduate student positions available.
4.2 Announcing defenses, graduations	Includes various announcements of events and jobs received by lab members.
4.3 Announcing papers published	Includes abstracts and papers that have been accepted for publication.
5 Teaching (being a teacher)	
5.1 Providing advice for students	These posts provide advice on how to teach and how to study hydrology. One example is Show me the data! (http://all-geo.org/highlyallochthonous/2011/10/show-me-the-data/ retrieved 7/4/2014). This post urges students to bring data to advisors early and often.
5.2 Recruiting students	In the interview, AJ mentioned that having a blog has been useful in attracting new students as it makes the research available and shows the kind of research being done by the lab.
5.3 Pointing to educational resources	On the lab blog she filters the literature, creating bibliographies of interesting articles for use in her classes. She points to videos, news stories, events that provide useful teaching cases.
5.4 Explaining how to teach	She describes to teachers how they can use rock cubes in a lab to learn about hydrogeology (http://all-geo.org/highlyallochthonous/2010/10/using-rock-cubes-to-learn-about-hydrogeology/ retrieved 7/4/2014).
6 Social/ coordinating	

6.1 Biographical/ confessional

AJ's posts in this category have been about her job moves. She does share some limited information about her children.

6.2 Coordinating

These posts just mention upcoming conferences and world travel.

7 Public communication of science

7.1 Explain a science concept

In these posts, AJ provides a small lecture on a topic within hydrology. The posts are often illustrated with pictures and videos and may include links for additional information. For example, in the post "Combined sewer overflows: Solving a 19th century problem in the 21st century" she describes different ways to handle storm water overflows in big cities with combined sanitary sewer and storm drains:

> Combined sewers are pipes that catch both sewage and storm water and route it to a waste water treatment plant. In dry weather, it's all sewage in the pipes. In small rain storms, the pipes carry sewage mixed with storm water and it all goes to the wastewater treatment plant to get cleaned up and returned to a stream or lake. The origins of combined sewers predate waste water treatment, when there was little distinction between storm water and sewage and stream and city dwellers just wanted the foul-smelling, disease-festering stuff out of their way as soon as possible. Later, engineers and public health folks added the crucial waste water treatment plant step to the system but the sewers remained combined. (http://all-geo.org/highlyallochthonous/2013/03/combined-sewer-overflows-solving-a-19th-century-problem-in-the-21st-century/)

In another example, in her post *When a tree falls in a stream, there's always something around to make use of it* (http://all-geo.org/highlyallochthonous/2011/06/when-a-tree-falls-in-a-stream-theres-always-something-around-to-make-use-of-it , retrieved 7/4/2014), she defines and describes what allochthonous means in hydrology.

7.2 Review a new finding in more comprehensible terms	On *Highly Allochthonous*, her blogs about new papers provide general overviews for experts in related fields (see below) instead of popular communication articles that describe the importance or relevance of a new finding.
7.3 Explain a natural hazard/disaster	AJ uses her understanding of the highly technical aspects of hydrology to explain hazards and causes from large storms, spills, and flood. Posts in this category include a series inventorying current flooding events around the world with maps and some analysis on economic and humanitarian impacts (see example in Figure 4). Other examples are her posts describing why slow moving hurricanes are more dangerous because of the flooding and how a 2014 West Virginia chemical spill ended up impacting a stream and the local water supply.
7.4 Review science history	These posts are thoughtful essays that review science and also the impact of various phenomena on society. For example, in "Where rocks, water, and history intertwine" (http://all-geo.org/highlyallochthonous/2009/06/where-rocks-water-and-history-intertwine/ retrieved 11/2/2014) she discusses a rock outcropping that had been used as a ford across the Catawba river and a canal built in the early 1800s that lets boats bypass the rocky area. The post includes images.
7.5 Review popular science books	AJ occasionally reviews more popular books on hydrology and other geoscience topics on her blog. In one case she suggested children's books on water-related themes (http://all-geo.org/highlyallochthonous/2009/12/gifts-for-future-hydrologists/). In her science example and basic science posts she also suggests popular science books for further reading (http://all-geo.org/highlyallochthonous/2010/07/todays-hot-topic-bottled-water/).
7.6 Explain a scientific controversy (for public)	Not observed

8 Entertainment	
8.1 General images	In addition to using images to illustrate and explain on historical and basic concepts posts, AJ posts images from her fieldwork and from vacations and trips she has taken. Her posts in this category are rarely annotated or serving didactic purpose.
9 Politics, Religion, and Society	
9.1 Reviewing books (not science)	Not observed
9.2 Commenting or advocating on political, religious, or social topics	Not observed
9.3 Commenting on news (not science)	Not observed
10 Meta (about the blog or Twitter)	Discussions of moving the blog and updates.

Flooding around the world (3 July edition)

Posted on July 3, 2011 by Anne Jefferson

Here is a brief update on the floods I covered in the last edition of flooding around the world. Note that there has also been flooding in Xiengkoung, Viengtian, Boolikhamxay, and Xayaboury provinces of Laos, as a result of heavy rainfall from a tropical storm; in Russia's Khabarovsk region (Kiya and Khor rivers), from heavy rainfall; and in the Philippines' Davao city, from heavy rainfall.

China and the Yangtze River

- Flood after drought, and they both hit the poor the hardest https://www.nytimes.com/cwire/2011/06/30/30climatewire-gone-with-the-flood-chinese-villagers-strugg-61962.html
- Heavy rains have caused a cave in and flooding in two Chinese coal mines, trapping at least 40 miners http://www.forbes.com/feeds/ap/2011/07/03/general-as-china-mine-flood_8547457.html
- Striking image of floods along the Yangtze River http://earthobservatory.nasa.gov/NaturalHazards/view.php?id=51232 (via @NASA_EO)

Flow from the Gavins Point Dam spillway was 150, 000 cubic feet per second on June 14, 2011. (SDNG photo by Master Sgt. Donald Matthews, image on Flickr)

Missouri River

- Why this spring's water in the Missouri River basin was so tricky for the Corps of Engineers to master http://www.kansascity.com/2011/07/02/2990252/missouri-river-defying-its-master.html
- Sand shortage causes concern for flood fighters along Missouri River (06/21/11) http://www.semissourian.com/story/1737873.html?response=no
- Continued Flooding near Hamburg, Iowa in this @NASA_EO image. [The result of 2 levee breaches] http://earthobservatory.nasa.gov/NaturalHazards/view.php?id=51236&
- Flooding Won't Overcome Nuclear Plants, Officials Say, but Ft Calhoun has a history of problems: http://www.npr.org/2011/06/28/137470320/wisch-nuclear-plants
- Flooding along the Missouri River from @NASA_EO http://earthobservatory.nasa.gov/NaturalHazards/view.php?id=51201

The Souris River, continues to flow over Minot, N.D. flood levees June 23, as the water begins to inundate residential neighborhoods. (DoD photo by Senior Master Sgt. David H. Lipp, image from Flickr)

Souris River

- A good overview of why flooding in Minot was so much greater than the community anticipated http://www.latimes.com/news/nationworld/nation/la-na-adv-minot-20110702,0,5569488.story
- Heart-wrenching before and after flooding aerial imagery of Minot http://www.latimes.com/news/nationworld/nation/la-na-minot-slider,0,5485991.htmlstory
- Manitoba towns frantically prepping as the Souris River rises http://www.cbc.ca/news/canada/manitoba/story/2011/07/03/mb-souris-floods-prep.html
- Historic Floodwaters Begin To Recede In Minot, N.D., now levee vigilance [I particularly liked how this story described discharge measurements on the flooded river.] http://www.npr.org/2011/06/27/137439779/minot-flooding
- Two Towns, Same Flooded River, Different Fates – one managed to sandbag high enough; the other did not http://www.npr.org/templates/story/story.php?storyId=137455189
- Historic Flooding along the Souris River from@NASA_EO http://earthobservatory.nasa.gov/NaturalHazards/view.php?id=51213
- Only 10% of Minot residents had flood insurance, but as Souris River Crests, Minot North Dakota Exhales http://online.wsj.com/article/SB10001424052702304447804576409581541554692.html (via @rivrchik)

Figure 4 Example of Flooding Around the World series
(http://all-geo.org/highlyallochthonous/2011/07/flooding-around-the-world-4/ retrieved 7/14/2014)

Getting good stream temperature measurements without losing your probes

June 24, 2011 | Filed under: doing science, stream temperature and tagged with: field methods, stream temperature

Note: I use stream temperature to understand groundwater-stream interactions and the response of streams to urbanization. Since ~2004, my stream temperature probe of choice has been the Tidbits temp probe, manufactured by Onset corporation. I like them because they are +/-0.2C and extremely durable, watertight, and reliable. Plus, I've had good customer service experiences with the manufacturer. What follows is my attempt to explain how I deploy them in the field, based on my cumulative experience and what I've learned from others. Please comment and add your own ideas and experiences, and I'll amend the protocol as needed.

Getting ready for the field

1. Obtain Tidbits temperature probes and the associated HoboWare Pro software. Read the documentation and learn how they work.
2. Using the delayed start feature in Hoboware, set all of the temperature probes to start at the same time and at the same sampling interval. I like to set them to start evenly on the hour. It makes analysis easier later.
3. You can't change the calibration of the temperature probes within the software, and they should come pre-calibrated, but you should still check the calibration of your temperature probes relative to a certified thermometer and to each other. I recommend a 3 stage calibration check process, but you'll want to do at least 2 temperatures that bracket the range of range conditions you expect to measure. You need to do each of these for a couple of hours, because while the response time in water is ~5 minutes, it is slower in air.
   - An ice bath (with stirring) or the refrigerator.
   - Room temperature, out of direct light, in a room with fairly stable temperatures for a couple of hours.
   - Depending on what temperature your streams are likely to be, you might want a temperature intermediate between the refrigerator and room temperature. (I'd love to hear your suggestions for an easy, good intermediate cool temperature.)
   - Or, if you are interested in summer headwater stream temperatures, you could use something like a consistenly shady area outside. I've also used my backpack, by putting all of the probes in the same container inside it, and then hiking around with them for several hours prior to installation.
4. Download the Tidbits after the calibration check, and reset them for a simultaneous start on the day you'll be deploying them in the field. I've used a 15 minute interval for projects where daily and seasonal fluctuations were of interest; but since we are now interested in storm response, I think we should set them to log at 5 minute intervals (in Celsius, please!).
5. If there are extra tidbits available, I recommend deploying one in the air, in a shady area near the stream at each field site. I've hung them from a tree branch with fishing line, and a homebuilt radiation shield. My radiation shield was a gallon milk jug with the bottom cut off. The tidbit fit through the top opening, and then I screwed the top back on, so that the Tidbit hung freely within an area shaded on the top and sides by the milk jug.

Selecting your field site

There are several very important things to consider when selecting your probe site. You are probably going to have to compromise somewhere in this list at some of your sites, but this is what to strive for.

1. It meets your scientific objectives (i.e., is positioned appropriately relative to a stormwater BMP, restoration structure, tributary junction, or other field sampling/equipment site.)
2. The probe will be under flowing water under a wide range of flow conditions. Good places include the channel thalweg or a pool that will not go stagnant (e.g., below a rock outcrop or structure that directs all streamflow into the pool).
3. The probe will out of direct sunlight at all times of day, as best as possible. Deep shade, an overhanging bank, or an incised reach is good. Peak water temperatures occur in the mid- to late-afternoon, so this is the most important time to check and make sure your site is out of the sun. Adding a cobble on top of your probe, without completely burying the probe in the streambed, is another good way to keep the sun off of it (and to make it less likely to be discovered or banged up during high flow). If you think sun exposure is likely to be a problem (or your data suggest that it is), you should take measurements of shading with a densiometer. Measuring shading won't fix the problem, but at least you'll be able to discuss it.
4. The probe placement is as geomorphically consistent with other probes in the project as possible.
5. The probe can be discretely and securely attach the probe to something very stable. I've almost always used streamside trees, but a post holding other equipment would work too.
6. The probe should be located somewhere it is possible to bring it up onto the bank while still cabled, so that the Tidbit can be downloaded into the laptop without having to balance the laptop in the middle of the stream.

Deploying the probe

1. Loop steel cable through the hole on the Tidbit, and crimp the loop shut with a hand swager (like this one). I have cabling, crimps, a swager, and a cable cutter available in my lab.
2. Measure out an appropriate length of cable to reach the secure attachment site, loop around it, and cut and crimp the cable. I like to give the cable enough room so that it can lie flush with the stream bed and bank and let the probe be in the thalweg, under a rock, but I try not to give it too much slack to get caught on things or let the probe go banging down the stream if it gets dislodged. And, of course, I never make a loop around a tree very tight
3. Put the probe in the stream. If possible, place a cobble on top of it so that water flows under the cobble and the probe doesn't get smooshed into the streambed.
4. Mark your field site with (1) GPS coordinates, (2) discrete flagging or a stake, (3) write down really good field notes describing the site and how you got there, and (4) take photos of everything (like the ones below). Write your field notes so that your advisor(s) can find the site 2 years from now without your help. (Thanks!)

Note: We have tried a variety of methods for securely attaching the Tidbits temperature probes to a fixed object. Rope gets abraded, degraded, and eventually breaks in high turbulence and velocity flows. High test fishing line broke as well during a high flow in a first order stream. We have settled on steel cable, thin enough to thread through the hole of the Tidbits and secured by crimping, as shown below. Recently, we discovered that several of the cables that had been deployed for ~2 years had rusted and broken and that we'd lost the temperature probes at some point since we'd last downloaded their data. I've now heard that some people are using plastic coated steel wire. Maybe we should consider that as an alternative to the unocated cable.

I still believe that the steel cabling is a good attachment method, but our experience reminds me of the importance of regularly checking on field equipment. Even if the temperature probe can collect a year's worth of data before its memory fills up, **I'd recommend downloading the data at least once every 3 months (in a non-flashy stream) and doing a thorough check of the cable integrity each time. In urban streams, I now recommend downloading table and checking cable integrity every 2 weeks**. *Data from a lost probe can never be recovered.*

Thanks to Sarah Lewis for adding her wise comments to via email. She taught me a lot of this stuff in the first place!

Attachment for temperature probe at Deep Creek site DC 12, during the fishing line-era of installation. The flagging was also labeled with a project and site identifier.

The Tidbits is under the triangular rock at the center of the photo. You might be able to see the line extending to it. Good points about this site: A rock protector with good water flow under and around it and good shading. Bad points: Not a lot of flow depth here, but we were at the seep initiating this stream. We had an air temperature probe at this site as well, and the water temperature was always significantly muted relative to the air temperature fluctuations.

Figure 5 Example Scientific Method Tutorial Post
(http://all-geo.org/jefferson/getting-good-stream-temperature-measurements-without-losing-your-probes/ retrieved 4/22/2015)

4.7.2.2 General tweeting

AJ joined Twitter under her current user name in December 2009 and has more than 20,000 tweets. She tweets on a broad variety of topics from posts on diversity and feminism to answering questions from school children (see Figure 6) to links to news reports, government documents, and published research articles on hydrology and floods in particular. For the most part, her tweets are pointers to popular and scholarly articles instead of new contributions.

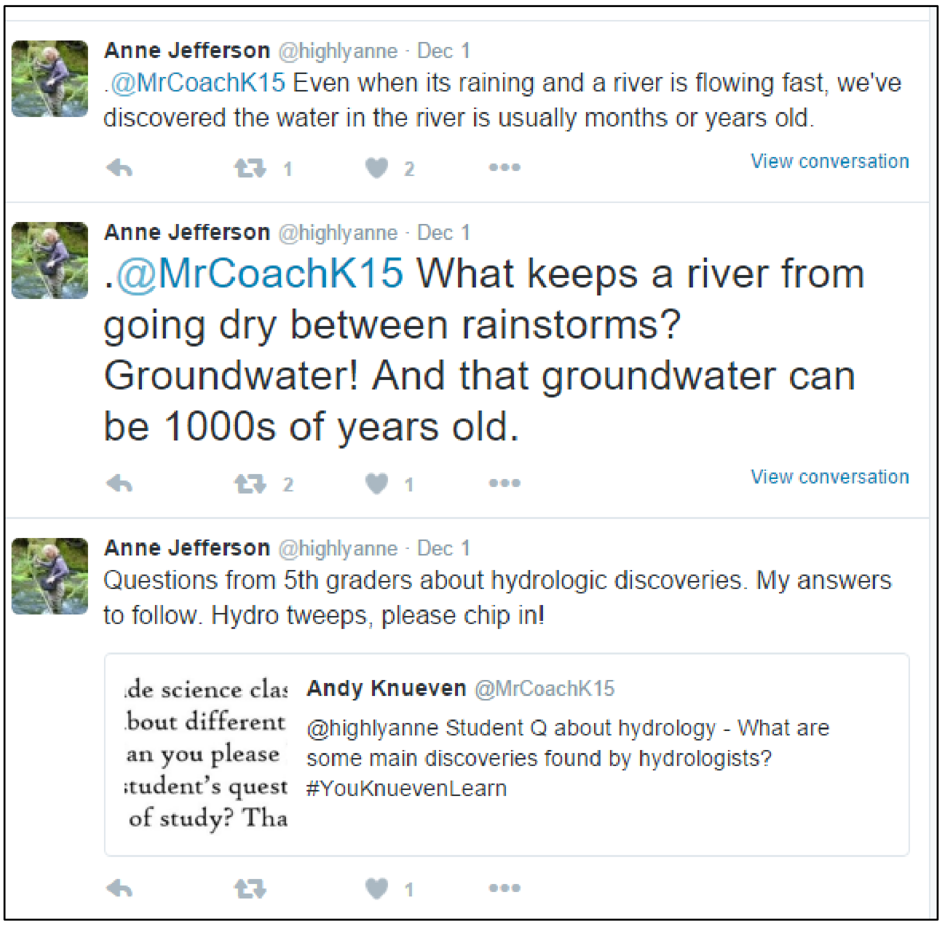


Figure 6 Example exchange with students answering hydrology questions.

Through her use of Twitter, she has met new research partners with whom she has gotten funding to mentor young students.

What follows are examples of AJ's general tweets organized using the unified schema of content types and communication functions.

1 Science (for scientists)	
1a Pointing to readings	In these cases AJ provides a link to an article with a very brief description of its value. `Study predicts bedrock weathering based on topography <-This is super-exciting. Can't wait to read. @CiaranJHarman http://phys.org/news/2015-10-bedrock-weathering-based-topography.html … (https://twittercom/highlyanne/status/660042064252432384 )` This year (2015) she has made an effort to read scientific articles every day and links to them on Twitter with the same hashtag.
1b Discussing scientific topics	One topic discussed on Twitter but not on her blogs is funding. AJ has been in several discussions regarding funding levels, diversity of funding, success in applications, and time spent in grant applications. A grant rejection to start the day. Reviews overwhelmingly positive, but funding rates are tiny, so rejections come with the territory.(https://twittercom/highlyanne/status/512594391253659649)
1c Tutorials for peers	Not observed.
2 Doing Science	
2a Reporting from field work	AJ often tweets from fieldwork sites. For the most part, she tweets about her activities in general such as downloading data from stream monitors and posts pictures of the field site.

2b Reporting lab work

AJ sometimes tweets from the lab, but just with overviews of what she's working on (see**Figure 7**)

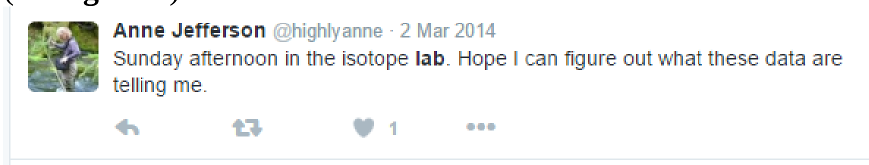


Figure 7 Example of a tweet from the lab

2c Analyzing

Not Observed

2d Requesting assistance

AJ occasionally asks to know the name of something, for a link to a good review of something, or suggestions for graphics or examples for conference presentations and teaching

2e Building science community

2e. Building Science Community
AJ links to and recommends other scientists to bring them more public attention. She also posts quite frequently on job conditions in science and fair treatment.

3 Conference-specific

See Section 5.1.2.3

3a Covering a session live

3b Color commentary

3c From away from the conference

3d Summarizing a conference

4 Science News/ Announcements

4a Announcing job openings

She uses Twitter to announce job openings both in her lab and elsewhere that might be of interest to her students.

4b Announcing defenses, graduations

She uses Twitter to announce major events for her lab members.

4c Announcing papers published

She also tweets about papers published by her lab and about conference abstracts accepted.

5 Teaching (being a teacher)

5a Providing advice for students

5b Recruiting students

5c Pointing to educational resources

AJ often points to videos, news stories, reports, and other items that she will use in her classes (see **Figure 8**).

Figure 8 Example educational resource

5d Explaining how to teach

Several of the discussions have centered on how and what to teach in various hydrology classes.

6 Social / coordinating	
6a Biographical/ confessional	
6b Coordinating	
7 Public communication of science	
7a Explain a science concept	One example of basic science explanation is her series of tweets to an elementary school class explaining groundwater hydrology.
7b Review a new finding in more comprehensible terms	This is typically done on her blog instead of on Twitter.

7c Explain a natural hazard/disaster	AJ does link to news articles and government reports and announcements on floods, tsunamis, and other water-related hazards.
	`Brazil dams burst: 'Hopes of finding survivors fading' http://wwwbbcco.uk/news/world-latin-america-34762396 …(https://twittercom/highlyanne/status/663451414887137280 )`
	`Can have two 1 in 1000 year floods within a few years. Or odds wrong. Or climate change may increase likelihood. RT @ruslandvalley In 2009 we had a "once in a thousand year flood" in Cumbria. Well we're having it again now, and it's worse.`
	(https://twittercom/highlyanne/status/673604976904552448)

7d Review science history	AJ has tweeted from talks that discuss history and mentioned papers that discuss history, but her primary reviews are located on her blog.
7e Review popular science books	Her book reviews are primarily posted on her blog. Her Twitter account is used to point to these.

7f Explain a scientific controversy (for public)	Not observed
8 Entertainment	
8a General images	
9 Politics, Religion, and Society	
9a Reviewing books (not science)	She has reviewed and recommended children's books to other parents on Twitter.
9b Commenting or advocating on political, religious, or social topics	
9c Commenting on news (not science)	
10 Meta (about the blog or Twitter)	

4.7.2.3 Conference-based tweets

AJ reports that she does not tweet too much from conferences because she is too busy going to meetings, catching up with colleagues, and mentoring students. She also reports that she doesn’t want to have her head down to her phone instead of paying attention and it’s too difficult to translate talks to 140 characters. She may tweet local events where no one else is tweeting. Still, she has tweeted GSA meetings including tweeting summarizing sessions as they are held.

There were 14 conference tweets 14 from 2012 even though she didn’t attend. There were 40 conference tweets in the set all together but most are about meeting submission deadlines, returning from the conference, and pointing to blog post conference reports. Some of these tweets were announcing blog posts from her co-blogger (there is a script to automatically announce any new posts, not just her own).

Examples:

```
I now *have* all the data for my #AGU10 talk. Now I just need to analyze it make it pretty and turn it into my talk. Still progress. #fb
```

```
Back from #AGU11, today = #gradingjail. The end of the semester cometh, whether I am ready or not.
```

4.7.2.4 Blogs and Tweets as Information Sources

AJ posts videos, images, and notes to her lab blog to support teaching. By archiving the links in one place, she is able to find and display them quickly in class. For her, posting to the lab blog serves a personal knowledge management function.

"a place for me to post all of my abstracts, papers, etc. so that I can easily find them again when I need to reference them"(http://all-geo.org/jefferson/how-i-use-new-media/)

4.7.2.5 The Online Geoscience Community

In a 2010 blog post, AJ quotes a geoscientist on what it means to be part of the online geoscience community:

> I am awestruck by the level of camaraderie and openness that exists in the geoblogosphere and how it allows for communication of real geologic wonderment. The vast expanse of specialties, geographic representations, and experience available at your fingertips as part of the geoblogosphere is unfathomable. True geology is shared en masse and those of us with desk jobs in cube farms bask in the joys shared by the offshore and overseas bloggers, the field geologists, and the twittering TA's. Perhaps the reverse is true, as the field geos are fighting off the cactus and the mosquitos. The opportunity to learn, share, and experience things beyond your own surroundings is a rich opportunity that shouldn't be skipped. (Geo Girl, http://eatsleepgeologyblogspotcom/2010/07/neogeo-bloggers-view-of-geoblogosphere.html , quoted in http://all-geo.org/highlyallochthonous/2010/07/geoblogospheric-community-what-is-it-good-for/)

5. Results

As described in the methods section, the transcripts, retrieved posts and tweets, and notes from observations were coded and analyzed. In addition to identifying features of the framework, the analysis revealed common categories of posts (see Table 17 for an overview).

The use of Twitter at conferences is anomalous from the remainder of the Twitter feed for all of the participants in the study. In fact, some warn followers of an increase in activity (from a few tweets a day to tens or a hundred) and narrowing of topic coverage when a conference starts. Also, whereas the dissemination of a typical tweet is to the followers and to the followers of anyone who re-tweets, in the case of a conference there are many other readers following the hashtag including attendees, journalists, society members, and interested non-attendees. Since the use and behavior varies from the quotidian, conference microblogging is treated as a separate macro case for cross-case analysis.

Chapter 5 is organized by the research questions first and then by the SCTs to show the differences between them.

Research questions repeated for ease of reference

RQ 1. How do scientists use SCTs, specifically blogging and microblogging?

1.1 How do these SCTs fit into the context of scientific work?

1.2 What functions do these SCTs serve?

1.3 What benefits do SCT participants report receiving?

1.4 How do participants and non-participants view these SCTs?

1.5 How do these modes of communication interact among themselves and with traditional modes of communication?

RQ 2. How do these ICTs support data, information, and knowledge creation, seeking, and use in science?

RQ3. Is the framework, based on the literature, suitable for describing communication in science?

5.1 RQ1 How Scientists use Blogs, Twitter, and Conference-Based Twitter

5.1.0 Overview of Blogging, Twitter, Conference-Based Twitter

5.1.0.1 Blogging Overview

All of the interview participants in the study have posted to a blog, if only as an infrequent guest on the Planetary Society or other blog. Four of the eight are well-known bloggers who have each maintained their blogs for close to ten years.

How scientists use blogs has evolved since 2004-2007 when blogging started to become more widely adopted. General discussions of blogs described them as informal conversations (Blood, 2002).Whereas these descriptions may have applied to blogs in general, science blogs developed more as short essays directed toward like-minded or at least sophisticated users. Bloggers reported that they started their blogs to communicate with the public but found that their readers were primarily other scientists and students. Bloggers reported spending more than an hour if not a few hours researching, preparing, and writing each post instead of the quick jottings early media reports assumed.

Many got involved in blogging as doctoral students looking for another outlet and practice for writing and then continued on through career and life changes. Familiarity with the blog content management software led to the scientists using blogs also for personal and lab or research group websites.

5.1.0.2 **Twitter Overview**

Many active geoscience bloggers were early adopters of Twitter and use of Twitter was widespread in geosciences by 2010. Like CB, many originally used Twitter to make broadcast announcements but later found that it was more useful for conversations with colleagues. The immediacy of Twitter and the quick back and forth, the crowdsourcing aspect of it lent itself to different communication than what was done on blogs:

> ‘It became less about sort of like “here’s a cool study that was done…” “here’s news about an earth quake that just happened” to “what do you guys think of this particular thing people do when they’re making a presentation” or “does anyone have a copy of this paper?”’ (CB Interview para 16)

Following relationships and the social network of connections changed as more geoscientists joined. Initially, participants followed all or many of the geoscientists they could find but as more and more geoscientists joined Twitter, the participants became more selective KA explains it

> So at first I would follow basically anyone that was a climate scientist or often I followed a lot of geoscientists who weren’t climate scientists. The explosion in popularity for scientists and students to be on twitter means that it’s sort of a stochastic process at this point. I’ll follow people that I know or whose work I respect or like. Now and then occasionally someone will tweet something cool and I’ll follow them. Maybe I’ll follow them for a while and they’ll be someone I’ll continue to follow or maybe after a little while their tweets are not on topic or I don’t find interesting and then I’ll unfollow. Now with the sheer number of earth scientists and ocean scientists on Twitter I’m much less commonly following everyone who does what I do. (Interview para 43)

In addition to following scientists in related research areas or popular scientists in the general field, scientists follow others using the same type of instrument, computer program or code, or analysis technique. These shared tools form boundary objects for very different communities who are using the same tools to study diverse phenomena and to come to diverse findings (Star & Griesemer, 1989; Star, 2010).

5.1.0.3 **Conference-Based Twitter Overview**

A specific case of scientists using microblogs is their use of Twitter before, during, and after a scientific conference or meeting. The data set included tweets from the AGU Fall Meeting for 2010, 2011, and 2012.

The AGU is a very general society with members studying all aspects of geosciences. The fall meeting is their largest with as many as 30,000 attendees from all over the world. Besides being attended by researchers, this meeting is attended by funders, vendors, and members of the press. It is always held in San Francisco in early December.

As illustrated in the overviews of tweets with the conference hashtags, quite a few people tweet and there are quite a few interactions among tweeters. This section provides an overview based on the random sample that were coded using the framework.

5.1.0.3.1 What is Tweeted?

The collection of tweets with a conference hashtag follow a general pattern. The first tweets in a collection are from the year prior with promises to return in a year. Subsequent tweets are reminders to submit abstracts and book travel. Next are social tweets about travel and registration. Then, during the conference there are a lot of coordination tweets and session tweets. After the conference there are tweets pointing to summaries, archived posters, and tweets about the trip home and reading accumulated e-mail.

5.1.0.3.1.1 Coordination Tweets

These tweets inform readers what to expect, where to find the author, and of upcoming events. Announcements from conference organizers, session conveners, and exhibitors that may have been done on a poster board in the lobby or even as an administrative announcement at the beginning or end of a plenary session are now also done by tweet:

> `Don't forget to check in @Spkr Ready Room 24 hours before your session #agu11 (from @theAGU agu2011-1399)`

Individual tweeters send messages like: I'm going to be here next. Want to meet here. … anyone up for dinner, or a list of sessions they will be tweeting from that day.

> `Current plan for #AGU12 tweet-up: Tuesday, 8.30 pm, Johnny Foley's http://bit.ly/V4z0tF  cc @LizNeeley @cbdawson"(agu2012-4973)`

5.1.0.3.1.2 Tweets from non-attendees

A good number of tweets are from people not attending the conference. Of these, some are just amplifying an interesting press release from the conference or scientific information shared at the conference.

Others are by geoscientists who might typically go to the conference, but are not able to attend this meeting. Some of these are expressing jealousy at not going. Some are amplifying reports from attendees. Some are social, tweeting to still be a part of the group and share the conference atmosphere:

> `"Hey, don't you wish you were at #AGU12? Me too. Too many friends there. Oh yeah, and scienceandstuff." (agu2012-4930)`

5.1.0.3.2 Why or why not read and send tweets?

One participant describe the benefits of reading:

> Meetings are a big deal as well because you can't possibly go to all these meetings so being able to follow each new meeting while I'm programming or while I'm writing a paper I can check in and see hey what's going on at EGU [European Geophysical Union] or small meetings, too. It's nice when people tweet from small meetings that you weren't able to get to. (KA Interview para53)

and of tweeting

> At a meeting I see all this brand new science people are presenting and you know or tweets on new analysis or new results so its kind of fun to share that meeting experience with people (KA Interview para 35).

One participant who has live-tweeted play-by-play notes discusses the personal and knowledge management aspects:

> "The tweets stem out of the notes I'm taking as the notes are going along. It's kind of more the mental exercise of doing it that's useful. Getting it straight in your head: Ok, what was the major theme of this session? What were people mainly talking about? Who was particularly the standout person who I should look up in a professional context? I think it's the think I'm trying to work toward: the balance between doing social media outreach and doing it so it still has professional value to me." (CR interview para 24)

More senior people have their days completely booked before arriving at conferences with necessary meetings and catching up with collaboration partners and colleagues. They find less time to tweet the science they see in sessions.

> "not in a play-by-play – I can't do that – I can't multitask like that. I'll write a comment, a couple of times a day but not like some people hundreds of posts a day – a play by play of various talks or something. But usually when I'm at a conference I'm too busy interacting in real life."(BR interview para18)

More junior people find that tweeting can help them get settled in a new conference and they are able to tweet out more of the science.

Some conferences may be less accepting of distraction caused by typing messages during sessions.

> "AGU is a conference I've been to most often. I've been to a couple of smaller workshop type conferences which on the whole I haven't felt comfortable tweeting from simply because it's very small. It's kind of more technical in

> ways. AGU is like a big conference. There's press there, there's an expectation that what you put up there is going to be shared to a wider audience. Some of the smaller ones I don't think so" (CR Interview para 22)

5.1.0.3.3 How scientists tweet from conferences

Because so many scientists are tweeting meetings, they can be more selective of which sessions they tweet from and how they tweet from the session. Factors that impact how and what they tweet include

- Availability of technology. This includes using a laptop, tablet, or phone as well as availability of Wi-Fi or network signal. Power and recharging is always an issue for long conference days.
- How long the participant has been attending meetings or their seniority in the field. More junior researchers tend to tweet more.
- Engagement and agreement with the talk. "I don't tweet every session that I'm in I don't tweet about talks I'm not finding interesting or convincing so when I'm usually tweeting it's about things I find interesting and convincing (KA Interview para 35)
- The number of attendees tweeting the session. "If there's only one person in the room people tend to take it more seriously because people feel that they are providing information from that room" (SH Interview para 18)
- Concern about politeness or response of the speaker. Some use their computer so they do not look like they are texting instead of paying attention. Instead they save tweets and post them later.

Coherence of Twitter conversations is better in later years due to discipline in marking tweets with the originator of the idea and some tweeters posting coordination posts with their schedules and names of sessions they're in/attending. Example of less coherent exchange from AGU2011:

```
Mercury high density b/c 1. formed in a c-rich inner disk of
dust 2. Low density mantle may have strip away after oblique
impact. #AGU11 [AllPlanets agu2011-619]
```

```
GRS is measuring gamma rays from Mercury's surface. There are
several theories as to Mercury's high density. #AGU11
[MESSENGER2011 agu2011-622]
```

5.1.0.3.4 Impact of Twitter on the conference

The use of Twitter at conferences has facilitated broader engagement and information exchange by disseminating information to scientists unable to attend. This has a particularly dramatic impact on small conferences held in remote locations previously requiring expensive travel.

A second form of impact is in the crosstalk among meeting attendees. Attendees in the same or different tracks can ask questions and get clarifications or commentary. It can make the conference more productive and successful

For conference organizers, tweets using the official hashtag advertise the conference to future attendees. Organizers also get better and more immediate feedback when things are not going well so they can address any problems.

In turn, organizers need to make changes to the conference policies and infrastructure to support use of Twitter by attendees. Policies should be updated to provide clearer guidelines for results that cannot be tweeted if, for example, they are embargoed by journal or if there is a patent or similar issue. Organizers need to provide the requisite infrastructure including high speed wireless internet capacity and power outlets or charging stations.

5.1.1 RQ 1.1 How do blogs and Twitter fit into the context of scientific work?

This section describes how the use of blogs and Twitter fit into scientific work such as finding and reviewing the literature, setting up experiments and field work, gathering data, doing analysis, and writing and presenting results.

5.1.1.1 **Blogs**

Blogs are useful in multiple stages of scientific work. First, bloggers in the study share readings and reactions to panels and presentations they attend as they explore, develop, and frame their research questions. They learn about new articles they should pursue through the literature filtering and dissemination (amplification) functions of other blogs as well as through comments and feedback on their posts, whether they explicitly ask for suggestions or not.

Next, some bloggers describe setting up equipment or lab spaces. Feedback on these posts might include congratulations on highly desired equipment or sympathy for small lab spaces. This type of interaction is more related to identity and group membership than furthering science, but there may be helpful tips in organizing the lab or even troubleshooting sensor or instrument locations.

Geoscientists with Earth-based research gather samples and explore waterways and rock formations in the field. These bloggers share notes, photographs, maps, and tentative explanations from field work. This can be a way to help better understand, organize, and preserve access to the data stored on project servers and in disciplinary repositories as well as to build identity and community. For one geoscientist, the annotated large pictures were part of his research output which he shares freely, but for the others, these images and notes do not provide enough information to enable a reader to scoop the author (Birnholtz, 2007).

Blogs support building scientific knowledge through research: working with and analyzing data. Back in the lab analyzing samples and working with data, some geoscientists share preliminary analysis or unexpected results to get suggestions of possible explanations or different approaches to solve a problem. As analysis is being completed and the research is being written up for publication, some of the scientists share details of programs and calculations used for the analysis and presentation of results. For the past few years, more of this sharing happens on Twitter than in blogs.

On the other hand, as has been reported elsewhere (Mewburn & Thomson, 2013; Steinke, 2013; Trench, 2012), most geoscientists do not share data as full data sets and research in progress as in pre-prints or early drafts through blogs. The participants, too, were reluctant to post their unpublished work but not because concern over being scooped, but because they value the input they get from expert peer reviewers to check that their methods were reasonable and their conclusions followed from their data, and they want to have this check before they go public.

Once the research is ready to be reported out and has been accepted for presentation at a conference or journal publication, geoscientists use their lab blogs to amplify the signal and provide details of when and where the work will be presented (coordination).

Blogs also support the work of being a scientist. They provide advice on job seeking, grantsmanship, working with others, dealing with difficult situations including potentially dangerous situations in the field, and other things scientists do that are not directly building new scientific knowledge. Experienced scientists provide advice with examples drawn from their own experience. Junior scientists present situations and ask for advice.

5.1.1.2 **Twitter**

For some users, Twitter has become part of the fabric of their day. It is something to leave open or check from time to time: "It's really become part of my everyday routine…I open it up every morning as soon as I get in like with email and everything else" (BR interview para 26).

Participants in the study tweet to get access to the literature (see RQ 1e), to share what they're reading, to show the lab and field work that they're doing, to discuss the analysis, and then to announce work they have done. Twitter is used in all phases of the research project.

Help with general things like coding, figures

> "more general problem solving like trying to write some code to make a certain kind of plot using a certain kind of software. I'll put out questions like that which is more general because that's a tool a lot of people use. So I found there's better interaction if you generalize the question if it's really specific there might be one or two other people who would be interested and then they'd have to see it." (BR interview para14)
>
> Sometimes if I post something like a figure.., people will inquire how I did something, what approach did I use, how did I write code so show a certain feature of that figure. I've definitely had people give advice on ways to change the figure so yeah I wouldn't say it's very common that I would get feedback on a figure beyond 'hey that's cool' or something positive but not with much detail but it has definitely happened where I've gotten feedback on that. (KA interview para 18)

5.1.2 RQ 1.2 What functions do blogging and microblogging serve?

The communication functions of blogs and Twitter can be described through evaluation of the communication purposes and categories of posts.

5.1.2.1 Communication purposes (Framework Section 2)

Table 16 provides an overview of communication purposes observed. Most of these purposes were in the original framework, but some are new. For example, in the case of dissemination, the subcategory “amplification” was added. This refers to communication to seek a broader audience beyond the original dissemination. For example, AJ wrote an article in the research literature to disseminate her results. Her department created a press release about it which she later brought attention to through a tweet (see Figure 9, RQ 1.5). This amplifies the signal and brings the article to the attention of new audiences. It is done for articles written by other authors as well.

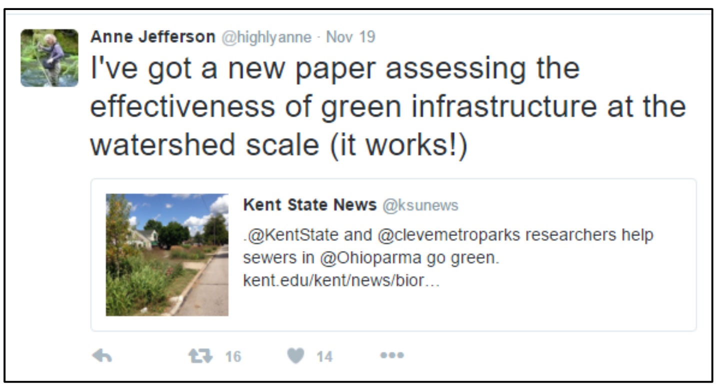


Figure 9 Example of Amplification Purpose

Additionally, the notion of a Follow Friday (#ff) social endorsement purpose is new with SCTs. In these tweets the author recommends other accounts to follow.

The prevalence of the various functions differs from blogs to Twitter. Blogs are more often used for persuasion than Twitter as the authors can explain their view more fully. Twitter is used more often to amplify dissemination of other content and for humor as it has a wider and more diverse reach. Twitter also seems to be used more for less formal communication. Conference Twitter is used more often to establish and maintain social identity.

5.1.2.2 **Categorization of Common Blog Posts and Tweets by content and communication function.** ***(Table 16)***

A second way to explore the functions of blogs and Twitter is through a better understanding of the categories of information posted. The following categories emerged through careful analysis of the data and then were refined through reading and re-reading the texts, searching for variations, and looking for counter examples. The categories were combined and placed into larger groupings. The order reflects the narrative of the study not the relative prevalence or stated importance to the participants.

The remainder of this section (after Table 16) discusses each of the categories. This scheme is important for a better understanding of communication in science as it applies to any mode of communication, not just blogs and Twitter. It is also important to teach science students about these message categories, particularly their use in blogs and Twitter.

Table 16 Overview of Communication Purposes Observed in Blogs and on Twitter

✓ Observed - Unknown [blank] Not Observed	CB			AJ			KA			SH			AR			CR			BR		
	Blog(s)	**Twitter (General)**	**Twitter (Conference)**	**Blog(s)**	**Twitter (General)**	**Twitter (Conference)**	**Blog(s)**	**Twitter (General)**	**Twitter (Conference)**	**Blog(s)**	**Twitter (General)**	**Twitter (Conference)**	**Blog(s)**	**Twitter (General)**	**Twitter (Conference)**	**Blog(s)**	**Twitter (General)**	**Twitter (Conference)**	**Blog(s)**	**Twitter (General)**	**Twitter (Conference)**
2.1 Dissemination	✓	✓	✓	✓	✓	✓		✓	✓	✓	✓	✓		✓	✓			✓		✓	✓
2.1.1 Amplification*		✓	✓	✓	✓	✓	✓	✓	✓		✓	✓		✓	✓	✓		✓		✓	✓
2.2 Preservation				✓				✓	✓					✓		✓	✓		✓		
2.2.1 Personal knowledge management				✓	✓			✓	✓					✓		✓	✓		✓		
2.3 Certification																					
2.4 Discourse	✓	✓						✓	✓		✓	✓		✓	✓	✓	✓	✓	✓	✓	✓
2.5 Societal Benefit	✓	✓		✓			✓	✓			✓		✓	✓		✓	✓		✓	✓	
2.6 Identity	✓	✓		✓	✓		✓	✓	✓	✓	✓	✓		✓	✓	✓	✓		✓	✓	
7 Rewards	✓			✓	✓						✓			✓		✓	✓		✓	✓	
2.8 Learning/Teaching	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
2.8.1 Mentoring	✓	✓		✓	✓	✓					✓			✓		✓	✓	✓	✓	✓	
2.8.2 Worked problem								✓											✓		
2.9 Persuasion	✓	✓		✓	✓			✓			✓		✓	✓		✓	✓		✓	✓	
2.10 Evaluation or Opinion	✓	✓	✓	✓	✓	✓		✓	✓		✓	✓		✓	✓	✓	✓	✓	✓	✓	✓
2.11. Coordination	✓	✓	✓	✓	✓	✓		✓	✓		✓	✓		✓	✓	✓	✓	✓	✓	✓	✓
2.12 Social																					
2.12.1 Be part of a group	✓	✓	✓	✓	✓	✓		✓	✓		✓	✓		✓	✓	✓	✓	✓	✓	✓	✓
2.12.2 Request comments	✓			✓										✓		✓			✓		

✓ Observed - Unknown [blank] Not Observed	CB			AJ			KA			SH			AR			CR			BR		
	Blog(s)	**Twitter (General)**	**Twitter (Conference)**	**Blog(s)**	**Twitter (General)**	**Twitter (Conference)**	**Blog(s)**	**Twitter (General)**	**Twitter (Conference)**	**Blog(s)**	**Twitter (General)**	**Twitter (Conference)**	**Blog(s)**	**Twitter (General)**	**Twitter (Conference)**	**Blog(s)**	**Twitter (General)**	**Twitter (Conference)**	**Blog(s)**	**Twitter (General)**	**Twitter (Conference)**
2.12.3 Identity			✓			✓		✓	✓			✓			✓			✓			✓
2.12.4 Endorsement (#ff)	✓	✓	✓	✓	✓	✓		✓	✓		✓	✓		✓	✓	✓	✓	✓	✓	✓	✓
2.12.5. Build Community	✓	✓	✓	✓	✓	✓					✓	✓		✓	✓	✓	✓	✓	✓	✓	✓
2.13 Entertainment																					
2.13.1 Humor				✓				✓			✓	✓		✓	✓	✓	✓	✓		✓	
2.13.2 Images	✓			✓	✓			✓			✓					✓	✓		✓	✓-	

* Includes announcements of paper acceptances and meeting abstracts

Table 17. Content types and communication functions of blog posts and tweets

✓ Observed - Unknown [blank] Not observed	CB			AJ			KA			SH			AR			CR			BR		
	Blog(s)	**Twitter (General)**	**Twitter (Conference)**	**Blog(s)**	**Twitter (General)**	**Twitter (Conference)**	**Blog(s)**	**Twitter (General)**	**Twitter (Conference)**	**Blog(s)**	**Twitter (General)**	**Twitter (Conference)**	**Blog(s)**	**Twitter (General)**	**Twitter (Conference)**	**Blog(s)**	**Twitter (General)**	**Twitter (Conference)**	**Blog(s)**	**Twitter (General)**	**Twitter (Conference)**
1. Science (for scientists)		✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
1.1 Pointing to readings				✓	✓			✓			✓			✓			✓		✓	✓	
1.2 Discussing scientific topics		✓		✓	✓		✓	✓		✓	✓			✓		✓	✓		✓	✓	
1.3 Tutorials for peers				✓															✓		
2 Doing Science	✓	✓	✓	✓	✓	✓		✓	✓		✓	✓		✓	✓	✓	✓	✓	✓	✓	✓
2.2 Reporting from field work	✓	✓		✓	✓			✓								✓				✓	
2.2 Reporting from lab work**					✓						✓			✓			✓				
2.3 Analyzing		-						✓						✓					✓	✓	
2.4 Requesting Assistance	✓	-			✓						✓			✓					✓	✓	
2.5. Building Sci Community	✓	✓	✓	✓	✓	✓		✓			✓	✓		✓	✓	✓	✓	✓	✓	✓	
3 Conference Specific	✓		✓	✓		✓			✓			✓			✓	✓		✓	✓		✓
3.1 Covering a session live			✓						✓			✓			✓			✓			
3.2 Color commentary									✓			✓			✓			✓			
3.3 From away from the conference			✓			✓			✓			✓			✓			✓			✓
3.4 Summarizing a conference	✓		✓	✓								-			✓	✓			✓		

✓ Observed - Unknown [blank] Not observed	CB			AJ			KA			SH			AR			CR			BR		
	Blog(s)	**Twitter (General)**	**Twitter (Conference)**	**Blog(s)**	**Twitter (General)**	**Twitter (Conference)**	**Blog(s)**	**Twitter (General)**	**Twitter (Conference)**	**Blog(s)**	**Twitter (General)**	**Twitter (Conference)**	**Blog(s)**	**Twitter (General)**	**Twitter (Conference)**	**Blog(s)**	**Twitter (General)**	**Twitter (Conference)**	**Blog(s)**	**Twitter (General)**	**Twitter (Conference)**
4 Sci News/ Announcements		✓		✓	✓			✓			✓			✓		✓	✓		✓	✓	
4.1 Announcing job openings				✓	✓			✓								✓			✓	✓	
4.2 Announcing defenses, graduations				✓	✓														✓	✓	
4.3 Announcing papers published		✓			✓						✓			✓		✓	✓		✓	✓	
5 Teaching (being a teacher)	✓	✓		✓	✓			✓			✓					✓			✓	✓	
5.1 Advice for Students	✓	✓		✓	✓			-			✓								✓	✓	
5.2 Recruiting Students				✓												✓			✓	✓	
5.3 Pointing to Educ. Resrces				✓	✓			✓			✓					✓	✓		✓	✓	
5.4.Discussing how to teach				✓							✓					✓	✓		✓	✓	
6 Social	✓	✓	✓	✓	✓	✓		✓	✓		✓	✓		✓	✓			✓	✓	✓	✓
6.1 Biographical/ Confessional	✓			✓															✓	✓	
6.2 Coordinating*	✓	✓	✓	✓	✓	✓		✓	✓		✓	✓		✓	✓			✓	✓	✓	✓
7 Public Comm. of Science	✓	✓		✓	✓			✓			✓			✓		✓	✓		✓	✓	
7.1 Explain a science concept	✓	✓		✓	✓			✓			✓			✓		✓	✓		✓	✓	
7.2 Review a new finding in more comprehensible terms	✓			✓				✓								✓					
7.3 Explain a natural hazard/disaster	✓	✓		✓	✓			✓						✓		✓	✓				

✓ Observed - Unknown [blank] Not observed	CB			AJ			KA			SH			AR			CR			BR		
	Blog(s)	**Twitter (General)**	**Twitter (Conference)**	**Blog(s)**	**Twitter (General)**	**Twitter (Conference)**	**Blog(s)**	**Twitter (General)**	**Twitter (Conference)**	**Blog(s)**	**Twitter (General)**	**Twitter (Conference)**	**Blog(s)**	**Twitter (General)**	**Twitter (Conference)**	**Blog(s)**	**Twitter (General)**	**Twitter (Conference)**	**Blog(s)**	**Twitter (General)**	**Twitter (Conference)**
7.4 Review science history				✓																	
7.5. Review popular scibooks	✓			✓															✓		
7.6 Explain a scientific controversy (for public)								✓											✓	✓	
8 Entertainment*	✓			✓							✓					✓					
8.1 Images*	✓			✓				✓			✓					✓					
9 Politics, Religion, and Society	✓	✓																		✓	
9.1 Reviewing books (not science)	✓			✓																	
9.2 Commenting or advocating on political, religious, or social topics		✓			-															✓	
9c Commenting on news (not science)	✓	✓			✓			✓			✓			✓			✓			✓	
10 Meta (about the blog or Twitter)	✓	✓		✓	✓			✓			✓			✓		✓	✓		✓	✓	

* Many posts are in some way related to science.
** Includes telescope sites.

1 Science (for scientists)

In these posts, the scientists in the study were communicating with other scientists either in their field or in adjacent fields about

- science;
- research, analysis, and visualization methods;
- writing;
- science careers;
- and related topics.

All of the participants in the study did this on Twitter, and those who maintain regular blogs did so on their blogs as well.

1.1 Pointing to readings

Several scientists created annotated bibliographies on their blogs for sharing with scientists in similar fields. In addition to the example given above in AJ's case study ("My picks from the [month] literature"), BR did a series of "Papers I'm reading" posts. In these he provides the full citations and brief descriptions.

On Twitter, KA filters the literature pointing to new and interesting articles he has uncovered in his alerts and browsing. He purposefully monitors journal alerts, looking for articles of interest to his readers and posts links with brief annotations.

1.2 Discussing scientific topics

Occasional blog posts from KA (on his shared blog) and SH provided descriptions and discussions of their work for other scientists. These posts cited references and assumed a good deal of background knowledge.

KA also described useful discussions on scientific topics, "It's one mode of having quick interactions with people. Other scientists - people working in the same areas as I am. Climatologists. People using similar instruments – mass spectrometers. Bounce ideas off each other, you can see what they're doing. They're all people I follow that do something similar to me, which is they'll do some on the spot analysis and so you can kind of see their approach, the statistics they are using, or how they're generating figures or something like that." (KA interview para 51)

Discussion about blog posts occurs in several different ways.

1) Some blog posts in the dataset had extensive threaded lists of comments from other geoscientists and hobbyists.
2) Some of these comments linked to blog posts in which the author took up the cue from the original post but had comments too extensive for the comment section. This also helps the commenter keep control of their contribution and makes it easier for them to find it later. In some cases blog software facilitates tracking of the comments across blogs by providing "ping backs" – automated links to other posts listed in the thread of comments. In other cases, commenters left a comment that they had posted on their own blog.
3) A blog post may be discussed on Twitter in a conversation sometimes linked to the author's automated announcement of a new blog post. A popular post by CR received 20 substantive comments. He then tweeted a link to a comment so that it would not be lost below the fold on his blog:

`Someone has left a detailed comment on my blog describing the events leading to the Deepwater Horizon explosion http://bit.ly/cicodl [new blog page: http://all-`

geo.org/highlyallochthonous/2010/05/drilling-for-oil-is-more-risky-than-it-used-to-be/]

AR, SH, and a few other planetary scientists often have discussions on scientific topics. Many of these are humorous and fun, but they also are useful for sharing scientific information (see an example quoted in Figure 17, Appendix 3).

More broadly, geoscientists on Twitter participate in fun hashtag memes such as one on which volcano would make the best lair for an evil scientist and another on how to summarize your research using *Lord of the Rings* terminology and characters.

1.3 Tutorials for Peers

These posts and tweets are intended for a sophisticated audience and show how to complete an analysis or create a visualization. Most of these are for techniques that are more broadly useful such as preparing a plot.

2 Doing Science

Posts in this category are about the practice of science, whether it is reading the literature, doing field or lab work, doing analysis, or writing up and presenting results. Posting can be part of personal knowledge management by helping authors work through readings and by encouraging them to read more broadly to explain news topics outside their primary field. Scientists also share methods they tried to attempt to solve a problem or code to do an analysis in order to get feedback. They explore ideas for future research and capture ideas and brainstorm approaches to problems.

Twitter is particularly useful in science to get quick help with an analysis problem, get feedback on a graphic, or to request a copy of a paper. Participants in the study also tweeted their activities in the lab and in the field.

Filter. Professionals in a field must read and keep up with the literature. Traditionally this was done through personal communications and preprints, through reading journals, and through attending local, regional, national and international meetings. More recently, scientists subscribed to e-mail lists and used automated alerts from databases and from journals (table of contents) sent by email. Some scientists use RSS feed readers to keep up with search alerts and journal tables of contents. The number of journals continues to grow and with increasing interdisciplinary work, it can be difficult to keep up unless a precise search is used for a database alert. Instead, many geoscientists use Twitter as a current awareness service, relying on colleagues to read and share interesting articles to narrow the firehose of new publications.

> "Makes me aware of literature and things like that that are coming out. I felt for a while that a part of my tweeting was part of that service…people were actually going and looking at what I was posting because it was so – almost like a journal feed. A curated journal feed if you want to look at it that way."(KA interview para 48)

Similarly, geoscientists who study phenomena related to natural disasters or who serve a practical role of early warning or advising preparation or recovery need to read and follow the news. Geoscientists in the study found that Twitter presented very early notice of natural hazards that posed great human and economic risks and had far reaching impacts. For example:

> "I was in New York and just prior to the science online conference and there was a big earthquake in Haiti and basically I wouldn't have known anything about it if I hadn't been looking at my Twitter account and it suddenly blew up. I knew to sort of check things out and it gave me an early example of how it was a useful way of keeping your finger on the pulse of what was going on" (CR interview para3).

Reading of natural hazards such as eruptions, mudslides, floods, tornadoes, and hurricanes, and then offering concise expert analysis also serves as communication with the public (see 6 below). The analysis makes the scientist more visible and available to journalists looking for expert commentary and explanations.

2.1 Reporting from field work

In both blogs and Twitter, the participants who go to the field to gather data (all but the planetary scientists) reported back if not in real time, then from the end of the day or the end of the trip. Most of the scientists did not share research data, but rather the difficulties of travel and the work, setting up and using the sensors and instruments, and pictures of beautiful scenery (see Figure 13). CB's purpose in field work is somewhat different. He leads groups of students and amateur enthusiasts and he takes high quality Giga-Pan images to be shared with other educators to be used in science labs to replace field work. He shares these images on his blog and so is sharing research data.

2.2 Reporting from lab work

Reporting from the lab was seen on Twitter, but not in the blogs in the study. SH often tweets from the lab while waiting for experiments to complete. She sometimes shares images from lasering rocks (see Figure 16).

2.3 Analyzing

These posts and series of tweets analyze data from public archives, show new visualizations, and present results. In some cases, they are in the format of small research articles and cite references. See Figure 14 for an example.

2.4 Requesting Assistance

In these posts the author explicitly asks readers to help solve a problem or provide resources such as copies of articles.

2.5. Building Science Community

Participants in this study care a great deal about the science community, communication with their peers, mentoring junior scientists, fair and just treatment of individuals, and inclusion. Over the years the scientists maintained their blogs, they used several different techniques to build the community.

1) They created and maintained a blog carnival called The Accretionary Wedge. A blog carnival is a periodic collection of posts. A leader will create a writing prompt or category and bloggers write on the topic and submit their posts. The leader then curates and annotates the posts and creates a summary. The summary can be posted on the leader's blog or on a blog just for the carnival.
2) They participate in memes and puzzles being sent around the community. These are common on Twitter as well as blogs.
3) They highlight new participants in the geoblogosphere and on Twitter. They also comment on blogs and reply to requests on Twitter.
4) They actively engage on workforce issues in science such as the leaky pipeline, harassment, and the underrepresentation of various groups. They comment on articles in their blogs and their Twitter streams and also write articles on how to be more inclusive.

3 Conference-Specific

Both blogs and Twitter are used to communicate about conferences.

3.1 Covering a session live

In early days of blogs, prior to Twitter, some scientists live blogged conference sessions. These posts were often stream of consciousness with some links to information as given out on the presenters' slides. With less reliable wireless internet access, posts were saved as drafts and sometimes posted later.

Participants in this study preferred Twitter over blogs for covering a session live.

Typology of session tweets:

- *Play-by-play*. These tweets are done as the speaker is talking and share what is being said.
- *Cross talk* among attendees or with remote parties. These tweets are with and among audience members in the room or readers not at the conference.

  `Intriguing hypothesis! #AGU12 RT @fiondella: I wonder if the #revolutionarywar led to a lot of forest gap disturbances, @YellowBuckeye? (AGU2012-3929)`

- *Color commentary* (3.2 Providing Color commentary) As in sports, color commentary is about the room, the audience, the method of presentation, and other aspects of the session beyond the substantive content.

  `Full house on Keith Beven's talk on #hydrology uncertainty and in next-gen hydrological models #AGU12 pic.twittercom/D514n9Sm (agu2012-2620)`

- *Summary*. These tweets encapsulate the major points of a talk in one to three tweets. These may be done during the question and answer period, the switch to a new speaker, or later.

  `“interesting talk by @MichaelEMann, including tree ring-only reconstructions underestimating vs. multi-proxy overestimating MWP warmth #AGU12” (agu2012-2047)`

- *Engagement with the topic.* Some session tweets work to make sense of, summarize, and link information from sessions to broader knowledge or other sessions.

  `Seems rather counterintuitive that smoother crust->more great earthquakes, but perhaps allows more coherent regional strain build-up? #AGU129 (AGU2012-3940)`

  Others just report the facts.

Attribution (or not) in session tweets

Methods used to attribute ideas to the speaker when tweeting from sessions has evolved. More recently, the convention is to put speaker’s last name, colon, and then statement of a research finding. In earlier conferences, names were often omitted. From time to time Twitter user names are also used, but not typically more than once per session. If no @ is used, why not? Possible reasons include: Because takes time to look up their account or because the writing is not for them. Perhaps some tweets from the middle of a series are intended for the people following in real time who are less likely to be confused. Tufekci (2014) describes subtweets as intentionally omitting the @username so that the person mentioned is not alerted.

3.2 Color commentary (see above)

3.3 From away from the conference

Some of the blog posts and tweets about conferences were lamenting missing a particular year or pointing to interesting things attendees shared.

3.4 Summarizing a conference

Conference reports – like trip reports – are common on the participants' blogs. At the most basic, these are compilations of tweets sent during the conference. More typically, the scientist provides a general overview of the conference or of a conference workshop or a particular day of the conference with highlights of interesting papers. Some posts also include links to the author's posters and talks (see Dissemination/Amplification).

4 Science News/Announcements

Lab blogs, in particular, are often used to announce job openings, accepted papers, defenses, etc. This is different from the news commentary explaining new research findings (6.2) and commentary on non-science news (9.3). Posts are often short with a summary and possibly a link.

4.1 Announcing job openings

Both blogs and tweets are used to share job openings in education, academia, including postdoc, and industry. Most of the blog posts announcing jobs were from that author's own institution, whereas jobs linked to on Twitter were from anywhere.

4.2 Announcing defenses, graduations

These announcements of upcoming defenses and successful outcomes as well as graduations are found on both lab blogs and on Twitter.

4.3 Announcing papers published

As with the other subcategories, these provide abstracts and links to the version of record. The dataset did not include examples of sharing pre-prints through the blog or Twitter or archiving pre-prints on the blog.

5 Teaching (being a teacher)

Three of the participants use their blogs to gather and embed YouTube videos that illustrate concepts for their classes. AJ pointed out that the videos can be kept there so during class she just needs to go there to find and play all of the links. She has gotten feedback from other teachers that these collections are useful to them, too.

Other posts in the category explain how to teach and talk about dealing with students, for example, dealing with students who have three grandmothers die during the course of a semester or whether or not to assign extra credit.

The professors reported the value they get in using both Twitter and blogs in their teaching. As they follow geoscientists outside their specific research area, they are exposed to news, updates, and media illustrating things they might discuss in more general lecture courses.

> "Little tips and tricks on certain things. Some web resource that has some interesting data or images that might be good for teaching. I'd say most of it is interesting science stuff I get on there [that] is more useful for teaching than for research. Teaching is more general. Once a week or so I'll find something really interesting through that medium that ends up being something I'll share with students."(BR Interview para 26).

5.1 Providing Advice for Students

Scientists in the study provided advice to students in picking advisors, picking programs, applying to graduate school, selecting research problems, and writing and presenting work.

5.2 Recruiting Students

Participants mentioned in interviews that their blogs and Twitter streams were useful in recruiting students. Besides announcements of openings (4a), advice to students applying (5a), getting to know the lab through the scientist's posts, there is some active recruiting encouraging candidates to apply.

5.3 Pointing to Educational Resources

Each of the participants who teaches described saving and also locating educational resources through blogs or Twitter. As CR said,

> "interestingly, now I have become a teacher I have found that having a number of years of blogging about [] in geology or earthquakes or things like that it has really given me a neat archive of material I try to put into lectures or use to provide a basic understanding. I would not have had that otherwise."(Interview para 35).

5.4 Explaining how to teach

Some posts discuss how to design a good lab experiment for students and, in particular, how to teach certain complex topics. For example, CB and his commenters discuss using Photoshop to better understand how two layers moved.

6 Social / Coordinating

Social posts serve to establish identity, build community, build group identity, and other social purposes. Participating in geoblogosphere memes serves a social function and the topics are often geosciences or teaching related.

6.1 Biographical/Confessional

These post discuss the person's life, their family, their jobs, and their goals for the future. Some are very introspective and intimate and others are biographical sketches that could appear at the end of an article.

6.2 Coordinating

Coordinating posts and tweets are used to arrange meetings, provide a schedule, and to find people in a crowd.

7 Public Communication of Science

Public communication is an important function for all the bloggers in the study. As found by Luzón (2013) in her study of posts that discuss literature, participants recontextualize scientific findings by providing definitions, paraphrasing, using metaphors, providing examples from daily life, links to additional research, and using visuals (p. 437).

The bloggers do public communication several different ways including posts explaining various concepts, popular science book reviews, commentary on new scientific findings, weighing in on a scientific controversy (or something that is not a controversy in science, but is in political or religious settings such as climate change and tectonic plate subduction).

Some scientists who use Twitter engage with followers who are not scientists by answering questions, debating or explaining controversies, and presenting more journalistic writing about science. Unlike blog posts with this function, tweets about hazards are usually one or two tweets with pointers to, for example, emergency management agencies or government data.

On Twitter it can be truly communicating with the public instead of at them:

> “You get to pick which scientist or whatever you want to get your information from instead of the normal model where it’s just like Fox News has picked this scientist to come talk to you and this is the one you’re going to get this information from whether you like it or not whereas on Twitter you can kind of choose your source” (SH para 48)
>
> If you tweeted me or [] or [] or all of these other people you’re much more likely to get an answer and get that personal interaction which is really valuable to see. I

can talk to a scientist. I could see that to settle bar disagreements. Why not?" (SH para 50)

7.1 Explain a science concept

In these posts the scientist provides an introduction to a basic concept at a high school or general college level. The posts are referenced later when discussing new work on a related theme. Together they can form a glossary or introductory text.

7.2 Review a new finding in more comprehensible terms

In contrast to posts for other scientists and similar to the basic science posts, these posts are used to discuss new results for a general audience. Sometimes they are used for a more realistic description of the importance of a finding.

7.3 Explain a natural hazard/disaster

For the two scientists who study hydrology and earthquakes, this category has particular relevance. The posts are used to gather witness reports from social media, official measurements from government instruments, news reports, and the author's expert analysis. The posts describe causes such as fault lines, impacts, and possible mitigations.

7.4 Review science history

In these posts, such as the example shown in Section 4.7.2, the author discusses the history of an instrument or a location or a method.

7.5 Review popular science books

These are book reviews for books found in a public library or on a news stand. Reviews cover treatment as well as accuracy.

7.6 Explain a scientific controversy (for public)

Other discussions of controversy are more about politics or religion. In this category of posts the author points to areas in which researchers disagree.

8 Entertainment

Posts for entertainment show beautiful landscape pictures (without detailed scientific explanations), share videos, or share comics.

8.1 Images

9 Politics, Religion, and Society

These posts are somewhat like the public communication posts, but are on topics outside of the author's research area. Example topics are creationism, school funding, gun control, and elections.

Some of the participants have tried to engage with "climate denialist trolls" on Twitter with limited success. KA found that trolls repeat boilerplate messages and disappear after a few tweets.

9.1 Reviewing books (not science)

Included in these are general and science fiction novels and children's books.

9.2 Commenting or advocating on political, religious, or social topics

Examples include discussing atheism.

9.3 Commenting on news (not science)

Examples include commenting on the Boston Marathon bombing, school education reform, elections, and gun control.

10 Meta (about the blog or Twitter)

These posts discuss the mechanics of the blog such as a change to the template or addition of a blogroll.

Blogs were used more often to post tutorials for peers, publish essays explaining basic science concepts, and for posting book reviews. Blogs are used for more thoughtful, well-developed, and edited essays. They are used to treat topics that require more explanation and context.

Twitter was used more often to point to readings, to request assistance, to announce new publications, and on topics related to politics or religion. Scientists in the study took advantage of the broader reach and quicker interaction to request assistance on Twitter. Participants of the study who either spent years building a reputation for the blog or who blogged as a guest on another site often did not want to post too much if any political or religious content so as not to distract from the primary message.

Conference Twitter was used more often to provide live coverage of conference sessions. Liveblogging of conference sessions was quite popular several years ago but has been almost entirely replaced by Twitter.

5.1.3 RQ 1.3 What benefits do participants report receiving as a result of using these new ICTs?

One way geoscientists make meaning of blogs is through community building and maintenance. As found by Dennan (2014) these blogs do form a sort of community of practice with, as she said, “mutual engagement, joint enterprise, and shared repertoire” (p. 353). Games such as “Where on Google Earth” and “geopuzzles” seek to include peripheral participants in a more active way.

5.1.3.1 **Blogs**

Posting some scientific explanation or analysis online makes it available for critique and comment. Participants found that readers commented on their posts with corrections and clarifications as well as to point to sources of additional information.

Sharing information in online forums such as blogs contributes to the author's profile and reputation (Wasko & Faraj, 2005) and is part of being a member of the community (Wasko & Faraj, 2000). Participants reported increased recognition, readership, and new collaboration opportunities as a result of sharing information on their blogs. Participants also became more findable as public experts (Peters, 2014) for journalists, advocacy groups, interest groups, and students. For example, local groups interested in guest speakers or tour guides on geological issues find participants through their blogs.

One participant found that tweeting and participating in a podcast helped her in her job search. The university was looking for a professor who was strong in public outreach and the podcast and Twitter stream demonstrated her proficiency. She attributes being brought in for an on campus interview to this exposure.

This increased findability also works for recruiting new students and finding new collaboration partners. Two participants indicated they had formed new collaborations and gotten new funding due to the information they posted on their blogs.

Efimova, Fiedler, Verwijs, and Boyd (2004) discuss the "distributed apprenticeship" function of the how-to descriptions on blogs. Scientists can use annotated images and detailed descriptions in blogs to learn how to do some aspect of scientific work; they can learn how to complete a task on their own time and in their own space perhaps distant from the original author. When analysis scripts are included or linked, it is even easier to incorporate the new knowledge into the reader's own work.

5.1.3.2 **Twitter**

Using Twitter and being retweeted by a celebrity scientist can raise the scientist's profile. Liang et al (2014) found that scientists whose research was mentioned on Twitter had a higher impact as shown by their h-index. There is a new research area studying if and how disseminating scholarly work in SCTs changes the impact (Altmetrics).

Several of the participants mentioned the benefits they get from bouncing ideas off one another (KA para 53)

> It would be a way to bounce things off of people …'Hey this is how I'm interpreting this' and [] who's a dynamics guy could say or [] could be like 'oh that's kind of crazy and here's why. Here's this paper that I'm working on that shows that this isn't what's going on' (AR Interview para 53)

5.1.4 RQ 1.4 How do participants and non-participants view the SCTs?

5.1.4.1 **Blogs**

Participants

Bloggers enjoy posting to their blogs and communicating with both regular readers and new readers who find their work through search engines. However, at this stage of adoption, the participants sometimes view blogging as a routine activity that can be a burden due to the time it can take to prepare a post to their high standards. An exception is lab blogs that are routinely used to share news and announcements and are easily kept up to date. Nevertheless, as Jarreau (2015) also found, the scientists are still motivated to blog for outreach, to counteract inaccurate media reports, and to interact with their community.

According to Luzon (2013) scientist bloggers view popular communication on their blogs as a duty to correct inaccurate media reports or pseudoscience. That is observed in this study; furthermore, participants feel a duty to report on local geological events and large-scale natural disasters even if the cause (e.g., hurricane, sink hole, tornado) is not directly in their field of research. There is tension between accurate reporting and the desire to contribute a timely report on an event. Blog reports are resources for journalists and the public, so early reports if inaccurate or if the science is not well-understood can cause damage.

Peripheral Participants

Readers of blogs report that they view blogs as providing valuable insight into an area of science they might not know much about and also into life as a scientist. For example, as in this observation on a peripheral participant in AJ's lab blog:

> Amateur geologist, author, and fantastic human being, Dana Hunter, has written a post in which she talks about how my blogging has inspired an appreciation for hydrology that she never otherwise would have developed. I won't quote from her post here, but I wanted to bookmark it someplace special so that I could come back to it when the demands of teaching, research, and parenting get me down. If nothing else, I now know my blogging has made a difference for somebody that I've never even met.
>
> I think that's part of the power of blogging – it not only can bring the world into the classroom, but it broadens the classroom into the world. (http://all-geo.org/jefferson/about-the-best-compliment-i-could-get-or-why-blogging-is-worthwhile/ retrieved 11/1/2014).

Non-Participants

The response of non-participant supervisors and co-workers depends very much on the institution and its public communication approach. Woods Hole and

Columbia's Lamont–Doherty Earth Observatory, for example, are very supportive of their researchers' blogging and tweeting. Other organizations are indifferent to their scientists' blogging as long as the scientists do not break any rules about sharing sensitive information. Co-workers are often skeptical of bloggers but will use information found on blogs as they would use any other information on the internet.

5.1.4.2 **Twitter**

Participants

Regular participants in tweeting report that it provides a strong communication link to a world of friends who are often connected, offer valuable advice quickly, and who are supportive of their efforts. It is also a way to keep apprised of the news both in science and in general.

Peripheral Participants

The eighth interviewee is more of a peripheral participant on Twitter. She joined to more easily keep up with blog posts by the Planetary Society and others. She had not used RSS feeds and the site was reorganized to make keeping up more difficult. She does post from time to time, but mostly amplifying dissemination of science team publications. Twitter is valued as a way to keep up without requiring peripheral participants to contribute new content.

Non-Participants

KA, who works in an organization heavily invested in outreach and public communication, has been supported in his tweeting. Other organizations are indifferent to their researcher's use of social media as long as there are no violations of any explicit or implicit rules such as divulging sensitive information.

AR has been teased at work for tweeting by scientists who are surprised anyone reads his tweets. For the planetary scientists, at least, there is an in-group that communicates regularly on Twitter and an out-group that does not.

5.1.5 RQ1.5 Interactions Among Channels

Participants in the study often maintain both blogs and Twitter accounts. They also attend scientific conferences and publish their work in scientific journals. They e-mail, talk on the phone, instant message, and use many other ICTs. How do these channels interact? Below are two possible combinations of channels.

5.1.5.1 **Interaction between Twitter and Blogs**

Many scientists who maintain blogs also tweet. This section discusses the interactions among blogs and Twitter for both readers and authors.

First, many bloggers started tweeting only after having an established blog. One participant described his initial use of Twitter to publicize his posts for wider distribution. Twitter is often used to announce new blog content as well as to link to other scientists' blogs as information sources and to recommend them.

Second, commenting on blog posts can happen on Twitter. Instead of commenting on the blog or writing a post on his or her own blog and linking back, readers post comments on Twitter so that the conversation is progressing in several different places at the same time.

Going in the other direction, as tweets are used to announce blog posts, sometimes blogs are used to expand on an idea or concept first mentioned in a Twitter conversation. Some bloggers in the study use a widget in their sidebar to display their tweets on their blog.

Finally, as mentioned above, Storify and embedding can be used to curate and preserve tweets on a blog for better access and future reference.

5.1.5.2 **Interaction Among Twitter, Blogs, and Conferences**

Twitter is often used at conferences to cover sessions with live substantive tweets, color commentary, and coordination tweets as well as before, during, and after conferences for coordination, social and dissemination purposes. Currently, blogs are not used much for live coverage of conferences but are used for coordination and announcement posts beforehand and summaries and trip reports afterwards. These SCTs in conjunction with video or audio feeds, print posters, and face to face interactions mean communication occurs in multiple channels simultaneously. In the data, there were traces of conversations switching between face-to-face and Twitter.

Quan-Haase and Wellman (2005) define local virtuality as communicating online even though physically proximate and hyperconnectivity as instant connectivity and also being connected via multiple channels simultaneously. In their series of studies, they look at communities of practice within a company that provides the employees with the communication tools and connectivity required. They also found that task interdependency was an important indicator. Ten years later (and thirteen years after the study), we find both local virtuality at the meeting within sessions and hyperconnectivity among geoscientists at the meeting, when the scientists are providing their own equipment and have no task interdependency. Others have studied shared backchannel communication at meetings (McCarthy &

boyd, 2005), but communication was maintained within the conference, and was not persistent.

Participants in the presentation with others tweeting report that it is helpful in providing links to additional information, answering questions, and repeating or clarifying anything that was missed. Scientists watching the hashtag while watching the streamed video also find the color commentary useful to get a better feel for the audience reactions to the talk.

5.2 RQ2 How do blogging and microblogging support data, information, and knowledge creation, seeking, and use in science?

5.2.1 Blogs

Knowledge creation in blogs happens through writing and through connecting with others (Fiedler, 2003; Paquet, 2002). In a knowledge management sense, blogs are used to codify and gather information from multiple places to make it more searchable and to learn by rephrasing and re-writing. One participant noted that you don't really know something until you try to teach it to someone else. By codifying the knowledge this way, it becomes available for searchers as well. For example, one image shared by a participant sparked a research project by a local student who later presented his work at a regional geology conference. Sharing code and citations makes it easier to reuse the information. Images of field sites and lab set-ups may convey more knowledge than is available in the limited write-ups available in published articles. Images of field sites shared on blogs as part of weekly series might preserve them for later reference should there be a mudslide, earthquake, or even manmade changes like those caused by resource extraction activities or construction. Bloggers who use geographic tags on their images make them findable for later researchers.

Schmidt (2007) outlines the process of selecting blogs to read as a set of procedural rules in the information management context of blogging practices. In his framework, selection is related to the topic as in for professional purposes to keep up-to-date or for social purposes to renew social ties. Participants in the study do both:

read blogs to learn about different areas of geosciences for their own knowledge and for material for teaching and to keep up with colleagues.

It is clear from comments the blogs receive as well as the statistics one participant shared that that blogs are easily findable by middle school, high school, and lifelong students. Posts with clear explanations are useful many years later. For example, CR's explanation of a mud volcano was referred to more than eight years later.

5.2.2 Twitter

Twitter is used as an alerting system and a filter system to maintain awareness of new research articles, conferences, data sets, funding opportunities, and educational resources. As CR said, "to make sure I'm … reading the right papers." KA scans new journal tables of contents and alerts for the articles he judges will be of greatest interest to his followers and then posts them to his stream. Twitter to some extent replaces RSS feed readers because the results are better curated and more relevant.

> "[Twitter] makes me aware of literature and things like that that are coming out. I felt for a while that a part of my tweeting was part of that service. I was reading interesting things and I thought, hey, I'll share this because people might find it interesting" (KA interview para 48)

Likewise, both BR and AJ have mentioned finding educational resources on Twitter that they then save on their lab blogs to share with their students. Searching Twitter has been difficult and unreliable[3], so monitoring the stream of posts is

[3] As of Fall 2015, it appears that the advanced search has been improved significantly.

important. This leads the scientists to choose accounts with the highest signal-to-noise ratio and to unfollow accounts that post too frequently. As SH said, “The more people tweet the more I’m likely to unfollow them if I’m not getting anything out of their content.”

5.3 RQ3 The Framework Revisited

The third research question asked if the framework, based on the literature, is suitable for describing communication in science. I found that the framework proved useful in describing the communication of geoscientists using blogs and Twitter. A type of communication partners was added: writing for oneself (see Section 5.3.1). Several additional purposes were discovered and others were modified (Section 5.3.2); these are more likely found in social media than in the traditional channels discussed in the literature used to build the framework.

This section looks at the same data through the lens of the framework, arranging findings for both blogging and microblogging in sections according to the framework. This serves two purposes: It gives a systematic description that unifies the findings and it illustrates the framework.

5.3.1 Communication Partners

This study examined, for the most part, only one side of conversations; the findings deal primarily with intended communication partners. Some conclusions can be drawn from feedback participants reported receiving in response to their communications. In blogs, for example, interactivity comes through commenting on the blog, but also elsewhere in social media. For example, posts are often announced by and linked from Facebook and Twitter feeds. Viewers of the announcement of a new post might comment at the announcement or on their own site instead of at the original post. Comments may also be received in person or through e-mail. Many readers of blogs never comment at all. A meme found in the data asks readers to “de-lurk" or announce themselves and provide some information. Comments and interactivity deserve further study.

The study did not attempt to compile complete conversations, but at least for conference tweets when it was clear a randomly selected tweet was part of a larger conversation the remaining tweets of the conversation were sought. Other tweets in the conversation not using the hashtag were omitted. Accordingly, the study provides only a fragmented and partial view of the communication partners.

Table 17. The framework of communication in science revisited

Section	Name	Subtypes
1	**Features of the Communication Partners**	
1.1	Number of communication partners	• *Self • One (interpersonal) • Few (small group) • Many (public) • Unknown
1.2	Individual features of the partners	• Education or sophistication General public • Interested public • General science • Same • Experience and training (communication specific) • Demographics • Cognitive dispositions • Social-personal dispositions • Communicative dispositions • Relational dispositions
1.3	Match and relationship of communication partners	• Match in education/sophistication • Pre-existing relationship • *Match in research paradigm
2	**Purpose of the communication activity**	
2.1	Dissemination	• *Amplification
2.2	Preservation	
2.3	Certification	
2.4	Discourse	
2.5	Societal Benefit	
2.6	Identity	
~~**2.7**~~	~~Rewards~~	
2.8	Learning/teaching	• Advice • How a tool works
2.9	Persuasion	
2.10	Evaluation or Opinion	
2.11	Coordination	

Table 17. The framework of communication in science revisited, cont.

2.12	Social	• Be part of a group • Request comments/interaction • Identity • *Community building • *Recommendation/endorsement
2.13	Entertainment	• Humor
	*Express Frustration	
3	**Features of the message**	
3.1	Topic	•
3.2	Type of Content	• Data • Methods/algorithms/workflows • Analysis • Theoretical/philosophical • Opinion/evaluation • Results • Memoir/confessional/biographical • *Bibliography/collection • *Observation • *Commercial • *Pointer Table 16 • Science (for scientists) ▪ Pointing to readings ▪ Discussing scientific topics ▪ Tutorials for peers ▪ Doing Science ▪ Reporting from field work ▪ Reporting from lab work ▪ Analyzing ▪ Requesting Assistance ▪ Building Sci Community • Conference Specific ▪ Covering a session live ▪ Color commentary ▪ From away from the conference ▪ Summarizing a conference • **Sci News/ Announcements** ▪ Announcing job openings ▪ Announcing defenses, graduations ▪ Announcing papers published • **Teaching (being a teacher)** ▪ Advice for Students ▪ Recruiting Students ▪ Pointing to Educational Resources ▪ Discussing how to teach • **Social**

		▪ Biographical/ Confessional ▪ Coordinating • **Public Comm. of Science** ▪ Explain a science concept ▪ Review a new finding in more comprehensible terms ▪ Explain a natural hazard/disaster ▪ Review science history ▪ Review popular science books ▪ Explain a scientific controversy (for public) • **Entertainment** ▪ Images • **Politics, Religion, and Society** ▪ Reviewing books (not science) ▪ Commenting or advocating on political, religious, or social topics ▪ Commenting on news (not science) • **Meta** (about the blog or Twitter)
3.3	Register	
3.4	Language	
3.5	Structure	None to well-structured or highly organized
3.6	Persistence	None to archived
3.7	Review or Quality Control	

Table 17 The framework of communication in science revisited, cont.

<table>
<tr><th>2.4</th><th colspan="4">Communication channel</th></tr>
<tr><td rowspan="3">Layer 1</td><td rowspan="3">Physical layer and basic transmission protocols</td><td>Face-to-face</td><td colspan="2" rowspan="3">Copresence
Visibility
Audibility
Cotemporality
Simultaneity
Sequentiality
Reviewability
Revisability
Coherence
Hyperlinking</td></tr>
<tr><td>Print</td></tr>
<tr><td>Technologically mediated (radio, telephone, internet)</td></tr>
<tr><td rowspan="7">Layer 2</td><td rowspan="7">Means of expression and advanced functions of software</td><td></td><td>Non-linguistic</td><td>Linguistic</td></tr>
<tr><td>Auditory</td><td>Sounds
Instrumental music</td><td>Spoken word</td></tr>
<tr><td>Visual</td><td>Images/pictures
Models
Still
Moving</td><td>Text</td></tr>
<tr><td></td><td colspan="2">Icons
Pictograms
Sign Language</td></tr>
<tr><td>Tactile</td><td>Models</td><td>Braille</td></tr>
<tr><td>Other senses (smell, taste, proprioception)</td><td colspan="2">Typically only applicable in virtual reality settings</td></tr>
<tr><td>Audiovisual, Multimedia/hypermedia</td><td colspan="2">Combining multiple means of expression.</td></tr>
<tr><td>Layer 3</td><td colspan="2">Conventions and etiquette</td><td colspan="2"></td></tr>
</table>

5.3.1.1 Number of communication partners

From the text and @s, some tweets were responses to individuals or small groups even though they are available for any follower of the stream or indeed any visitor to read. This differs from hallway conversations in person at conferences where discussions may be overheard, but social norms typically restrain others from following the conversation and reporting on it. In other words, the variable *number of communication partners* has not changed in the framework, but there should be a more nuanced view due to the affordances of the channel.

Many of the blog posts were intended for broad audiences of like geoscientists or the interested public or, in the case of two posts on *Clastic Detritus*, for a group of Subduction Deniers.

5.3.1.2 Education or sophistication

The scientific background knowledge is clearly a factor in how the participants in this study crafted their messages on Twitter and on blogs. On the one hand, the planetary scientists chatting amongst themselves on Twitter make jokes about physics, chemistry, dwarf planets, and about obscure funding mechanisms. On the other hand, three of the scientists created blog posts explaining concepts in geoscience for members of the interested public who may not have recent or significant study or training in the field.

Book reviews posted on *Mountain Beltway* were not always related to science, but were written in a sophisticated way that would not be of interest to the least educated members of society.

In both blog posts and tweets, the authors were posting advice for students. For example, on *Highly Allochthonous* there is a post about a summer research experience program for undergraduates. Posts for students and prospective students assume interest and some disciplinary knowledge beyond what is expected of members of the public, but not to the level of scientists in or outside of the research area. These posts may also have more links to additional information and may be more likely reveal life as a scientist descriptions as a recruiting technique.

5.3.1.3 **Match and Relationship of communication partners**

In addition to the concept of matching with respect to educational background or research experience, match includes research paradigms (Kuhn, 1996) or social worlds (Fujimura, 1992). In other words, the parties in the communication may have similar educational backgrounds and may be part of the same research area but differ in research methodologies, interpretations, or philosophies. In terms used by Kuhn (1996), communicating across paradigms can be very difficult.

An example scientific controversy from the dataset among researchers with matching research backgrounds is the "arsenic life" controversy, which was discussed primarily during the AGU 2010 conference Twitter stream but also in two blog posts. An astrobiology researcher reportedly found an extremophile bacteria that used arsenic instead of phosphorus to build its DNA (see summary here: http://www.theatlanticcom/technology/archive/2012/07/the-case-study-of-arsenic-life-how-the-internet-can-make-science-better/259581/). The results were questioned immediately on Twitter and blogs, but the researcher and her organization discounted concerns because they were expressed outside of traditional channels. Later, two organizations did publish peer-reviewed refutations in the same scholarly journal.

5.3.1.4 **Self as communication partner**

Blogs can be useful for personal knowledge management, learning a new topic, or keeping track of what you have seen or read. In these cases, the intended or unintended audience is the future self.

5.3.2 Purpose

In the literature and therefore the framework, both explicit and implicit purposes are combined with motivations. Some of these motivations or even unanticipated consequences of the communication are important in understanding how scientists make meaning of blogs and Twitter, but they are not strictly speaking communication purposes. For example, a scientist may post links to videos to be shown in class that afternoon for ease of access. This is a preservation purpose as well as teaching. When those same videos are found in a search she does later to prepare for another course, they serve a personal knowledge management function. When potential students find the blog and view all of the interesting content, the collection of posts may be persuasive. When colleagues find them they often do give feedback and this may help form a community of educators. Likewise, the primary communicative purpose to publish a journal article is to disseminate the results, but the motivation may be more of a requirement for tenure or promotion. This study focuses primarily on communication purpose and less on rewards and motivation.

5.3.2.1 Dissemination

The primary tool for disseminating geoscience research is the peer-reviewed journal article. Depending on the area of geoscience and the funding source, data sets, conference presentations, and monographs are also used.

Add Amplification. Blogs and Twitter are also used for dissemination in amplifying the signal from the scientific literature published through traditional means.

Add Filter. Filtering is an important function in successful dissemination. Use of blogs as a filter has been noted from some of the earliest descriptions (e.g., Blood, 2002). Authors collect, link, and annotate information from around the internet. In the dataset, this is sometimes compiling a list of tweets on a subject as in Figure 10 but it can also be a carefully curated collection as in the Accretionary Wedge blog carnivals, or an effort over time to point to the best articles on a topic.

> “[Twitter] makes me aware of literature and things like that that are coming out. I felt for a while that a part of my tweeting was part of that service. I was reading interesting things and I thought hey I’ll share this because people might find it interesting. … people were actually going and looking at what I was posting because it was almost like a journal feed. A curated journal feed if you want to look at it that way.” (KA interview para 48)

Participants who are also educators do this filtering for use in class as examples or directly for their students to access: “I felt like I had a lot of stuff coming across my radar, a lot of it was cool, if I could sort of filter out the coolest 30% and put that into a stream then I could address my students to sip from that stream.” (CB interview para 10).

> “When I'm going to show a video for class... I'll post it there. I got some feedback the other day that the blog is great because it has some really great teaching resources” (AJ interview para 29)

5.3.2.2 **Preservation**

In describing preservation when laying out the framework in Section 2.2.2 above, the concept was more archiving for longer term preservation and access to a broader audience. In practice, Twitter with its difficulties in search and retrieval from the archive does not do preservation in this sense. Blogs and Twitter do, however, work for short-term preservation in the sense of personal knowledge management and keeping found things found (Bruce, Jones, & Dumais, 2004). Users may tweet conclusions drawn from reading an article or things they want to remember to read later.

While this is done some in Twitter, it is more common in blogs. Scientists may use their blog as a sort of lab notebook to record and preserve how they solved a problem. Their primary purpose may be to get feedback or ideas how to solve the problem more efficiently, but the preservation purpose is still important. They may also use their blog to preserve notes they have taken and reactions they had to readings they completed or conference sessions they attended.

Interestingly, blogs are also used to preserve Twitter content. Through tools like Storify (http://storifycom) and the embedding feature from Twitter, bloggers can capture and annotate a collection of relevant Tweets in a timeline while still retaining time stamping, geocoding, and attribution to the originator (see Figure 10). Both services maintain the text of the tweet even if the original is deleted.

5.3.2.3 **Validation and Certification of Content**

Certification was not observed in the data. As mentioned above, certification is communicating information to receive an *imprimatur* or official recognition of an idea. Paul (2004) suggested that scientists may use informal communication with the public to certify ideas or to gain wider recognition as the source or authority on an idea, but that was not observed in this data.

5.3.2.4 **Discourse**

The discourse described in the framework is more the conversation that happens through citation networks and building on other work. This is not visible in the dataset; however, there is significant ongoing discussion on Twitter and in the comment sections of blogs. On Twitter, groups of scientists online at the same time discuss papers, events, memes, and news.

5.3.2.5 **Societal benefit or applications**

Blogs and twitter are often used to increase dissemination of research for societal benefit and applications. For example, AJ often posts analyses and summaries of the literature to describe key concepts for flood mitigation and ground water safety. KA has gotten feedback that his analyses of drought conditions and historical precedents are useful to farmers who also interact with him via Twitter to ask questions and get additional details.

5.3.2.6 **Identity**

The concept of identity appears two times in the modified framework. Here it is used for disseminating scientific results and building a research identity as a scientist through this dissemination. See Section 5.3.2.12 for building of a social identity. Blogs, when used to disseminate the products of research (or amplify the formal dissemination), the data sets, or the research methods, can be very useful in establishing a research identity. Recent articles analyzing the utility of web and social media references in measuring scientific impact (altmetrics) show this posting of information does have a role in establishing identity.

5.3.2.7 **Rewards**

Visibility of research is important in getting positions in science, winning grants, and attracting students. Tweeting or blogging about published research increases the visibility and may increase the number of article downloads and eventually citations received. The altmetrics research area of bibliometrics studies the use of this type of metric to assess impact. One scientist reported that being offered a professorship was related in part to her participation on blogs, Twitter, and podcasts as it demonstrated she was comfortable communicating science with the public, which was an important skill for the position. Two other participants reported new international research collaborations stemming from their use of social media.

5.3.2.8 **Learning/teaching**

Participants mentioned aspects of learning and teaching throughout the dataset and the interviews. One participant reported “I do learn things from people I follow. Little tips and tricks on certain things.”(BR interview para 26).

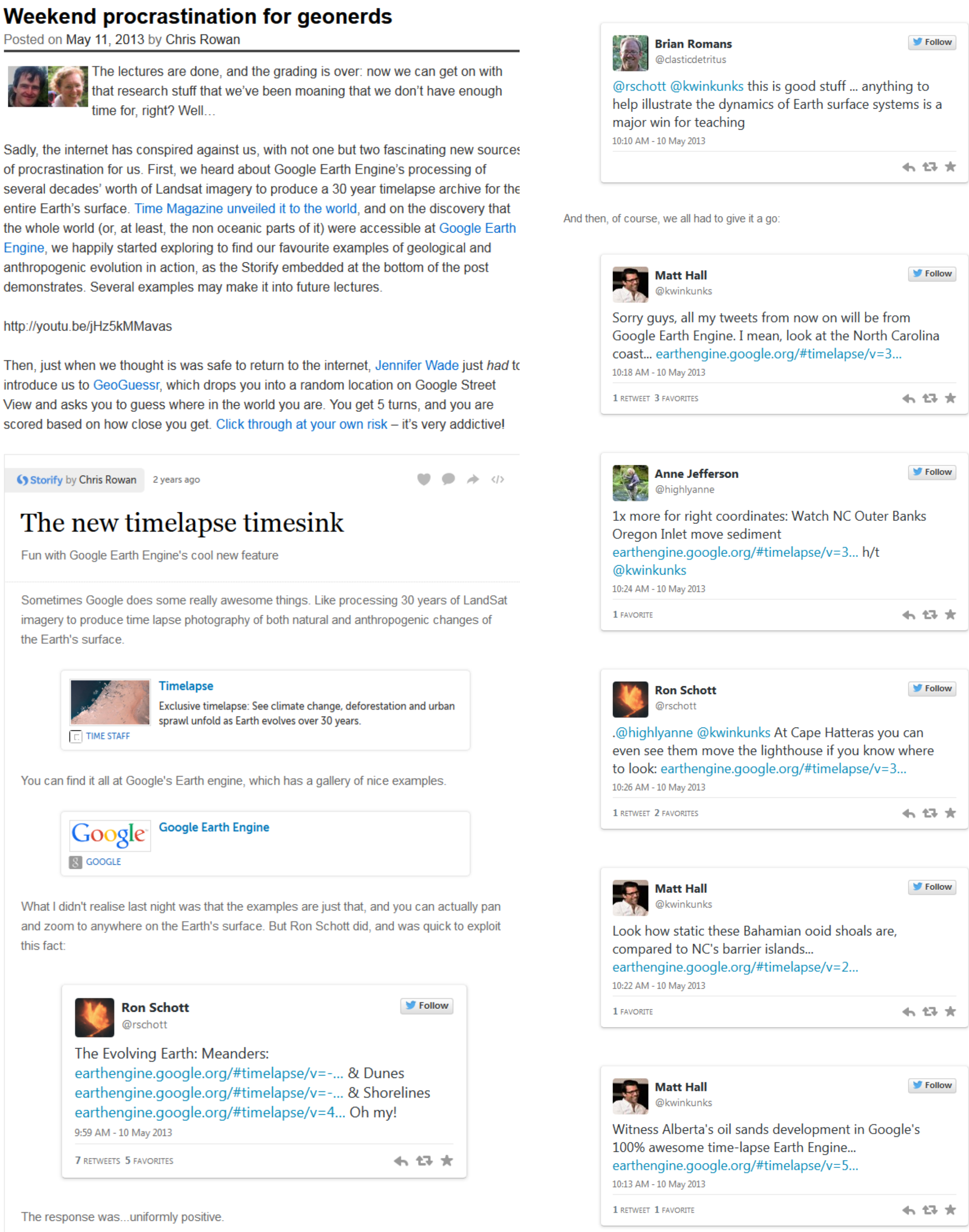
Teaching was a primary reason several participants started using blogs and why they continue

> “After my PhD when I was working in industry for a few years it kind of fulfilled a teaching itch – sharing things. Not teaching in an interactive way but just writing and sharing something interesting – people could learn from it maybe.” (BR para 32).

Some blog posts are long articles explicitly intended to teach interested readers a concept from the author’s field. These posts outline the topic and use metaphors, diagrams, annotated images, and other methods to convey the scientific meaning in an understandable language. Most of these posts cite literature, as well, as an authority and a source of additional information.

Other ways of teaching and learning found in the dataset include asking questions, describing life in academia or as a scientist, providing advice, and teaching how a specific tool can be used.

Asking a question. Part of using a blog or Twitter for learning is working through articles and writing up the results “That process of having to break it down and deal with it – put it into simpler words – I find helpful to me because it makes me... Old saying you don’t really understand something until you can explain it to someone else”(CR interview para 35). Another part is explicitly asking for assistance in understanding something or posting a tentative understanding and requesting



Weekend procrastination for geonerds

Posted on May 11, 2013 by Chris Rowan

The lectures are done, and the grading is over: now we can get on with that research stuff that we've been moaning that we don't have enough time for, right? Well…

Sadly, the internet has conspired against us, with not one but two fascinating new sources of procrastination for us. First, we heard about Google Earth Engine's processing of several decades' worth of Landsat imagery to produce a 30 year timelapse archive for the entire Earth's surface. Time Magazine unveiled it to the world, and on the discovery that the whole world (or, at least, the non oceanic parts of it) were accessible at Google Earth Engine, we happily started exploring to find our favourite examples of geological and anthropogenic evolution in action, as the Storify embedded at the bottom of the post demonstrates. Several examples may make it into future lectures.

http://youtu.be/jHz5kMMavas

Then, just when we thought is was safe to return to the internet, Jennifer Wade just *had* to introduce us to GeoGuessr, which drops you into a random location on Google Street View and asks you to guess where in the world you are. You get 5 turns, and you are scored based on how close you get. Click through at your own risk – it's very addictive!

Storify by Chris Rowan 2 years ago

The new timelapse timesink

Fun with Google Earth Engine's cool new feature

Sometimes Google does some really awesome things. Like processing 30 years of LandSat imagery to produce time lapse photography of both natural and anthropogenic changes of the Earth's surface.

Timelapse
Exclusive timelapse: See climate change, deforestation and urban sprawl unfold as Earth evolves over 30 years.
TIME STAFF

You can find it all at Google's Earth engine, which has a gallery of nice examples.

Google Earth Engine
GOOGLE

What I didn't realise last night was that the examples are just that, and you can actually pan and zoom to anywhere on the Earth's surface. But Ron Schott did, and was quick to exploit this fact:

Ron Schott @rschott Follow
The Evolving Earth: Meanders: earthengine.google.org/#timelapse/v=-... & Dunes earthengine.google.org/#timelapse/v=-... & Shorelines earthengine.google.org/#timelapse/v=4... Oh my!
9:59 AM - 10 May 2013
7 RETWEETS 5 FAVORITES

The response was...uniformly positive.

Brian Romans @clasticdetritus Follow
@rschott @kwinkunks this is good stuff ... anything to help illustrate the dynamics of Earth surface systems is a major win for teaching
10:10 AM - 10 May 2013

And then, of course, we all had to give it a go:

Matt Hall @kwinkunks Follow
Sorry guys, all my tweets from now on will be from Google Earth Engine. I mean, look at the North Carolina coast... earthengine.google.org/#timelapse/v=3...
10:18 AM - 10 May 2013
1 RETWEET 3 FAVORITES

Anne Jefferson @highlyanne Follow
1x more for right coordinates: Watch NC Outer Banks Oregon Inlet move sediment earthengine.google.org/#timelapse/v=3... h/t @kwinkunks
10:24 AM - 10 May 2013
1 FAVORITE

Ron Schott @rschott Follow
.@highlyanne @kwinkunks At Cape Hatteras you can even see them move the lighthouse if you know where to look: earthengine.google.org/#timelapse/v=3...
10:26 AM - 10 May 2013
1 RETWEET 2 FAVORITES

Matt Hall @kwinkunks Follow
Look how static these Bahamian ooid shoals are, compared to NC's barrier islands... earthengine.google.org/#timelapse/v=2...
10:22 AM - 10 May 2013
1 FAVORITE

Matt Hall @kwinkunks Follow
Witness Alberta's oil sands development in Google's 100% awesome time-lapse Earth Engine... earthengine.google.org/#timelapse/v=5...
10:13 AM - 10 May 2013
1 RETWEET 1 FAVORITE

Figure 10 Example of embedded Tweets

clarification. On a blog this may be less successful than on Twitter because the request might not be seen by the people who know the answer and have time to respond. If the blog does have high visibility, the ability to include code and output and explain the issue is more attractive. Other places specifically for asking questions like StackOverflow get more visibility from people who can answer quickly if it is a programming issue.

> "I wonder how the findings in talk by @holy_kau influences interpretation of Koutavas individual foram analysis? #agu12" (AGU2012-1447)

> "Ok brilliant geo tweeps. What's an LIP? #AGU12"

How academia/life as a scientist works. Mentoring is a specific type of teaching. In the blogs, in particular, but also in the Twitter streams, scientists provide advice and mentoring on completing graduate work, doing a job search, negotiating start up details, getting tenure, and working on grants.

Advice. Tweets and blog posts in this category include information primarily from the author's experience in science and in mentoring through citation of the scientific literature. They included posts on how to prepare a poster, how to prepare images, how to give presentations (e.g., "#AGU10 speakers! Please don't read text off your slides. Look at the audience talk about your science with us. Reading slides aloud = lame."), how to conduct a job search, selecting publication venues, and other similar topics.

How a tool works. These blog posts and tweets were aimed at different audiences. Some, like what is shown in Figure 5, could be used for scientific purposes by geoscientists or could be used for fun by curious or interested non-scientists. Other blog posts provided details and software scripts for complicated analysis that only a scientist in the research area would do. These posts also serve a personal knowledge management function (see5.3.2.14).

5.3.2.9 **Persuasion**

As mentioned in Chapter 2, some persuasion is found in most scientific writing to convince the reader of the interest of the research problem, the appropriateness of the research method, and of the interpretation of the results. Beyond that level of persuasion, in the conference tweets there were advertisements for sessions (see also Coordination 5.3.2.11), and in both tweets and blogs there were examples such as encouragement to fill out surveys, participate in blog carnivals, submit papers and comment on blog posts to answer questions or de-lurk (see 5.3.2.12).

Beyond this mild persuasion, three of the bloggers participated in political or religious discussions. Posts were geared toward persuading readers to be atheist, vote Democrat, and contact lawmakers about state laws about how science is taught in schools. A guest post by a scientist who primarily tweets aimed to persuade the reader to contact his or her congressman regarding NASA funding for planetary science.

Unlike articles from the marketing literature that describe product endorsements and aim to increase conversion of readers to purchasers through virtual community creation, the persuasion to action here is primarily non-commercial. Similarly, the blogger participants are aware of approaches to blogging that gain broader readership and are persuasive, but for the most part do not expend effort in persuading readers to visit their site, comment, or reshare for the site’s own sake, only to build community, encourage participation, or fundraise for charity (compare to top bloggers in Ranger & Bultitude, in press).

5.3.2.10 **Evaluation or opinion**

Some amplification tweets and posts provided commentary and evaluation on the linked item. Also in the set were book reviews.

5.3.2.11 **Coordination**

Coordination activities were overwhelmingly related to coordinating activities at conferences (151 of 153 times the code was applied). Neither channel studied has cotemporality to the extent that they can be used to, for example, coordinate measurements using a shared instrument. The coordination found typically describes where the author will be for the day with room numbers and maybe if they plan to tweet the talk. Occasionally the messages will be more personal, @ a user to ask where they are or to schedule a meeting. Online acquaintances may not have detailed contact information so may broadcast location in order to have a safe and non-threatening meet-up.

5.3.2.12 **Social**

As is to be expected from social media, many of the posts were social in nature, used to build community, to establish and maintain social contacts, and to build social identity (compare to identity establishment as part of dissemination, Section 2.2.6).

Community building. Notwithstanding that these communication channels were initially built to encourage individual expression, many different methods to build cohesive communities have developed. For example, the Accretionary Wedge blog carnival is now inactive but was a popular collaborative activity. Each issue – each month in its heyday – a volunteer editor would select a topic, geoscientists would write posts on the topic and submit them for inclusion, and the editor would post an introduction and curated list. The topics were general to be inclusive for the wide variety of geoscientists but would still form a writing prompt.

Individual participants also work to build and maintain the geoblogosphere community. CR of *Highly Allochthonous* created a collection of feeds from blogs and lists new posts on Twitter. CR and AJ also mentor newer bloggers with the Erratics series hosted on their site. Likewise, BR has posted summaries of events around the geoblogosphere to bring attention to other bloggers.

Other quizzes and memes also serve to reinforce the community. The most popular of these is the "What on Google Earth" series which posts a screenshot from Google Earth and asks readers to guess the location and phenomenon shown.

Add Recommendations (Follow Friday, Blogrolls, etc.). The #ff tag, used for Follow Friday, is used to recommend accounts for readers to follow. Sometimes it is just used with a list of five or so accounts and other times a single account is given with a reason for the recommendation or a review of the kind of information provided.

"#ff to many folks who did such a fantastic job tweeting #AGU12 @msanclem @thirstygecko @stressrelated @subsurface_life @Allochthonous et al" (AGU2012-298)

In this same category, I place blog posts recommending other bloggers and discussions of blogrolls – lists of recommended blogs.

Group membership. Participating in a meme, particularly an emergent micro-meme (Huang, Thornton, & Efthimiadis, 2010) on Twitter also asserts membership in a small group of geoscientists. Participating in fast-moving conversations on Twitter by real-time followers also serves group formation. This function would be served even better if Twitter were to improve its algorithm to collect related tweets in real time. The quick-moving discussion of the funding of another Mars rover in the AGU2012 tweets illustrates this point.

Geoscientists unable to attend the AGU conference may also use the conference hashtag to remind attendees that they are part of the group.

"Hey, don't you wish you were at #AGU12? Me too. Too many friends there. Oh yeah, and scienceandstuff."

(AGU2012-4930)

Identity/Reputation. Many if not all posts and tweets serve to build identity. Three participants discussed this in more detail in the interviews. One blogger describes how he includes information about his life and family instead of keeping only to geoscience topics as he sees his blog as an extension of his other work. Another blogger describes using care when responding to news, natural disasters, and controversies "to maintain some reputation for thoughtful and not sort of turning into a wild west of lots of speculation and not much self-criticism." A scientist who primarily tweets describes using posts from the lab and about the process as a way to build her identity as an active scientist in the research area. As Dennen (2009) found, bloggers establish their identities through name and blog title, writing style, affiliation (sidebar and profile links), and visual design.

Request comments or interaction. A particular meme that travels through the science blogosphere from time to time is a request for readers to de-lurk or comment if they have not commented recently and provide feedback on the blog. Here is an example from *Highly Allochthonous*:

> One of the blogging commandments should probably be: know thy readers! Therefore we are following the example of Janet, DrugMonkey and various others (who are themselves riffing from Ed Yong's original idea) and asking you, our readers, to tell us a little about yourselves.
> Who are you? Academic or professional geologist, student, enthusiastic rock hound, general browser?
> What's your level of science education? Postgraduate, undergraduate, school, dropped it like a hot potato at earliest opportunity?
> What originally brought you to this blog, and what keeps you coming back (if indeed, you intend to)?
> Which of the topics covered here do you particularly enjoy? Is there anything you tend to skip?
> Are there any topics that would you like us to write about more often?
> If you lurk rather than commenting, are you content with that? Are there conditions that you think might suck you into commenting?
> If you could ask us to write one post explaining one basic concept in earth science, what would that concept be?
> And finally, we have to ask: which is better, water or rocks?

Similarly on *Clastic Detritus* BR used “blogiversaries” or blogging anniversaries as occasions to review the contents of the blog and to request readers provide feedback on what topics they would like to see covered.

5.3.2.13 **Entertainment**

These posts and tweets are humorous and engaging without being overly didactic or persuasive. Included in this category are amusing observations from conference sessions:

"Award for most desperately punning experiment of #AGU11: B4WARMED from UMN http://bit.ly/uYouiF" (AGU2011-391)

"Joe Kirschvink quote of the day: 'Fortunately, bird retinas are eminently flattenable' #AGU12" (AGU2012-1391)

Also included are pointers to songs, videos, cartoons, and other media:

"A snippet of my rendition of Planetary Blues at the #AGU12 Open Mic night: http://youtube/2gih1VcppWs" (AGU2012-82)

The following three additional functions emerged from the data.

5.3.2.14 **Personal Knowledge Management**

When deciding to post to her lab blog, AJ evaluates if the information will be useful to her class or will be useful to her later. She uses the blog for personal knowledge management with her future self as the audience as well as other readers. Likewise, users of Twitter may occasionally tweet something they intend to read to keep track of it. More often, however, is favoriting something someone else has tweeted or compiling tweets in a blog post for later reference.

5.3.2.15 **Request Assistance**

Asking a question as a subset of Learning/Teaching (Section 5.3.2.8) addresses asking for information or an explanation to better understand a concept. Here, requesting assistance addresses asking for materials or resources or recommendations and advice. One example found in the study was the use of the #icanhazpdf, a special hashtag in Twitter that is used to request that someone with access to an article e-mail it to the requestor.

5.3.2.16 **Express frustration/vent**

A number of tweets, not blog posts, seem to exist only to allow the author to let off steam. Sometimes these receive commiserating or sympathetic responses and sometimes they are ignored.

5.3.3 Features of the message

5.3.3.1 **Topic**

Topics found in the dataset were varied, but not as diverse as all of Twitter or all blogs. Most posts and conference tweets were about geosciences in general if not the specific research area of the author. Other popular topics included public communication, politics, natural disasters, being a professor, being a scientist, women and minorities in science, pseudoscience, field work, and writing. There were also blog posts about blogging and tweets about using twitter.

5.3.3.2 **Type of Content**

Type of content is a way of describing the genre and the way the message is constructed to achieve the author’s purpose.

Data. This category is intended to represent sharing raw or processed research data, often prior to publication. Sharing like this rarely happens through Twitter and blogs for many reasons (Acord & Harley, 2013; Birnholtz, 2005; Tenopir et al., 2011). The sharing that does happen includes images from field work, occasional graphs and data from public repositories to support original analysis, and graphs in progress.

One participant reported:

> "When I'm tweeting articles, I'm tweeting outcomes, but when I'm writing about fieldwork or occasionally I'll do something from the lab. Samples or new equipment in the lab. If I'm working on a figure for a paper that's not published yet that I'm putting together to submit sometimes I'll post a version of that."(KA interview para 15)

Methods/algorithms/workflows. Methods, algorithms, and workflows are posted for the purpose of personal knowledge management and for learning and teaching. One participant who was learning how to do an analysis in R instead of using Excel posted scripts and algorithms for grain settling based on what another blogger had posted in Python. Another participant posted how to use image processing software to study and understand how various rock layers had moved relative to one another.

Analysis. Analytic content was found in different forms in the study. In blogs, posts analyzing the literature to further disseminate it for amplification or societal benefit were a regular feature. Analysis of public communication, political issues, and ethical issues in the conduct of science were found on some blogs. Some more interesting posts analyzed the literature, news reports, data, and social media reports to come to a conclusion about a scientific controversy such as Arsenic Life (mentioned above) or the cause of a deglaciation 12-13,000 years ago (see http://all-geo.org/highlyallochthonous/2008/03/keep-your-impacts-out-of-our-deglaciation/)

A surprising finding was the presence of analysis in Twitter which with the limitation of 140 characters per post seems to be a less likely type of contribution. When the Chelyabinsk meteor hit in Russia in February 2014, AR did some analysis and posted the results to Twitter. His initial tweets were links to videos and news feeds, but he responded to questions and feedback and did some original calculations and analysis, one tweet at a time. Likewise, KA posted a series analyzing California's drought conditions. In this series, he linked to the literature in early tweets, linked to data archives, posted some purpose-made graphics, and finished with an analysis.

Theoretical/philosophical. This type was not observed in the dataset.

Opinion or Evaluation. Blogs are used to express opinions about a number of issues, as in book reviews on science and popular books and evaluation of scholarly work including journal articles and results reported in press releases and conferences (e.g., "if interested in surface processes and landscape evolution I recommend Taylor Perron's (MIT) talk from #AGU11 last week http://vimeocom/33384452" or "Maurice Tivey has some beautiful magnetic anomaly data from enigmatic Jurassic-age crust in the W Pacific. #AGU12"). At times the critique is not of the science, but of the way the press officer or reporter conveys it.

Results. Results, findings, and outcomes of research are tweeted for dissemination and other purposes. Session tweets, for example, often succinctly summarize the main findings presented by a researcher at a conference. Likewise, tweets and blog posts providing pointers to literature to read might summarize key results to indicate why the work is worth reading.

Memoir/confessional/biographical. This is another of the original purposes identified in early studies of blogs (Blood, 2002). Blog posts in this category provide insights into the life in science, provide advice to students, and help build relationships. Sometimes these posts are added to apologize for a lack of new content.

> "Over the summer, people asked me whether I was taking the summer off, and I had to explain to them that it wasn't so much that I had a new job, as that I was simply moving my old job to a new place.* And that's true in the sense that I am continuing to teach, do research, publish, write grants, review papers and grants, advise students, serve on committees and all those million other things professors do. But now that we are two weeks into the semester in the Department of Geology at Kent State University, I realize that it's not entirely true, because there are a lot of new things about being in a new place.
>
> My first time starting a professor job, I think I couldn't truly appreciate and enjoy the "getting to know you" phase of the job, but this time I am trying to actually savor these moments of everything being new and shiny. And I thought I'd share them with you, so that any interested readers could see what it's like to be a (more or less) newbie professor. Over the last two weeks, I've shared a few things on Twitter, but I thought I'd add a little more context here…." (AJ, http://all-geo.org/highlyallochthonous/2012/09/the-view-from-two-weeks-in/)

The following additional types of content were found in the data.

Add Bibliography or Collection. Two of the blogs posted annotated collections and bibliographies. Some of these included the blog carnivals and collections of tweets mentioned earlier. *Clastic Detritus* has a series of posts reviewing activity on the geoblogosphere over the course of a week. Elsewhere on the blog, there was a post containing a bibliography of references for a series of posts on Subduction Denialism.

Conference report posts from *Highly Allochthonous* included links to blogs with conference reports. *Highly Allochthonous* also included picks of recently published research articles.

Add Observation. This category is emergent from the data. There are many tweets in the dataset that make simple observations about the surroundings, the lines at the airport, the sky in the morning, etc. Some of these may have social or coordination purposes, but others are just observations.

"Waiting for my plane to San Francisco and #AGU11. Only seen one poster tube in the lounge so far..."(AGU2011-2755)

"Got in thru security in less than 5mins. #AGU2010 (@ University Park Airport (SCE)) http://4sqcom/91oNbX" (AGU2010-83)

"Cold today here at #AGU10"

News/Announcement. On lab blogs, these tend to be of events such as thesis defenses or speakers, of acceptances or publishing, or of changes in the members of the group. Tweets in this category sometimes overlapped with coordination (Section 5.3.2.11) tweets listing an accepted conference panel or talk. Blog announcements encompassed host/location changes and life events of the author.

Add Commercial. Generally the dataset was intended to cover only the work of individual scientists, but mixed in to the conference collections were tweets from companies and organizations marketing goods and services to attendees as well as doing public relations for large science projects and spacecraft missions.

Pointer. Pointers have less content themselves but serve to direct readers' attention to other information. This is a very common use for Twitter, particularly when used as a filter, for learning or teaching, or for dissemination for amplification or societal benefit/applications. They may take the form of a url and a recommendation but they may also be included with some analysis, critique, or evaluation.

> "I like to try to add a bit of value to it, so I want to find things on the wider internet or a new scientific article or information about an earthquake that has just happened or something and put that up there. For other people to see. And obviously retweeting stuff you find of interest or pointing people in the right direction but also having new information to enter their stream for other people to find" (CR interview para 7)

5.3.3.3 **Structure**

Blog posts in the set did not exhibit internal structure as is found in journal articles and other formal publication venues (i.e., abstract, introduction, literature review, methods, results, conclusions). In that some bloggers have series posts (Scenic Saturdays, Friday Fold, Friday Field Foto) there some regularity over the course of a blog, but not structure as such.

5.3.3.4 **Persistence**

Blog posts are as persistent as other web pages. They can be and are archived by the Internet Archive and the two largest hosts Google (through Blogger) and WordPress maintain older posts. For this reason, participants in the study used their blogs for thoughtful articles with purpose-made graphics and full citations. Authors can delete posts and hosts can delete entire blogs but this is rare. If an author moves to a new platform or host, it is easy to export and move the content over.

The persistence of Twitter is questionable. Until very recently, visitors could not search the entire archive from the Twitter site. The free API retrieves only about two weeks of data for a search on a subject and 3,200 tweets along a particular user's timeline. There are paid services to license older data, but this is not reasonable for an individual for everyday use such as trying to recall a conversation or find a recommended resource. Library of Congress negotiated with Twitter to archive content but public access is not currently available.

5.3.3.5 **Review or Quality Control**

Review or quality control rarely occurs for individual blog accounts and is not a feature of individually run Twitter accounts. Institutional or organizational accounts may have an approval process in place as they would for any public affairs communication. In rare cases, science blogs hosted on mainstream media websites such as *Scientific American, Wired, Discover Magazine*, *The Guardian, National Geographic* or on society sites like AGU's might undergo some review or quality control processes for branding but also for legal liability purposes. Although all of the blogs in the study had been, at some point, part of a blog network or hosted by a media site, none of the participants indicated that their posts were externally reviewed or edited prior to publication. Nevertheless, this is an important feature of other types of scientific communication so should be studied further and the framework edited or improved as future study warrants.

5.3.4 Communication channel

I anticipated that features of the communication channel could be identified and described in advance of the empirical study and could be described independently of message features. For many years, CMC researchers have preferred the term affordance which incorporates aspects of actual use with the technical features. Developing the channel part of the framework required experimentation with several alternate approaches. In the final version, the third layer of the channel describes etiquette and conventions. These do go with the channel but are also closely tied to features of the communication partners and purposes. Because these aspects are linked, it is very difficult and perhaps less useful to describe an SCT mode of communication separate from the purposes it is being put to in the instance being studied. For example, Twitter in general versus studying Twitter for conference session tweeting. A productive approach may be to select one or more purposes prior to addressing the channel aspects of the framework.

Moreover, I anticipated that most of the reinvention and adaptation had already occurred prior to the study as the two channels were widely adopted and in use. In other words, rapid adaption happened as scientists adopted, but the rate of adaptation would have slowed. Instead, I found that the adaptation process is continuing at a fast pace, even for blogging. New platforms such as Medium emphasize readability and user experience. In Twitter, one example of continuing adaptation is coherence – or the extent to which conversations hang together and threads can be followed. Coherence has been a big problem in Twitter (Honeycutt & Herring, 2009), but the company has invested heavily in algorithms and updating display methods to make following conversations easier. In the display, there is a link to “View Conversation” which expands the page to show related tweets (see Figure 11). Additionally, conversation participants and observers sometimes extract the tweets that for conversations of interest and embed them with commentary on a blog or web page.

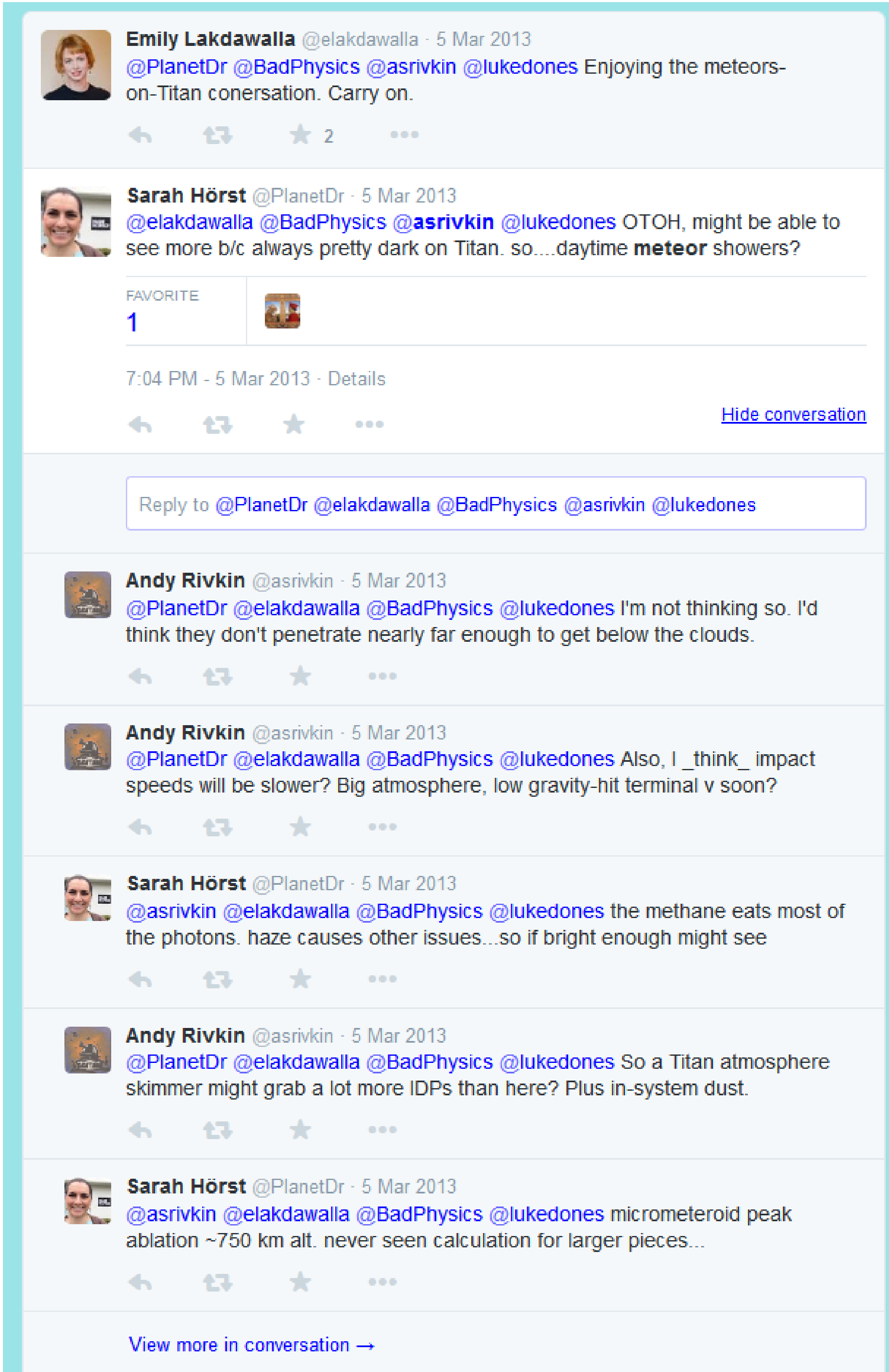


Figure 11 Twitter Screenshot showing support for tracking conversations

6. Discussion, Recommendations, and Conclusion

This dissertation draws broadly from the literature of library and information science, communication, science and technology studies, computer mediated communication, and computer science to build a comprehensive framework to describe communication in science. This framework serves to better understand new technologies and how they might be useful to scientists, design or invent new technologies, or make the case for institutional support of new technologies. After building the initial framework, I studied two social communication technologies (SCTs) in wide use in science and examined if the framework was useful in describing the use of these tools and their value to scientists. Specifically, I looked at how geoscientists use blogs and Twitter both in everyday life and around conferences. Through these studies I found new audience, purpose, and message features to add to the framework. I also learned a great deal about how geoscientists make meaning of these SCTs, incorporate their use in to scientific work, and how this has changed over time.

This chapter highlights additions to the framework (see Section 5.3 for more detailed treatment), assessing the match with the findings from the research and proposes some modifications and additions. It suggests changes to ICTs based on the results, discusses limitations, and describes future work suggested by the research findings.

6.1Findings

Communication and working with information comprise a large part of a scientist's day. Geoscientists use an ecosystem of tools tailored to their needs and their research area to communicate. They continue to communicate formally in journals that have changed little in the past century; informally at conferences, in person, and online; and with the public through public affairs representatives, press releases, and interviews with journalists from magazines, newspapers, and radio programs. To these, many scientists have added new ICTs such as instant messaging and video messaging and SCTs such as Facebook, blogs, and Twitter. Science as a whole is rather conservative in adopting new tools, but many individual scientists experiment with new tools and adopt or adapt those they consider of value. Each new tool, then, whether introduced by an organization, from another field of science or from outside of science, by colleagues, or developed locally, has to serve some function and contribute value to the ecosystem. Because the framework is comprehensive across the ecosystem, it is useful in identifying gaps, situating new tools, or adapting existing tools to science uses.

The case studies of the geoscientists were productive in adding features to the framework. For framework component *1 Partners*, discussions about communicating with students made clear that students are neither interested public nor really in the same research area. Depending on their level, they may know more or less about the research area and scientists communicate with their students differently. Also in partners, despite my previous research on personal information management (Pikas, 2007), I omitted *Self/Future Self* from possible communication partners. Writing a blog post or using a hashtag “#toread” is an example of personal knowledge or information management.

In *1.3 Match of and relationship of communication partners*, in addition to differences in education or sophistication one must also consider differences in ideological, political, research methodological viewpoints is different.

In framework component *2 Purpose of the communication activity*, *2.1 Dissemination*, a new subtype *Amplification* was added. This is a purpose that could be found in a magazine news article, a press release, or editorial on a research paper, but is also often found on Twitter when scientists broadcast announcements of new publications, for example. In *Learning/Teaching*, subtypes were added for asking a question and life as a scientist. In *Persuasion*, commercial speech was added. In *Social*, the Twitter technique of providing a blogroll-like listing of recommended accounts to follow, the #ff Follow Friday was added. In future studies this term may be renamed and adjusted to account for other types of social recommendations.

New purposes found more often in SCTs than in traditional channels were also added. Popular author and researcher Clay Shirky famously said, “It’s not information overload, it’s filter failure” (http://blip.tv/web2expo/web-2-0-expo-ny-clay-shirky-shirky-com-it-s-not-information-overload-it-s-filter-failure-1283699 retrieved 4/24/2015). In other words, the answer to proliferating information is to have a better filter to see the most useful and relevant information. Geoscientists who sift through database alerts and tables of contents and select the most interesting articles act as a filter for their followers.

Other new purposes need less explanation. Blogs and Twitter are used to express frustration and to ask for help or information (Efron & Winget, 2010). As mentioned above, both also are used for personal knowledge management.

New *Types* of message were added. *Bibliography or collection* posts provide a curated list of web pages, Tweets, blog posts, articles, or other messages. In the dataset some collections were on a defined theme and others were items published or viewed over a certain time period (e.g., articles I read this month). *Observation* messages are simple statements the authors make about their surroundings or experience. *Pointer* messages link to articles, blog posts, web pages, and other things.

Applying the framework to a particular use of a channel often results in one or a few values of a variable being present, while an entire channel often has multiple possibilities. Blogs and Twitter are versatile communication tools that are used in different ways in science. The partners, purposes, and types of message change vary widely over the collection.

6.2 Blogs and Twitter Benefit Science

Communication is a vital part of science. This study shows that moving some of the communication from older channels (such as telephone, e-mail, in person) to SCTs benefits science. This section describes some ways the use of blogs and Twitter, in particular, benefit science.

6.2.1 Blogs and Twitter Build Community

This study shows the importance of SCTs for building and maintaining geoscience communities. Participating in a community through conference tweeting, engaging in scientific conversations on Twitter, or maintaining a geoscience blog, can lead to new research collaborations, a higher profile in the geoscience community, and increased exposure to diverse areas of geoscience. With increased exposure to new information come opportunities to mobilize knowledge from these connections which may prove helpful in tackling interdisciplinary research problems.

6.2.2 Improved Mentoring

Community in Twitter and the geoblogosphere provides mentoring and support for students, junior scientists, and scientists in remote locations or in uncommon research specialties. A junior scientist in the study reported how her Twitter connections facilitated her participation in a large, somewhat intimidating conference. Jefferson, Hannula, Campbell, and Franks (2010) propose blogs and Twitter as a source of mentoring and support for women and minorities in geoscience.

6.2.3 Increased Public Engagement

Comments on blogs and conversations on Twitter show that non-scientists and students have better access to scientific content and better engagement with active scientists. Funding and policy decisions can be driven by a misunderstanding of the relevance or value of the science. Worse, the view of scientists as “other” with possibly nefarious goals can lead to deprioritizing or defunding their research.

Other studies have enthused about the value of blogs for public communication. From this study, it is clear that the majority of the communication observed was intended for other scientists or at least sophisticated science information consumers. Nevertheless, the blogs and Twitter accounts show the scientists as real people with diverse interests who may be approached with questions.

6.2.4 Improved Dissemination and use of Traditional Communications

Improved dissemination of the journal literature has some nuances. Listing new articles in the Twitter stream may bring them increased attention. More significantly, the volume of scientific literature is expanding and it is difficult to keep up with new research. Community filtering and highlighting of literature through annotation on Twitter can help scientists direct their limited attention.

Post-publication review of articles on blogs or over the course of a few tweets is valuable in identifying new applications of the data and new research or analysis methods. Journal clubs held at the lab or departmental level treat articles in greater depth but are limited in the range of expertise brought to the discussion and the number of articles that can be covered (perhaps one per month or one per week). Further, these discussions are typically not archived for later use. Because they are not archived, they may be more aggressive in criticizing research. Scientists are more careful in criticizing research in public archived forums.

6.2.5 Recommendations for Scientists and Organizations

The benefits of blogs and Twitter to science could be further increased by following these recommendations:

6.2.5.1 **Recommendations for Scientists**

Geoscientists should consider joining Twitter and following other scientists and organizations in their specialty. Using Twitter as a substitute for a feed reader is a good way to learn before actively contributing content. Then, once they are comfortable they should start contributing.

6.2.5.2 Recommendations for Scientific Organizations

Science organizations should support the use of blogs and Twitter by their scientists. For example, organizations should provide clear policies on what information can be shared. Some industry and government scientists may be reluctant to participate fully because they believe all content must be approved by a reviewer and they do not want to get into trouble. If the organization can clarify boundaries, it will benefit everyone.

Along the same lines, organizations should monitor their scientists' streams not to necessarily enforce policy, but to amplify their signals when appropriate and provide other support as needed. Librarians at the organization can respond to any #icanhaspdf requests from their researchers. This could provide a training opportunity.

It may not be appropriate to invite scientists to blog on the organization's official site as professional science communicators and public affairs experts perform these tasks for the most part. However, recruiting blogging scientists to guest post from time to time would be useful to get high quality content.

6.3 Implications for ICT Design and Use

The analysis of how blogs and Twitter are used by scientists yields suggestions for improvements to the ICTs

6.3.1 Make blog posting quicker

Long-time bloggers have enjoyed writing for their blogs and the benefits they have received from blogging, but sometimes they see maintaining their blog at the level they have set over the years as a burden. Some ways to add content to blogs with less time investment are to include minimally annotated collections of bookmarks, citations to scholarly articles, or tweets. Other scientists have started lab blogs or personal blogs for which they do not maintain the same standards. Guidance from marketing professionals typically suggests regular, frequent posts to increase readership; however, it is better to post at all and gain the community maintenance and personal knowledge management benefits than to forego these completely because posts are not carefully crafted communications. Scientists might try to post to their blogs from their mobile devices or using bookmarklets to save time.

6.3.2 Add Function Tags to Blog Posts

It may be helpful for the scientists and for those retrieving information from the blogs to mark the posts consistently by the purpose or function. Most of the participants in the study created series of posts on a theme: Friday Field Foto, Friday Fold, Scenic Saturday, Flooding Around the World. Where the series name formed the first part of the post title and the first few posts describe the purpose of the series. Most of the participants use some categorization scheme for their posts. These category tags can be used to retrieve the posts. Categories are sometimes geographic locations, eras, scientific concepts, general topics (e.g., gifts), or functions (e.g., “ranting”). They appear to build up over time with new ones added to describe new posts. If some of these categories could be agreed upon within the community and were used to reflect the intended function of the post, it would be easier for the scientists and other users to locate the information they want. For example, most participants provide some advice to students in higher education. If the same category tag were used, a society or other organization could provide an easy roundup of these posts to serve as a guide for students. The categories proposed in the framework and its extensions might be a starting point.

Research Blogging (Shema et al., 2014) is an effort in the same vein. To participate, bloggers must register and have their blog reviewed to determine if it contains posts on scholarly research. The author must have read the research, must provide a citation, and must describe the research study. Once accepted, bloggers can provide an article identifier or citation, and the site will provide the code to show a marked up citation and logo. The site scans the accepted blog and maintains a list of the Research Blogging posts. This service is necessarily more complicated than a similar service for mentoring for new professors, fieldwork experience, visualization suggestion, and other categories of information would need to be.

6.3.3 Conference Organizers Should Provide Better Access to Tweets

Geoscientists derive value from using Twitter at conferences, but the quality of the search function in the native interface, the limitations placed on the API, and the high quantities of tweets coming from recent meetings makes future use difficult if not impossible. Societies should consider publicly archiving session tweets with meeting abstracts and presentation files. Further, they should facilitate retrieval by adding additional keywords and details that might be missing from the abstracts and bulleted slides. To do this, it would be best to select the tweets for each session and post them on the abstract page for the session instead of just archiving the entire collection of tens of thousands of tweets although that, too, would be helpful.

6.3.4 Tweet Collection, Retrieval, and Curation Should be Improved

Twitter's native interface and helper applications facilitate embedding tweets in other pages, and the careful curatorial work that scientists do to keep these compilations do help archive and provide information on the topic. I found this process to be cumbersome when trying to extract Twitter conversations for this dissertation. There needs to be better advanced search that goes back to the beginning and there needs to be a way to check boxes or similar to create compilations of tweets as you read them beyond just favoriting or re-tweeting.

6.3.5 Librarians Should Use Blogs and Twitter as Information Sources

As the findings make abundantly clear, there is a wealth of information in blogs that is not available in books or journal and conference papers. Librarians should use this rich information source.

Retrieving information from conferences can be quite difficult in some areas of science in which there are no published proceedings. Twitter can help here; librarians might try searching conference tweets to identify relevant researchers and their follow-on publications.

Liaison librarians should monitor tweets from their scientists to identify new materials that should be acquired (for example if several #icanhazpdf requests are placed (Gardner & Gardner, 2015)

6.4 Limitations of the Study

6.4.1 Discipline studied

Geoscientists' use of Twitter and blogs were chosen for the reasons listed in section 4.2.1 above, namely:

- geosciences is a well-established field with well documented scholarly and public communication practices
- there is a significant amount of public communication of geoscience
- geoscientists were early adopters of both Twitter and blogs and remain heavy users of Twitter (and to a lesser extent blogs)
- institutions funding and professional societies supporting geoscience support the use of Twitter and blogs
- geoscientists have openly discussed their use of these tools and are reflective on their utility and value.

Inasmuch as geoscientists' use of Twitter and blogs are interesting and informative case studies, there are limitations when used to inform and test the construction and testing of a *comprehensive* framework. Although they did not study geoscientists, Holmberg and Thelwall (2014) found that there were disciplinary differences in how researchers use Twitter. They found differences in the number of tweets posted in the study period, links shared, and the proportion of tweets with scholarly content in the author's discipline. The scholars in their sample shared links more often than was found in general studies of Twitter. Accordingly, the study of how geoscientists use Twitter is not completely transferable to how Twitter is used in other areas of science, but the differences are likely to be found in the relative prevalence of various modes of communication and not completely different behavior.

6.4.2 Particular SCTs Studied

These two technologies have certain layer 1 channel characteristics that change slowly. They do not generally support copresence, visibility, or audibility although media can be attached for a recorded visibility and audibility. The sequentiality and coherence of Twitter has improved over the course of the study and is improving. The native web interface attempts to indicate threads with a vertical blue line. It now compiles replies on the same subject and allows the user to expand a conversation to see users who contribute but who are not followed. Several months ago Twitter introduced a new way to re-tweet that captures the initial tweet and allows a 140 character annotation. This should improve coherence as well.

Likewise, the purposes of certification, preservation, and some types of dissemination were not observed in the study. The types of content were limited to what is found in blogs and on Twitter.

6.4.3 Sample Selection and Data Collection

In addition to the aspects of the framework not studied because of the nature of Twitter and blogs, the number of blogs and Tweets collected is limited, and there may be other purposes or content types used by other geoscientists or outside of geosciences. The interview participants were selected from active participants at a major conference and may be atypical of geoscientists in general. This selection was necessary to identify the best informants on the value and use of SCTs, but makes the results less easily transferable to the general population of geoscientists.

This study was somewhat longitudinal with tweets from three years of conferences covered, but these tools are updated and their uses change over time. Additional purposes may be found as use continues over time and by the next generation of adopters and users.

Data on the general use of Twitter were gathered through participant observation, and not through a complete download, sample, and code method as the conference data were. This means that no statements can be made about the frequency of various categories of post or the likelihood of certain categories being absent.

6.4.4 Sample Size and Coding

For the conference Twitter stream, a small proportion of the total were coded (6-9%, see Table 14 Data Summary). This limits the transferability of the results. In addition, only the author coded the data. Employing a second coder and checking for intercoder agreement would provide greater transferability; however, the framework evolved through the course of the study and relied on my interpretation, which is informed by a deep knowledge of the scientific community and its use of blogs and Twitter. Using two coders would be more appropriate in later studies that use the framework now that it is more stable.

6.4.5 Research Fatigue

Some of the participants in the study have been interviewed multiple times and have written blog posts and magazine articles and given conference presentations and tutorials about their use of SCTs. Choosing to interview these participants meant that their answers were well-considered and well-informed, but also might be better constructed to convey the desired positive message about the medium. The scientists who have advocated for the use of blogs will provide positive examples of how their use supports science, but might downplay their use in informal scholarly communication, community building, and other areas of communication by scientists. Future studies should go beyond the "usual suspects" in recruiting participants to avoid research fatigue (Clark, 2008).

6.5 Future Work

The nature of this research is to form a foundation and a framework useful for studying and implementing communication technologies in science. Two of the many technologies were studied as examples. In this section I describe additional social computing technologies used in science that are good candidates for analysis using this framework. Then I describe aspects of scientists' communication and use of these technologies emergent from the empirical study that merit further research.

6.5.1 Applying the framework to other technologies

This dissertation studied only two of many SCTs in wide use in science. This section reviews other SCTs worthy of study that would benefit from using the framework.

6.5.1.1 **Q&A Sites**

Question and answer sites allow users to post an *answerable* question on a specific topic, receive multiple answers, and to vote to promote useful answers or demote non-useful answers. Users who ask good questions or provide good answers as rated by other users receive reputation points in a form of gamification. Although there are large, general-use question answering sites, the ones most used in science run the StackExchange software (Posnett, Warburg, Devanbu, & Filkov, 2012). The initial StackExchange site is focused on computer programming questions including scientific analysis programming using R, Matlab, and Python. Relevant Question and Answer sites include ones on theoretical computer science, bioinformatics, mathematics, and experimental chemistry.

6.5.1.2 **Protocols/Workflows**

Protocols provide instructions for performing some function in experimental science. Protocols are available as print materials and from individual labs but are also published in large databases by international science publishers. More recently, protocols have been made available in video format in the *Journal of Visualized Experiments*.

Workflows are collections of computer programming modules that are reusable and perform some data gathering or analysis function. There are several different software products to support workflow development and management such as Trident, Kepler, VisTrails, and Taverna. One web-based tool, MyExperiment, allows for social sharing of workflows and modules from workflows with appropriate attribution (Goble et al., 2010).

6.5.1.3 **Social Data and Computer Program Repositories**

Recently new SCTs have been developed to increase openness, transparency, and reproducibility in science. Some of these have found more broad adoption in the biological sciences due to funder requirements. Traditional data repository use is required by geoscience funders, as well, but these repositories do not have many social features. The increasing uptake of FigShare for data and GitHub for scripts poses many interesting research questions and may add new purposes and types to the framework.

6.5.1.4 **Post Publication Peer Review**

In addition to using blogs and microblogs for commenting on papers, there are ICTs set up primarily to facilitate commenting on research papers. Faculty of 1000 (F1000) is a subscription product that has commentary on papers from a select group of experts in the field (the faculty) and also allows users to post comments on papers. F1000 is available only in biology and medicine.

6.5.1.5 **Wikis**

Wikis are web-based SCTs that allow for collaborative editing. Some examples of how they are used in science include:

- as encyclopedias,
- for project documentation,
- as lab notebooks,
- as ways to annotate biology databases.

6.5.1.6 **Social Bookmarking/Citation Managers**

Social bookmarking is using a web service to manage webpage addresses to remember or re-find instead of using browser bookmarks or favorites. In addition to the benefits of being online, the site allows users to share their bookmarks with others, search them, and assign keywords or tags to make them easier to find. Some of these tools are specifically meant to facilitate management of scientific articles and citations like citation managers. For example, CiteULike is able to import the metadata from PubMed and many journal web pages. Groups of scientists share and comment on the references. Another tool in this category, Mendeley (Elsevier), is closer to the standard reference manager, but has more social and recommendation features. Users are encouraged to annotate articles and Mendeley helps them manage PDF copies of the articles on their computer.

6.5.1.7 **Social networking**

Social networking tools have a number of features that allow users to connect online. In addition to general use tools like Facebook and LinkedIn, there are tools that are specifically intended for researchers. According to the *Nature* study, ResearchGate is second only to Google Scholar in the proportion of science and technology researchers who visit regularly (Van Noorden, 2014).

6.5.2 Use of Twitter at Conferences

As mentioned above, the SCTs integrate with the pre-existing channels of communication at conferences. More research is needed to understand switching among channels and how they interact.

Less research has been done with peripheral participants who read Twitter and blogs about conferences, but do not contribute content. What benefits do they receive?

Likewise, many non-scientists participate through tweeting or through reading meeting and other geoscience tweets. Why? How does it benefit them?

How has conference tweeting changed? Some indications are found in this 3-year dataset, but more research is needed to understand the changes more broadly.

How does attribution of ideas work in Twitter feeds in real time and later? Are tweets without attribution subtweets or only shorthand? What happens when audience members get the point wrong when tweeting from a session?

6.5.3 Community in blogs and Twitter

The study clearly shows traces of community building in blogs and twitter. Is there a virtual sense of community (Blanchard, 2007)? More research is needed.

6.5.4 Public Communication

To produce high quality, well-thought out posts intended to enlighten the public requires a lot of effort. With science becoming an ever more competitive enterprise, scientists may not have the time required. AJ tweets more about climate change now than writing blog posts. It is high stakes to write something more lasting and in more detail about a controversial subject and this takes time she needs to do other work. Tweeting interesting things on a controversial topic still helps with public communication and persuasion but with less time commitment. Some research has been done on climate change tweeting, but more research would show how scientists decide what messages to convey, in which channels, or if they decide not to, in order to avoid trolls.

Have geoscientists put so much pressure on themselves to do high quality, well-thought out posts, that they then no longer blog at all? Twitter, which doesn't serve all the same purposes, has taken the quick pointer posts from blogs. This may be a useful evolution.

6.5.5 Integrating Publicly Available, Team, and Personal Communications

The participants in the study make careful distinctions on what information can be shared on their blogs or on Twitter and what must be kept to members of their research project or in their own files. One participant, for example, gave his employer's review requirements as a reason not to blog. Another participant rarely tweets her own research because of embargos. Their own data, early analyses intended for publication, and writings for future publication are not shared. For the most part, it is not a concern about being scooped but instead that the information has not been properly reviewed, is not complete, or involves other students and research teams that would have to give permission.

Internal blogs within even large organizations are often not successful as there are not enough readers to form a viable community. On the other hand, some large governmental organizations have successful internal Twitter-like platforms. Should large science teams have their own internal social media platforms? Could sponsors like NASA and ESA provide these platforms for teams, archive the conversations, and release appropriate ones after the data have been reviewed? Could security be enough on public SCTs to allow the choice to share with only certain groups? If so, would this be too much hassle to use?

6.6 Conclusions

Communication is the essence of science. Through analyzing two example technologies, this dissertation has illustrated how social communication technologies (SCTs) enhance communication through complementing and improving on more traditional channels and thereby help science. SCTs weave a richer web of communication and support exchange of ideas among many and distant participants. They can spark collaborations among scientists that would otherwise not have met, and they facilitate the execution of collaborative ventures. SCTs may well have the potential - not investigated here - of helping scientists discover researchers in other disciplines working on the same problems or working on techniques that might contribute to the solution of a problem. In this way, SCTs may foster collaboration across disciplines and team science, possibly in geographically distributed teams.

This connecting potential of SCTs is particularly important for scientists at small and perhaps remote institutions who up to now have had limited opportunities to connect with other researchers in their field. SCTs are also important for junior scientists and those from underrepresented groups by opening opportunities to locate mentors without geographical restrictions.

To increase the impact of SCTs on the scientific enterprise, adoption should be increased through education at all levels, including established scientists, through improvements that make SCTs even easier to use, and through institutional support.

Communication is the dominant force in the reward system of science. But recognition is still largely bound to publication in established channels, especially refereed journals (preferably journals that are in the "top tier"), and to citations that a publication receives. It is time for science organizations to recognize the contributions and measures of influence in SCTs, Altmetrics, which gathers multiple measures of influence from SCTs should become a prominent part of the toolbox of metrics used to evaluate scientists. Such recognition would also speed the adoption of SCTs and foster communication in that venue when most beneficial to science.

SCTs also have great potential for lifelong education. They can manage the involvement of students in research. They could support the integration of research and teaching. They can provide a forum for interested readers no longer in formal education to not only read but engage with practicing scientists.

SCTs also have great potential for communicating scientific results to a larger public. There are translations into practice that must be communicated to the workforce that can use these results to improve our daily lives. There are implications for planning and policy formulation that must be communicated to policy makers.

SCTs are evolving rapidly. The social, political, and legal frameworks of science must follow suit to enable progress in increasing scientific productivity and translation of scientific results into improved practice.

Appendix 1: Interview Guide

1. How long have you been using Twitter? Has your use of Twitter changed since you started?
2. Why did you decide to start using Twitter?
3. What types of things are you sharing on Twitter?
4. How do you pick the people you follow on Twitter?
5. Have you tweeted scientific meetings? Why?
6. Are you following any new people because of conferences? Whom? Why? In general?
7. For what purposes do you use Twitter?
    a. How does tweeting fit into your work practices?
    b. How does tweeting fit into your participation in the scholarly community?
    c. How does Twitter change the way you experience meetings?
8. Is there anything else about your use of Twitter or tweeting that you'd like to tell me?

Additional questions for bloggers:

1. How long have you been blogging?
2. Why did you decide to start a blog?
3. For what purposes do you use your blog?
4. How does blogging fit into your work practices?
5. How does blogging fit into your participation in the scholarly community?
6. Has blogging replaced any other communications medium?
7. Have you had any feedback from colleagues, employers, students, or the public on your blog? If so, please describe it.

8. Is there anything else about your blog or blogging that you'd like to tell me

9. Any other geoscientists I should talk to?

Appendix 2: Glossary

Blog Carnival A blogging community activity in which a volunteer host proposes a topic, community members write posts on the topic and submit them using a form or by e-mailing a link to the host, the host then curates and annotates the submissions and publishes this annotated collection on their blog or the community website. The primary one in geosciences was *The Accretionary Wedge.*

Blogroll a listing on the side of the blog of suggested blogs to read. Typically seen as an endorsement.

Bookmarklet A short Javascript program that lives in a button in the web browser's link bar. When the button is clicked, information from the page is gathered and submitted to a service. A common use is for bookmarking or citation manager services. These work in most browsers and do not require installing software but their functionality is more limited than browser plug-ins or add-ons.

Geoblogosphere A term for the collection of interconnected blogs on geoscience topics maintained by geoscientists, amateur enthusiasts/citizen scientists, geoscience organizations, space and ocean missions, science communicators, and science educators.

Meme "An activity, concept, catchphrase or piece of media which spreads, often as mimicry, from person to person via the Internet" (http://en.wikipedia.org/wiki/Internet_meme , retrieved 4/23/2015). http://knowyourmeme.com/ is a useful database of internet memes.

Micro-meme Huang, Thornton, and Efthimiadis (2010) coined this term to describe the short lived ad hoc hashtag memes on Twitter.

Appendix 3: Individual Case Studies

This appendix contains the full individual case studies for the rest of the participants in the study.

A3.1 Callan Bentley

Callan Bentley is a geologist who studies the structure of formations. He teaches introductory geology courses at a community college and views teaching and community outreach as his primary responsibilities. He has goals of increasing the science literacy of students who take his courses to fulfill requirements but then continue in diverse unrelated fields and of encouraging beginning students to consider pursuing geoscience careers: “creating a society that is more scientifically literate and inspiring more people to go into science” (Interview para 4).

He spends significant time in the community giving lectures to local groups and leading field trips to local rock formations. He publishes primarily on pedagogical methods in geosciences, including how to capture and share large scale detailed pictures to be used in schools in place of visits to geographically remote geological formations.

Mr. Bentley views blogging and tweeting differently. He uses his blog to publish original essays, book reviews, and annotated images showing rock formations. He uses Twitter to amplify and point to others’ work of interest and also to have conversations with other geoscientists. He has 2,350 followers on Twitter.

A3.1.1 Blogging

Callan Bentley has blogged since 2007. First blog was created in Blogger and was posted on his professional college website with his course information, CV, and research information. When Google deprecated the transfer feature, he moved his blog to WordPress.com, and he has been a member of AGU's blog community from 2010.

Mr. Bentley describes how blogging fits into his work as follows:

> [My] job at NOVA is to teach introductory level geoscience classes. I see my goals with that job in terms of creating a society that is more scientifically literate and inspiring more people to go into science. Those goals are essentially identical to the goals I'm pursing when I'm blogging … Essentially it's about outreach and promoting science outreach and excitement, enthusiasm.(Interview para 4)

He views his blog as a conversation with his readers, tailoring his content to their explicit feedback through comments, emails, and shares, as well as through the implicit feedback of visits and page views. His biggest source of visitors is from Google searches (about half) and 22% from people going directly to the URL (Interview para 40).

B1 Science - Public Communication

B1a Science example

A large proportion of his blog posts are devoted to educating interested members of the public. These posts take several forms.

Images

Many of these are high quality large images of rock formations he has studied in his fieldwork. The images often have references for scale and are annotated with arrows and lines to describe what mechanisms caused the specific phenomenon (See **Figure 12** for an example). From time to time, the posts ask readers to contribute additional information or quiz the readers. Geographical information is included to enable local readers to visit the site to make their own observations.

Models

Another form of public education post is one presenting a model or metaphors to teach various concepts. For example, his post *Diaper-Diapir, Convection in a dirty dish* (10/17/12) shows a model of a diapir – a formation in which a sort of bubble is pushed through the harder rocks on the surface – made of diapers.

B1b Science new paper/new finding

B1c Natural hazard/disaster explanation

Even though he is not a specialist in seismology, tectonics, or related fields, he does live in Virginia so he posted extensively about the rare earthquake and aftershocks in August 2011. He saw this as part of bringing information to his local community.

B1d Science basics post

B1e Science controversy (for public)

B1f Science funding

B1g Science history

B1h Science book review

Book reviews, some of which are also published in magazines and journals, are included for popular science books.

B2 Doing Science

B2a Community Building Activities

Mr. Bentley uses his blog to participate in blog carnivals such as the *Accretionary Wedge*. He has hosted some editions, submitted posts, and has pointed to other editions. He also occasionally participates in memes in the geoblogosphere such as “favorite geoword” (boudinage) and quizzes such as “Where on Google Earth.”

B2b Requests for Assistance

B2c Pointing to readings

B2d Field work

There are several series of posts providing a mix of cursory and detailed reports from field work. In his “Transect Trip” series from 2010, he first posted smart phone pictures from the field with very brief descriptions. Once he returned from the field, he provided detailed information on what the images showed, where they were taken, and what science was being done. Although similar to the posts mentioned under educational materials, these posts provide more data from the field and might be more useful to other geoscientists.

B2e Lab work

B2f Analysis

B2g Tutorials (for peers)

B2h Conference reports

Mr. Bentley typically prepares only a single summary post after conferences. These summaries do not go into detail about the science, but are more trip summaries listing who he met, what talks he gave, and what local visits he made.

B4 Teaching (being a teacher)

B4a Recruiting students

B4b Pointer to educational resources

B4c Advice to students

These posts are primarily aimed at undergraduates and are on topics like giving presentations (http://mountainbeltway.wordpresscom/2010/03/03/advice-for-giving-a-talk/) and applying for graduate school (http://blogsagu.org/mountainbeltway/2013/11/07/how-to-apply-for-grad-school-in-geology/).

B4d How to teach

Mr. Bentley discusses various teaching methods on his blog and interacts with his commenters on related subjects. For example, in 2013, he provided his opinion and experience with giving extra credit and requested feedback from commenters (http://blogsagu.org/mountainbeltway/2013/02/07/extra-credit/).

B5 Social

B5a Biographical

Callan Bentley talks about his life and family on the blog, sharing pictures of his wife and son, and discussing their home and trips they take. He sees his blog as "an extension of my life rather than as something that is separate from my life. For me that feels like a natural choice but it's not one everyone makes" (Interview para 54). By doing so, he builds and reinforces the relationship he has with his readers and commenters.

B5b Coordination

Callan Bentley maintains a regular posting rhythm and posts in various series on different days. When travel or other events (e.g., the birth of his child) prevent regular posting, he posts to forewarn readers and set expectations. Also as a form of coordination, he posts his schedule going to meetings and giving local lectures if readers want to meet with him.

B6 Social Issues

B6a. Reviewing books (not science)

B6b. Commenting or advocating on political, religious, or social topics

Callan Bentley is an atheist who blogs infrequently about creationism when popular news stories introduce the topic or when his blog attracts the attention of creationist critics. His posts tend to be dismissive of these views as “silly”:

> There’s only one conclusion to a young Earth creationist, and no data can ever dissuade him or her. 4,500 years ago, there were bristlecone pine trees growing in the White Mountains of eastern California. One wonders how Clarey reconciles that fact (a matter of counting tree rings) with his silly idea that the whole planet was under seawater.
>
> I am amazed anew by the young-Earth perspective. It is a blinkered, resolute, evidence-free piece of sacrosanct silliness immune to any rational line of argument.” (http://blogsagu.org/mountainbeltway/2014/03/18/on-ignorance-bias-data-and-the-tentative-nature-of-interpretations/)

B6c. Commenting on news (not science)

Mr. Bentley occasionally posts commentary on general news such as the Boston Marathon bombing.

B7 Entertainment

B7a Pretty pictures

Callan Bentley enjoys sharing pictures of insects, spiders, worms, and birds from more of a citizen scientist or enthusiast point of view. He uses the scientific name of the subject but presents as a guide.

B7b Book reviews – not science

B8 News/Announcements

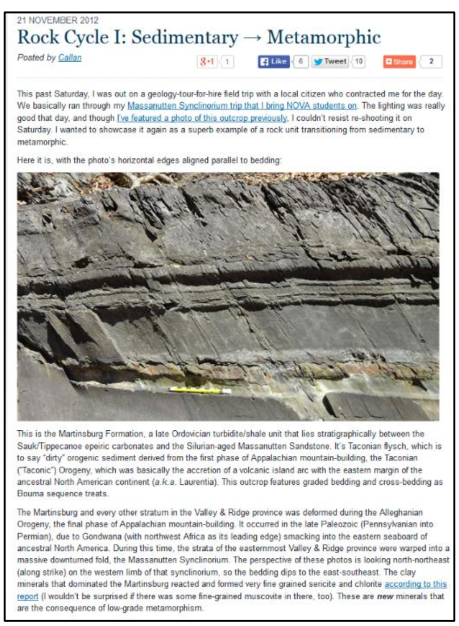
B8a Jobs open

B8b Graduations/Defenses

B8c Papers published

B9 Meta (about the blog)

Uncommon functions


21 NOVEMBER 2012

Rock Cycle I: Sedimentary → Metamorphic

Posted by Callan

g+1 1 Like 6 Tweet 10 Share 2

This past Saturday, I was out on a geology-tour-for-hire field trip with a local citizen who contracted me for the day. We basically ran through my Massanutten Synclinorium trip that I bring NOVA students on. The lighting was really good that day, and though I've featured a photo of this outcrop previously, I couldn't resist re-shooting it on Saturday. I wanted to showcase it again as a superb example of a rock unit transitioning from sedimentary to metamorphic.

Here it is, with the photo's horizontal edges aligned parallel to bedding:

This is the Martinsburg Formation, a late Ordovician turbidite/shale unit that lies stratigraphically between the Sauk/Tippecanoe epeiric carbonates and the Silurian-aged Massanutten Sandstone. It's Taconian flysch, which is to say "dirty" orogenic sediment derived from the first phase of Appalachian mountain-building, the Taconian ("Taconic") Orogeny, which was basically the accretion of a volcanic island arc with the eastern margin of the ancestral North American continent (*a.k.a.* Laurentia). This outcrop features graded bedding and cross-bedding as Bouma sequence treats.

The Martinsburg and every other stratum in the Valley & Ridge province was deformed during the Alleghanian Orogeny, the final phase of Appalachian mountain-building. It occurred in the late Paleozoic (Pennsylvanian into Permian), due to Gondwana (with northwest Africa as its leading edge) smacking into the eastern seaboard of ancestral North America. During this time, the strata of the easternmost Valley & Ridge province were warped into a massive downturned fold, the Massanutten Synclinorium. The perspective of these photos is looking north-northeast (along strike) on the western limb of that synclinorium, so the bedding dips to the east-southeast. The clay minerals that dominated the Martinsburg reacted and formed very fine grained sericite and chlorite according to this report (I wouldn't be surprised if there was some fine-grained muscovite in there, too). These are ***new*** minerals that are the consequence of low-grade metamorphism.

Figure 12 Rock Cycle I: Sedimentary → Metamorphic from http://blogsagu.org/mountainbeltway/2012/11/21/rock-cycle-1/

A3.1.2 Twitter

Callan Bentley joined twitter in February 2010. He originally started using twitter to support his blog. He used it "basically as a replacement for that stream of interesting tidbits that was crossing my radar, if you will. The theme with both of these was sort of creating a place to highlight other people's content and then with blogging the focus shifted to my own content" (Interview para 16). As he continued to use Twitter, he found it became more conversational and not just amplifications of interesting things he'd read: "the focus shifted to conversation with other people on Twitter – the immediacy of it and the quick back and forth, the crowdsourcing aspect of it. It became less about sort of like 'here's a cool study that was done…' or 'here's news about an earthquake that just happened' to 'what do you guys think of this particular thing people do when they're making a presentation' or 'does anyone have a copy of this paper?'"(Interview para 16)

Mr. Bentley is indifferent about tweeting conferences. There are 68 tweets from him in the collection with the tags AGU10, AGU11, or AGU12. Of these, only two are from 2012 as he did not attend that year. The majority of his tweets are social, coordination, or observation tweets. He tweeted events he was going to attend and tweeted at other attendees to ask where they were sitting in large events. Examples:

> `About to hear John Holdren speak at #AGU10... Up in front right @jrepka - where are you?`

> `@jrepka looks like I missed you. Headed back to West for pm talks. #AGU10`

> `Geotweeps still @ #AGU10 - @ugrandite @tuff_cookie & I are going for beer w/ the William & Mary crowd at 6pm. Meet outside the exhibit hall.`

He tweeted a series of observations about posters and occasional broad statements about sessions, but the tweets were not detailed scientific content and also do not attribute content to the original speaker or poster presenter. For example:

> `Slow seismic velocities under the Basin & Range and the Rio Grande Rift but why is the inner Col. Plateau slower than its edges? #AGU10`

> "I tried it and what I found is that there was sort of this sense of responsibility to be tweeting that didn't come close to capturing the nuances of the meetings. So it was sort of dissatisfying like I was putting out an inferior product and then I never really got any feedback that would sort of suggest it was useful to anybody so that basically dissuaded me from spending too much time on that." (Interview para 48)

A3.1.3 Blogs and Tweets as Information Sources

A3.1.4 The Online Geoscience Community

A3.2 Anne Jefferson

See Section 5.1 of the main text.

A3.3 Kevin Anchukaitis

Kevin Anchukaitis is a paleoclimatologist and dendrochronologist at a private research institution on Cape Cod in Massachusetts[4]. He uses cores harvested from trees in various forests around the world to study climate, weather, and geologic events. As part of this, he is very interested in climate change and in droughts. He has posted on a blog from time to time and even posted from the field on a *New York Times* blog, but does not consider himself a blogger. He joined Twitter in 2010 after following some other geoscientists. He tweets frequently.

A3.3.1 Blogging

Dr. Anchukaitis does not maintain a blog because he doesn't "have time to edit blog posts and referee comments in those blog posts but [he] find[s] that [he] can generate a figure pretty quickly and generate a few 140 character tweets" (Interview para 24). He has, however, contributed to two different blogs. First, he participated in a *New York Times* scientists-at-work blog. These posts were like travelogues with

[4] Dr. Anchukaitis moved to a large public university in the Southwest in mid-2015.

beautiful pictures and descriptions of the field and his team's day and work as they gathered data (**Figure 13**).

In 2012 Dr. Anchukaitis joined a colleague's blog but posted only two entries. The entries were long descriptions of the hurricane history of New England and viewing historic droughts through tree rings. Both posts referenced peer-reviewed literature and were aimed at a sophisticated audience but not necessarily members of the same research area. These posts could have been articles in a general geosciences society member magazine like *EOS* from the AGU.

Scientist at Work

Notes From the Field

A Curious Patch of Trees Before the Descent

By KEVIN ANCHUKAITIS MARCH 26, 2012 11:59 AM 9 Comments

Becky BricA A nearby peak emerges from a sea of clouds during a sampling session.

Kevin Anchukaitis, an assistant research professor at the Lamont-Doherty Earth Observatory at Columbia University, is conducting a tree-ring study to analyze drought patterns in Guatemala.

Still in search of older trees in less disturbed strands, we head out north and east of camp, slightly downhill along the edge of a patch of beetle-killed forest. Some distance from camp, we walk into an open area around a dry stream bed and, spotting a few larger trees downstream, we pick our way downhill to see if we'll have some better luck. The first few trees we sample are at least intriguing — a bit older, with somewhat tighter rings. Our interest roused, we again split into two teams and work across the steep slope.

Something about this part of the forest is different — the lower branches on the trees are intact, and there is deadwood lying on a cushion of pine needles. It looks to me as if, for whatever reason,

Figure 13 New York Times blog post. Retrieved from http://scientistatworkblogs.nytimescom/2012/03/26/a-curious-patch-of-trees-before-the-descent/?_r=0 (1/13/2015)

A3.3.2 Twitter

Dr. Anchukaitis is a prolific user of Twitter. He authors tweets primarily for other scientists and sophisticated, interested audiences.

1. Science (for scientists)

1a. Pointing to readings

Dr. Anchukaitis acts as a filter for journal articles in his areas of interest. He browses tables of contents and subject alerts and tweets relevant articles. Relevance does not necessarily mean applicable to his current research; he also selects articles he believes will be of interest to his audience based on their feedback: “I go through something I might not be working on at the moment but I find interesting that’s relevant” (Interview para 24). His followers (audience) include journalists and farmers who might not typically follow the science literature on their own.

1b Discussing scientific topics

Dr. Anchukaitis has many discussions in which he goes back and forth with other scientists discussing a paper or new finding.

1c Tutoring peers

2. Doing Science

Most of Dr. Anchukaitis’ tweets are related to his scientific work whether it is keeping up with the literature, doing field work, analyzing data and preparing visualizations.

2a. Reporting from field work

Dr. Anchukaitis travels to some exotic locations to do field work. When logistics (battery, signal, etc.) support it, he posts pictures of the fieldwork locations either in real time or when he gets back to a camp where he has internet access.

“I kinda like to do that because I feel like it gives a sense of scientist out there doing things, discovering things, part of the process instead of just outcomes” (Interview para 15)

2b Reporting from lab work

Not Observed.

2c Analyzing

Dr. Anchukaitis performs and posts new analysis and research using archived data for Twitter in response to queries from followers and feedback from previous efforts. In a series of tweets, he performs a small literature review, briefly describes methods, shows some purpose-made graphs and analysis, and then post conclusions. Each of the tweets in the series is retweeted and results in questions, comments, and clarifications from other scientists in the research area, other geoscientists, farmers, journalists, and other members of the interested public. He reports

> With the California drought recently there was a lot of stuff going around where people were saying it was the worst drought in 500 years or something so I thought, well let’s see if that’s true and I ended up actually posting a bunch of figures I had created of paleoclimate data from California and trying to put the present drought in context of that. Those were figures that weren’t for any publication or even something I was necessarily working on although it’s related to my interests. (Interview para19)

His posts about climate change issues occasionally receive negative attention or are “high jacked” to imply that because the climate has changed in the past there isn’t anthropogenic climate change now. Typically after a few tweets the trolls go away. He believes he gets fewer nasty comments and trolls than other climate change researchers because he tries to stay apolitical and does not share information from political or partisan websites (Interview para 40).

Links to analysis computer code

Dr. Anchukaitis shares links to MATLAB code stored on GitHub. The code is for processing climate change data and making figures for the most part.

2d. Requesting Assistance

“If I’m working on a figure for a paper that’s not published yet that I’m putting together to submit sometimes I’ll put a version of that [on Twitter]” (Interview para15).

These figures are sometimes used to request assistance or feedback but are also posted to show work that he was proud of or was having trouble getting to work like he wanted.

He also requests assistance in programming issues for analysis.

2e. Building Science Community

3. Conference Specific

3a. Covering a session live

3b Providing Color commentary

3c From away from the conference

3d Summarizing a conference

4. Science News/Announcements

4a. Announcing job openings

4b Announcing defenses, graduations

4c Announcing papers published

5. Teaching (being a teacher)

5a. Providing Advice for Students

5b Recruiting Students

5c Pointing to Educational Resources

5d Explaining how to teach

6. Public Communication of Science

6a. Explain a science concept

6b Review a new finding in more comprehensible terms

6c Explain a natural hazard/disaster

6d Review science history

6e. Review popular science books

6f. Explain a scientific controversy (for public)

7. Social

7a. Biographical/Confessional

7b Coordinating

8. Entertainment

8a. Images

9. Politics, Religion, and Society

9a. Reviewing books (not science)

9b Commenting or advocating on political, religious, or social topics

9c Commenting on news (not science)

10. Meta (about the blog or Twitter)

News/Announcements

Dr. Anchukaitis sometimes posts job listings, calls for papers, announcements of his published work, announcements of interviews he has given in the media, announcements of colloquia and seminars, and similar short posts.

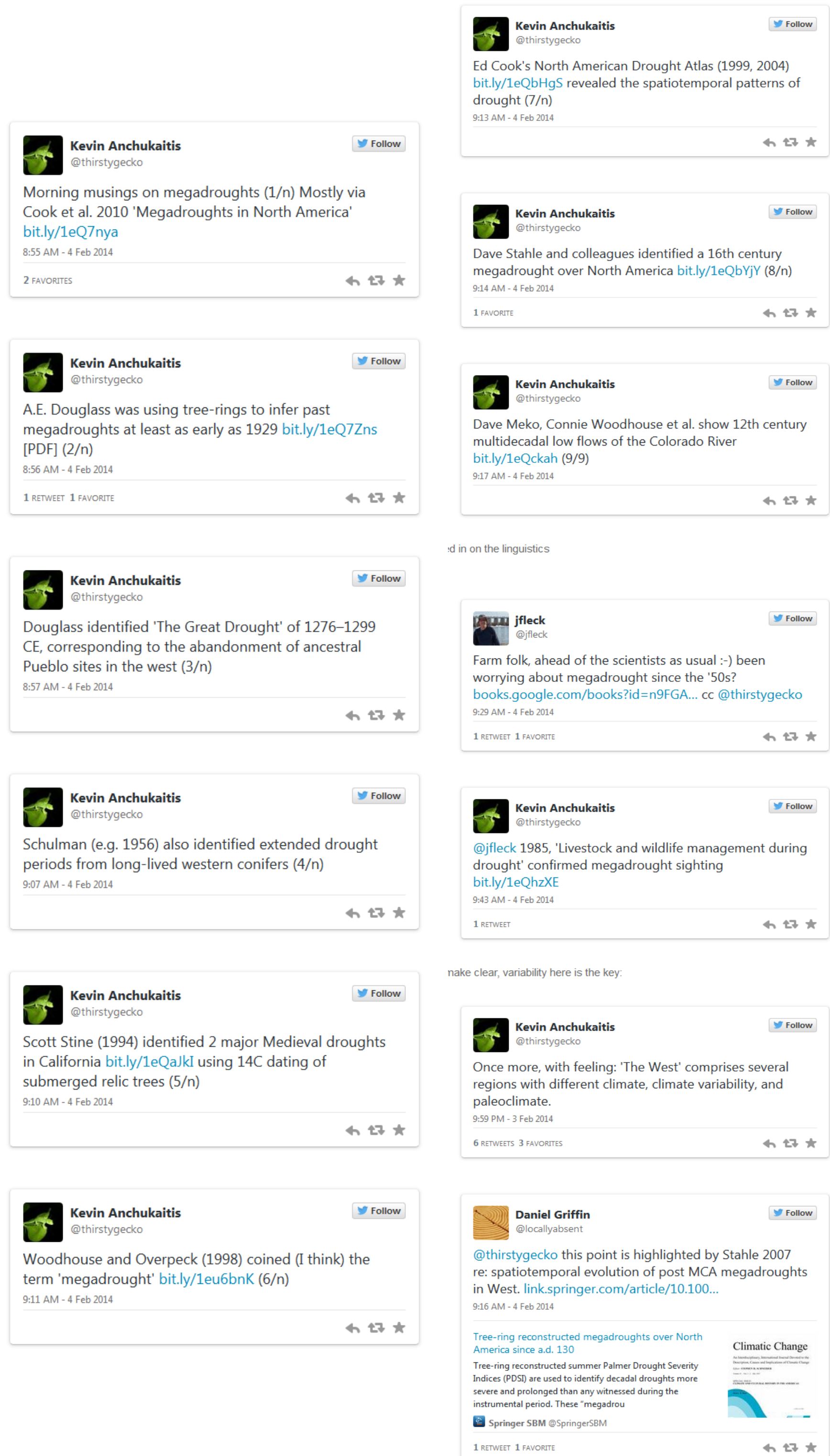


Figure 14 Example of Original Review for Twitter (@thirstygecko , archived at http://www.inkstain.net/fleck/2014/02/megadroughts-thirsty-geckos-twitter-literature-review/, retrieved 1/21/2015)

6.6.1.1 **Functional Categories of Conference Tweets**

Kevin Anchukaitis tweeted from all three conferences in the study for a total of 187 conference tweets. His first tweets with a conference hashtag are about submitting abstracts, preparing posters and talks, and finally preparing to travel to the conference location. He then typically makes general observations about the conference. Each day or half day, he lists what sessions he will be attending.

He sometimes tweets multiple times from a session. First, he introduces speakers, then he provides short summaries of their results mixed with play by play and occasional asides or comments. Here is an example of a session from AGU2012:

Up next, Kim Cobb (@coralsncaves) on late 20th century ENSO variability in the context of natural variability #agu12

Kim shows requisite amazing field photo of tropical island beach #agu12 #shouldhaveworkedoncorals

```
Cobb ( @coralsncaves ): natural variability presents challenge to detecting recent ENSO change #agu12

Cobb showing data from Line Island corals #agu12

Cobb: large range of ENSO variability over last 7k #agu12

Cobb: test coral ENSO variability against long unforced GCM runs #AGU12

Cobb detects no significant mid Holocene ENSO variability change vis a vis long GCM runs #AGU12
```

The emphasis Dr. Anchukaitis places on tweeting from conferences changed over the three years studied. In 2010, session tweets were only 25% (10/40) of all of his conference tweets, in 2011 about 60% (32/56), whereas in 2012, they were about 70% (62/91). The number of tweets per session seems higher in 2012 as well.

He explained why he started tweeting from conferences: “At a meeting I see all this brand new science people are presenting and you know or tweets on new analysis or new results so it’s kind of fun to share that meeting experience with people so I think that’s kind of why I originally got into it.”(Interview para 35). He generally tries to have only one tweet per talk but will have four to five if the talk engages him. He doesn’t “tweet about talks [he’s] not finding interesting or convincing so when [he’s] usually tweeting it’s about things [he] find[s] interesting and convincing and within climate, tree rings sort of things” He takes notes in a text file and tweets later so it’s less disruptive.

Social

The majority of Dr. Anchukaitis’ meeting tweets are related to the science being discussed, but there are some social tweets included. For example, in 2012 he posted a #ff (Follow Friday) tweet in which he recommends his readers follow these other accounts.

Coordination

He sometimes tweets which session he will be attending next and if he intends to tweet it.

A3.3.3 Blogs and Tweets as Information Sources

Personal knowledge management:

`One for the post #AGU12 reading list: Isotopic and hydrologic responses of small, closed lakes to climate variability http://bit.ly/YJQ67S` (AGU2012-539)

A3.3.4 The Online Geoscience Community

Recommendations of who to follow:

`#ff #AGU12 paleo folks @DustyBowl @leafwax @arvegroup @coralsncaves @scottstgeorge @Caroline_Leland @lah_Laia @YellowBuckeye @locallyabsent` (AGU2012-1817)

A3.4 Sarah Hörst

Sarah Hörst is a new assistant professor at a large private university. She recently moved East after completing a post-doctoral fellowship in Colorado. She is a planetary scientist who studies atmospheric chemistry and hazes most recently focusing on Saturn’s moon Titan.

A3.4.1 Blogging

Although Dr. Hörst does not maintain a blog, she has guest posted on the Planetary Society’s blog twice. These posts are detailed descriptions of methods used to study Titan’s atmosphere and an overview of the results her team has found. The posts are quite long (about 3,000 words) and are aimed at scientists outside the immediate field or sophisticated non-scientists. Figure 15 shows graphics from her post.

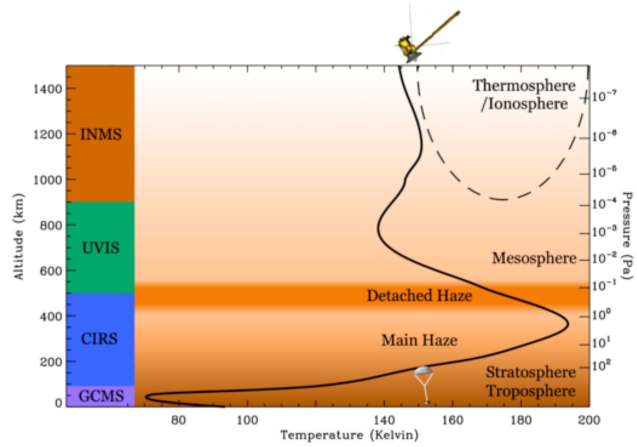


Figure 15 Image of Titan's atmosphere NASA / JPL / SSI / Gordan Ugarkovic (left) and Sara Hörst’s diagram of Cassini instruments used to measure Titan’s atmosphere (from http://www.planetary.org/blogs/guest-blogs/2013/20130824-probing-titans-atmosphere.html retrieved 4/22/2015)

A3.4.2 Twitter

Dr. Hörst started using Twitter with the encouragement of her undergraduate advisor who is also a popular tweeter. She is fairly prolific, with more than 30,000 tweets since she joined in 2009. She tweets frequently from conferences but also from the lab while waiting for equipment to finish and while working on papers.

Dr. Hörst is followed by many interested in Planetary Sciences after being recommended Emily Lakdawalla from the Planetary Society and after participating in NASA tweet-ups, but often doesn’t follow back. “They’re part of my professional network and you don’t want people to feel slighted because they follow you and you don’t follow them but I have to keep my life under control .” (Interview para36) She also has a lot of followers who do not identify as scientists or tweet scientific information but enjoy reading the tweets of scientists. “There are a lot of people out there who are just interested in science that like to listen to scientists ramble”

(Interview para 48). She also follows and is followed by scientists in other fields who have similar interests such as running.

When asked about the impact Twitter has had on her career, she reported: “when I was interviewed for faculty positions last year at both places I interviewed people told me they had watched [a video interview posted on a blog] before they asked me to come out. One of them mentioned that as one of the things that pushed things in my favor because they were able to see how I can communicate and how I talk about my science without actually having to bring me out.”(Interview para44)

6.6.1.2 **Functional Categories of Tweets**

Public Communication

Sharing funny geoscience-related pictures and cartoons

Dr. Hörst communicates with the public about her science using humor and providing entertaining media. Many of these images are reshared from elsewhere.

Scientific Life, Being a Scientist

Dr. Hörst uses her Twitter feed to show a well-rounded life as a scientist. She expresses frustration with the writing process, complains about broken lab equipment, discusses lab set up, and so on. In addition to these posts, she also contributed to a #manicuremonday theme found elsewhere on Twitter to show her hand using lab equipment or otherwise in science-related activities. In this way she performs outreach to the mostly women on Twitter who are following the #manicuremonday hashtag.

Figure 16 Example Image from Sarah Hörst's Twitter feed (retrieved 4/23/2015)

Doing Science-

Debate/Discussion

She communicates frequently in exchanges with a small group of planetary scientists in which individual tweets in the exchanges do not stand alone.

> "We've built this core group of planetary people on twitter that started as an online thing has really become more of a real life thing. Whenever we're all at the same meeting inevitably we end up hanging out a whole lot together which is always weird to other people because we all study different kinds of things. They're like, 'How do you guys know each other so well?' We know each other on Twitter. That's nice to have, I consider our little group a bit of a family. We definitely have reached that extra level beyond just professional colleagues in terms of the way that we interact both on Twitter and in real life." (Interview para 40)

A recent exchange about meteor showers on Titan was captured by Emily Lakdawalla and posted on the Planetary Society blog (see **Figure 17** for an excerpt). Initially these collections of tweets may seem to only serve a social function, but closer inspection shows that the topics are scientific and the conversation builds knowledge in planetary sciences.

Requests for Assistance

Sarah Hörst occasionally asks a question about coding for analysis and asks for assistance getting copies of journal articles using the #icanhazpdf hashtag.[5]

Social(Community Building)

Other exchanges have been more entertaining and humorous, for example riffing on planetary science-based song titles or movie characters. These serve social purposes of identity, group formation, and community maintenance.

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[5] #icanhazpdf is an informal way to crowdsource access to scholarly literature via Twitter. Someone who needs an article can tweet the citation and contact information with the hashtag and someone with access will send. Once the document is received the tweet is deleted. See Gardner and Gardner (2015) for more information.

Meteor showers on Titan: an example of why Twitter is awesome for scientists and the public

Posted by Emily Lakdawalla

2013/03/06 18:48 UTC

Topics: meteors, Titan, explaining science

I use a variety of social networking tools to perform my job, but there's one that's more in and valuable to me than all the rest combined: Twitter. When I first started using Twitter I only as a means to put information out, kind of like my blog only very much shorter. But time I've come to rely upon it as my single source of news, whether it be space news or news. Through my carefully cultivated and pruned list of people and organizations that I fo Twitter is where I hear about press releases, new images from Mars, space news like the Russian meteor, world news like earthquakes and the deaths of political leaders, and loc like wildfires.

And Twitter is, more and more, the place where I interact with readers, fellow journalists, scientists. Through Twitter I watch and, often, participate in ongoing discussions about journalism, space policy, and science. When I have a question, I ask it on Twitter and I g answers within minutes (sometimes, seconds). When I attend a conference, I can discus news and science with my peers through Twitter. Since the discussion is public, anyone jump in to the conversation, and if their contribution is valuable, it will be amplified througl retweets. Sometimes the discussion can get snarky but several studies have shown that Twitter, a positive attitude has much more traction than a negative one, and that's definite on my feed; I routinely trim the list of people that I follow to remove people who get me dc

Yesterday afternoon there was a discussion on Twitter that exemplifies its value and fun, thought that I'd reproduce it here for the benefit of readers who have yet to be convinced t Twitter is anything but people posting photos of their dinners. One important Twitter conve be aware of here is that when you begin a tweet with the "@" symbol and the Twitter use of another person, that's called a "mention" and it's a way of directing your statement or at a specific person. But it's a conversation that's taking place out in public, which means other people can jump in and join the conversation, as several do here.

Andy Rivkin @asrivkin Follow
@BadPhysics @elakdawalla Also relevant: adsabs.harvard.edu/abs/2005Natur....
5:51 PM - 5 Mar 2013

lukemeister @lukedones Follow
@BadPhysics @elakdawalla Earth meteors ablate at altitudes where atmos pressure is << Mars surface pressure, so Martian meteors visible.
5:51 PM - 5 Mar 2013
1 FAVORITE

lukemeister @lukedones Follow
@BadPhysics @elakdawalla e.g. this paper by Tolis Christou et al.: adsabs.harvard.edu/abs/2012P%26SS...
5:52 PM - 5 Mar 2013

One thing that's happening here is that although the statements of each person are indivi quite brief, there is a TON of substance in this conversation in the form of four links to authoritative articles: one an online FAQ about fireballs, one a transcript of a NASA podc lunar impact flashes, and two peer-reviewed papers about meteor flashes in the Martian atmosphere: one on a flash observed by Spirit and the other on a proposed wide-angle m flash-hunting camera for a Martian orbiter. I had seen the first two links before but had be unaware of the two papers, which were fascinating.

A little later, a third scientist, Titan-atmosphere-making Sarah Horst, said this:

Sarah Hörst @PlanetDr Follow
@asrivkin @BadPhysics @elakdawalla @lukedones I just had a sad when I realized you probably can't see meteor showers on Titan :(
6:20 PM - 5 Mar 2013
1 FAVORITE

(Note: Sarah's unusual "I had a sad" syntax here is LOLspeak, an Internet lingo. As with slang, linguistics researchers have described LOLspeak as "a form of language play that in-group cohesion: if you're in on the joke, you're part of the community.")

Sarah's comment inspired a lot of responses.

Andy Rivkin @asrivkin Follow
@PlanetDr @BadPhysics @elakdawalla @lukedones Probably could do the radio meteor thing with the right equipment, though.
6:22 PM - 5 Mar 2013

Exclamation Snark @BadPhysics Follow
@PlanetDr @asrivkin @elakdawalla @lukedones Do a science: Factor in haze/ambient light/darkness adaption. Make graph size/velocity. Plot vis
6:23 PM - 5 Mar 2013

lukemeister @lukedones Follow
@PlanetDr Not from the surface, but just another reason we need to watch Titan at all times with ALL the telescopes.
6:24 PM - 5 Mar 2013
1 FAVORITE

Exclamation Snark @BadPhysics Follow
@PlanetDr @asrivkin @elakdawalla @lukedones If it is big enough you will probably see something. Russian meteor was brighter sun, even here.
6:24 PM - 5 Mar 2013

Figure 17 Excerpt from Planetary Society Blog Showing Twitter Conversation (by E. Lakdawalla, http://www.planetary.org/blogs/emily-lakdawalla/2013/03061019-twitter-meteor-titan.html retrieved 4/7/2015)

6.6.1.3 **Functional Categories of Conference Tweeting**

Sara Hörst tweeted from AGU2011 (23 tweets) and AGU2012 (66 tweets).

"I tweet at meetings and that's like halfway as a service to everyone else who is at the meeting but not in that session or who can't be at the meeting but also I try with varying degrees of success to make the tweets at least somewhat comprehensible so the people who follow me because they are interested in planetary science can actually learn what's the cutting edge. What are people talking about at meetings" (Interview para 14)

Tweets are often humorous, picking out the entertaining as well as the informative parts of presentations. For example

> On slide about giant storm on Saturn "storm bit own tail, died" #AGU11

If there are multiple attendees tweeting, she might focus less on informative summaries or analysis and tweet more "snark" or commentary. "Sometimes I'll tweet something I hear the audience say during talks … sometimes you'll hear the person behind you say bull[…] under their breath … so you give people a sense of what it's like in the room."(Interview para 19). An example

Advice to presenters: Pro tip: if the entire room leans forward each time you put up a new slide, your font is WAY too small #AGU11

Dr. Hörst also reports that having made friends on Twitter prior to meetings can make first meetings easier for junior scientists: "You go to meeting and you don't know anyone else and that's a really scary thing to do and I think twitter helps that way cause people can always just tweet is anyone going to dinner tonight and you don't necessarily have to know a lot of people at a meeting to feel you belong" (Interview para 40)

A3.4.3 Blogs and Tweets as Information Sources

A3.4.4 The Online Geoscience Community

A3. 5 Andy Rivkin

Andy Rivkin is a planetary scientist at a university-affiliated research center. He studies asteroids and uses spectroscopy to study their surfaces. He started tweeting in 2008 and has over 30,000 tweets.

A3.5.1 Blogging

Dr. Rivkin does not keep a science blog. He has one guest post on the Planetary Society blog and another on a *Scientific American* blog about contacting Congress about threatened cuts to NASA planetary science funding. He does maintain a music blog, on which he posts recordings of original songs and covers. Some of the original songs are on planetary science topics. Dr. Rivkin has a few reasons not to keep a science blog. First, he is constrained in what information he can post publicly by his employer's policies. Second, he would prefer to post videos and images over text. Third, he enjoys the more interactive nature of Twitter and prefers that to the type of interaction on blogs (Interview para 75 and 79).

A3.5.2 Twitter

1. Science (for scientists)

1a. Pointing to readings

1b Discussing scientific topics

Dr. Rivkin participates in frequent exchanges with a small group of planetary scientists. Topics vary widely from remakes of song or movie titles with science terms to speculation on meteors on Titan (see discussion in Section A3.4 for Sarah Hörst who also participates).

1c Tutoring peers

Not observed.

2. Doing Science

2a. Reporting from field work

Not relevant.

2b Reporting from lab (telescope) work

Whereas other geoscientists go to the field to gather data, Dr. Rivkin uses a telescope and other remote sensors. When he has control of a telescope he sometimes tweets actions and observations as he is working (not technical astronomical observation data, but observations as used in this study).

2c Analyzing

Like Kevin Anchukaitis, Andy Rivkin occasionally tweets back of the envelope calculations, analysis, and pointers to the literature in response to questions and musings from elsewhere on Twitter. An example of this is the original research he posted over the course of the day after the Chelyabinsk meteor entry in February 2013 (see Figure 18). He said:

> "When the Chelyabinsk bolide happened that was really exciting and I felt like I was able to go and get online and I knew the tools and I was able to [post] 'Just based on this video that we're seeing the bolide the original body was probably this big that means it happens about this often' and kind of be a first responder so to speak" (Interview para 49)

Dr. Rivkin would like to do more of this and post more research in progress, but is constrained by his employer's review and release policies. He is not concerned about being scooped because of his seniority and his specialization (Interview para 51).

!!! Just woke up, will try to catch up on this. RT @cnnbrk: Meteor blast injures four in southern Russia http://t.co/ccEZAz2X #cnn
Would be "loud as heavy traffic" 50 km away, overpressure sufficient to break many windows. No crater, airburst 34k feet. #russian meteor
Reference for overpressure bit, which is what I'm hanging much (too much?) of my interpretation on. #russianmeteor http://t.co/vaaqmyjA
Still playing with Purdue impact site. Higher reported speed (30 vs 11 km/s) and flatter angle (~15? vs 45 deg) cancel out. #russianmeteor
Well, my 40-m guesstimate is a factor of 5-10 larger than the official one. But info is still coming in. #livescience #russianmeteor
Viz "Largest impact in a century" quotes, also consistent with ~20 m impactor. Still seems a bit small to me. :) #russianmeteor
Looks like #RussianMeteor is a top US trending hashtag, along with #2012DA14, #DA14, and "Asteroid 2012 DA14". Yay asteroids! :)
The Chelyabinsk impactor would not have been considered a Potentially Hazardous Asteroid (PHA) had it been found: too small. #RussianMeteor

Figure 18 Tweets from Andy Rivkin on the Chelyabinsk meteor (February 15, 2013)

2d Requesting Assistance

Like Dr. Hörst, Dr. Rivkin uses Twitter to poll his colleague to get quick answers to questions he encounters in his research. In the interview he said, “there are times when one of us will have a question: ‘Hey I’m looking up …What’s the fraction of Kuiper belt objects with satellites? Well, I think it’s this, I heard it’s that. Come up with a follow up: ‘Well do you think this is what’s going on or that’s what’s going on?’”(para 49).

2e. Building Science Community

3. Conference Specific

3a. Covering a session live

3b Providing Color commentary

3c From away from the conference

3d Summarizing a conference

4. Science News/Announcements

4a. Announcing job openings

4b Announcing defenses, graduations

4c Announcing papers published

5. Teaching (being a teacher)

5a. Providing Advice for Students

5b Recruiting Students

5c Pointing to Educational Resources

5d Explaining how to teach

6. Public Communication of Science

6a. Explain a science concept

6b Review a new finding in more comprehensible terms

6c Explain a natural hazard/disaster

6d Review science history

6e. Review popular science books

6f. Explain a scientific controversy (for public)

7. Social

7a. Biographical/Confessional

7b Coordinating

8. Entertainment

8a. Images

9. Politics, Religion, and Society

9a. Reviewing books (not science)

9b Commenting or advocating on political, religious, or social topics

9c Commenting on news (not science)

10. Meta (about the blog or Twitter)

6.6.1.4 Functional Categories of Conference tweeting

Andy Rivkin tweets frequently from conferences, but he doesn't regularly attend AGU conferences, instead preferring Lunar and Planetary Sciences Institute, American Astronomical Society Division for Planetary Sciences, and other smaller conferences. He has 46 tweets from the 2012 AGU conference in the dataset of which 18 are session tweets. Several other tweets were from an AGU-related open mike night held at a local bar.

He originally started tweeting from conferences when he was attending small foreign conferences and thought he should share what he was learning since many of his colleagues were unable to attend. He has signed up to be an official microblogger for the Lunar and Planetary Science Conference to get preferential access to the wireless internet. There were general guidelines for approaching tweeting as an official representative, but he found these to be common sense and not overly restrictive.

A large portion of his tweets from conferences are session tweets. His approach to these has changed:

> For at least a year or so I would be the only person who would be tweeting a session but then there would be two people and then I switched over to be a color commentator. You only need so many people in a session saying the Dawn spacecraft found the radius of Vespa is 250 and so I wanted to give more of a “people have been thinking about this for a while” or “hey the room is 2/3 full for this and this is great, or this is not great.” I think there’s been some amount of self-organizing as it’s gone from one person in the room to two people in the room to a dozen here at the meeting “where are you going to be …” “hey can you let me know when this talk is a couple of minutes away from beginning” (Interview para 40)

Besides the session tweets, he tweets mostly coordination and social tweets. Coordination tweets describe upcoming sessions he plans to attend and encourage attendees to attend an open mike night and other events.

A3.5.3 Blogs and Tweets as Information Sources

A3.5.4 The Online Geoscience Community

Dr. Rivkin maintains relationships with colleagues from graduate school and college as well as scientists he has met at meetings through Twitter. Through light banter, sharing memes, and asking/responding to questions and shared information, he helps build the planetary sciences community.

A3.6 Chris Rowan

Dr. Rowan is an Assistant Professor in the Department of Geology at a large Midwestern public university. He studies paleomagnetism, tectonics, and geophysics. Dr. Rowan is an early adopter of SCTs, starting his first blog in 2005 and joining Twitter in 2009. He advocates for scientists using social media and maintains a database and Twitter stream of geoscience blogs (@GeoBlogFeed). Additionally, he has given numerous talks on using Twitter and blogs and attends blogger and social media meetings at the various conferences he attends.

A3.6.1 Blogging

Dr. Rowan started his blog as he was finishing up his dissertation in 2005. He took a course on communicating science to the public and wanted to continue to practice to develop his skills also as a potential career path if the research path did not work out for him. He directs his posts toward the interested public: not making things overly simplified, but understandable with thought and careful reading (Interview para 33). His most popular posts provide scientific context and explanation for earthquakes. “Where there’s a big earthquake I try to put up a map of where it is and where the plate boundaries are if there is one. What kind of earthquake happened. Complete with sources and like that.” (Interview para 33)

A use Dr. Rowan mentioned that was not mentioned by others was the value gained in his process of developing his research agenda after graduating. He read more broadly to cover topics for the blog.

> I think one of the interesting things is that it has made my science grow in directions it might not have otherwise. When I was in the stage when I was more likely to be motivated by to feed the blogging beast. I would look around at what was interesting and being published and that made me more aware. One of the problems of all

> scientists when they go from their PhD to becoming a fully-fledged researcher is that you spend several years on the PhD focusing extremely narrowly on one piece of the problem and then you're expected to come up with your research ideas which are not the same as your PhD supervisor's. Focus on this one area and you suddenly have to step back…What other things which are like that are out there that I can apply my skills to and start addressing and build up my own career. Quite a bit of time to survey the field and writing and thinking about. Understand why these things are interesting. Always valuable. I'm not sure I would have done this in the same way, but it's hard to untangle. I have often felt that being involved in blogging and social media has made me a more well-rounded scientist than otherwise. (Interview para 38)

Dr. Rowan's blog posts are almost always thoughtful analyses that are carefully written with his audience in mind. Diagrams are created and images are selected to illustrate his points. Many of these posts have received at least a few substantive comments, and he engages with his readers to answer questions and refer them to additional sources of information. Because of this high quality and self-imposed requirements, blogging has become a burden when there are so many other pressing needs for his time. It appears he briefly experimented with a lab blog in 2014, but there are only a few posts.

1. Science (for scientists)

1a. Pointing to readings

Dr. Rowan often points to scholarly and technical articles

1b Discussing scientific topics

1c Tutoring peers

2. Doing Science

2a. Reporting from field work

2b Reporting from lab work

2c Analyzing

2d Requesting Assistance

2e. Building Science Community

Using SCTs to build and support the geosciences community is important to Dr. Rowan. Many of his posts are more in support of community building within the geoblogosphere, continuing discussions from other blogs and from Twitter; participating in memes; participating, hosting or linking to blog carnivals; and supporting other geoscientists. He does polls, quizzes and puzzles to involve readers in conversations about geosciences.

3. Conference Specific

3a. Covering a session live

He does not live blog, as he said on his blog:

> What is the most effective way of blogging/tweeting a conference? Does an effective way actually exist?
>
> I have myself done a bit of conference blogging. With one (prompted) exception, I've eschewed true 'liveblogging'– writing up conference sessions on the fly– because the demands of producing legible prose– or, at least, prose that my pedantic inner copy-editor is happy publishing– distracts me too much from actually following the presentations (http://all-geo.org/highlyallochthonous/2009/10/blogging-tweeting-and-conferences/)

3b Providing Color commentary

3c From away from the conference

3d Summarizing a conference

Dr. Rowan posts reviews of conferences he has attended. He does find writing up notes later for his blog useful as a sort of trip report. He also has posted collections of links to conference reports from other attendees.

4. Science News/Announcements

4a. Announcing job openings

4b Announcing defenses, graduations

4c Announcing papers published

5. Teaching (being a teacher)

5a. Providing Advice for Students

5b Recruiting Students

5c Pointing to Educational Resources

5d Explaining how to teach

6. Public Communication of Science

6a. Explain a science concept

These posts show examples of a phenomenon and provide the explanation for them. For example, Dr. Rowan posts a regular series called “Friday Focal Mechanisms” in which he reviews a recent earthquake and explains the focal mechanisms for it. See an example in Figure 19.

6b Review a new finding in more comprehensible terms

Some posts aimed at an interested public reference scholarly literature, others reference open websites (NASA, Wikipedia, university pages), describing a phenomenon with images and diagrams. “That process of having to break it down and deal with it – put it into simpler words – I find helpful to me because it makes me... Old saying you don’t really understand something until you can explain it to someone else” (Interview para 35)

6c Explain a natural hazard/disaster

6d Review science history

6e. Review popular science books

6f. Explain a scientific controversy (for public)

7. Social

7a. Biographical/Confessional

Over the course of the ten years he has maintained a blog, Dr. Rowan has shared information on career moves and job hunting as he has moved from being a graduate student in Scotland to a researcher in South Africa and then the United States.

7b Coordinating

8. Entertainment

8a. Images

In a series named “Scenic Saturdays”, Dr. Rowan posts images from his travels with short descriptions. The purpose appears to be to share appreciation for the beauty of nature more than communicating a scientific concept or sharing fieldwork data

9. Politics, Religion, and Society

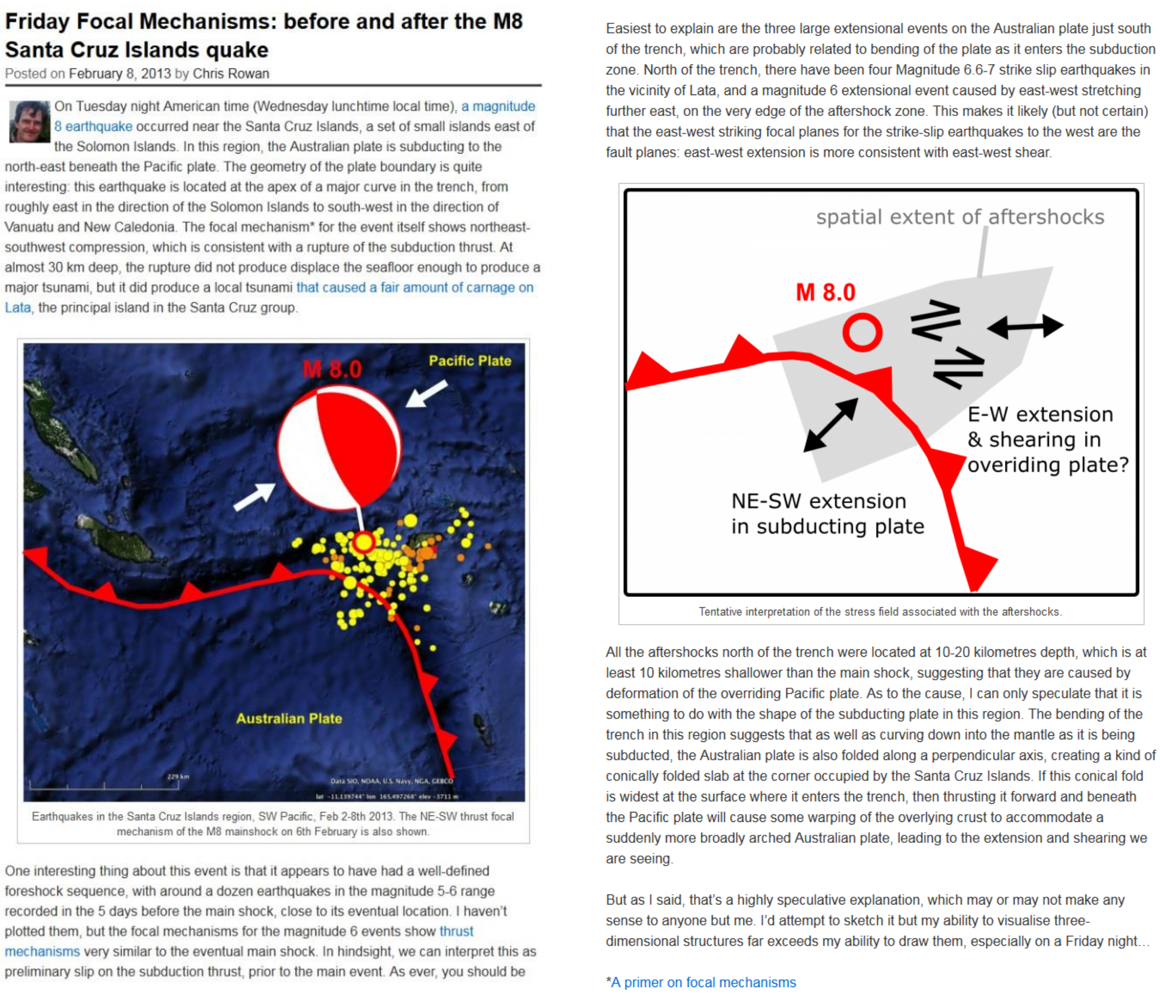
9a. Reviewing books (not science)

9b Commenting or advocating on political, religious, or social topics

9c Commenting on news (not science)

10. Meta (about the blog or Twitter)

These include posts about the blog such as adding a new feature, changing platforms, updating software, lists of the first post each month for the past year, asking readers to tell about themselves. Also in this category are weekly round-ups of interesting things posted to Twitter.



Friday Focal Mechanisms: before and after the M8 Santa Cruz Islands quake

Posted on February 8, 2013 by Chris Rowan

On Tuesday night American time (Wednesday lunchtime local time), a magnitude 8 earthquake occurred near the Santa Cruz Islands, a set of small islands east of the Solomon Islands. In this region, the Australian plate is subducting to the north-east beneath the Pacific plate. The geometry of the plate boundary is quite interesting: this earthquake is located at the apex of a major curve in the trench, from roughly east in the direction of the Solomon Islands to south-west in the direction of Vanuatu and New Caledonia. The focal mechanism* for the event itself shows northeast-southwest compression, which is consistent with a rupture of the subduction thrust. At almost 30 km deep, the rupture did not produce displace the seafloor enough to produce a major tsunami, but it did produce a local tsunami that caused a fair amount of carnage on Lata, the principal island in the Santa Cruz group.

Earthquakes in the Santa Cruz Islands region, SW Pacific, Feb 2-8th 2013. The NE-SW thrust focal mechanism of the M8 mainshock on 6th February is also shown.

One interesting thing about this event is that it appears to have had a well-defined foreshock sequence, with around a dozen earthquakes in the magnitude 5-6 range recorded in the 5 days before the main shock, close to its eventual location. I haven't plotted them, but the focal mechanisms for the magnitude 6 events show thrust mechanisms very similar to the eventual main shock. In hindsight, we can interpret this as preliminary slip on the subduction thrust, prior to the main event. As ever, you should be

Easiest to explain are the three large extensional events on the Australian plate just south of the trench, which are probably related to bending of the plate as it enters the subduction zone. North of the trench, there have been four Magnitude 6.6-7 strike slip earthquakes in the vicinity of Lata, and a magnitude 6 extensional event caused by east-west stretching further east, on the very edge of the aftershock zone. This makes it likely (but not certain) that the east-west striking focal planes for the strike-slip earthquakes to the west are the fault planes: east-west extension is more consistent with east-west shear.

Tentative interpretation of the stress field associated with the aftershocks.

All the aftershocks north of the trench were located at 10-20 kilometres depth, which is at least 10 kilometres shallower than the main shock, suggesting that they are caused by deformation of the overriding Pacific plate. As to the cause, I can only speculate that it is something to do with the shape of the subducting plate in this region. The bending of the trench in this region suggests that as well as curving down into the mantle as it is being subducted, the Australian plate is also folded along a perpendicular axis, creating a kind of conically folded slab at the corner occupied by the Santa Cruz Islands. If this conical fold is widest at the surface where it enters the trench, then thrusting it forward and beneath the Pacific plate will cause some warping of the overlying crust to accommodate a suddenly more broadly arched Australian plate, leading to the extension and shearing we are seeing.

But as I said, that's a highly speculative explanation, which may or may not make any sense to anyone but me. I'd attempt to sketch it but my ability to visualise three-dimensional structures far exceeds my ability to draw them, especially on a Friday night…

*A primer on focal mechanisms

Figure 19 Example Friday Focal Mechanisms post (http:/ /all-geo.org/highlyallochthonous/2013/02/friday-focal-mechanisms-before-and-after-the-m8-santa-cruz-islands-quake/ retrieved 4/4/2015)

A3.6.2 Twitter

CRuses Twitter irregularly between conferences. He usually checks for updates once a day but may miss a few days if he is too busy. He finds Twitter useful as a source of news and for early alerts to earthquakes and other interesting news:

> I was in New York and just prior to the science online conference and there was a big earthquake in Haiti and basically I wouldn't have known anything about it if I hadn't been looking at my twitter account and it suddenly blew up.(Interview para3)

He also finds twitter useful for bouncing ideas off of other scientists.

Dr. Rowan is a consistent conference tweeter with 229 tweets in the three-year AGU dataset of which more than half were session tweets.

Session Tweets

How CRtweets sessions changed over the three years. In 2012 tweets, the first tweet from a session has the speaker's first and last name and then subsequent tweets has the speaker's last name and a colon before the content. There may be additional tweets from a session providing color commentary, opinion, analysis, or to add details from his own knowledge and not attributable to the speaker:

> Glen Biasi using the wonderful 8,000 yr Hokuri Creek paleoseismic record for the Alpine Fault to compare with the San Andreas #AGU12 (AGU2012-509)

> Seems that the Alpine Fault is much more time-predictable (quakes at more regular intervals); possibly because of simpler structure #AGU12 (AGU2012-505)

In contrast, in 2010 tweets, there are many that appear to be session tweets, but provide no attribution to a speaker.

> Early work on turbidite paleoseismology for Sumatran subduction zone: seems to match records from coral reef uplift etc. #AGU10.(Tue Dec 14 01:10:26 +0000 2010)

This series of tweets from the 2010 meeting illustrates his early style.

> Kelvin Berryman presents 8000 year paleoseismic record of Alpine fault NZ: average time between quakes 328 years 'quasi-periodic' #AGU10 (Thu Dec 16 17:46:20 +0000 2010)

> 'quasi-periodic' means there is variation in time between consecutive quakes there are no long-term trends in

average repeat time #AGU10 (Thu Dec 16 17:48:41 +0000 2010)

Next speaker shows there are small (+/- 50yrs) changes in average time between Alpine Fault quakes over millennial timescales #AGU10 (Thu Dec 16 18:04:20 +0000 2010)

Some of the session tweets each year are from the poster sessions. These are often general overviews of the topics covered in the session:

Browsing the paleomag posters. Experimental dynamos, Pangea reconstructions, the timing of the India-Asian collision, oh my! #AGU11 (AGU2011-2468).

He does however spotlight particular posters of interest tweeting a summary of the main points as he tweets other sessions.

Dr. Rowan's session tweets often add value beyond summarizing or reporting the speaker's main points. He points out the significance of the findings or what is interesting about the method or equipment used. For example:

Maurice Tivey has some beautiful magnetic anomaly data from enigmatic Jurassic-age crust in the W Pacific. #AGU12 (AGU2012-1026)

Why is the data so good? Collected from a magnetometer fitted to bottom-hugging AUV, so much closer to source. #AGU12 #wehavesuchlovelytoys" (AGU2012-1024)

And

Dietmar Muller follows up with a global analysis: 90% of great earthquakes fall within 150 km of a subducted fracture zone. #AGU12 (AGU2012-1151)

Muller used filtering algorithm related to Amazon recommendations. For great earthquakes also favours fast convergence & shallow dip #AGU12 (AGU2012-1147)

> Of course, this sort of analysis is limited by relatively short historical record: more data has often weakened similar relationships #AGU12 (AGU2012-1141)

Social

Meta Conference

Before the conference, CRtweets about preparing submissions to the conferences, preparing the posters and slide decks, and traveling to the conference.

> At 'trying to explain results in as few words as possible' stage of #AGU10 poster. Antithesis of usual writing style; every syllable counts!

Coordination

During the conference he tweets to say where he is and what sessions he will be attending

> Fate has contrived to have me presenting a talk on NZ tectonics at 4.45pm, Room 307 Moscone S. I'm almost as surprised as you are... #AGU11 (AGU2011-291).

After the conference he tweets more on travel, etc.

> SF airport a seething mass of humanity not many of whom seem to be going anywhere. Is @theAGU punishing me for leaving #AGU10 early?

A3.6.3 Blogs and Tweets as Information Sources

Personal knowledge management:

"my liveblogging endeavors thus far have been, for want of a better word, selfish. The exercise has some value to me, by helping to organize and preserve my thoughts and impressions of the talks that I attended."(Interview)

"interestingly, now I have become a teacher I have found that having a number of years of blogging about [] in geology or earthquakes or things like that it has really given me a neat archive of material I try to put into lectures or use to provide a basic understanding. I would not have had that otherwise."(Interview)

A3.6.4 The Online Geoscience Community

> "directing you too people of similar interest around the world regardless of where they are which is nice because sometimes as a scientist you have very esoteric interests and actually having that tool to use to connect with people who have similar interest in the next town over or continent over is quite nice and quite useful." (interview)

> Our goal in starting Earth Science Erratics was to promote and encourage new voices to take there first steps into the geoblogosphere. But we also want to make sure that people who have taken those first steps already, but have perhaps flown a little under the internet radar, are given the attention they deserve. http://all-geo.org/highlyallochthonous/2011/02/new-at-erratics-whats-up-with-cu/

A3.7 Brian Romans

Brian Romans is a sedimentary geoscientist and assistant professor at a large southern research university. Prior to being a professor, he worked for a large multi-national corporation that does petroleum exploration and extraction.

A3.7.1 Blogging

Dr. Romans has been blogging since 2006. He started when he was still working on his dissertation at Stanford and continued through his time working in industry and now as a professor. He originally started his blog as "productive procrastination" and as a way to write on geoscience topics but in a more general way than what he was doing for his dissertation. While in industry, he found it a useful outlet for teaching which he missed from academia. In his current position, his blogging has tapered off on his primary blog but, like Anne Jefferson, he does keep up a lab blog to use for reporting his lab's activities and as a recruiting tool. "In terms of students it's definitely helped. There have been students I've talked to or interviewed at conferences that mentioned that they saw the web presence" (Interview para 47).

1. Science (for scientists)

1a. Pointing to readings

Dr. Romans posts lists of articles he has read. Unlike Anne Jefferson's posts, his have little annotation.

1b Discussing scientific topics

1c Tutoring peers

2. Doing Science

2a. Reporting from field work

2b Reporting from lab work

2c Analyzing

2d. Requesting Assistance

2e. Building Science Community

Like the other bloggers in the study, Dr. Romans participates in blog carnivals by contributing, hosting, and linking to the collections. He also participates in quizzes and memes like geopuzzles (posts an image and asks commenters to guess what it is) and the "Where on Google Earth" series. For a short period, he regularly compiled a bibliography of interesting posts and events called *Geoblogosphere Week in Review*.

3. Conference Specific

3a. Covering a session live

3b Providing Color commentary

3c From away from the conference

3d. Summarizing a conference

4. Science News/Announcements

4a. Announcing job openings

4b Announcing defenses, graduations

4c Announcing papers published

5. Teaching (being a teacher)

5a. Providing Advice for Students

5b Recruiting Students

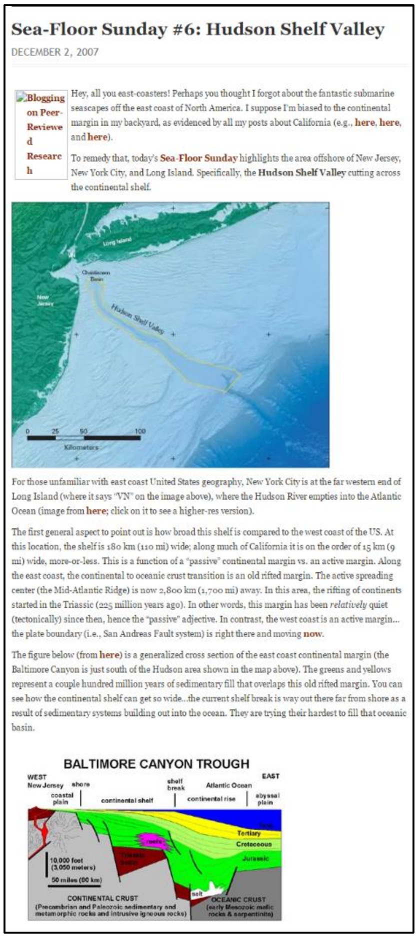
5c Pointing to Educational Resources

5d. Explaining how to teach

6. Public Communication of Science

6a. Explain a science concept

Dr. Romans has several series running for years in his blog. The *Seafloor Sundays* posts show drawings, maps, and images of various seafloor regions and provide explanations and geologic details. Some of these reference scholarly literature and provide resources for additional information. Figure 20 shows an early post in the series that is particularly detailed.


Sea-Floor Sunday #6: Hudson Shelf Valley

DECEMBER 2, 2007

Blogging on Peer-Reviewed Research

Hey, all you east-coasters! Perhaps you thought I forgot about the fantastic submarine seascapes off the east coast of North America. I suppose I'm biased to the continental margin in my backyard, as evidenced by all my posts about California (e.g., **here**, **here**, and **here**).

To remedy that, today's **Sea-Floor Sunday** highlights the area offshore of New Jersey, New York City, and Long Island. Specifically, the **Hudson Shelf Valley** cutting across the continental shelf.

For those unfamiliar with east coast United States geography, New York City is at the far western end of Long Island (where it says "VN" on the image above), where the Hudson River empties into the Atlantic Ocean (image from **here**; click on it to see a higher-res version).

The first general aspect to point out is how broad this shelf is compared to the west coast of the US. At this location, the shelf is 180 km (110 mi) wide; along much of California it is on the order of 15 km (9 mi) wide, more-or-less. This is a function of a "passive" continental margin vs. an active margin. Along the east coast, the continental to oceanic crust transition is an old rifted margin. The active spreading center (the Mid-Atlantic Ridge) is now 2,800 km (1,700 mi) away. In this area, the rifting of continents started in the Triassic (225 million years ago). In other words, this margin has been *relatively* quiet (tectonically) since then, hence the "passive" adjective. In contrast, the west coast is an active margin... the plate boundary (i.e., San Andreas Fault system) is right there and moving **now**.

The figure below (from **here**) is a generalized cross section of the east coast continental margin (the Baltimore Canyon is just south of the Hudson area shown in the map above). The greens and yellows represent a couple hundred million years of sedimentary fill that overlaps this old rifted margin. You can see how the continental shelf can get so wide...the current shelf break is way out there far from shore as a result of sedimentary systems building out into the ocean. They are trying their hardest to fill that oceanic basin.

Figure 20 Example Seafloor Sunday Post (http://clasticdetrituscom/2007/12/02/sea-floor-sunday-6-hudson-shelf-valley/, retrieved 4/23/2015)

6b Review a new finding in more comprehensible terms

6c Explain a natural hazard/disaster

6d. Review science history

6e. Review popular science books

Like Callan Bentley, Dr. Romans includes reviews of popular science books in his blog. In two cases in addition to the review, he interviewed the author and the author also answered questions from commenters. The books are related to geosciences but aimed more at a general audience.

6f. Explain a scientific controversy (for public)

In 2008, Dr. Romans posted a series of analyses rebutting claims in another blog community that the Earth is expanding and that there is no subduction of one plate under another. In these, he evaluates the statements made by several contributors on another blog, reviews the literature, and illustrates his points with annotated maps and graphs. He also engages with the contributors to the other blog in the comments. In a previous era this engagement may have taken place on a radio call-in show or through newspaper editorials and letters, but it would not have allowed for immediate and broad interactivity.

7. Social

7a. Biographical/Confessional

7b Coordinating

8. Entertainment

8a. Images

Unlike his *Seafloor Sunday* series, Dr. Roman's *Friday Field Foto* series does not provide detailed scientific descriptions or analysis of the image. Instead, these are shared because they show beautiful scenery.

9. Politics, Religion, and Society

9a. Reviewing books (not science)

9b Commenting or advocating on political, religious, or social topics

9c Commenting on news (not science)

10. Meta (about the blog or Twitter)

A3.7.2 Tweeting

Brian Romans joined Twitter in 2009 because other bloggers he followed started using it. He has about 18,000 tweets. He started using Twitter by following general scientists and news outlets but mostly only follows geoscientists now. He uses it to share links to things he encounters online but unlike other participants, he does not carefully craft messages with his audience in mind.

Like Anne Jefferson, he uses Twitter to create a collection of resources for teaching,

> "Some web resource that has some interesting data or images that might be good for teaching. I'd say most of it is interesting science stuff I get on there is more useful for teaching than for research . Teaching is more general. … once a

week or so I'll find something really interesting through that medium that ends up being something I'll share with students." (Interview para 26)

Brian Romans doesn't share his own work in progress on social media because it is often collaborative with students or other researchers and he feels he would have to coordinate with them prior to posting and that would make it less spontaneous and more formal.(Interview para 12) He does, however, help to disseminate his published research by linking to it and highlighting key findings (see)

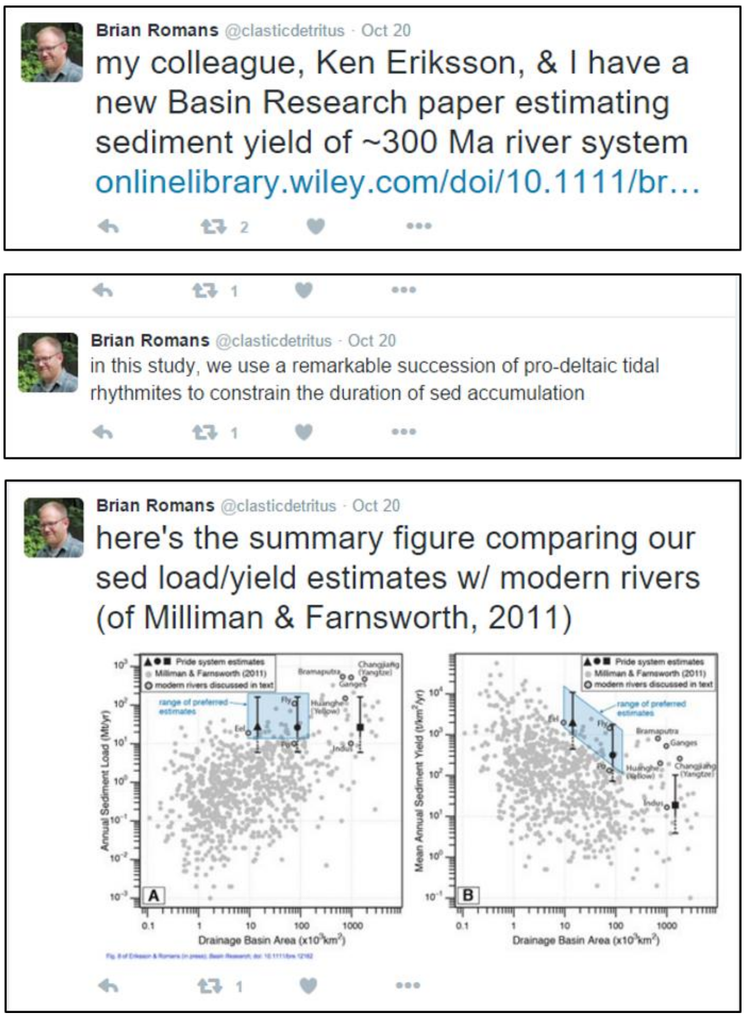


Figure 21 Example Dissemination/Amplification Tweets from Brian Romans

Functional Categories of Conference Tweeting

Dr. Romans has 87 conference tweets in the collection, primarily from 2010 and 2011 when he attended but also a few from 2012 when he did not.

Meta Conference

Many of BR's conference tweets are observations documenting his conference preparation process:

> Just spent 3.5 hours trying to plot my #agu10 poster and failed – awesome,"

his travel, or his enjoyment of the conference itself:

> Another awesome day at #agu10 ... saw some really great stuff and caught up with some old friends too."

News/Announcements

Another group of his tweets are announcing and repeating posts announcing events at the conference such as the Social Media Soiree sponsored by AGU.

Social - Coordination

While at the conference there are more coordination tweets with what sessions he plans to see than tweets sent during sessions. The few session tweets are general summaries:

> Caught a nice talk from Gehrels et al about adding Hf isotopes to their giant detrital zircon database for North American evolution #AGU11(AGU2011-1596)

A3.7.3 Blogs and Tweets as Information Sources

A3.7.4 The Online Geoscience Community

"Only a couple months into starting the blog I quickly came to appreciate one of the most valuable aspects – interacting with other geoscientists in a whole new way. As I commented on and linked to other people's blogs, a social network began to develop. That was nearly four years ago and the web of people I interact with online now is significant. Besides a love for geology, the only thing the people in this network have in common is communicating that passion online. The result is an extremely rich diversity of disciplines, scientific interests, stages in careers, experience, locations, ages, backgrounds, lifestyles, political views, and so on." http://blogsagu.org/sciencecommunication/2010/06/23/why-i-blog-brian-romans/)

Follow Friday. Recommendation of other blogs or twitter streams

One of my favorite blogs that I wish I had more time to read… One of the aspects I like about this blog are the informative and visually-pleasing plots, charts, and graphs.

http://clasticdetrituscom/2008/03/17/creation-of-a-sustainable-planet

References

Acord, S. K., & Harley, D. (2013). Credit, time, and personality: The human challenges to sharing scholarly work using web 2.0. *New Media & Society, 15*(3), 379-397. doi:10.1177/1461444812465140

Argyle, M. (1972). Non-verbal communication in human social interaction. In R. A. Hinde (Ed.), *Non-verbal communication* (pp. 243-268). Cambridge, U.K.: Cambridge University Press.

Barjak, F. (2006). The role of the internet in informal scholarly communication. *Journal of the American Society for Information Science and Technology, 57*(10), 1350-1367. doi:10.1002/asi.20454

Batts, S. A., Anthis, N. J., & Smith, T. C. (2008). Advancing science through conversations: Bridging the gap between blogs and the academy. *PLoS Biology*, *6*(9), e240. doi:10.1371/journal.pbio.0060240

Baumer, E., Sueyoshi, M., & Tomlinson, B. (2008). Exploring the role of the reader in the activity of blogging. *26th Annual CHI Conference on Human Factors in Computing Systems, CHI 2008,* 1111-1120. doi:10.1145/1357054.1357228

Beaulieu, A. (2010). Research note: From co-location to co-presence: Shifts in the use of ethnography for the study of knowledge. *Social Studies of Science*, *40*(3), 453-470. doi:10.1177/0306312709359219

Berkenkotter, C., & Huckin, T. N. (1995). *Genre knowledge in disciplinary communication: Cognition/culture/power*. Hillsdale, N.J.: L. Erlbaum Associates.

Biber, D., & Conrad, S. (2009). *Register, genre, and style*. New York: Cambridge University Press.

Bichteler, J. (1991). Geologists and gray literature: Access, use and problems. *Science and Technology Libraries*, *11*(3), 39-50.

Bijker, W. E. (1995). *Of bicycles, bakelites, and bulbs : Toward a theory of sociotechnical change*. Cambridge,MA: MIT Press.

Birnholtz, J. P. (2005). *When do researchers collaborate? toward a model of collaboration propensity in science and engineering research.* (Unpublished Doctor of Philosophy (Information)). The University of Michigan, (3186579)

Birnholtz, J. P. (2007). When do researchers collaborate? toward a model of collaboration propensity. *Journal of the American Society for Information Science and Technology, 58*(14), 2226-2239. doi:10.1002/asi.20684

Birnholtz, J. P., Finholt, T. A., Horn, D. B., & Bae, S. J. (2005). Grounding needs: Achieving common ground via lightweight chat in large, distributed, ad-hoc groups. *CHI '05: Proceedings of the SIGCHI Conference on Human Factors in Computing Systems,* Portland, Oregon, USA. 21-30.

Bishop, A. P. (1999). Document structure and digital libraries: How researchers mobilize information in journal articles. *Information Processing & Management, 35*(3), 255-279.

Blake, C., & Pratt, W. (2006a). Collaborative information synthesis I: A model of information behaviors of scientists in medicine and public health. *Journal of the American Society for Information Science and Technology, 57*(13), 1740-1749. doi:10.1002/asi.20487

Blake, C., & Pratt, W. (2006b). Collaborative information synthesis II: Recommendations for information systems to support synthesis activities. *Journal of the American Society for Information Science and Technology, 57*(14), 1888-1895. doi:10.1002/asi.20486

Blanchard, A. L. (2007). Developing a sense of virtual community measure. *CyberPsychology & Behavior, 10*(6), 827-830.

Blood, R. (2002). *The weblog handbook practical advice on creating and maintaining your blog*. Cambridge, MA: Perseus Pub.

Borgman, C. L. (2007). *Scholarship in the digital age: Information, infrastructure, and the internet*. Cambridge, MA: MIT Press.

Borgman, C. L., & Furner, J. (2002). Scholarly communication and bibliometrics. In B. Cronin (Ed.), *Annual review of information science and technology (ARIST)* (pp. 2-72). Medford,NJ: Information Today. doi:10.1002/aris.1440360102

Bowker, G. C. (2000). Biodiversity datadiversity. *Social Studies of Science, 30*(5), 643-683. doi:10.1177/030631200030005001

boyd, d. m. (2006). A blogger's blog: Exploring the definition of a medium. *Reconstruction*, *6*(4) Retrieved from http://reconstruction.eserver.org/064/boyd.shtml

Bruce, H., Jones, W., & Dumais, S. T. (2004). Information behaviour that keeps found things found. *Information Research-an International Electronic Journal, 10*(1), 207.

Bryant, J., & Pribanic-Smith, E. J. (2010). A historical overview of research in communication science. In C. R. Berger, M. E. Roloff & D. R. Roskos-Ewoldsen (Eds.), *The handbook of communication science* (2nd ed., pp. 21-36). Los Angeles: Sage.

Carley, K., & Wendt, K. (1991). Electronic mail and scientific communication A study of the soar extended research group. *Science Communication, 12*(4), 406-440. doi:10.1177/107554709101200405

Chen, G. M. (2011). Tweet this: A uses and gratifications perspective on how active twitter use gratifies a need to connect with others. *Computers in Human Behavior*, *27*(2), 755-762. doi:10.1016/j.chb.2010.10.023

Chin, J., George, Myers, J., & Hoyt, D. (2002). Social networks in the virtual science laboratory. *Communications of the ACM, 45*(8), 87-92. Retrieved from http://doi.acm.org/10.1145/545151.545156

Clark, T. (2008). `We're over-researched here!': Exploring accounts of research fatigue within qualitative research engagements. *Sociology, 42*(5), 953-970. doi:10.1177/0038038508094573

Clarke, H. H., & Brennan, S. E. (1993). Grounding in communication. In R. M. Baecker (Ed.), *Readings in groupware and computer-supported cooperative work: Assisting human-human collaboration* (pp. 222-233). San Mateo, CA: Morgan Kaufmann Publishers.

Cobley, P., & Schulz, P. J. (2013). *Theories and models of communication*. Berlin: De Gruyter.

Collins, H. M. (1985a). *Changing order: Replication and induction in scientific practice*. Beverly Hills, CA: Sage Publications.

Collins, H. M. (1985b). The scientist in the network. *Changing order: Replication and induction in scientific practice* (pp. 129-157). Beverly Hills, CA: Sage Publications.

Crane, D. (1972). *Invisible colleges: Diffusion of knowledge in scientific communities*. Chicago: University of Chicago Press.

Creswell, J. W. (2002). *Research design: Qualitative, quantitative, and mixed method approaches* (2nd ed.). Thousand Oaks, CA: Sage Publications.

Daft, R. L., & Lengel, R. H. (1986). Organizational information requirements, media richness and structural design. *Management Science*, *32*(5), 554-571.

Daly, J. A. (2011). Personality and interpersonal communication. In M. L. Knapp, & J. A. Daly (Eds.), *The sage handbook of interpersonal communication* (4th ed., pp. 131-165). Thousand Oaks, CA: Sage.

Darling, E.,S., Shiffman, D., Côté, I. M., & Drew, J.,A. (2013). The role of twitter in the life cycle of a scientific publication. *PeerJ PrePrints, 1*, e16v1. doi:10.7287/peerj.preprints.16v1

Dennen, V. P. (2009). Constructing academic alter-egos: Identity issues in a blog-based community. *Identity in the Information Society, 2*(1), 23-38. doi:10.1007/s12394-009-0020-8

Dennen, V. P. (2014). Becoming a blogger: Trajectories, norms, and activities in a community of practice. *Computers in Human Behavior, 36*, 350-358. doi:10.1016/j.chb.2014.03.028

Dennis, A. R., & Kinney, S. T. (1998). Testing media richness theory in the new media: The effects of cues, feedback, and task equivocality. *Information Systems Research, 9*(3), 256-274.

Dumlao, R., & Duke, S. (2003). The web and e-mail in science communication. *Science Communication, 24*(3), 283-308.

Dunwoody, S., Brossard, D., & Dudo, A. (2009). Socialization or rewards? predicting U.S. scientist-media interactions. *Journalism and Mass Communication Quarterly, 86*(2), 299-314. Retrieved from http://aejmc.org/topics/wp-content/uploads/2009/09/3-Dunwoody-et-al.pdf

Ebner, M., & Reinhardt, W. (2009). Social networking in scientific conferences: Twitter as tool for strengthening a scientific community. Paper presented at the *Proceedings of the EC-TEL 2009,* Retrieved from http://www.telearn.org/warehouse/Ebner_2009_TelSci2.0_%28002197v1%29.pdf

Efimova, L. (2009). *Passion at work: Blogging practices of knowledge workers*. Enschede, Netherlands: Novay. Retrieved from http://blog.mathemagenic.com/download/passionAtWork.pdf

Efimova, L., Fiedler, S., Verwijs, C., & Boyd, A. (2004). Legitimised theft: Distributed apprenticeship in weblog networks. *I-Know 04,* Graz, Austria.

Efron, M., & Winget, M. (2010). Questions are content: A taxonomy of questions in a microblogging environment. Paper presented at the *Proceedings of the American Society for Information Science and Technology,* Pittsburgh, PA. , *47*(1) 1-10. doi:10.1002/meet.14504701208

Ess, C., & AoIR ethics working committee. (2002). Ethical decision-making and internet research: Recommendations from the AoIR ethics working committee. Retrieved from http://aoir.org/reports/ethics.pdf

Fahnestock, J. (1986). Accommodating science: The rhetorical life of scientific facts. *Written Communication, 3*(3), 275-296.

Feilzer, M. Y. (2010). Doing mixed methods research pragmatically: Implications for the rediscovery of pragmatism as a research paradigm. *Journal of Mixed Methods Research, 4*(1), 6-16. doi:10.1177/1558689809349691

Fiedler, S. (2003). Personal webpublishing as a reflective conversational tool for self-organized learning. Paper presented at the *Blog Talks,* Vienna, Austria. 190-216. Retrieved from http://static.cognitivearchitects.com/gems/Seblogging/FiedlerBlogTalk1.pdf

Fleck, L. (1979/1935). In Trenn T. J., Merton R. K. (Eds.), *Genesis and development of a scientific fact* [Entstehung und Entwicklung einer wissenschaftlichen Tatsache] (F. Bradley, T. J. Trenn Trans.). Chicago: University of Chicago Press.

Fujimura, J. H. (1992). Crafting science: Standardized packages, boundary objects, and 'translations'. In A. Pickering (Ed.), *Science as practice and culture* (pp. 168-214). Chicago: University of Chicago Press.

Fulk, J. (1993). Social construction of communication technology. *Academy of Management Journal, 36*(5), 921-950.

Garcia, A. C., Standlee, A. I., Bechkoff, J., & Yan Cui,. (2009). Ethnographic approaches to the internet and computer-mediated communication. *Journal of Contemporary Ethnography, 38*(1), 52-84. doi:10.1177/0891241607310839

Gardner, C. C., & Gardner, G. J. (2015). Bypassing interlibrary loan via twitter: An exploration of #icanhazpdf requests. *Acrl 2015,* Portland, OR.

Garfield, E. (1979). Perspective on citation analysis of scientists. *Citation indexing: Its theory and application in science, technology, and humanities* (pp. 240-252). NY: Wiley.

Garvey, W. D. (1979). *Communication, the essence of science: Facilitating information exchange among librarians, scientists, engineers, and students*. New York: Pergamon Press.

Garvey, W. D., & Griffith, B. C. (1967). Scientific communication as a social system. *Science*, *157*(3792), 1011-1016.

Garvey, W. D., & Griffith, B. C. (1972). Communication and information processing within scientific disciplines - empirical findings for psychology. *Information Storage and Retrieval, 8*(3), 123-136.

Garvey, W. D., Lin, N., Nelson, C. E., & Tomita, K. (1970). Information exchange associated with national scientific meetings in relation to the general process of communication in science. *The role of the national meeting in scientific and* *technical communication* (pp. 1-47). Baltimore: Johns Hopkins University. Center for Research in Scientific Communication.

Garvey, W. D., Tomita, K., Lin, N., & Nelson, C. E. (1972). Research studies in patterns of scientific communication .2. role of national meeting in scientific and technical communication. *Information Storage and Retrieval, 8*(4), 159-169. doi:10.1016/0020-0271(72)90001-0

Gieryn, T. F., Bevins, G. M., & Zehr, S. C. (1985). Professionalization of american scientists: Public science in the creation/ evolution trials. *American Sociological Review, 50*(3), 392-409. Retrieved from http://www.jstor.org/stable/2095548

Glanzel, W., & Moed, H. F. (2002). Journal impact measures in bibliometric research. *Scientometrics, 53*(2), 171-193.

Glaser, J. (2003). What internet use does and does not change in scientific communities. *Science Studies, 16*(1), 38-51.

Goble, C. A., Bhagat, J., Aleksejevs, S., Cruickshank, D., Michaelides, D., Newman, D., . . . De Roure, D. (2010). myExperiment: A repository and social network for the sharing of bioinformatics workflows. *Nucleic Acids Research,* doi:10.1093/nar/gkq429

Gould, C. C., Pearce, K., & Research Libraries Group.Program for Research Information Management. (1991). *Information needs in the sciences :An assessment*. Mountain View, Calif.: The Group.

Grant, R. P. (2011). A journal club with a difference. Retrieved from http://blog.the-scientist.com/2011/06/06/a-journal-club-with-a-difference/

Griffiths, A. (2009). The publication of research data: Researcher attitudes and behaviour. *The International Journal of Digital Curation, 4*(1), 46-56. Retrieved from http://ijdc.net/index.php/ijdc/article/viewFile/101/76

Guba, E. G. (1981). Criteria for assessing the trustworthiness of naturalistic inquiries. *Educational Communication and Technology: A Journal of Theory, Research, and Development, 29*(2), 75-91.

Hallett, R. E., & Barber, K. (2014). Ethnographic research in a cyber era. *Journal of Contemporary Ethnography, 43*(3), 306-330. doi:10.1177/0891241613497749

Hara, N., Solomon, P., Kim, S., & Sonnenwald, D. H. (2003). An emerging view of scientific collaboration: Scientists' perspectives on collaboration and factors that impact collaboration. *Journal of the American Society for Information Science and Technology, 54*(10), 952-965. doi:10.1002/asi.10291

Harley, D., & Krzys Acord, S. (2011). *Peer review in academic promotion and publishing: Its meaning, locus, and future.* (). Berkeley, CA: Center for Studies in Higher Education. Retrieved from http://escholarship.org/uc/item/1xv148c8

Heidorn, P. B. (2008). Shedding light on the dark data in the long tail of science. *Library Trends, 57*(2), 280-299. doi:10.1353/lib.0.0036

Herring, S. C. (1999). Interactional coherence in CMC. *Journal of Computer-Mediated Communication, 4*(4) Retrieved from http://jcmc.indiana.edu/vol4/issue4/herring.html

Herring, S. C. (2002). Computer-mediated communication on the internet. *Annual Review of Information Science and Technology, 36*, 109-168.

Herring, S. C. (2007). A faceted classification scheme for computer-mediated discourse. *Language@Internet, 4*(1) Retrieved from http://www.languageatinternet.org/articles/2007/761/

Herring, S. C. (2010). Web content analysis: Expanding the paradigm. In J. Hunsinger, L. Klastrup & M. Allen (Eds.), *International handbook of internet research* (pp. 233-249). New York: Springer. doi:10.1007/978-1-4020-9789-8_14

Herring, S. C., Scheidt, L. A., Bonus, S., & Wright, E. (2004). Bridging the gap: A genre analysis of weblogs. *Proceedings of the 37th Hawaii International Conference on System Sciences- 2004, , IV*

Hine, C. (2000). *Virtual ethnography*. Thousand Oaks, CA: Sage.

Hine, C. (2002). Cyberscience and social boundaries: The implications of laboratory talk on the internet. *Sociological Research Online, 7*(2), May 22, 2010. Retrieved from http://www.socresonline.org.uk/7/2/hine.html

Hine, C. (2006). Databases as scientific instruments and their role in the ordering of scientific work. *Social Studies of Science, 36*(2), 269-298. doi:10.1177/0306312706054047

Hine, C. (2007). Connective ethnography for the exploration of e-science. *Journal of Computer-Mediated Communication, 12*(2), 618-634. doi:10.1111/j.1083-6101.2007.00341.x

Holmberg, K., & Thelwall, M. (2014). Disciplinary differences in twitter scholarly communication. *Scientometrics, 101*(2), 1027-1042. doi:10.1007/s11192-014-1229-3

Honeycutt, C., & Herring, S. C. (2009). Beyond microblogging: Conversation and collaboration via twitter. Paper presented at the *42nd Hawaii International Conference on System Sciences, 2009. HICSS '09.* Big Island, HI. 1-10. doi:10.1109/HICSS.2009.89

Hsieh, H., & Shannon, S. E. (2005). Three approaches to qualitative content analysis. *Qualitative Health Research, 15*(9), 1277-1288. doi:10.1177/1049732305276687

Huang, J., Thornton, K. M., & Efthimiadis, E. N. (2010). Conversational tagging in twitter. Paper presented at the *Proceedings of the 21st ACM Conference on Hypertext and Hypermedia,* Toronto, Ontario, Canada. 173-178. doi:10.1145/1810617.1810647

Hurd, J. M. (1996). Models of scientific communications systems. In S. Y. Crawford, J. M. Hurd & A. C. Weller (Eds.), *From print to electronic: The transformation of scientific communication* (pp. 9-33). Medford, NJ: Published for the American Society for Information Science by Information Today.

Hyland, K., & Salager-Meyer, F. (2008). Scientific writing. *Annual Review of Information Science and Technology, 42*, 297-338.

Jakobson, R. (1960). Closing statement: Linguistics and poetics. In T. A. Sebeok (Ed.), *Style in language* (pp. 350-377). New York: Wiley.

Jarreau, P. B. (2015). *All the science that is fit to blog: An analysis of science blogging practices.* (Unpublished Doctor of Philosophy). Louisiana State University, Baton Rouge, LA. Retrieved from http://etd.lsu.edu/docs/available/etd-04072015-094935/ (etd-04072015-094935)

Jasanoff, S. S. (1987). Contested boundaries in policy-relevant science. *Social Studies of Science, 17*(2), 195-230.

Jaworski, A. (1999). Register. In K. Johnson, & H. Johnson (Eds.), *Encyclopedic dictionary of applied linguistics* (). Cambridge, MA: Blackwell. doi:10.1111/b.9780631214823.1999.x

Jefferson, A. J., Hannula, K. A., Campbell, P. B., & Franks, S. E. (2010). The internet as a resource and support network for diverse geoscientists. *GSA Today,* , 59-61. doi:10.1130/GSATG91GW.1

Johnson, P. R., & Yang, S. (2009). Uses and gratifications of twitter: An examination of user motives and satisfaction of twitter use. Paper presented at the *Communication Technology Division of the Annual Convention of the Association for Education in Journalism and Mass Communication in Boston, MA,*

Kazmer, M. M., & Xie, B. (2008). Qualitative interviewing in internet studies: Playing with the media, playing with the method. *Information, Communication & Society, 11*(2), 257-278. doi:10.1080/13691180801946333

Kent, M. L. (2015). Social media circa 2035: Directions in social media theory. *Atlantic Journal of Communication, 23*, 1-4. doi:10.1080/15456870.2015.972407

Kiesler, S. B., Siegel, J., & McGuire, T. W. (1984). Social psychological aspects of computer-mediated communication. *American Psychologist, 39*(10), 1123-1134.

Kirkup, G. (2010). Academic blogging: Academic practice and academic identity. *London Review of Education, 8*(1), 75-84. doi:10.1080/14748460903557803

Kjellberg, S. (2009). Scholarly blogging practice as situated genre: An analytical framework based on genre theory. *Information Research, 14*(3), 410. Retrieved from http://InformationR.net/ir/14-3/paper410.html

Kleinman, D. L. (1998). Untangling context: Understanding a university laboratory in the commercial world. *Science, Technology, & Human Values, 23*(3), 285-314.

Kling, R., McKim, G., & King, A. (2003). A bit more to it: Scholarly communication forums as socio-technical interaction networks. *Journal of the American Society for Information Science and Technology*, *54*(1), 47-67.

Knapp, M. L., & Daly, J. A. (2011). Background and current trends in the study of interpersonal communication. In M. L. Knapp, & J. A. Daly (Eds.), *The sage handbook of interpersonal communication* (4th ed., pp. 3-22). Thousand Oaks, CA: Sage.

Knorr, K. D., & Knorr, D. W. (1978). From scenes to scripts: On the relationship between laboratory research and published paper in science. Paper presented at the *Annual Meeting of the American Sociological Association,* San Francisco. Retrieved from https://www.ihs.ac.at/publications/ihsfo/fo132.pdf

Knorr-Cetina, K. (1995). Laboratory studies: The cultural approach to the study of science. In S. Jasanoff, G. E. Markle, J. C. Petersen & T. J. Pinch (Eds.), *Handbook of science and technology studies* (pp. 140-166). Thousand Oaks, CA: Sage Publications.

Kousha, K., Thelwall, M., & Abdoli, M. (2012). The role of online videos in research communication: A content analysis of YouTube videos cited in academic publications. *Journal of the American Society for Information Science and Technology*, *63*(9), 1710-1727. doi:10.1002/asi.22717

Kouzes, R. T. (2000). Electronic collaboration in environmental and physical sciences research. In S. H. Koslow, & M. F. Huerta (Eds.), *Electronic collaboration in science* (pp. 89-112). Mahwah, N.J.: Lawrence Erlbaum.

Kraut, R. E., Egido, C., & Galegher, J. (1990). Patterns of contact and communication in scientific research collaboration. In J. Galegher, R. E. Kraut & C. Egido (Eds.), *Intellectual teamwork :Social and technological foundations of cooperative work* (pp. 149-171). Hillsdale, N.J.: L. Erlbaum Associates.

Kuhn, T. S. (1996). *The structure of scientific revolutions* (3rd ed.). Chicago, IL: University of Chicago Press.

Kyvik, S. (2005). Popular science publishing and contributions to public discourse among university faculty. *Science Communication, 26*, 288-311. doi:10.1177/1075547004273022

Lamb, R., & Davidson, E. (2005). Information and communication technology challenges to scientific professional identity. *Information Society, 21*(1), 1-24.

Lamb, R., Sawyer, S., & Kling, R. (2000). A social informatics perspective on socio-technical networks. Paper presented at the *American Conference on Information Systems,* Long Beach, CA. Retrieved from http://lamb.cba.hawaii.edu/pubs/stnwtppr.htm

Larsen, M. T. (2011). The implications of academic enterprise for public science: An overview of the empirical evidence. *Research Policy, 40*(1), 6-19. doi:10.1016/j.respol.2010.09.013

Latour, B., & Woolgar, S. (1986). *Laboratory life :The construction of scientific facts*. Princeton, N.J.: Princeton University Press.

Levy, S. (2009, November). Mob rule! how users took over twitter. *Wired, 17*

Liang, X., Su, L. Y. -., Yeo, S. K., Scheufele, D. A., Brossard, D., Xenos, M., . . . Corley, E. A. (2014). Building buzz: (Scientists) communicating science in new media environments. *Journalism & Mass Communication Quarterly, 91*(4), 772-791. doi:10.1177/1077699014550092

Lievrouw, L. A. (2006). New media design and development: Diffusion of innovations v social shaping of technology. In L. A. Lievrouw, & S. Livingstone (Eds.), *Handbook of new media* (Updated Student Edition ed., pp. 246-263). Thousand Oaks, CA: Sage.

Lin, N., & Garvey, W. D. (1972). Information needs and uses. In C. A. Cuadra, & A. W. Luke (Eds.), *Annual review of information science and technology* (pp. 5-37). Washington: American Society for Information Science.

Litt, E. (2012). Knock, knock. who's there? the imagined audience. *Journal of Broadcasting & Electronic Media, 56*(3), 330-345. doi:10.1080/08838151.2012.705195

Lorigo, L., & Pellacini, F. (2007). Frequency and structure of long distance scholarly collaborations in a physics community. *Journal of the American Society for Information Science and Technology, 58*(10), 1497-1502. doi:10.1002/asi.20638

Luzón, M. J. (2013). Public communication of science in blogs: Recontextualizing scientific discourse for a diversified audience. *Written Communication, 30*(4), 428-457. doi:10.1177/0741088313493610

Lynch, M. E. (1982). Technical work and critical inquiry: Investigations in a scientific laboratory. *Social Studies of Science, 12*(4), 499-533. doi:10.1177/030631282012004002

Lynch, M. E. (2002). Protocols, practices, and the reproduction of technique in molecular biology. *British Journal of Sociology, 53*(2), 203-220. doi:10.1080/00071310220133304

MacKenzie, D. A., & Wajcman, J. (1999). Ntroductory essay: The social shaping of technology. In D. A. MacKenzie, & J. Wajcman (Eds.), *The social shaping of technology* (2nd ed., pp. 3-27). Philadelphia: Open University Press.

Mark Ware Consulting. (2008). *Peer review in scholarly journals: Perspective of the scholarly community – an international study.* (). Bristol, UK: Author.

Marwick, A. E., & boyd, d. m. (2011). I tweet honestly, I tweet passionately: Twitter users, context collapse, and the imagined audience. *New Media & Society, 13*(1), 114-133. doi:10.1177/1461444810365313

Matzat, U. (2004). Academic communication and internet discussion groups: Transfer of information or creation of social contacts? *Social Networks*, *26*(3), 221-255.

Maxwell, J. A. (2005). *Qualitative research design : An interactive approach* (2nd ed.). Thousand Oaks, CA: Sage Publications.

McCain, K. W. (1991). Communication, competition, and secrecy: The production and dissemination of research-related information in genetics. *Science, Technology, & Human Values*, *16*(4), 491-516.

McCain, K. W. (2011). Eponymy and obliteration by incorporation: The case of the "Nash equilibrium". *Journal of the American Society for Information Science and Technology*, *62*(7), 1412-1424. doi:10.1002/asi.21536

McCarthy, J. F., & boyd, d. m. (2005). Digital backchannels in shared physical spaces: Experiences at an academic conference. Paper presented at the *CHI '05: CHI '05 Extended Abstracts on Human Factors in Computing Systems*, Portland, OR, USA. 1641-1644. Retrieved from http://doi.acm.org/10.1145/1056808.1056986

Menzel, H. (1966a). Information needs and uses in science and technology. *Annual Review of Information Science and Technology, 1*, 41-69.

Menzel, H. (1966b). Scientific communication: Five themes from social science research. *American Psychologist*, *21*(11), 999-1004. doi:10.1037/h0024056

Menzel, H. (1968). Informal communication in science: Its advantages and its formal analogues. Paper presented at the *The Foundations of Access to Knowledge; a Symposium.* Syracuse, NY. 153-163.

Merton, R. K. (1988). The matthew effect in science, II: Cumulative advantage and the symbolism of intellectual property. *Isis, 79*(4), 606-623. Retrieved from http://www.jstor.org/stable/234750

Merton, R. K. (1973a). Priorities in scientific discovery. In N. W. Storer (Ed.), *The sociology of science: Theoretical and empirical investigations* (pp. 286-324). Chicago: University of Chicago Press.

Merton, R. K. (1973b). Science and the social order. In N. W. Storer (Ed.), *The sociology of science: Theoretical and empirical investigations* (pp. 254-266). Chicago: University of Chicago Press.

Mewburn, I., & Thomson, P. (2013). Why do academics blog? an analysis of audiences, purposes and challenges. *Studies in Higher Education, 38*(8), 1105-1119. doi:10.1080/03075079.2013.835624

Miles, M. B., & Huberman, A. M. (1994). *Qualitative data analysis :An expanded sourcebook* (2nd ed.). Thousand Oaks,CA: Sage.

Miller, V. (2008). New media, networking and phatic culture. *Convergence: The International Journal of Research into New Media Technologies, 14*(4), 387-400. doi:10.1177/1354856508094659

Mischaud, E. (2007). *Twitter: Expressions of the whole self.* (Unpublished MsC). London School of Economics and Political Science, London. Retrieved from http://www2.lse.ac.uk/media@lse/research/mediaWorkingPapers /MScDissertationSeries/Past/Mishaud_Final.pdf

Moser, S. C. (2010). Communicating climate change: History, challenges, process and future directions. *Wiley Interdisciplinary Reviews: Climate Change, 1*(1), 31-53. doi:10.1002/wcc.11

Mulligan, A., & Mabe, M. (2011). The effect of the internet on researcher motivations, behaviour and attitudes. *Journal of Documentation, 67*(2), 290-311. doi:10.1108/00220411111109485

Mullins, N. C., Snizek, W., & Oehler, K. (1988). The structural analysis of a scientific paper. In A. F. J. van Raan (Ed.), *Handbook of quantitative studies of science and technology* (pp. 81-106). New York: Elsevier Science. Retrieved from http://JHU.eblib.com/patron/FullRecord.aspx?p=1829210

Murray-Rust, P. (2008). Chemistry for everyone. *Nature, 451*, 648-651. doi:10.1038/451648a

Nabi, R. L., & Oliver, M. B. (2010). Mass media effects. In C. R. Berger, M. E. Roloff & D. R. Roskos-Ewoldsen (Eds.), *The handbook of communication science* (2nd ed., pp. 255-271). Los Angeles: Sage.

Nardi, B. A., Whittaker, S., & Bradner, E. (2000). Interaction and outeraction: Instant messaging in action. *CSCW '00: Proceedings of the 2000 ACM Conference on Computer Supported Cooperative Work,* Philadelphia, Pennsylvania, United States. 79-88. doi:10.1145/358916.358975

National Space Science Data Center. (2007). White paper on NASA science data retention. Retrieved from http://nssdc.gsfc.nasa.gov/nssdc/data_retention.html

Nature Publishing Group. (2014). *NPG 2014 social networks survey [data set]* doi:10.6084/m9.figshare.1132584

Nentwich, M. (2003). *Cyberscience : Research in the age of the internet*. Vienna: Austrian Academy of Sciences Press.

Neylon, C., & Wu, S. (2009). Article-level metrics and the evolution of scientific impact. *PLoS Biol, 7*(11), e1000242. doi:10.1371/journal.pbio.1000242

Nicolaisen, J. (2007). Citation analysis. In B. Cronin (Ed.), *Annual review of information science and technology* (pp. 609-641). Medford, N.J.: Information Today. doi:10.1002/aris.2007.1440410120

Nisbet, M. C. (2014). Engaging in science policy controversies: Insights from the U.S. climate change debate. In M. Bucchi, & B. Trench (Eds.), *Routledge handbook of public communication of science and technology* (2nd ed., pp. 173-185). New York: Routledge.

Ochsenbein, F., Williams, R., Davenhall, C., Durand, D., Fernique, P., Giaretta, D., . . . Wicenec, A. (2009). VOTable format Definition1.2. Retrieved from http://www.ivoa.net/Documents/VOTable/20091130/REC-VOTable-1.2.html

Paquet, S. (2002). Personal knowledge publishing and its uses in research. Retrieved from http://radio.weblogs.com/0110772/stories/2002/10/03/personalKnowledgePublishingAndItsUsesInResearch.html

Parsons, M. A., Duerr, R., & Minster, J. -. (2010). Data citation and peer review. *Eos, 91*(34), 297-298.

Pasquali, M. (2007). Video in science. protocol videos: The implications for research and society. *EMBO Reports, 8*(8), 712-716. doi:10.1038/sj.embor.7401037

Patton, M. Q. (2002). *Qualitative research & evaluation methods* (3rd ed.). Thousand Oaks, CA: Sage Publications.

Paul, D. (2004). Spreading chaos: The role of popularizations in the diffusion of scientific ideas. *Written Communication, 21*(1), 32-68. doi:10.1177/0741088303261035

Penrose, A., & Katz, S. B. (1998). *Writing in the sciences: Exploring conventions of scientific discourse*. New York: St. Martin's Press.

Pepe, A., & Mayernik, M. S. (2012). The use of microblogging for field-based scientific research. Paper presented at the *45th Hawaii International Conference* *on System Science (HICSS), 2012,* Maui, HI. 1666-1675. doi:10.1109/HICSS.2012.589

Peters, H. P. (2014). Scientists as public experts: Expectations and responsibilities. In M. Bucchi, & B. Trench (Eds.), *Routledge handbook of public communication of science and technology* (2nd ed., pp. 70-82). New York: Routledge.

Peters, H. P., Brossard, D., de Cheveigne, S., Dunwoody, S., Kallfass, M., Miller, S., & Tsuchida, S. (2008). Science-media interface: It's time to reconsider. *Science Communication, 30*(2), 266-276. doi:10.1177/1075547008324809

Pew Research Center. (2015). *How scientists engage the public.* (). Washington, D.C.: Pew Research Center.

Pikas, C. K. (2007). Personal information management strategies and tactics used by senior engineers. *Proceedings of the Annual Meeting of the American Society for Information Science and Technology,* Milwaukee, WI. *, 44* paper 14.

Pikas, C. K. (2008a). Detecting communities in science blogs. Paper presented at the *eScience '08. IEEE Fourth International Conference on eScience, 2008.* Indianapolis. 95-102. doi:10.1109/eScience.2008.30

Pikas, C. K. (2008b). *How and why chemists and physicists use blogs.* Unpublished manuscript. Retrieved November 9, 2010, Retrieved from http://hdl.handle.net/10101/npre.2010.4429.1

Polanyi, M. (2000). The republic of science: Its political and economic theory. *Minerva, 38*(1), 1-21.

Posnett, D., Warburg, E., Devanbu, P., & Filkov, V. (2012). Mining stack exchange: Expertise is evident from initial contributions. Paper presented at the *2012 International Conference on Social Informatics,* Lausanne. 199-204. doi:10.1109/SocialInformatics.2012.67

Postmes, T., Spears, R., & Lea, M. (2000). The formation of group norms in computer-mediated communication. *Human Communication Research, 26*(3), 341.

Price, D. J. d. S. (1986). *Little science, big science--and beyond*. New York: Columbia University Press.

Priem, J., & Costello, K. L. (2010). How and why scholars cite on twitter. Paper presented at the *Proceedings of the 73rd ASIS&T Annual Meeting,* Pittsburgh, PA.

Priem, J., Costello, K. L., & Dzuba, T. (2011). Prevalence and use of twitter among scholars. Paper presented at the *Metrics 2011 Symposium on Informetric and Scientometric Research,* doi:10.6084/m9.figshare.104629

Proctor, R., Williams, R., & Stewart, J. (2010). *If you build it, will they come? how researchers perceive and use web 2.0.* (). London: Research Information

Network. Retrieved from http://www.rin.ac.uk/system/files/attachments/web_2.0_screen.pdf

Puschmann, C. (2014). (Micro)blogging science? notes on potentials and constraints of new forms of scholarly communication. In S. Bartling, & S. Friesike (Eds.), *Opening science* (pp. 89-106). New York: Springer. doi:10.1007/978-3-319-00026-8_6

Quan-Haase, A., & Wellman, B. (2005). Local virtuality in an organization: Implications for community of practice. In P. v. d. Besselaar, G. d. Michelis, J. Preece & C. Simone (Eds.), *Communities and technologies 2005: Proceedings of the second communities and technologies conference, milano 2005* (pp. 215-238). Dordrecht, Netherlands: Springer.

Ranger, M., & Bultitude, K. (in press). 'The kind of mildly curious sort of science interested person like me': Science bloggers' practices relating to audience recruitment. *Public Understanding of Science*, doi:10.1177/0963662514555054

Reips, U. (2008). How internet-mediated research changes science. In A. Barak (Ed.), *Psychological aspects of cyberspace: Theory, research, applications* (pp. 268-294). New York: Cambridge University Press. Retrieved from http://gsb.haifa.ac.il/~sheizaf/cyberpsych/12-Reips.pdf

Richardson, L. (2003). Writing: A method of inquiry. In N. K. Denzin, & Y. S. Lincoln (Eds.), *Collecting and interpreting qualitative materials* (2nd ed., pp. 499-541). Thousand Oaks, CA: Sage.

Rogers, E. M. (2003). *Diffusion of innovations*. New York, N.Y.: Simon & Schuster.

Rogers, E. M., & Kincaid, D. L. (1981). The convergence model of communication and network analysis. In E. M. Rogers, & D. L. Kincaid (Eds.), *Communication networks: Toward a new paradigm for research* (pp. 31-78). New York: Free Press.

Rojo, A., & Ragsdale, R. G. (1997). A process perspective on participation in scholarly electronic forums. *Science Communication, 18*(4), 320-341.

Roosendaal, H. E., & Geurts, P. A. T. M. (1997). Forces and functions in scientific communication: An analysis of their interplay. Paper presented at the *CRISP 97: Cooperative Research Information Systems in Physics,* Oldenburg, Germany. Retrieved from http://www.physik.uni-oldenburg.de/conferences/crisp97/roosendaal.html

Rowley-Jolivet, E. (1999). The pivotal role of conference papers in the network of scientific communication. *ASp.La Revue Du GERAS,* (23-26), 179-196. doi:10.4000/asp.2394

Rowley-Jolivet, E. (2002). Science in the making: Scientific conference presentations and the construction of facts. In E. Ventola, C. Shalom & S. Thompson (Eds.), *The language of conferencing* (pp. 95-125). New York: Peter Lang.

Rubin, H. J., & Rubin, I. (2005). *Qualitative interviewing: The art of hearing data* (2nd ed.). Thousand Oaks, CA: Sage Publications.

Rubin, R. B., Perse, E. M., & Barbato, C. A. (1988). Conceptualization and measurement of interpersonal communication motives. *Human Communication Research, 14*(4), 602-628. doi:10.1111/j.1468-2958.1988.tb00169.x

Schmidt, J. (2007). Blogging practices: An analytical framework. *Journal of Computer-Mediated Communication, 12*(4), May 22, 2010. Retrieved from http://jcmc.indiana.edu/vol12/issue4/schmidt.html

Schramm, W. L. (1971). The nature of communication between humans. In W. L. Schramm, & D. F. Roberts (Eds.), *The process and effects of mass communication* (Rev. ed., pp. 3-53). Urbana, IL: University of Illinois Press.

Shanahan, M. (2011). Science blogs as boundary layers: Creating and understanding new writer and reader interactions through science blogging. *Journalism, 12*(7), 903-919. doi:10.1177/1464884911412844

Shankar, K. (2007). Order from chaos: The poetics and pragmatics of scientific recordkeeping. *Journal of the American Society for Information Science and Technology, 58*(10), 1457-1466. doi:10.1002/asi.20625

Shannon, C. E. (1948). A mathematical theory of communication. *Bell System Technical Journal, 27*, 379-423 and 623-656.

Shannon, C. E., & Weaver, W. (1963). In Shannon C. E., Weaver W. (Eds.), *The mathematical theory of communication* (Illini Books ed.). Urbana, IL: University of Illinois Press.

Shapin, S. (1995). Here and everywhere: Sociology of scientific knowledge. *Annual Review of Sociology, 21*(1), 289-321.

Shema, H., Bar-Ilan, J., & Thelwall, M. (2014). How is research blogged? A content analysis approach. *Journal of the Association for Information Science and Technology,* , n/a-n/a. doi:10.1002/asi.23239

Shotton, D., Portwin, K., Klyne, G., & Miles, A. (2009). Adventures in semantic publishing: Exemplar semantic enhancements of a research article. *PLoS Computational Biology, 5*(4), e1000361. doi:10.1371/journal.pcbi.1000361

Soergel, D. (1985). *Organizing information: Principles of data base and retrieval systems*. Orlando, FL: Academic Press.

Sonnenwald, D. H. (2007). Scientific collaboration: A synthesis of challenges and strategies. In B. Cronin (Ed.), *Annual review of information science and technology* (pp. 643-681). Medford, NJ: Information Today.

Sproull, L., & Kiesler, S. (1986). Reducing social context cues: Electronic mail in organizational communication. *Management Science, 32*(11), 1492-1512.

Star, S. L. (2010). This is not a boundary object: Reflections on the origin of a concept. *Science, Technology & Human Values, 35*(5), 601-617. doi:10.1177/0162243910377624

Star, S. L., & Griesemer, J. R. (1989). Institutional ecology, `Translations' and boundary objects: Amateurs and professionals in berkeley's museum of vertebrate zoology, 1907-39. *Social Studies of Science, 19*(3), 387-420. doi:10.1177/030631289019003001

Steinke, J. (2013). In her own voice: Identity centrality and perceptions of workplace climate in blogs by women scientists. *International Journal of Gender, Science and Technology, 5*(1), 25-51.

Sturgis, P., & Allum, N. (2004). Science in society: Re-evaluating the deficit model of public attitudes. *Public Understanding of Science, 13*(1), 55-74. doi:10.1177/0963662504042690

Sundar, S. S., & Limperos, A. M. (2013). Uses and grats 2.0: New gratifications for new media. *Journal of Broadcasting & Electronic Media, 57*(4), 504-525. doi:10.1080/08838151.2013.845827

Sundberg, M. (2010). Cultures of simulations vs. cultures of calculations? the development of simulation practices in meteorology and astrophysics. *Studies in History and Philosophy of Science Part B: Studies in History and Philosophy of Modern Physics, 41*(3), 273-281. doi:10.1016/j.shpsb.2010.07.004

Swales, J. M. (1990). *Genre analysis: English in academic and research settings*. New York: Cambridge University Press.

Swales, J. M. (2004). *Research genres: Explorations and applications*. New York: Cambridge University Press.

Talja, S., Savolainen, R., & Maula, H. (2004). Field differences in the use and perceived usefulness of scholarly mailing lists. *Information Research-an International Electronic Journal, 10*(1), paper 200. Retrieved from http://InformationR.net/ir/10-1/paper200.html

Tanis, M., & Postmes, T. (2003). Social cues and impression formation in CMC. *Journal of Communication, 53*(4), 676-693. doi:10.1111/j.1460-2466.2003.tb02917.x

Tenopir, C., Allard, S., Douglass, K., Aydinoglu, A. U., Wu, L., Read, E., . . . Frame, M. (2011). Data sharing by scientists: Practices and perceptions. *PloS One, 6*(6), e21101. doi:10.1371/journal.pone.0021101

Tenopir, C., & King, D. W. (2000). *Towards electronic journals : Realities for scientists, librarians, and publishers*. Washington, DC: Special Libraries Association.

Tracy, K., & Naughton, J. (1994). The identity work of questioning in intellectual discussion. *Communication Monographs, 61*(4), 281-302.

Traweek, S. (1988). *Beamtimes and lifetimes : The world of high energy physicists*. Cambridge, Mass.: Harvard University Press.

Treem, J. W., & Leonardi, P. M. (2012). Social media use in organizations: Exploring the affordances of visibility, editability, persistence, and association. *Communication Yearbook, 36*, 143-189.

Trench, B. (2007). Internet - turning science communication inside-out? In M. W. Bauer, & M. Bucchi (Eds.), *Journalism, science and society: Science communication between news and public relations* (). New York: Routledge. Retrieved from http://doras.dcu.ie/14807/1/internet_science_communication.pdf

Trench, B. (2008). Towards an analytical framework of science communication models. In D. Cheng, M. Claessens, T. Gascoigne, J. Metcalfe, B. Schiele & S. Shi (Eds.), *Communicating science in social contexts* (pp. 119-135). New York: Springer. doi:10.1007/978-1-4020-8598-7_7

Trench, B. (2012). Scientists' blogs: Glimpses behind the scenes. In S. Rödder, M. Franzen & P. Weingart (Eds.), (pp. 273-289) Springer Netherlands. doi:10.1007/978-94-007-2085-5_14

Tufekci, Z. (2014). Big questions for social media big data: Representativeness, validity and other methodological pitfalls. Paper presented at the *ICWSM '14: Proceedings of the Eighth International AAAI Conference on Weblogs and Social Media,* Ann Arbor, MI. Retrieved from http://arxiv.org/abs/1403.7400

Tufekci, Z. (2011). Why twitter's oral culture irritates bill keller (and why this is an important issue) | technosociology. Retrieved from http://technosociology.org/?p=431

Van Noorden, R. (2014). Online collaboration: Scientists and the social network. *Nature, 512*(7513), 126-129. doi:10.1038/512126a [doi]

Ventola, E. (2002). Why and what kind of focus on conference presentations? In E. Ventola, C. Shalom & S. Thompson (Eds.), *The language of conferencing* (pp. 15-50). New York: Peter Lang.

Verderber, K. S., Verderber, R. F., & Sellnow, D. D. (2014). *Communicate!*. Boston: Wadsworth Cengage Learning.

Vetere, F., Smith, J., & Gibbs, M. (2009). Phatic interactions: Being aware and feeling connected. In P. Markopoulos, B. De Ruyter & W. Mackay (Eds.), *Awareness systems: Advances in theory, methodology, and design* (pp. 173-186) Springer. doi:10.1007/978-1-84882-477-5_7

Walsh, J. P., & Bayma, T. (1996a). Computer networks and scientific work. *Social Studies of Science, 26*(3), 661-703.

Walsh, J. P., & Bayma, T. (1996b). The virtual college: Computer-mediated communication and scientific work. *Information Society, 12*(4), 343-363.

Walsh, J. P., Kucker, S., Maloney, N. G., & Gabbay, S. (2000). Connecting minds: Computer-mediated communication and scientific work. *Journal of the American Society for Information Science, 51*(14), 1295-1305.

Walsh, J. P., & Maloney, N. G. (2002). Computer network use, collaboration structures, and productivity. In P. Hinds, & S. B. Kiesler (Eds.), *Distributed work* (pp. 433-458). Cambridge, MA: MIT Press.

Walsh, J. P., & Maloney, N. G. (2007). Collaboration structure, communication media, and problems in scientific work teams. *Journal of Computer-Mediated Communication, 12*(2), 19. doi:10.1111/j.1083-6101.2007.00346.x

Walther, J. B. (1992). Interpersonal effects in computer-mediated interaction: A relational perspective. *Communication Research, 19*(1), 52-90. doi:10.1177/009365092019001003

Walther, J. B. (2011). Theories of computer-mediated communication and interpersonal relations. In M. L. Knapp, & J. A. Daly (Eds.), *The sage handbook of interpersonal communication* (4th ed., pp. 443-479). Thousand Oaks, CA: Sage. Retrieved from http://wiki.commres.org/pds/TheoriesInNewMedia/42241_14.pdf

Wasko, M. M., & Faraj, S. (2000). “It is what one does”: Why people participate and help others in electronic communities of practice. *The Journal of Strategic Information Systems, 9*(2-3), 155-173. doi:10.1016/S0963-8687(00)00045-7

Wasko, M. M., & Faraj, S. (2005). Why should i share? examining social capital and knowledge contribution in electronic networks of practice. *MIS Quarterly, 29*, 35-57.

Welland, M. (2010, May). The geoblogosphere. *Geoscientist, 20*, [online supplement]. Retrieved from https://web.archive.org/web/20101015212333/http://www.geolsoc.org.uk/gsl/geoscientist/page7580.html

Weller, A. C. (2001). *Editorial peer review : Its strengths and weaknesses*. Medford, N.J.: Information Today.

Wenger, E. (1998). *Communities of practice: Learning, meaning, and identity*. Cambridge, England: Cambridge University Press.

White, M. D., & Marsh, E. E. (2006). Content analysis: A flexible methodology. *Library Trends, 55*(1), 22-45.

Wood, D. N. (1984). The collection, bibliographic-control and accessibility of grey literature. *IFLA Journal-International Federation of Library Associations, 10*(3), 278-282. doi:10.1177/034003528401000308

Wynne, B. (1995). Public understanding of science. In S. S. Jasanoff, G. E. Markle, J. C. Petersen & T. J. Pinch (Eds.), *Handbook of science and technology studies* (pp. 361-388). Thousand Oaks, CA: Sage.

Yin, R. K. (2003). *Case study research: Design and methods* (3rd ed.). Thousand Oaks, CA: Sage Publications.

Ziman, J. M. (1968). *Public knowledge: An essay concerning the social dimension of science*. London: Cambridge U.P.

Zimmerman, A. S. (2008). New knowledge from old data - the role of standards in the sharing and reuse of ecological data. *Science, Technology, & Human Values, 33*(5), 631-652.

Zuckerman, H., & Merton, R. K. (1971). Patterns of evaluation in science: Institutionalization, structure and functions of the referee system. *Minerva*, *9*(1), 66-100.