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A Science Instrument for the Digital Age: #Scistuchat Participants' Perceptions of Twitter as a Tool for Learning and Communicating Science

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A SCIENCE INSTRUMENT FOR THE DIGITAL AGE:
#SCISTUCHAT PARTICIPANTS' PERCEPTIONS OF TWITTER AS A TOOL FOR
LEARNING AND COMMUNICATING SCIENCE

A Dissertation Presented

by

Ryan L. Becker

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Abstract

The integration of digital technologies in K-12 education is ubiquitous. Web 2.0 technologies enable students who were once passive consumers to become active participants in, and even creators of, dynamic digital experiences. Social media, in particular, can connect disparate populations, minimizing traditional barriers such as time, space and geography. Similarly, science communication has also been influenced by an expanding array of media through which scientists can now connect directly with the public. #Scistuchat, the focus of this study, uses the social media platform Twitter to bring together scientists, secondary science students and teachers outside of school in monthly, science-focused Twitter chats. Using a multiple-case (embedded) design, this study sought to answer the question “How do #scistuchat participants perceive Twitter as a tool for learning and communicating science?” Thematic, cross-case analysis of four #scistuchats revealed themes specific to the #scistuchat experience, as well as the broader use of Twitter for science learning and communication. In addition to real-time observations of each chat and later analysis of the archived tweets, videoconferencing technology was used to conduct individual interviews with participating scientists (n=16) and teachers (n=6), as well as focus groups with students (n=17). Notable #scistuchat-specific findings include a recognition of the experience as dynamic and student-focused. Regarding student outcomes, although gains in science content knowledge were limited, an evolving understanding of scientists and the nature of their work was prominent. Findings regarding the broader use of Twitter for science purposes highlighted its multidimensional, professional utility and its unique contributions when leveraged in classroom settings.

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Chapter 1: Introduction

New technologies have led to a shift in the ways that science is communicated to and consumed by the public (Bik & Goldstein, 2013; Brossard, 2013; Brossard & Scheufele, 2013; Holcomb, Gottfried, Mitchell & Schillinger, 2013; Scheufele, 2013; Wilcox, 2012). Increasingly, scientists recognize that communicating with the public has potential benefits related to career development and advancement (Liang et al., 2014). Furthermore, with the diversity of communication channels growing exponentially, opportunities to share science with wider audiences, without the need for media outlets to act as conduits, are growing.

Reflecting their eagerness to engage, a recent Pew survey (Rainie et al., 2015) found that fully 87% of scientists believed they should “take an active role in public policy debates about issues related to science and technology” and that “engagement with citizens and journalists is necessary to further their work and career” (p. 3). Moreover, the same survey found that nearly half of the scientists surveyed (47%) “use social media to talk about science or read about scientific developments at least some of the time” (p. 4). This shifting science communication landscape, enhanced by increasing numbers of individuals who access their news across social media platforms (Holcomb et al., 2013) and who own smartphones (Smith, McGeeney & Duggan, 2015), will continue to evolve. Among younger scientists and citizens in particular, social media has been an important contributor to this shift. Platforms like Twitter, Facebook, YouTube, Google+ and others have opened up a host of new, multidimensional ways to share and communicate science, often in real-time. The pace of this shift, coupled with its pervasiveness, is well ahead of

our understanding of related implications, outcomes and consequences—both positive and negative.

In much the same way that emerging technologies have influenced science communication, K-12 education has also been impacted by technology—perhaps to an even greater degree. For many reasons, including students’ affinity for technology-rich learning experiences (Project Tomorrow, 2013a; Project Tomorrow, 2012a; Project Tomorrow, 2012b; Project Tomorrow, 2014a), teachers’ increasing familiarity with and appreciation for technology (Project Tomorrow, 2013b; Project Tomorrow, 2014b; PBS, 2011), and the research and financial support of large organizations and governmental institutions (Atkins et al., 2010; Cator & Adams, 2013), schools across the country are investing in and embracing technology.

As a result of these significant investments, and the accompanying expectations related to learning outcomes, it is not surprising that spirited debate has emerged among stakeholders—parents, students, teachers and administrators—concerning how technology can, and should, be best used to maximize learning. The technology debate, with its many tentacles, covers a vast spectrum of topics. Issues concerning one-to-one programs, the role of mobile technologies in the classroom, online and blended learning, broadband capabilities, professional development, learning management systems, privacy and confidentiality, and digital citizenship, among others, are familiar topics for many in today’s K-12 school communities.

The prevalence of technology in schools and homes, coupled with its increasingly networked nature, has led to a situation where the lines between students’ in-school and out-of-school lives are more blurred than ever before. Social media has played a critical

role in this shift. Social networking in the lives of teens has become ubiquitous (boyd, 2014; Lenhart et al., 2015; Lenhart et al., 2011; Madden et al., 2013; Rideout, 2012b). Despite near blanket adoption of social media by teens, however, the vast majority of schools have resisted the integration of social media as part of students' educational experiences. In schools where social media has been welcomed, accompanying research is thin. For example, research concerning the use of Twitter—the social media platform at the heart of this study—for teaching and learning is sparse, with most studies having been conducted only in higher education settings (Johnson, 2011; Junco, Heiberger & Loken, 2010; Kassens-Noor, 2012; Lin, Hoffman & Borengasser, 2013; Prestridge, 2014; Rinaldo, Tapp & Laverie, 2011; Skiba, 2008).

Despite continued resistance to the use of social media for teaching and learning in public K-12 educational settings, there are educators who have attempted to leverage its strengths to provide new and unique learning experiences for their students, as I have done in my own eighth grade physical science classroom. With regard to the science-specific use of Twitter in secondary settings, there are a growing number of applications that provide students with opportunities to engage in dialogue about science well beyond the walls of their classrooms. Three specific examples include #scistuchat, “Do Now Science” and my own efforts to incorporate Twitter as part of my students' science experience, each of which leverages the power of Twitter to foster science communication and engagement in creative ways among diverse audiences. Brief overviews of the latter two follow. Understanding more about each will provide a sense of how Twitter can be used with secondary science students on both a large scale and at

the classroom level and, thus, give helpful context for an in-depth exploration of #scistuchat, the particular focus of this study.

“Do Now Science” is a science-specific application of Twitter created by KQED, a public media organization serving Northern California. “Do Now Science” is part of a multi-discipline “Do Now” program in which students “engage and respond to current issues using social media tools like Twitter” (KQED, 2015). As the KQED website explains:

KQED aims to introduce 21st Century skills and add value to learning through the integration of relevant local content and new media tools and technologies.

“Do Now” gives students a chance to practice civic engagement and digital citizenship skills while they explore ways to connect topics in their classes to the present day. (KQED, 2015)

“Do Now Science” consists of a bi-weekly science question that is posed to students, along with related written and video resources. Students are asked to arrive at position regarding the science question and to support their stance with relevant evidence. Students are also encouraged to engage in dialogue with others, with all tweets using a topic-specific hashtag. In this way, students from throughout the United States can communicate with one another around a shared science question. To date, dozens of “Do Now Science” activities have been posted, with questions addressing a variety of topics ranging from what to do with space junk (#DoNowJunk) to the modification of DNA in human embryos (#DoNowBabies).

In my own eighth grade Physical Science classes, my students and I have used Twitter to complement and extend classroom learning for each of the past four academic

years. To this end, students create their own science-specific Twitter accounts and are encouraged to follow and engage with individual scientists, as well as reputable science organizations and institutions. Students are also encouraged to tweet their own science questions, ideas and connections, and to reply to those of their classmates. As a teacher using Twitter, I leverage Twitter to connect with the same scientists and organizations my students follow, as well as a tool for sharing many science articles, videos and current events that we otherwise do not have time to fully explore in class. I also reply to as many student tweets as possible, which enables me to engage in science dialogue with my students outside of our limited class time. Lastly, I use Twitter as a formative assessment tool. From having students tweet initial understandings of science to using tweets as archivable digital exit tickets, Twitter acts as an efficient way to gain insight into students' science thinking.

Despite the unique work of educators involved in these efforts, and others, very few studies have been conducted that explore associated learning outcomes nor the perspectives of participating students and teachers. Thus, collectively, the evolving nature of science communication, the prevalence of social media in the lives of teens, an awareness of the unique work of others using Twitter with their science students, and my own experiences using Twitter in my science classroom acted as the impetus to develop this study designed to explore the use of Twitter as a tool for science learning and communication.

#Scistuchat

This study focuses on #scistuchat, a monthly, science-themed Twitter chat that brings together scientists, secondary science students and teachers from across the

country and, in some cases, throughout the world. A Twitter chat is a real-time conversation that occurs via Twitter and centers on a specific topic or question. One or two individuals familiar with Twitter chats, as well as the topic of discussion, typically moderate a chat. Conversations have a pre-defined start time and, importantly, use a specific hashtag determined by the organizer of the chat and its facilitators.

In the case of #scistuchat, the hashtag used throughout the chat is simply the title of the chat—#scistuchat. Taking place on the second Thursday of every month during the school year, from 9:00-10:00 pm EST, #scistuchat is moderated by two student-facilitators and centers on a pre-defined science topic. Table 1 displays the diverse science topics that have been the focus of #scistuchat over the last several years. The organizer of #scistuchat reaches out to potential scientist-participants each month via Twitter and, because Twitter is such a networked platform, interested scientists can easily share the opportunity with other like-minded scientists who are also on Twitter. Students usually participate, figuratively, alongside their science teachers, having learned of #scistuchat through their teachers' involvement with Twitter. Because #scistuchat requires only a Twitter account and an Internet connection to participate, participants are not limited by geographic proximity. Appendix A details the geographic diversity of participants' locations during the four chats that comprise this study. These four 2014 chats occurred during the months of February (black holes), March (human genetic engineering), April (green chemistry) and May (volcanoes), and each acted as a separate “case” for this study.

Table 1

A history of #scistuchat topics (2012-2015)

2012-13		2013-14		2014-15	
Month	Topic	Month	Topic	Month	Topic
September	Sharks	September	What is Science?	September	Nature of Science
October	Bugs	October	Will the Sun Die?	October	Going to Space
November	DNA	November	Bioluminescence	November	Ebola
December	Life on Other Planets	December	Sharks	December	Strange Science
January	Genetically Modified Foods	January	Human Brain	January	Sound
February	Cloning	February	Black Holes	February	Human Brain
March	Evolution	March	Human Genetic Engineering	March	Science in Hollywood
April	Bringing Back Dinosaurs: DNA	April	Green Chemistry	April	Evolution
May	Why isn't Pluto a Planet?	May	Volcanoes	May	Science Influence + Impressions

A typical #scistuchat starts promptly at 9:00 pm EST and begins with participants introducing who they are and where they are from. After several minutes of introductions, the student-moderators for the chat tweet the first question to participants. Participants often retweet the moderators' question before tweeting their own response to the question in a separate tweet—being sure to include the hashtag #scistuchat. After several minutes, moderators will tweet the second question, give time for responses to accumulate, and then continue tweeting questions accordingly. Because participants are responding to questions almost simultaneously, tweets come in very quickly.

Furthermore, because participants are encouraged to tweet individual scientists with specific questions that may be unrelated to the moderated questions, and because retweets add even additional tweets to the mix, #scistuchat is a dynamic, fast-paced affair. A typical chat ends with moderators asking participants to share two or three things they learned during the chat and a request of participants to thank a participating scientist. Although the official chat ends at 10:00 pm EST, conversations that extend beyond the conclusion of the chat are encouraged.

Research Statement and Sub-Questions

The purpose of this study was to explore #scistuchat participants' perceptions of Twitter as a tool for learning and communicating science. Drawing on the perspectives of participating scientists, students and teachers, this study sought to answer the following research questions:

- How do participants understand #scistuchat as a digitally-mediated learning experience?
- How do participants understand #scistuchat as a formal vs. informal science learning experience, particularly as it relates to in-school science learning?
- How do participants use, and perceive, Twitter as a medium for teaching, learning and communicating science outside of the confines of #scistuchat?

Significance

Knowledge. Many reports highlight the prevalence of the Internet, mobile technologies and social media in the lives of adolescents (boyd, 2014; Lenhart et al., 2015; Lenhart et al., 2011; Madden et al., 2013; Rideout, 2012b). Significantly less is known about the impact of these technologies on teaching and learning, including both

in-school and out-of-school settings and across instances of formal and informal learning. There is a void in the research on the use of social media in 7-12 settings in general, and as it relates to teaching and learning science specifically.

Theory. Several related theoretical frameworks informed my research design. Foundational to my study is Barron's (2006) "learning ecology framework" for studying the development of technological fluency. Conceptualizing various contexts of fluency development (e.g., school, home, peers, etc.) as analogous to natural features of an ecological system, this theory maintains "new technologies can help make boundaries more permeable and allow for new kinds of agency in learning" (p. 200). Central to the framework are three conjectures: 1. Within any life space, a variety of ideational resources can spark and sustain interest in learning; 2. People not only choose but also develop and create learning opportunities once they are interested, assuming they have time, freedom and resources to learn; 3. Interest-driven learning activities are boundary-crossing and self-sustaining (p. 200).

My research is particularly interested in areas of overlap between in-school and out-of-school learning, as mediated by technology and Twitter specifically. As such, the purpose of my study is consistent with numerous points-of-emphasis important to Barron's framework. For example, Barron states, "We have little information on synergies between participation in technologically mediated informal learning activities and more formal educational environments and the conditions that make boundary-crossing activities possible" (p. 198). Considering strategies to extend learning and contexts within which they might be employed, Barron also asserts, "These examples also point to the importance of thinking beyond physical contexts, to consider the role of

distributed learning resources such as books, magazines, and those offered through the Internet” (p. 217). Participation in #scistuchat and the broader use of Twitter for science purposes both have the potential to act as digital catalysts for synergistic, boundary-crossing activities where learning in out-of-school contexts may complement more formal instances of in-school learning.

A second, related theoretical framework, referred to as an “ecological framework for learning in places and pursuits” (NRC, 2009), draws from cognitive and sociocultural theories and seeks to integrate “three cross-cutting aspects of learning that are evident in all learning processes; people, places and cultures” (p. 31). The “people” aspect of this framework posits that “what learners understand about the world is perhaps as important as what we wish for them to learn through a particular experience” and that, as a result, “efforts to teach should not merely be about abstractions derived in knowledge systems like science, but should also focus on helping learners become aware of and express their own ideas” (p. 34). Importantly, unlike a strictly cognitive perspective, a people-centered analysis of learning can “explore people’s social actions, practices and emotional worlds” (p. 35).

The second prong of the National Research Council’s three-pronged ecological framework considers the notion of “place.” This dimension of the theory maintains that learning can occur within and across particular places and that “material and technological objects, including visual representation of data and technological tools, constitute the foundational resources through which people individually and collectively engage in learning activities” (p. 37). Artifacts, the materials and technological objects mentioned above, include digital media and “provide a specific infrastructure for learning

that is historically unique” (p. 38). Expanding on this idea, the theory points out that “Electronic gadgets have become a pervasive fixture of the toolkit of personal activity and learning” and that “Many people routinely develop and share media objects that involve sophisticated learning and social interaction” (p. 38).

The third and final dimension of the NRC’s framework addresses “culture” and situates it as central to the learning process. Emphasizing that culture is “bidirectional and dynamic” as well as “distributed variably among group members,” this theory considers culture a fluid construct that both influences and is influenced by the individual. Particularly relevant to this study, the cultural prong of the theory points out that, “research on scientific discussions and in active research groups reveals that many practices in which scientists engage are not recognized as useful or as a part of science in the classroom” (p. 40). Furthermore, it asserts that, “The observation that science and science learning are richly social also underlines the opportunity of educators working with designed environments to better take advantage of the cultural practices that a diverse set of learners might bring to the environment” (p. 40).

Each dimension of the NRC framework connects directly to some aspect of this study. As will be described in detail in the findings chapter, the deeply student-centered nature of #scistuchat dovetails nicely with the “people” aspect of this theory. The notion of Twitter as a digital space and #scistuchat as a digital experience, both necessitating the use of distinct and personal technological artifacts, directly connects with the “place” dimension of the framework. Finally, as will also be described in detail in this study’s findings, #scistuchat represents a dynamic, social experience that participants describe as distinctly democratic. This conceptualization of the nature of #scistuchat, and its

existence as a function of both the inherent features of Twitter and the product of participant interactions, is consistent with the “culture” dimension of the theory.

A third, related theoretical framework that has helped to inform my study was offered by Ito et al. (2013) and is referred to as “connected learning.” Also based on an ecological metaphor, the connected learning approach “is socially embedded, interest-driven, and oriented toward expanding educational, economic or political opportunity” (p. 4). Similar to the previous two theoretical frameworks in that it considers gaps between in-school and out-of-school learning, the connected learning framework differs in its emphasis on the role of new media for advancing learning and its particular concern for equity and opportunity as they relate to vulnerable and non-dominant populations. As the authors point out:

Connected learning centers on an equity agenda of deploying new media to reach and enable youth who otherwise lack access to opportunity. It is not simply a “technique” for improving educational outcomes, but rather seeks to build communities and collective capacities for learning and opportunity. (p. 8)

The above three theories form the theoretical backbone of my study. Although they differ in some ways, each stresses the overlapping nature of individuals’ life spheres, the interconnections afforded by technology, and the belief that learning and development are embedded within social relationships and cultural contexts.

Policy. My research has direct policy implications. Because I sought to explore a specific use of Twitter for learning and communicating science—with student involvement occurring both inside and outside of the classroom—there is clear evidence of ties between students’ formal, in-school science experiences and their less formal, out-

of-school science experiences. Furthermore, with participating science teachers interacting in #scistuchat with and beside their students, traditional boundaries separating students and teachers, and the public, are now called into question.

Many school districts have policies related to the use of social media by both students and teachers, as well as guidelines, trainings and workshops aimed at clarifying norms and expectations related to the use of these new technologies. Notable examples, including a National School Boards Association report (Vockley, 2007), a National Association of Secondary School Principals position statement (NASSP, 2011), and a New York City Department of Education social media guidelines document (NYC, 2013) serve as evidence of prevalent concerns about the appropriate use of social media in educational settings. Each directly addresses the use of social media in schools and the need to be more proactive in the development and implementation of policies related to Web 2.0 technologies.

On a school level, using social media, including Twitter, for educational purposes has many potential policy implications. Issues around privacy, confidentiality, acceptable use agreements, Internet filters, cyber bullying and cyber harassment, and student-teacher communication, must continually be addressed. Concern regarding the impact of social media on the well-being of adolescents outside of school is also significant (Lenhart et al., 2011; Lenhart, Madden, Cortesi, Gasser & Smith, 2013). With the potential for applications of social media in educational settings to expand, and the inevitability of interactions occurring over social media outside of school impacting students' in-school experiences, there will likely be a continued need to formulate and refine policies concerning social media.

The prevalence of social media in the lives of teens shows no signs of abating. Moreover, as one-to-one programs expand and as schools and districts throughout the country increasingly welcome mobile technologies in the classroom, social media will continue to permeate traditional school-home, teacher-student and public-school boundaries. The development of policies flexible enough to address current concerns yet responsive to evolving media and associated concerns will be an ongoing need.

Practice. This research has the potential to contribute to practice in important ways. The primary focus of my research is to explore #scistuchat participants' perceptions of Twitter as a learning and communication tool. With a chief goal of every teacher-practitioner being their students' learning, the findings of this study could be appealing to any teachers considering using, or who already are using, Twitter with their science students.

Using Twitter in a secondary science classroom has the potential to impact a wide range of learning phenomena. Possible benefits include enhancing opportunities for personalized learning, expanding authentic audiences, increasing experiences with embedded literacy (both traditional and new literacies), expanding real-world and real-time content connections, diversifying formative assessment opportunities, and practicing digital citizenship skills in an authentic context as part of a core academic class (Becker & Bishop, in press).

Although students' use of Twitter requires teachers to relinquish a degree of control over their students that most are accustomed to having and, instead, to place in their students a degree of trust that many are unfamiliar giving, the possibilities are promising. Foremost, traditional conceptions of what constitutes a classroom, a teacher or

a reliable resource are challenged. Importantly, rather than supplanting conventional curricula and instruction, embracing Twitter as a learning tool may offer a multidimensional means by which key outcomes and objectives can be enhanced. For example, in addition to citing a reputable source, students may now be able to follow and even interact with the author of that source. In addition to linking concepts to past science experiments or missions, students may now be able to follow, in real-time, current ones. In addition to sharing their learning with a single individual, their teacher, students may now contribute to (or at the very least observe) wider discussions involving experts in the field, thereby expanding the audience for their work and broadening their understanding of discussions they can be privy to. In short, this research may broaden one's conception of what it means to learn, as well as diversify the means by which one can learn.

Lastly, this research could have implications for the manner in which teachers introduce, implement and reflect on the specific use of a technology—in this case, Twitter—for learning and communicating science in their classrooms. As research shows, simply introducing a technology into the science classroom does not ensure positive outcomes or improved learning (Campbell & Abd-Hamid, 2012; Guzey & Roehrig, 2009; Guzey & Roehrig, 2012). Strategic measures must be taken throughout the implementation process, and reflective analysis exercised at key benchmarks, if success is to be realized. A pre-existing framework can help in this regard, as it typically offers both the theoretical foundation and the practical considerations that predispose success. For example, the Technological Pedagogical and Content Knowledge (TPACK) Framework (Koehler & Mishra, 2009) is a well-known framework that delineates the theoretical and practical background teachers need to successfully integrate technology in

their teaching. Findings from this study may help to inform and deepen existing frameworks like TPACK, as well as the degree to which a given teacher makes sense of and has context for such frameworks.

Chapter 2: Literature Review

There is a paucity of research that explores the role of social media, and Twitter specifically, in K-12 educational contexts. As such, I was unable to find studies that aligned in any significant way with the research design and findings described herein. There is, however, much literature that considers relevant aspects of my research. Exploring this literature I believe frames my work and provides a helpful academic context within which my findings can be situated. The research examined for this literature review considers the following eight areas: 1. evolution of the digital learner; 2. emergence of the digital educator; 3. teens' use of social media and Twitter; 4. Twitter chats; 5. lack of research at the secondary level; 6. technology in science teaching and learning; 7. the evolving nature of science communication and 8. formal vs. informal science learning.

Evolution of the Digital Learner

Today's learners are surrounded by technology and expect it to play a significant role in their education (Beckman, Bennett & Lockyer, 2014; Heidenrich, 2013; Project Tomorrow, 2012a; Project Tomorrow, 2012b; Project Tomorrow, 2013a; Project Tomorrow, 2014a). In 2013, Project Tomorrow, an education nonprofit organization, released results from its 2012 *Speak Up* survey. This survey drew on the perspectives of more than 364, 240 K-12 students from more than 8,000 public and private schools representing 2,431 districts. Such a vast survey clearly recognized the voices and perspectives of students. However, given that the 2012 report (released in 2013) was the 10th annual report, and specifically compared the ideas of students in that year with their predecessors over the previous nine years, the findings were especially noteworthy.

Not surprisingly, the survey results painted a picture of increasingly connected students, many of whom have morphed from simple consumers of information to creators and sharers of content, experiences and discoveries (p. 3). The report described four distinct, emerging technologies as having “the largest impact so far on students’ self-efficacy as self-directed, independent learners” (p. 3). These technologies included mobile devices, Internet access, social media and online learning. Students’ identification of these technologies reflects a broader shift from access alone in 2003 to “how to use a wide range of digital tools and resources to enable a highly personalized learning experience” in 2013 (p. 14).

More recently, the 2014 report (representing the 2013 national findings from K-12 students) aimed to “focus on getting beyond the anecdotally-driven stereotypes of student technology use to establish a more comprehensive understanding of the myriad of different ways that students are currently personalizing learning using technology” (p. 2). The report specifically looked at the use of digital tools to support schoolwork and to enable out-of-school learning, as well as probed students’ aspirations related to new innovative learning environments (p. 2). Important points from the report that are particularly relevant to this study include the fact that students are increasingly using a range of digital tools to support both teacher-facilitated *and* student-initiated learning pursuits (p. 3), and that students reported “less regular interaction with traditional social networking sites such as Facebook,” instead turning to other social media apps such as Instagram, Vine and Snapchat, with Twitter “also becoming a preferred digital medium for communications and information for many students including 28 percent of high school students” (p. 7). The number of Twitter users jumped to 46% for 9-12th graders

according to an infographic representing data collected in 2014 (Project Tomorrow, 2015). This percentage represents a growth of more than four times what it was in 2011 when only 11% of 9-12th grade students were tweeting. When asked to how their schools could make it easier for them to leverage technology to support learning, student responses included “greater access to online sites, use of mobile devices and social media, and digital tools that help to facilitate collaboration, communication and self-organization” (p. 11). It is clear that today’s students understand technology as an inherent dimension of their lives, both within and outside of school, and as an expected and critical component of their learning experiences.

Emergence of the Digital Educator

In much the same way that students have embraced technology, many teachers, too, point to technology as being critical to their jobs and to the success of their students (Atkins et al., 2010; Gray, Thomas & Lewis, 2010; Project Tomorrow 2013a; Project Tomorrow 2013c; PBS, 2009; PBS, 2011; Purcell, Heaps, Buchanan & Friedrich, 2013). A 2013 Pew report (Purcell et al.) found that 92% of teachers said “the internet has ‘a major impact’ on their ability to access content, resources, and materials for their teaching” (p. 2). Similarly, a 2011 PBS report found that, “The vast majority of K-12 teachers (97 percent) use digital media for classroom instruction” (p. 2). Educators’ use of technology in the classroom mirrors their above-average use of technology in their personal, out-of-school lives. As the 2013 Pew report noted:

When compared with the U.S. adult population, the AP and NWP teachers in this sample are more likely to own each of the seven tech gadgets asked about. These teachers particularly outpace all adults on laptop ownership (93% teachers vs.

61% of all adults), desktop computers (87% of teachers vs. 58% of all adults, and iPods (78% vs. 44% of adults. (p. 13)

Concerning social media, like many other measures of their use of technology, teachers' use outpaces that of all U.S. adults. As reported in the 2013 Pew survey, the percent of teachers who used social networking sites (78%), as well as the percent that used Twitter (26%), were “considerably higher than national figures for adult internet users” (p. 18). When the lens was turned to *aspiring teachers*, as was the focus of a 2013c Project Tomorrow Report, the findings are even more pronounced.

This report found, “The inherent digital native-ness of this next generation of teachers is more evident however, when we compare how these college students are tapping into social media tools in their personal lives with the activities of in-service teachers” (p. 2). Although aspiring teachers used social media a greater percent of the time, across all questions, when compared with current teachers, their use of Twitter was especially noteworthy. As the report noted, “And in regards to Twitter, the percentage of aspiring teachers that ‘tweet’ is three times the percentage for teachers who are in the classroom today” (p. 2). Furthermore, this unparalleled use of Twitter by aspiring teachers was not just for personal reasons. As the report pointed out, “When asked about their extended use of Twitter to support their professional needs as well as their personal interests, 20 percent of the aspiring teachers said that they are in fact already using that social media tool to enhance their professional knowledge” (p. 3). This was unique in that, at the time, only 8% of classroom teachers surveyed identified Twitter as a professional support tool.

Ultimately, teachers' use of technology is about connections. As Atkins et al. (2010) pointed out, "Teaching today is practiced mostly in isolation. Many educators work alone, with little interaction with professional colleagues or experts in the outside world" (p. 39). Technology can be leveraged to empower teachers, providing them with a means to a more interactive, dynamic and connected working experience. In their conceptualization of connected teaching, Atkins et al. call for teachers who have "24/7 access to data about student learning" are "connected to their students and to professional content, resources and systems that empower them to create, manage and assess engaging and relevant learning experiences for students both in and out of school," and who "engage in personal learning networks that support their own learning and their ability to serve their students well" (p. 40). Here, like was the case above, social media is already playing a role in supporting such aspirations. A Project Tomorrow poll of teachers (2013a) found that the percent of teachers who maintain a professional social networking site had almost doubled over a four year period, rising from 22% in 2008 to 39% in 2012.

While it is clear that technology is vital to most educators' professional practice, embracing a particular classroom technology does not ensure improved learning outcomes or even increased student engagement. As digital tools have evolved and empowered users to create, share and connect, teachers have recognized that a simple model of adoption often fails in realizing lofty purported outcomes. Rather, a system of supports must be implemented—often in the form of professional development—for teachers to create truly technology-enhanced, learner-centered classrooms. Reflecting this need, often in the context of one-to-one programs, there is considerable research that explores these environments in the field (An & Reigeluth, 2011; Bielefeldt, 2012; Rosen

& Beck-Hill, 2012; Spires, Morris & Zhang, 2012, Wetzel & Marshall, 2012) and through the lens of theory (Barron, 2006; Dilworth et al., 2012; Koehler & Mishra, 2009; Mishra & Koehler, 2006; Spires, Oliver & Corn, 2011; Spires, Wiebe, Young, Hollebrands & Lee, 2012). It should also be noted that there is not blanket support of teachers regarding the integration of technology in the classroom, particularly when it comes to entertainment media (Rideout, 2012a). Four out of ten teachers surveyed in this report believed that students' use of entertainment media (TV shows, music, video games, texting, iPods, cell phone games, social networking sites, apps, computer programs, online videos, and websites students use for fun) had a negative impact on their academic performance. This finding is especially relevant to this study, as more than half of those teachers who believed entertainment media had a negative impact on their students academic skills cited social networking as the most harmful medium.

Teens' Use of Social Media and Twitter

Despite its questionable utility in the eyes of some teachers, the use of social networking sites (SNS), or social media, is ubiquitous among today's teens (boyd, 2014; Lenhart, 2012; Lenhart et al., 2015; Lenhart et al., 2011; Madden et al., 2013; Rideout, 2012b). In the words of Rideout (2012b), "Using social media like Facebook and Twitter has become part and parcel of modern adolescence" (p. 7). In their seminal piece, boyd and Ellison (2007) offered a now much-cited definition of social network sites. In their words:

We define social network sites as web-based services that allow individuals to 1. construct a public or semi-public profile within a bounded system; 2. articulate a

list of other users with whom they share a connection, and; 3. view and traverse their list of connections and those made by others within the system. (p. 211)

Today's teens are online for significant portions of every day. A recent Pew report (Lenhart et al., 2015) noted that 92% of teens go online daily, including 24% who say they are online "almost constantly" (p. 2). More than half surveyed (56%) go online "several times a day," while just 2% report going online less than weekly (p. 16). While their time online is spent among a variety of applications, and for myriad pursuits, particularly significant is their time spent engaging with social media.

The same Pew report mentioned above found that, "When asked about seven specific sites (Facebook, Twitter, Instagram, Snapchat, Tumblr, Google+ and Vine), and given the option to report another site, 89% of all teens reported that they used at least one of the sites (p. 25). Among these sites, Facebook is most popular, with 71% of all teens saying that they use it (p. 26). Behind Facebook, according to percentage used most often by American teens, respectively, ranked Instagram, Snapchat, Twitter, Google+, Tumblr and Vine (p. 3).

While Facebook is still the dominant form of social media among teens today, Twitter, the form of social media that is the focus of this study, has shown notable, recent growth (Lenhart et al., 2011; Madden et al., 2013; Lenhart et al., 2015; Project Tomorrow, 2015; Rideout, 2012b). As noted in Madden et al., Twitter draws a far smaller crowd than Facebook for teens, but its use is rising. One in four online teens uses Twitter in some way. As the Madden et al. report shared, "While overall use of social networking sites among teens has hovered around 80%, Twitter grew in popularity; 24% of online

teens use Twitter, up from 16% in 2011 and 8% the first time we asked this question in late 2009” (p. 5).

More recently, as described previously, Project Tomorrow (2015) found 44% of grades 9-12 students now tweet, a four-fold increase since 2011. Although less than the Project Tomorrow report, the 2015 Pew report (Lenhart et al.) found a third of all teens (33%) use Twitter. The Pew report is particularly interesting in that it breaks down teens’ use of Twitter according to gender, race/ethnicity, age, gender by age, household income, parent educational attainment and urbanity. Notable findings include the fact that teens’ use of Twitter increases in a statistically significant manner as age increases (21% for ages 13-14 vs. 42% for ages 15-17), and that among older teens (ages 15-17) girls use Twitter more than boys (49% vs. 34%). Interestingly, whereas both Madden et al. and Rideout, found that African-American teens were substantially more likely to use Twitter as compared to their white counterparts, the Pew report did “not show statistically significant differences by race, locale or a teen’s socio-economic status” (p. 32).

Lack of Research at the Secondary Level

Considering the ubiquitous use of social media among teens, it is surprising to note that there is relatively little research concerning how these tools are used in educational contexts. In their review of empirical research related to the use of social media in schools, Henderson, Snyder and Beale (2013) pointed out “empirical research literature is more limited, despite scholarly interest in the benefits of social media applications,” and, because of this, “The result is a poorly defined body of literature which cannot easily be leveraged by practitioners to help in their design of educational experiences, or used by researchers in further refining our understanding of the issues”

(Introduction). It is interesting to note, however, that the National School Boards Association released a report all the way back in 2007 encouraging school board members to “explore social networking sites,” to “find ways to harness the educational value of social networking” and to “reexamine social networking policies,” among other recommendations (Vockley, 2007, p. 8-9).

Concerning Twitter, specifically, the vast majority of studies focus on applications and outcomes at the post-secondary level. These studies have considered Twitter in the contexts of nursing education (Skiba, 2008), marketing classes (Rinaldo, Tapp & Laverie, 2011), Computers in Education and Mobile Learning classes (Lin, Hoffman & Borengasser, 2013), student perceptions of instructor credibility (Johnson, 2011), and college students’ grades and academic engagement (Junco, Elavsky & Heiberger (2012); Junco, Heiberger & Loken, 2010). In addition to these studies, there have been efforts to study and review pertinent bodies of Twitter-related literature (Dhir, Buragga & Boreqqah, 2013; Gao, Luo & Zhang, 2012; Williams, Terras & Warwick, 2013). In the majority of cases, recommendations for next steps and future research include expanding research sites, often including K-12 settings.

Research, including but not limited to examples cited above, frequently encourages the casting of a wider net in terms of the sites, participants and contexts within which Twitter is studied. Many recommendations offered are consistent with the aims of this study. For example, in laying out opportunities for further inquiry, Greenhow and Gleason (2012) point out that research should be conducted that consists of “large-scale, in-depth studies that examine tweeting practices among various learner subgroups...to discern commonalities and variation in practices” (p. 473). Second, they

assert that studies are needed that collect data on “youth-initiated tweeting practices—and the potential learning opportunities therein across school and non-school settings” (p. 473). Third, they call for research that “examines not just individual tweets, tweet streams and other online evidence, but attends to how participants understand their experiences and place within the Twitter community and beyond” (p. 473). Lastly, they call for studies that explore the integration of Twitter in secondary schools and higher education, noting that, “Such studies ought to examine teachers’ purposes for social media integration, their development of technological pedagogical content knowledge (Mishra and Koehler, 2006), and the effect of their technology-mediated practices on students’ learning or the effectiveness of the teaching” (p. 474).

If one expands their search for relevant literature in secondary settings beyond Twitter, or social media, to include Web 2.0 technologies, a more robust collection of work can be found. “Web 2.0” is a term that refers to the notion of a participatory, “read and write” web experience (McManus, 2005). Web 2.0 technologies include social media, as well as other participatory media such as YouTube, Diigo, Wikipedia, podcasts and videocasts, and content aggregation and organization tools such as RSS feeds and tagging tools (Greenhow, Robelia & Hughes, 2009, p. 247). Studies concerning the application of Web 2.0 technologies in school settings address learners as early as middle school (Taranto & Abbondanza, 2009; Taranto, Dalbon & Gaetano, 2011), as well as those concerning a wider spectrum of middle and secondary students (Crook, 2012; Crook, 2008; Crook et al., 2008; Schuck, Aubusson & Kearney, 2010; Yuen, Yaoyuneyong & Yuen, 2011).

Overall, there is little consensus among the perspectives represented in various Web 2.0-based literature. Some tout the benefits of Web 2.0 technologies in unequivocal terms, stating, “banning social networking or even denying its popularity is not only inappropriate but also borderline irresponsible when it comes to providing the best educational experiences for students” (Taranto & Abbondanza, 2009, p. 38). Others, uncertain of the promise of Web 2.0 technologies, are equally forthright. As Crook (2012) stated, “We are living in a time of participatory tools, participatory attitudes and participatory aspirations; yet educational practice does not seem to be easily bringing these elements into an expected alignment” and, as result, “a close look at the intersection of educational practice and digital technology suggests tensions rather than transformations” (p. 64). Still others were deliberately non-committal, as evidenced by the conclusion offered by Schuck et al. in which they posited:

We cannot predict the influence of new technologies on adolescent behavior in 5 years’ time. Web 2.0 may corrupt school learning, promoting anarchy that may be inimical to school as a center of knowledge exchange. Or Web 2.0 might be transformed, tamed and safe. (p. 242)

Twitter Chats

A Twitter chat can be defined as “a thematic multilogue (i.e., a many-to-many conversation focused on a given theme/topic) often situated within a community of practice (CoP) and/or community of interest (CoI)” (Megele, 2014, p. 47). #Scistuchat is a Twitter chat that takes place during a set time each month. The event utilizes Twitter’s hashtag function to enable participants to engage in dynamic, real-time dialogue around a given science topic. Although there are thousands of Twitter chats, with varying degrees

of structure and participation, related research appears limited (Amiruddin, 2015; Budak & Agrawal, 2013; Cook, 2014; Cook, Kenthapadi & Mishra, 2013; Ford, Veletsianos & Resta, 2014; Herbert, 2012; Megele, 2014).

The research that does exist tends to conceptualize Twitter chats as falling into one of two camps: 1. spontaneous group chats that emerge in an organic fashion, particularly temporally, while using an existing, pre-established hashtag to collate discussion; and 2. group chats that meet with regularity, often taking place on a set date and at a set time. With regard to the former, these organic group chats both differ from #scistuchat in important ways and are similar in others. For example, Ford et al. (2014) sought to answer the question, “What is the structure and characteristics of the network that has formed around the #PhDchat hashtag on Twitter?” (p. 2). One of the distinguishing features of #PhDchat that drew the authors to study the chat included the fact that it “has formed organically and appears to have little in the way of a central structure” (p. 2). Like #PhDchat, #scistuchat uses a specific hashtag to bring together individuals with shared interests, however, unlike #PhDchat, #scistuchat is used most widely during its scheduled, monthly chats —from 9:00-10:00 pm EST. During these times, it is characterized by a flexible yet defined central structure (i.e., its protocol). During times outside of its regularly scheduled chats, #scistuchat is used in much the same way that #PhDchat is, and possesses virtually no central structure.

Cook et al. (2013) refer to Twitter chats using the term “group chats,” which they define as events in which there are “periodic, synchronized conversations focused on specific topics.” Furthermore, unlike #PhDchat, they point out that “In addition to agreeing on a hashtag, members also agree on a day and time” with many of the group

chats moderated to “ensure that the meeting has a focused subject” (Section 1). These features are virtually identical to those of #scistuchat, thus offering a closer alignment than #PhDchat.

Examples of Cook et al.’s notion of group chats exist by the hundreds in the field of education. Including both national and local audiences, education-related Twitter chats abound. One of the most recognizable Twitter chats in education is #edchat. Started in 2009, #edchat has grown to become one of the most well-attended, education-themed chats on Twitter. With numbers of participants sometimes reaching into the thousands, additional #edchat times have been added to accommodate an overseas contingent of participants (Herbert, 2012, p. 52). Often credited with being a trailblazer for education-related Twitter chats, offshoots of #edchat quickly arose that focused on specific subfields and topics (e.g., administration, special education, science, educational technology, etc.).

Regardless of the structural characteristics of Twitter chats, and the haphazardness with which they can appear to function, these events often have dedicated participants who consider their experiences to be meaningful, exciting and inspiring. Megele (2014) offers a host of reasons why Twitter chats are appealing to such broad audiences. Two reasons particularly relevant to this study include: 1. Although to an outside observer tweets within a chat might appear to be sent to “diverse, ambiguous and/or imagined audiences,” in fact, “This seemingly non-directed and chaotic communication...does not negate the foundational element inherent in all communication, that all tweets are directed at some form of audience” (p. 48); and 2. Because there is a “suspension of the turn-taking norms of face-to-face interaction in

multilogues,” events such as #scistuchat allow for “an increased number of participants, and an increase in number of each participants’ postings/tweets, while on the other hand, the multi-strand nature of discussion broadens the scope of discussion” (p. 47).

Technology in Science Teaching and Learning

The most recent research, and thinking, related to the teaching and learning of science in the United States is laid out in two documents: 1. *A Framework for K-12 Science Education: Practices, Crosscutting Concepts, and Core Ideas* (NRC, 2012); and the resulting 2. *Next Generation Science Standards (NGSS): For States, by States* (2013). Although these resources convey a vision for the future of science education in America, they are careful not to prescribe what individual classrooms, and related curriculum, instruction and assessment, should look like. As the *Framework* notes:

Much of the complexity of science education systems derives from the multiple levels of control—classroom, school, school district, state, and national—across which curriculum, instruction, teacher development, and assessment operate; thus what ultimately happens in a classroom is significantly affected by decision making distributed across the levels and multiple channels of influence. (p. 243)

While the *Framework* does not delineate specific pedagogical approaches, it does stress that students should be “actively involved in the kinds of learning opportunities that classroom research suggests are important” (p. 250). These learning opportunities for students must involve: 1. their understanding of science concepts; 2. their identities as learners of science; and 3. their appreciation of scientific practices and crosscutting concepts (p. 250). Important to this study, the *Framework* notes, “the development of standards, curriculum, instruction, and assessment that successfully integrates the three

dimensions [practices, concepts and core ideas] is an area ripe for research and innovation” (p. 218)

As might be expected then, the *Framework* and *NGSS* do not address the role of technology, specifically, as a means of achieving the kind of learning described above. While there is not current research that explores the role of technology in the teaching and learning of science specific to these two documents, there are studies that analyze the integration of technology in secondary science settings (Campbell & Abd-Hamid, 2013; Guzey & Roehrig, 2009; Guzey & Roehrig, 2012; Pringle, Dawson & Ritzhaupt, 2015; Yerrick & Johnson, 2009). Importantly, virtually all of these studies utilize the Technological Pedagogical Content Knowledge (TPACK) Framework (Mishra & Koehler, 2006; Koehler & Mishra, 2009).

The TPACK framework identifies the essential aspects of knowledge teachers must possess in order to integrate technology meaningfully into their pedagogy. The seven knowledge areas include: 1. content knowledge; 2. pedagogical knowledge; 3. technology knowledge; 4. pedagogical content knowledge; 5. technological content knowledge; 6. technological pedagogical knowledge; and 7. technological pedagogical content knowledge. In studies that explore the intersection of TPACK and science teaching and learning, educators’ motivations for adopting a given technology (often driven by prior experience with the technology) are particularly important. Furthermore, regular, disciplined reflection on practice and implementation appears to be positively linked to sustained, successful integration. As Guzey and Roehrig (2009) noted, “The findings of this study also suggest that teachers should reflect on their classroom practices in order to incorporate technology and inquiry into their teaching more

effectively” (p. 41). Similarly, in their more recent work with early-career science teachers, Guzey and Roehrig (2012) again found that “sustained technology integration involved continuous reflection on classroom practices,” and that “through reflection on what and how students learn, how technology tools influenced students’ learning, and how the lesson might be modified,” teachers were able to accurately and actively evaluate their teaching (p. 178).

Many science teachers are in the process of reworking their curricula and assessments to better align with the *NGSS* and the ideals set forth in the *Framework*. At the same time, they are confronting questions regarding how best to leverage existing technology in a way that complements, and perhaps even enhances, students’ ability to realize what is a pronounced shift in expected outcomes for today’s science students. It is likely that frameworks such as TPACK, and others like it, will offer valuable insight into how best to achieve these objectives.

The Evolving Nature of Science Communication

As shared in the introduction, it is well documented that new technologies have led to a shift in the ways that science is communicated to and consumed by the public (Bik & Goldstein, 2013; Brossard, 2013; Brossard & Scheufele, 2013; Holcomb et al., 2013; Scheufele, 2013). However, as Brossard (2013) explained, many of the interactions, norms and best practices around online communication of science “are based on experiential rather than on empirical understandings of the broad outcomes that could be expected from current efforts” (p. 14099). Speaking about social media specifically, she noted “The influential microblog Twitter has yet to be empirically tested as a science communication platform from an audience perspective,” and, similarly, “the potential of

social networks for science communication has yet to be explored empirically, a puzzling circumstance considering that two-thirds of online American adults are now Facebook users” (p. 14100). When one considers the prevalence of social media, it is hard not to agree with the conclusion of Brossard and Scheufele (2013), when they stated, “A world in which one in seven people actively use Facebook, and more than 340 million tweets are being posted everyday is not the future of science communication any more. It is today’s reality” (p. 41).

Recognizing this changing science communication landscape, scientists are increasingly turning to new media as they explore novel ways to consume and share science (Baker, 2015; Bik & Goldstein, 2013; Liang et al., 2014; Van Noorden, 2014). As Bik and Goldstein noted, “In the age of the internet, social media tools offer a powerful way for scientists to boost their professional profile and act as a public voice for science” (p. 2). Vying for the attention of scientists, to this point, Twitter is used only sparsely. In Van Noorden’s 2014 survey, only 12% of the 3,500 scientists from 95 different countries who responded to the survey reported using Twitter regularly. And yet, among those who did, Twitter far outperformed LinkedIn and Facebook in terms of the intensity with which its users follow science discussions, comment on science research and post science (work) content (p. 129).

Curious about the potential benefits of a tool like Twitter, Baker (2015) spoke with numerous scientists about their introductions to and experiences with Twitter. As one scientist who was initially skeptical of Twitter shared, it was her observation that her graduate students were being offered professional opportunities through Twitter that provided the impetus for her to give the micro-blogging site a try. Like Bik and Goldstein

(2013), Baker not only shared the perspectives of scientists who made the leap to Twitter, but also offered numerous suggestions for those interested in exploring the medium as well as advice regarding what to expect once there.

In perhaps the most compelling case for scientists' adoption of Twitter, Liang et al. (2014) used data from completed surveys of more than 200 leading U.S. nano-scientists to "explore the effects of scientists' public communication behaviors via traditional and new media on their scientific impact as measured by the *h*-index" (p. 781). Findings suggested that the professional status of nano-scientists was correlated with mass media interactions as well as being mentioned on Twitter, and that online "buzz"—being mentioned on Twitter—"further amplifies the impact of communicating science through traditional outlets on the scholar's scientific impact" (p. 782). Importantly, "Neither science blogging nor interacting with non-scientists had any significant effect on scientific impact" (p. 782).

Formal vs. Informal Science Learning

To this point, the discussion of the literature related to my study has focused, implicitly, on learning, and the possibilities for learning, in traditional educational settings (i.e., schools, classrooms, etc.). However, a potentially powerful feature of social media is its ability to foster and support interactions outside of traditional educational settings, and across traditional boundaries of time, space and geography. Moreover, it can also provide a means for individuals to interact across traditional intergenerational barriers. To fully understand these opportunities, and the potential they hold, one must shift their focus outside of traditional educational settings in an effort to explore these less-studied, but perhaps equally influential experiences. The research related to informal

learning of science is limited (Ainsworth & Eaton, 2010; Falk & Dierking, 2010; McCallie et al., 2009; NRC, 2009; NRC, 2010; Tal & Dierking, 2014). As is pointed out in the NRC (2009) publication, this lack of attention to informal learning experiences is surprising, as “What is often overlooked or underestimated is the potential for science learning in non-school settings, where people actually spend the majority of their time” (p. 1). This sentiment was echoed by Falk and Dierking (2010). They claimed that “an ever-growing body of evidence demonstrates that most science is learned outside of school” (p. 486), as much as 95 percent.

The notion of informal learning is particularly important to this study, as #scistuchat represents a learning opportunity that occurs outside of the classroom and school day, and which, in many ways, straddles the divide between formal and informal learning. Furthermore, #scistuchat leverages Twitter, itself an understudied technology, to create a digitally-mediated, science-related learning opportunity. In 2009, the NRC stated, “Science media are qualitatively shaping people’s relationship with science and are a new means of supporting science learning.” It was also noted that while educational television was the primary source of evidence related to media and informal science learning, “substantially less evidence exists on the impact of other media—digital media, gaming, radio—on science learning” (p. 3). Even in the most recent effort to paint a vision for science learning in the United States (NRC, 2012), the committee recognized that, “We also do not discuss informal settings for science education, which provide many opportunities for learning science that complement and extend students’ experiences in school” (p. 243).

There is a clear need for research that sheds light on informal opportunities to explore, experience and communicate about science. This is particularly true in cases where media and emerging technologies act as the medium for these experiences. Given the diverse settings within which such informal science experiences can occur, the unique tools that can be utilized, and the highly personal and varied starting points from which informal learners access these experiences, a research agenda for informal learning is likely to be complex and layered. As was pointed out in *Surrounded by Science: Learning Science in Informal Environments*, “Learning to communicate in and with a culture of science is a much broader undertaking than mastering a body of discrete conceptual or procedural knowledge (NRC, 2010, p. 21).

Chapter 3: Methodology

Rationale for Qualitative Methods

The goals of my research were to observe participants' interactions in #scistuchat in real-time, to explore how participants made sense of their respective experiences, and to probe participants' perspectives related to the use of Twitter as a medium for teaching, learning and communicating science. In these ways, this study sought to “understand some phenomena from the perspectives of those involved,” and to “gain access to the multiple perspectives of participants” (Glesne, 2006, p. 4-5). I believe that this study, and the resulting data collected, is consistent with what Miles and Huberman (1994) described as being “fundamentally well suited for locating the meanings people place on the events, processes and structures of their lives” (p. 10). Rather than seeking to demonstrate cause-effect relationships or correlations, which would require an approach reliant, at least in part, on the collection and analysis of quantitative data, this study is particularly well-suited for a qualitative methodological approach in which the experiences and perceptions of individuals are paramount.

Specifically, this study used a multiple-case (embedded) design. According to Yin (2014), determining whether a case study method is applicable reflects a two-pronged conceptualization of the approach in which both scope and features are considered. First, concerning scope, a case study should “a. investigate a contemporary phenomenon (the “case”) in depth and within its real-world context, especially when...b. the boundaries between phenomenon and context may not be clearly evident” (p. 16). Second, concerning features, a case study “a. copes with the technically distinctive situation in

which there will be many more variables of interest than data points, and as one result...b. relies on multiple sources of evidence, with data needing to converge in a triangulating fashion, and as another result...c. benefits from the development of theoretical propositions to guide data collection and analysis” (p. 17).

This study analyzed four #scistuchats, occurring during the months of February, March, April and May of 2014. Consistent with Yin’s two-fold criteria for determining the applicability of a case study approach, each #scistuchat represented a contemporary event in which contextual factors were inextricable and whose analysis (guided by a research-based theoretical framework) necessitated diverse, triangulating sources of data. #Scistuchat is a Twitter chat that represented a “bounded system” that could be explored “over time, through detailed, in-depth data collection involving multiple sources of information...” (Creswell, 2007, p. 73).

This study is most accurately described as a multiple-case (embedded) design (Yin, 2012; Yin, 2014). It falls under the “multiple-case design” umbrella because it analyzed four separate #scistuchats over the course of four months, with each being essentially a replication of the other (same medium via which the chat occurred, same start time and duration, identical organizational protocol, same categories of participants, etc.). It is an “embedded” form of a multiple-case design because it considered three distinct participant populations—scientists, students and teachers—as the embedded unit of analysis over the course of each month’s chat (Figure 1).

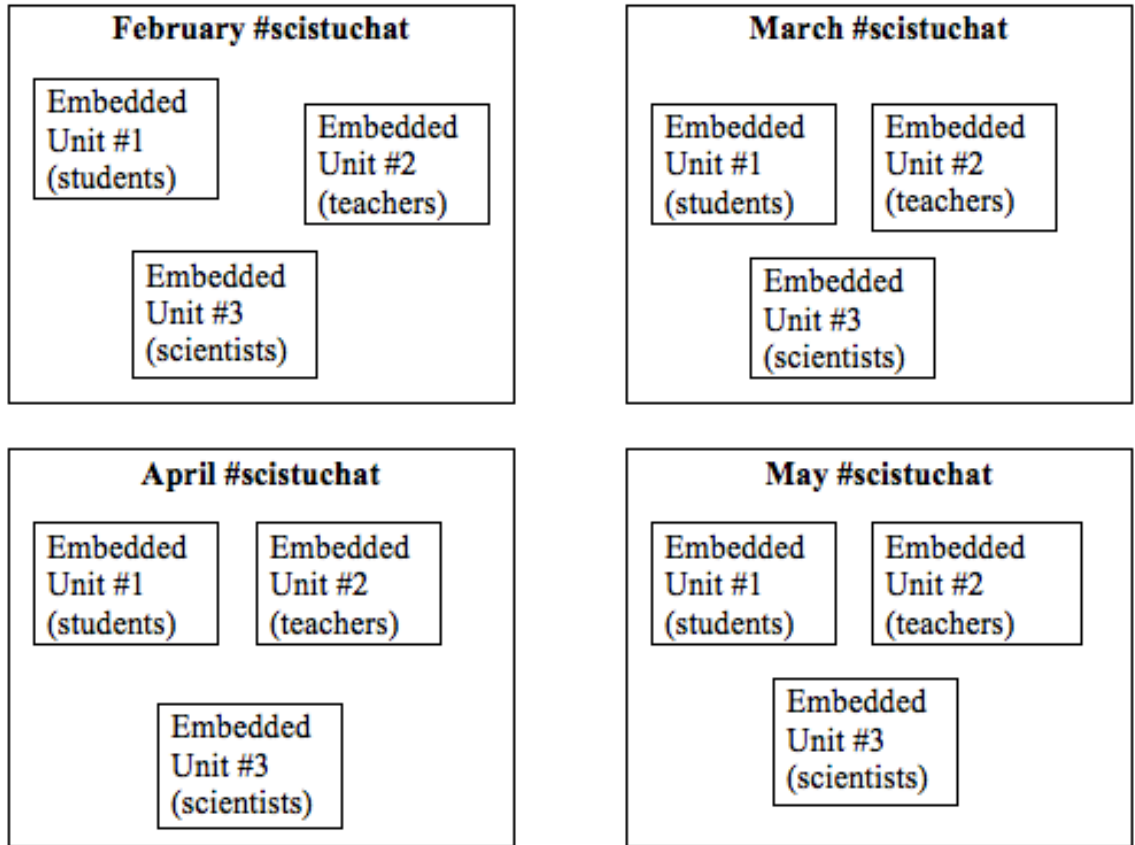


Figure 1. Visual representation of this study's multiple-case (embedded) design

Research Purpose and Questions

The purpose of this study was to explore #scistuchat participants' perceptions of Twitter as a tool for learning and communicating science. Drawing on the perspectives of participating scientists, students and teachers, this study sought to answer the following research questions:

- How do participants understand #scistuchat as a digitally-mediated learning experience?
- How do participants understand #scistuchat as a formal vs. informal science learning experience, particularly as it relates to in-school science learning?

- How do participants use, and perceive, Twitter as a medium for teaching, learning and communicating science outside of the confines of #scistuchat?

Site/Participant Selection

Describing the “site” of this study is difficult to do given the traditional physical and geographic conceptualization of the term. Because #scistuchat is a digitally-mediated event that takes place via Twitter, it has no physical location. However, the participating students, scientists and teachers are of course affiliated with specific and diverse geographic locations and institutions.

Purposeful sampling was used to recruit participants (Creswell, 2007; Glesne, 2006; Patton, 2002). Recruitment of participants for the study occurred on a case-by-case basis (i.e., from #scistuchat to #scistuchat) and began in the immediate aftermath of each month’s chat. Because each month’s #scistuchat was a public event, and was observed in real-time, I was able to track the interactions/contributions of participating scientists, students and teachers during the chat. From these observations I identified numerous scientists and teachers to whom I planned to reach out to immediately following the conclusion of that month’s #scistuchat. I did not reach out to any students directly, instead committing from the outset to have teachers act as the conduit through which all interactions with students were initiated and conducted. I was purposeful in reaching out to participants in the chat who contributed frequently to that month’s #scistuchat and, when possible, in a way that maximized geographical representation (geography was one of the only identifiable measures of diversity that I could glean directly from observing the chat). In these ways, I hoped my efforts at purposeful sampling would result in study

participants having as much information and context from which to draw during subsequent interviews. As Patton (2002) explained:

The logic and power of purposeful sampling lie in selecting *information-rich* cases for study in depth. Information-rich cases are those from which one can learn a great deal about issues of central importance to the purpose of the inquiry, thus the term *purposeful* sampling. (p. 230).

The logistics of participant recruitment were dictated by the information available from each prospective participant's Twitter profile. Following the identification of potential participants through real-time observation of a specific month's #scistuchat, I then reached out directly to these individuals in one of two ways: email (if an address was able to be located through following a link provided in an individual's Twitter profile) or via a tweet sent directly to their Twitter handle. My first choice was email for two specific reasons: First, because Twitter is a public forum, all tweets are publicly available (furthermore, any tweets containing the hashtag #scistuchat—which was necessary to include in tweets sent directly to prospective participants—are both public and archived under the hashtag #scistuchat). I was conscious of not wanting to publicly solicit potential participants, nor have this interaction archived. Second, sending an email enabled me to provide background and context for my request that I would not be able to otherwise given the 140-character limit of Twitter. Ultimately, my recruitment efforts occurred via both email and Twitter. Following initial contact and agreement to further consider participating in my study, specifics of my study, including all information and safeguards mandated by the University of Vermont's Institutional Review Board (IRB), were communicated electronically via a detailed "Research Information Sheet." Scientists and

teachers were able to discuss questions or concerns regarding participation directly with me. Teachers assisted me in ensuring that student-specific Research Information Sheets were copied and distributed to potential student participants. Participating students provided verbal acknowledgement that they had read and understood the Research Information Sheet (and that their parents had read and granted permission, if applicable) and provided verbal consent prior to participating in the focus group interviews.

Screenshots of participants' tweets are used throughout this dissertation. These screenshots do not anonymize participants. This approach to visually representing tweets was approved by the University of Vermont's Institutional Review Board (IRB), as well as by participants during the consent process.

Data Collection

Participant observation. Because #scistuchats occur via Twitter, they are inherently open to the public, both in terms of observation and participation. Thus, I was able to observe, in real-time, each of the four #scistuchats that are the focus of my study. Although I was not able to physically observe participants as they operated their devices while participating, I was able to see the tweets of all participants in real-time. This form of observation seemed both appropriate and authentic to the nature of the event. Yin (2014) cautioned researchers to “exercise care when using data from electronic sources” (p. 129). Although I recognized the potential concerns associated with electronic sources, and social media in particular, I believe strongly that the reasons behind these concerns made my study even more important. I appreciated Creswell's perspective on this issue. With regard to challenges and concerns regarding new forms of data, he stated, “Despite problems in innovative data collection, I encourage individuals designing qualitative

projects to include new and creative data collection methods that will encourage readers and editors to examine their studies” (p. 129). I believe that observing the chats in real-time provided authentic, invaluable context that assisted me in identifying prospective study participants and informed both my interview questions and additional data collection efforts, as well as later data analysis.

Interviews. Glesne (2006) noted, “Observation puts you on the trail of understandings that you infer from what you see, but you cannot, except through interviewing, get the actor’s explanations” (p. 80). Indeed, although I was able to observe #scistuchats in real-time, and refer to the archived versions of the chat via use of the hashtag and the website maintained by the creator/facilitator of the chat, interviews were critical in understanding the feelings, thoughts, intentions and takeaways of participants.

In total, 16 individual interviews were conducted with scientists, six individual interviews were conducted with teachers, and five separate focus group interviews were conducted with students (see Table 2 for a case-by-case breakdown and Figure 2 for a map of participants’ geographic locations).

Table 2

Case-by-case breakdown of participants in the study

#Scistuchat Topic/Month	Number of Participating Scientists	Number of Participating Students	Number of Participating Teachers
Black Holes (February 2014)	5	Two focus groups (one with 5 students, one with 2 students)	2
Human Genetic Engineering (March 2014)	3	One focus group with 3 students	1
Green Chemistry (April 2014)	4	One focus group with 2 students	1
Volcanoes (May 2014)	4	One focus group with 5 students	2



Figure 2. Map of geographic locations of research participants

All interviews were semi-structured in nature and consisted of open-ended questions (see Appendix B). Because I interviewed individuals from differing locations throughout the country and, in some cases, other countries as well, video conferencing technology was used to provide electronically-mediated, “face-to-face” interview experiences. Prior to interviews, participants were asked to specify their video conferencing preference. Choices included Google Hangout, Skype and FaceTime. The majority of interviews occurred via Skype, with others occurring via Google Hangout. In a couple of instances, interviews started via videoconference and were interrupted part-way through (due to computer batteries dying, disruptions in internet service, etc.). In these rare cases, the remainder of the interview was conducted via phone conference. One interview was conducted entirely via phone conference. Verbal consent was obtained following successful video connection and prior to beginning the interviews. All interviews were recorded using a digital voice recorder for later transcription. Interviews with scientists and teachers lasted an average of 45-60 minutes. Focus group interviews with students lasted an average of 35-45 minutes.

Prior to conducting the interviews mentioned above, questions were piloted, as was the process of conducting an interview using video technology, with a focus group of students who had participated in #scistuchats during the previous academic year. As described by Glesne, this pre-pilot/pilot phase acted as a four-way interaction among myself as researcher, my tentatively formed topic, my interview questions and, eventually, collaborators in the form of gracious students willing to assist me in piloting my interview questions (p. 85).

Document analysis. Following each #scistuchat, the organizer of the event archives all tweets exchanged during that chat. These archived versions of the #scistuchats provide a convenient and potentially rich source of data in the form of documents (individual tweets), or, if the record of the chat is considered in its entirety, a single document. Archived versions of each chat were gathered from the #scistuchat website. These documents consist of spreadsheets containing all tweets that were exchanged during a particular chat and which contain the hashtag #scistuchat. These archived versions of the chats involved in my study consist of between 900-1400 tweets each. Although these archives provide a record of the text included in tweets exchanged during a given #scistuchat, they do not include visuals of the exact tweets as they were seen by participants during the chat. However, through Twitter search tools, and the use of the #scistuchat hashtag, entire records of the chat can also be viewed. These records are even more information-rich than the archived version on the website, as they contain individuals' Twitter profile pictures, Twitter handles, number of tweets, favorites and retweets, exact time the tweet was sent, and, importantly, a means to view conversations with others that may have stemmed from a given tweet.

I reviewed the archived versions of the chats to copy participants' responses to a standard, concluding question in #scistuchat: "What are two things you learned tonight?" These tweets were then entered into HyperRESEARCH, the computer assisted qualitative data analysis software (CAQDAS) I used to code and analyze my data. I used Twitter's search tools to review each month's #scistuchat and to view tweets and conversations as they were seen by participants during the chat. I also used this search capability to view

specific tweets referenced by participants during interviews. The screenshots that are included in this study are the product of those search and analysis efforts.

Data Analysis

Coding. Saldana (2013) defined codes as “a word or short phrase that symbolically assigns a summative, salient, essence-capturing and/or evocative attribute for a portion of language-based or visual data” (p. 3). Glesne, in describing the process of coding, refers to it more simply and directly as “a progressive process of sorting and defining and defining and sorting those scraps of collected data (i.e., observation notes, interview transcripts, memos, documents and notes from relevant literature) that are applicable to your research purpose” (p. 152). Both code-related descriptions resonated with me, as my coding process included moments of essence-capturing glee as well as long hours of meticulous, repeated analysis of myriad “scraps” of collected data...the heart of any qualitative study.

In retrospect, consideration of possible codes began early in the research process, long before reviewing interview transcripts. As early as conducting initial research for a draft of my literature review, I realize now that I was developing the beginnings of a rudimentary coding scheme. Throughout the process of observing chats and conducting interviews, I would capture informal notes or observations, some of which, looking back, eventually morphed into *a priori* or provisional codes (Miles, Huberman & Saldana, p. 77). Once interviews were conducted and transcripts generated, the intensive work of coding began.

Drawing on the work of Saldana (2013), Miles, Huberman and Saldana break the coding process into First and Second Cycle phases, in which initial codes are created and

applied and then collapsed into a smaller number of categories, themes or constructs (p. 86). I began First Cycle coding by uploading interview transcripts into the qualitative data analysis program HyperRESEARCH. Transcripts were then carefully coded using the provisional codes mentioned above and the creation of a host of new codes as the data dictated—a process referred to as inductive coding. This First Cycle coding process greatly expanded my codebook as it generated a variety of types of codes, including descriptive, *In Vivo*, evaluation and attribute codes, as well as a series of sub-codes and numerous examples of simultaneous codes (p. 74-81). I also defined each code within HyperRESEARCH so that I would be able to quickly reference the symbolic meaning of each in the event that I experienced uncertainty due to time away from my codes, subtle differences between codes or simply due to the sheer number of codes I was considering at any given point during the coding process. My codebook, the product of First Cycle coding, can be found in Appendix C. As Miles et al. emphasized, “clear operational definitions are indispensable so they can be applied consistently by a single researcher over time and multiple researchers will be thinking about the same phenomena as they code” (p. 84).

Following the coding of all interviews and related data drawn from the archives of each #scistuchat, further analysis of my codes, as well as their frequencies, led to the generation of pattern codes (p. 86). Speaking to the link between codes and the possibilities of their subsequent analysis, Saldana (2009) explained, “Qualitative codes are essence-capturing and essential elements of the research story, that when clustered together according to similarity and regularity—a pattern—they actively facilitate the development of categories and thus analysis of their connections” (p. 8). With the

convenience of report functions within HyperRESEARCH, I was easily able to look at frequencies of codes across my entire study, individual cases, or even among specific participant groups (within a case and across cases). Combined with easily viewable annotations or jottings that were electronically attached to many of my codes, this data helped me get a sense of significant codes from a frequency perspective, as well as specific codes and ideas to later consider in theme development. Ultimately, numerous pattern codes were created. Some of these pattern codes were literally preexisting codes from my codebook (e.g., experts) while others were created to reflect relationships between or among codes (e.g., student-focused).

Theme analysis. The process of culling and exploring significant codes as well as the generation of broader pattern codes prepared me to dive deep into their analysis and, over time, identify resulting themes that emerged. As Glesne (2006) noted, analysis inevitably necessitates a shift from “staying close to data as originally recorded,” to “identifying essential features and the ways in which the features interact” (p. 164). For me, this stage involved moving away from my computer screen and, refreshingly, to working with paper, markers and dry-erase whiteboards. Having identified an array of pattern codes, typically with clusters of related codes from my codebook nested within, I decided to print the many pages of corresponding coded passages from my transcripts in order to literally lay out and physically see/manipulate the data. This process of highlighting, cutting and rearranging enabled me to more holistically consider the decisions I had made and relationships I had tentatively committed to in the formation of pattern codes described above. As Miles et al. explained, “When you’re trying to determine what someone’s actions ‘mean,’ the mental exercise involves connecting a

discrete fact with other discrete facts, then grouping these into comprehensible and more abstract patterns” (p. 292). Through the iterative process of physically arranging chunks of data, mapping resulting patterns and relationships on a large whiteboard, and reflecting on and revising the resulting arrangements, I arrived at six themes that I believe capture the essence of the cases that comprise my study. Moving from codes to patterns to themes shifted my analysis from “the empirical trenches to a more conceptual level of the landscape” and was the product of careful attention to observables and unobservables and the deliberate action of “connecting the two with successive layers of inferential glue” (Miles et al., p. 292).

Cross-case analysis. Multiple-case studies have the potential to “see processes and outcomes across many cases, to understand how they are qualified by local conditions, and thus to develop more sophisticated descriptions and more powerful explanations” (Miles et al., p. 101). Furthermore, multiple cases may “increase generalizability” and ensure that “events and processes in one well-described setting are not wholly idiosyncratic” (p. 101). Similar to the process of identifying themes, my efforts at cross-case analysis included toggling back and forth between electronic and physical analysis of my themes and data. Because my study involved three subgroups of participants (scientists, students and teachers) from four cases (monthly #scistuchats), and because my themes broke down along two dimensions (#scistuchat-specific and, more generally, Twitter-related), keeping track of data for the purposes of cross-case analysis quickly became an organizational challenge. To address this, I adopted a strategy where I imported all coded passages that applied to specific themes into theme-specific Google Docs. Within each theme-specific Google Doc, I further organized the data according to

case and, within each case, differentiated the data according to participant sub-group (by font and color). Following the importation of my data into separate Google Docs, and the delineation of the data within each according to respective case and participant group, I printed all for the purpose of being able to lay out and visualize, collectively, the accumulated data for each theme/sub-theme across all cases.

An outgrowth of this cross-case analytical strategy was the creation of a matrix display. This matrix display, consisting of quotes from each participant group that spoke to the essence of each theme/sub-theme, was subsequently shared with the creator/facilitator of #scistuchat (himself a study participant) as a form of member-checking (see Appendix D). My efforts to creatively and thoroughly analyze my data across cases were consistent with several analytical strategies recommended by Yin (2014), including “putting information in different arrays, making a matrix of categories and placing the evidence within such categories, creating data displays—flowcharts and other graphics—for examining the data, and tabulating the frequency of different events” (p. 135). Ultimately, cross-case analysis allowed me to consider individual, case-specific outcomes in the context of a more holistic, multi-case landscape and arrive at a more nuanced and complex understanding of my research questions. As stated at the outset, being able to “transcend the particular in order to understand the general” and to “develop more sophisticated descriptions and more powerful explanations” indeed are the goals of cross-case analysis.

Trustworthiness

Qualitative researchers, at some point, inevitably consider the questions “How might I be wrong?” (Maxwell, 2005) and “Is it possible to even have a ‘right’ answer?”

(Creswell, 2007). Further complicating the picture, as Creswell pointed out, is the fact that “Many perspectives exist regarding the importance of validation in qualitative research, the definition of it, terms to describe it, and procedures for establishing it” (p. 202). Despite its murkiness, striving to ensure high standards for the quality of conclusions generated through qualitative inquiry is, at the very least, a responsibility all researchers have to their participants. In the case of this study, several tactics were used in an effort to ensure maximum trustworthiness.

Triangulation. Triangulation involves the purposeful use of one or more of the following: multiple sources of data; multiple methods of data collection; multiple investigators; multiple theories (Creswell, 2007; Miles et al., 2014). Additionally, Miles et al. included a fifth method of triangulation, multiple types of data. This study leveraged triangulation with regard to sources, methods of data collection and types of data. First, in terms of sources of data, a distinguishing feature of my research is that I sought the perspectives of scientists, students and teachers. This deliberate effort to compare/contrast the perspectives of three distinct groups of participants regarding their shared #scistuchat experience is a strength of this study. Second, concerning data collection methods, I was able to directly observe each #scistuchat in real-time prior to interviewing participants from their respective chats. Furthermore, because every chat was archived, with the text of every tweet shared available via the organizer’s archives and the actual tweets themselves searchable via Twitter’s search functions, I was also able to revisit the content and flow of the chat at later points and at a pace of my choosing. Thus, I was able to utilize several methods of data collection. Finally, regarding types of data, although interview transcripts comprised the bulk of my coded

data, as mentioned above, I was able to review and analyze every tweet sent during each of the four #scistuchats my study followed.

Member checking. Member checking involves “sharing interview transcripts, analytical thoughts, and/or drafts of the final report with research participants to make sure you are representing them and their ideas accurately” (Glesne, p. 38). Lincoln and Guba consider this quality control measure to be “the most critical technique for establishing credibility” (as cited in Creswell, 2007, p. 208). In an effort to maximize the credibility of my data and conclusions, efforts were made to solicit feedback from participants in the form of member checking. First, all transcribed interviews were emailed to all respective study participants. Participants were asked to review the transcripts and to offer any clarifications, additional points or elaborations, or questions. Second, as mentioned above, the themes matrix (Appendix D) was shared with the creator/facilitator of #scistuchat and discussed via Google Hangout. The purpose of this virtual “face-to-face” communication was to have a more personalized discussion of the themes and sub-themes of my study, particularly considering that this individual was both a study participant and the single person with the most intimate and longstanding knowledge of #scistuchat.

Researcher identity and assumptions. All researchers bring to their studies related experiences, knowledge and assumptions that can act to bias the many dimensions of their research endeavor. And although one can strive to eliminate these factors, success in doing so is less than probable and, in the eyes of many, unnecessary (Creswell, 2007; Glesne, 2006; Maxwell, 2005; Yin, 2014). As Maxwell noted, “*Any view is a view from some perspective, and therefore is shaped by the location (social and theoretical) and*

‘lens’ of the observer” (p. 39). Reason (1988) understood this and coined the term “critical subjectivity” to address the recognition of a researcher’s values and assumptions, as well as their role in the research process. Speaking to the nature of critical subjectivity, he described it as:

A quality of awareness in which we do not suppress our primary experience; nor do we allow ourselves to be swept away and overwhelmed by it; rather we raise it to consciousness and use it as part of the inquiry process” (as cited in Creswell, p. 38).

Through careful attention to my motivations, goals and prior experiences, it is my hope that I have been able to raise them to a level of personal consciousness in which their influence has not surreptitiously influenced my analysis and interpretations.

I leaned heavily on the work of Maxwell, as well as his recommended exercises (p. 27), as a primary means to examine my identity as a researcher. I took great care to articulate my various personal, practical and intellectual goals (p. 16) and to examine related experiences, assumptions, feelings and values, at the outset of my work. Although he stresses that the product of this deep reflection—the researcher identity memo—is intended mainly for the researcher’s own benefit, it necessarily influenced the various points I share below.

There are numerous factors that relate to my research that I believe are important to disclose. First, I am a middle level science teacher and have incorporated Twitter as part of my students’ science experiences for several years. Second, part of my work with Twitter in my science classroom stemmed from a class I took via the University of Vermont (UVM). In this class, facilitated by two individuals from UVM and the Tarrant

Institute for Innovative Education (TIEE), I was supported in setting up accounts with my students, considering uses, reflecting on successes and challenges and presenting at a statewide technology conference. Moreover, throughout my time in the doctoral program a recurring interest has been the role/applicability of emerging technologies in the classroom (especially the science classroom). I completed an independent study on online learning in K-12 classrooms, took an online *Technology, Schooling and Society* class, and completed various papers/projects related to technology in the classroom (e.g., literature review of online learning in the middle level, study of clickers in science classroom, etc.). Lastly, several assumptions emerged as a result of the experiences I shared above. These assumptions, although they may have evolved throughout the course of my research, informed the initial design of my study:

1. I believe that digital technologies have the potential to positively impact the educational experiences of K-12 students.
2. I believe that learning is for many a social experience and that, as a result, social media has the potential to be leveraged for good.
3. I believe that there are many individuals throughout the world who want to share their own experiences, passions, areas of expertise and love of learning with students, whether that be face-to-face or through digital means.
4. I believe that the perspectives of students are important to any effort designed to provide them with a positive learning experience.

Throughout the design, data collection and analysis stages of my research I have made deliberate efforts to monitor my subjectivity. In the words of Glesne, I believe that in doing so I have increased my awareness of the “ways it might distort,” as well as my

awareness of its “virtuous capacity” (p. 123). At the same time, I drew from relevant experiences and knowledge to inform many aspects of these same design, collection and analysis stages, embracing the advice of Yin to “use your own *prior, expert knowledge* in your case study” and to “demonstrate current thinking and discourse about the case study topic” (p. 168).

Summary

This study sought to understand #scistuchat participants’ perspectives of Twitter as a tool for learning and communicating science. Its design, analysis, interpretation and display all are consistent with, and leverage the strengths of, qualitative inquiry to better understand the phenomena of study. In doing so, a richer sense of the meaning participants made of their experiences can be unveiled, particularly against the backdrop of the context and processes within which they acted.

Chapter 4: Findings

This chapter presents the findings of my thematic, cross-case analysis. Findings are presented according to six themes, and related sub-themes, that I identified in my data and that I believe capture the essence of #scistuchat participants' perceptions of Twitter as a tool for learning about and communicating science. Screenshots of actual tweets exchanged during the four #scistuchats that I studied are woven into this thematic presentation of findings. It is my hope that seeing examples of tweets, especially where they complement and support narrative descriptions, will help the reader better understand the dynamics of #scistuchat, as well as the perspectives of participants.

The six identified themes address both the #scistuchat experience and the use of Twitter beyond #scistuchat. The first four themes speak specifically to the #scistuchat experience and include: 1. nature of interactions; 2. outcomes; 3. limitations and challenges; and 4. formal vs. informal learning. The last two themes speak specifically to the use of Twitter beyond #scistuchat and include: 1. Twitter and professional practice; and 2. Twitter as an educational tool (see Appendix D for a condensed version of findings in matrix form). Themes are presented according to the extent to which participants emphasized them. For example, #scistuchat was discussed with greater frequency, and in many cases in more depth, than was the use of Twitter more broadly. Thus, #scistuchat, and its four themes and related sub-themes, is presented first. Furthermore, respective themes and sub-themes are also presented according to the degree to which participants spoke to them. For example, of the four #scistuchat-related themes, the "Nature of Interactions" theme was the most prominent and, thus, is presented first.

Lastly, in an attempt to share my findings in an organized and consistent manner, each theme explores the perspectives of scientists first, then students and then teachers. This approach purposefully utilizes the name of this particular chat, “*sci* (scientists) *stu* (students) *chat*,” as an organizational framework to present my findings in what I hope is a reader-friendly manner.

Nature of Interactions

At its most fundamental level, #scistuchat is a social experience. Although digitally-mediated, and geared towards a different, predefined science topic each month, participants none-the-less spoke frequently about the interactive dimensions of this social endeavor. It is the nature of these interactions that I explore in this first #scistuchat-specific theme. Both direct interactions and the perceptions of audience-related phenomena are discussed, all within the context of the following five sub-themes (in order of significance): 1. student-focused interactions; 2. dynamic interactions; 3. scientific interactions; 4. expanded, authentic audience; and 5. scientists as experts.

Student-focused interactions. By its very nature, #scistuchat leans towards being student-focused. As the name of the chat suggests, #scistuchat aims to provide a forum in which students can interact directly with scientists. As a result, it is perhaps not surprising that participants in my study referred both directly and indirectly to the student-focused nature of their interactions as a defining characteristic of their experience.

Scientists. Participating scientists referred often to their perceptions of students’ #scistuchat experiences. Some reflected on their own experiences as students, as one scientist in the human genetic engineering chat recollected, “I didn’t have resources like this when I was in high school or middle school, really as an undergrad either” and, as a

result, explained “...if you’re here and if you’re interested in what the topic is, then I’m interested in giving you as much information as I know.” Other scientists acknowledged the opportunity to inspire students and to show a more humanistic side of the traditional scientist stereotype. In the words of one green chemistry scientist, “So we – all of us, we enjoy talking with students who are at that age where you can really put sort of – light a fire in them. And also show that there’s a human side to scientists, too.” Yet other scientists alluded to the challenge of communicating with students of varying technical backgrounds and prior experiences. A scientist in the volcanoes chat recounted his efforts to respond in a manner beneficial to a particular student “it took me a few tries to make sure I was answering the question at a level that this particular person could get something from.” Speaking to these student-focused perspectives, a scientist in the human genetic engineering chat perhaps summed it up best when, considering the chat through the lens of a student they explained, “it’s been a very good way to sort of try out...[talking] about this in a way that is interesting to them that doesn’t bastardize the science in some weird way” and “how do I begin to think of myself as a high schooler and what one would want to hear.”

While there were recurring examples of genuine interest on the part of scientists in making the chat as student-friendly as possible, scientists were especially enthusiastic about the curiosity displayed by students and the democratic nature of the interactions. Below are several reactions of scientists to the curiosity they witnessed by students during the chats. A scientist who participated in the black holes chat explained the ease with which student curiosity was detectable, and the resulting excitement he felt, despite the 140 character-limit of Twitter:

When you get students who are genuinely curious about the universe, curious about any aspect of it, that shines through. Even when you're limited to 140 characters, you can tell who's there genuinely asking a question because they want to increase their understanding of the universe. And those are the ones that excited me...here's someone who really wants to know something that they've thought about and don't have the full answer to or full explanation for.

These sentiments were echoed by a scientist who participated in the human genetic engineering chat, who spoke to the following realization about student participants:

I didn't realize that they cared as much about science as they – or at least that they appear to care as much about science...if [you] were just doing this to be an assignment, you would log on, you would say one tweet, whatever, and that would be it, you'd get your credit for participating or whatever. But they're asking questions that are not things that they're getting graded on, [things] that require thought, and they show that they care about this.

Lastly, speaking to both the frequency with which she normally encounters chemistry-averse individuals and her pleasant surprise that #scistuchat was different, a scientist in the green chemistry chat shared:

Most people don't [enjoy chemistry] and whenever I tell people that I'm even studying chemistry, I get usually very negative reactions. They always say something, like...oh I hated that in high school and they just have this wall that goes up...But I found that with the chat, with how it's intended for high school students who ask questions about it, and especially with the direct question that

was asked to me, it just kind of made me realize that high school kids do want to know more.

In addition to their excitement about students' interest in the topics discussed, scientists were equally expressive about the democratic nature of #scistuchat. Traditional, face-to-face interactions between students and scientists often involve implicit power dynamics, frequently reinforced by situational factors and differences in age and educational achievement. In the eyes of participants, #scistuchat seemed to offer a more equalizing experience. As one scientist described:

It's a bit of an equalizer, right? Because you can just have a conversation with anybody. They don't know who you are. They maybe look at your biography but it's not like – they're really not treating you as this sort of expert on high. It's just somebody who happens to be in a position to answer some questions. So I think that's maybe liberating for a lot of people.

Another scientist elaborated on this point, explaining, "Twitter is democratizing. You may not get the opportunity to speak with certain people because of their stature in business, their stature in politics, etc., but you can say something on social media and somebody may respond."

Several scientists referenced how important it was that student questions drove the course of the conversation. A scientist in the human genetic engineering chat noted:

I think it's an excellent place to have a conversation because the conversation is not initiated by me – it's not me initiating the conversation about gene therapy. It's an educator and students raising a conversation about a particular science topic. And they're in control of the direction of the conversation. And so that in

itself empowers students and educators...at least to get responses to the questions they've thought of...And that's where it's important versus joining a conversation where people already hold positions on.

Recognizing a blurring of the metaphorical lines that typically delineate scientists and students, and that function to reinforce unspoken norms and expectations regarding communication between the two, another scientist expressed their mild surprise and delight at the nature of the interactions that #scistuchat fosters:

And I would say the one thing that maybe surprised me a little bit, and maybe it shouldn't have, but the one thing that surprised me a little bit is I felt that when students saw a good response or saw a response that resonated with them, they were sort of emboldened to just tweet directly at that person once or repeatedly with a number of questions that they had; that they felt like hey, you know what, I think this person is someone I'll be able to get a good answer out of for this question. And sometimes other people would answer it, sometimes that person would answer it and sometimes both. And I thought that was great.

In addition to the importance of student-generated questions, others noted an appreciation for what they discovered to be a collaborative learning endeavor. One scientist who participated in the volcanoes chat alluded to this quality:

I liked that I was able to have the occasion to learn along with the students. I was learning about volcanoes along with the students. But my thing was I was able to do it faster and deeper than the students could.

He further shared how, in preparing for the chat, he had referenced a number of resources, including some of those provided to students via the #scistuchat website. "That

one [the volcano chat] was very interesting because I was learning right along and I think I read two review articles and one very recent research article. I was also learning right along with the students there.”

Throughout the course of my interviews, scientists repeatedly recognized that the primary goal of #scistuchat was to provide students with an inviting forum where they could communicate directly with scientists. While the scientists spoke in varying ways about the student-centered nature of the experience, like other stakeholders they cited student curiosity and the democratic nature of #scistuchat as two qualities that make it an inherently student-focused space. While summing up his experience in #scistuchat, one scientist shared the impact it had on his perceptions of students:

[When you] get the opportunity to interact with students that there’s no connection with, then you get a better perspective of what they’re thinking about and you realize, kids are probably smarter – students are probably smarter than they’ve ever been.

Students. While they were less direct than scientists and teachers in their references to the student-focused nature of #scistuchat, students none-the-less alluded to an appreciation for the aspects of the chat that met the needs and desires of a high school science student. Namely, the chat leveraged a popular communication medium that many were already familiar with, and it provided opportunities to interact with scientists in a relaxed setting in which traditional, defined roles were less emphasized.

Many students appreciated that #scistuchat provided them with an opportunity to diversify the means through which they encountered science content and engaged in science discourse. Often, and understandably, using their classroom experiences as points

of reference, students lauded the fact that #scistuchat is so many things that pencil and paper are not. As one student shared (with uh-hums all around from their classmates in the focus group), “Because everybody uses Twitter...[it’s] more our generation...it’s easier for me to get on Twitter and use it.” Expressing similar sentiment, another student appreciated the fact that #scistuchat occurred via Twitter, a place she already frequents. In her words:

It seems really cool to me, honestly, because for me I like to be on Twitter anyway, so to know that I can just go on there and tweet questions and stuff and actually get answers. It’s pretty cool to me.

While students appreciated that #scistuchat utilized a popular social networking Platform—one which offered, in their opinion, distinct advantages over traditional pencil and paper—like scientists, they also spoke glowingly of the democratic nature of the experience. In their descriptions, students repeatedly referenced feeling as though they were part of a collaborative experience with scientists in which both parties were learning as they went. One student described her initial reservations and, to her relief, how different her subsequent experience actually was:

It was a lot different than I expected. Because I was kind of expecting it to be like very intelligent people who like LOVE science...If you said something that had even a fraction of something they didn’t believe in, they’d go off on you. Like so I was really scared it was going to be like that, but it wasn’t bad at all. Like everyone kind of had respect for each other.

Another student described the sense of equality they perceived in participating in the chat:

I think it's kind of unusual how like a scientist will ask you something or like a question would just pop up and you can figure out the answer for yourself. You feel like, like you are the same as them, able to find out something.

Still other students described the sense of satisfaction that came with feeling as though they were contributing meaningfully to a science-focused discussion in which all involved were learning simultaneously. As one girl recounted, "They were asking questions and stuff too, and posing like ideas. They didn't know for sure answers of things..." Explaining a similar sense of the experience, another student stated, "I thought it was cool because we weren't totally sure. They were kind of learning also so it wasn't just like them lecturing us either. It was us all giving input...I thought it was cool."

Teachers. Prior to a Twitter chat taking place, significant student-focused work goes on behind the scenes to set the stage for a given month's #scistuchat. A teacher in my study, and the creator of #scistuchat, provided a window into the inner workings of the chat as well as the rationale for certain chat-specific decisions and adjustments. In discussing the creation and evolution of the chat, he spoke to what I believe is clear evidence of the student-centered nature of his initial intentions and subsequent design decisions. Speaking specifically to the origin of #scistuchat, he shared:

I was having [students] get online at night so we could have a class discussion about things unrelated to our particular content...Like we'd talk about animal rights or human genetic engineering or something. We do that every semester and then one summer I found out that there were scientists on Twitter and I just was ecstatic. So I knew right away I wanted to get connected with them on Twitter during class and possibly after class and so we started tweeting them in the fall of

2011. Then I noticed several scientists responding and so I contacted them late in the fall and said hey, would you be willing to have an organized discussion with us in the evening and they said yes. So that January we tried our first one and that's where it began.

Finding success with these initial efforts at connecting students with scientists, he elaborated further on his intentions for doing so:

I wanted to expose them to as much science as often as I could and from different sources. Like those years, well since 2009, all the way up to last year, I had a scientist in my classroom for the whole year...coming in during the week during the school year, and I really liked that exposure....Twitter was another way to get more scientists talking science with the students and that way the students could see more about the scientist's lives, the kind of scientists that are out there, [their] diversity and what not.

Although #scistuchat has been in existence since 2012, over the years its organizer has worked to tweak the protocol in an effort to improve the experience for students and scientists alike. Speaking to these changes he explained:

The first six or seven months that we were having the discussion it was a free for all. I would get a bunch of scientists for a particular topic, I'd say okay, let's start, and the kids' questions would just go flying in and the scientists are working as hard as they could to answer the questions. But it was so chaotic that a lot of students were feeling ignored because their questions weren't being answered and so we changed it in a lot of ways. First of all, we started having student moderators. The student moderators would come up with a list of

questions...And then we started having, well I started giving more instructions for students. Okay, if you're going to ask a question, you have to reply or tag a particular scientist; otherwise, it's just going to get missed in the chaos...Anyway, we started having questions organized. The students answer, or retweet the questions, then everybody who wants to tries to answer the question as well and that has made it a lot more, [it] has a better flow and has some organization. I'd rather not have organization, to be more organic, but it's the only way to keep the kids feeling like they're being heard and also to help the scientist not feel like they're dying trying to keep up.

Even with many of these adjustments in place, during chats the organizer isn't entirely removed nor does he halt efforts at promoting a participant-friendly experience, particularly for students and student-moderators:

Currently my role is more of helping remind students or scientists how the discussion runs. I start sending out pre-scheduled tweets at ten to the hour asking people okay, we're going to start the official questions at five after the hour. Introduce yourselves. Here's the protocol. Here's the video about how to participate...I try to answer questions when I can or guide questions or remind people to use the hashtag or whatever. Then I also gently guide the moderators. Usually once we get them started, they're good to go...generally I try to leave the moderators alone as much as I can. Let it be their thing.

#Scistuchat not only has student moderators and protocol-related expectations designed to facilitate dialogue and maximize student voice, it also seeks the input of students in the selection of the monthly #scistuchat topics. As the organizer explained:

Typically the way I go is I go through a couple of news websites that have a section on science or whatever, and I'll make a list of the hot topics, or things that have been covered that week and then I'll put it out there for a vote by the students.

Further emphasizing his commitment to making the experience student-centered, he went on to share:

In fact, once in a while, teachers will request particular topics because they're covering it in class, and I'll add it to the list, but if it doesn't get voted for, then I'm not stressed about it because I want the kids to be interested in what they're talking about.

In addition to the clear, student-centered framework of the chat, participating teachers recognized other noteworthy dimensions. Like scientists, teachers appreciated that #scistuchat offered their students an opportunity to inquire about sometimes very personal points of curiosity. Describing this phenomena, one teacher explained "...they're making questions about something they actually want to know, not something that is coming on their evaluation...that makes a big difference." Another teacher echoed this sentiment, in her words "...the students make up the questions, which is a really powerful thing and something that I think that [the creator of the chat] values very much." One teacher spoke at length about the benefit of students feeling empowered to seek answers to highly individualized questions. He specifically compared the types of questions he often fields in class versus the types of questions he observes in #scistuchat:

Students always make questions to you as a teacher most of the time because they're afraid that it's going to be the content that's going to be on the test...So in

the chat, they have questions like: Are black holes only black? Is there any other color for black holes? Or did they name black holes after whoever discovered them? So those were the type of questions. They...were questions just to satisfy curiosity.

Many teachers noted that student curiosity was not limited to science content. Students, especially those nearing the end of high school and considering their post-secondary futures, often have questions that relate to science majors and career choices. For these students, #scistuchat presents an opportunity to speak with scientists who are currently in the field and who might have valuable insight regarding educational or career pathways. Teachers recognized that for these students #scistuchat acted an additional resource. One teacher explained:

And then some of them, the students that are older, have really started to think about what they might major in in college. So if they happen to meet a scientist in that field, then they can ask them questions about that career choice and really value that kind of interaction that I think is difficult for students to get. And it's different than reading about a career on the internet or talking to an admissions person, talking to somebody really immersed in the discipline.

Another teacher shared a similar perspective, and elaborated on the approachability of the scientists as well as the potential for positive role-modeling. Speaking to these features of the chat, she explained:

I just love how down to earth the scientists are and how they're approachable to students...I think this is kind of a way for them to make connections to the scientists. And also, well they're not going to follow them like celebrities, but in a

sense they kind of look up to them more and maybe want to be that more instead of what they see on TV...

From teachers' perspectives, the student-focused nature of #scistuchat lies both in the design of the chats, which allows students to approach scientists with individualized questions, as well as the potential for interactions well after the chat ends. Teachers mentioned numerous instances in which students followed up with scientists after the chat to extend their conversations. As one teacher explained, "Several of the scientists have been gracious enough to interact with the students after #scistuchat, so when the students have a question about something that they're personally interested in, the scientists can converse back and forth with them." However, both scientists and teachers wished these follow-up conversations happened more frequently. As one teacher matter-of-factly stated, "As far as reaching a deeper point where the kids are actually contacting [scientists] later, it's nowhere near where I would like it to be."

Despite room for growth in the number of interactions between students and scientists outside of the chats, the democratic nature of #scistuchat, and the eagerness with which scientists sought to answer student questions, were both important attributes that teachers cited as being fundamentally student-focused.

Dynamic interactions. Because #scistuchat is a social experience that capitalizes on the inherent brevity of tweets to foster dialogue about science in real-time, it is not surprising that participants frequently referenced its dynamic nature. Participants in this study cited the inherently social nature of the chat and the fact that it occurred in real-time as two particularly powerful qualities. It should be noted that, within the chat,

participants can both answer questions posed by moderators and tweet directly to other participants (via “mentioning” a person within the text of a tweet).

Scientists. Scientists spoke affectionately about their opportunities to communicate about science within #scistuchat, particularly when these communications went beyond simply answering questions posed by moderators and, in addition, involved communicating directly with others. Many recognized that Twitter is fundamentally conversation-friendly due to its structure and associated user norms and expectations. As a green chemistry scientist shared:

Twitter is one of the best media for enabling conversations. If a student were to send me an email, I may reply and my response is going to be varied just depending on the time that I have. I think Twitter also emboldens people to reply to questions...On email you can write something back and you wait a while. There might be a wait. But if I send something off and send something back, sometimes I assume that's going to be the end of it. And on Twitter, there is more conversation. It is more conversational, just by definition of what it is. And I think that helps a lot, too, with getting people to respond to questions and [share] curiosity and things like that.

Piggy-backing on this conception of Twitter and its utility as a conversational tool, a black holes scientist described what he believed was an advantage of Twitter, particularly when compared to other forums where participants must converse in very linear and prescribed manners. He highlighted the ability to be selective in his interactions:

As an expert, you can sort of look through the stream of what's there and say, you know what, that thing brings up an interesting point, let me address it. And so

that's, I think, an advantage to something on Twitter that you wouldn't get on a Google Plus hangout where only one person can talk at a time, that you wouldn't get in a forum where you have a moderator, that you wouldn't get in a question-and-answer session where only a few people got to ask their questions.

Beyond references to the utility of Twitter as a conversational tool, many scientists spoke directly to the satisfaction that came from having direct interactions with students. As mentioned previously, scientists were responding to moderated questions and, importantly, also communicating *directly* with individual students at the same time. These direct exchanges consisted of questions initiated by students, who were either pursuing a question of interest or as a follow-up to a scientist's tweet, or by the scientists themselves. And it was these direct exchanges that allowed for the most personalized interactions within #scistuchat, as one black holes scientist recounted:

And it was fun also when I answered a question, I got a couple of people responding to me with follow-up questions. So it was not just going out there into the ether, but I was actually having a conversation with some people.

A scientist participating in the volcanoes chat was more specific, describing his experience fielding direct questions from students while also still responding to the moderated questions:

There were a number of people that were asking me questions, and they were based out of Central America I think, that ended being...outside of the main chat, just with back-and-forth questions about how we know different volcanoes or whether they're going to erupt or not, and whether certain volcanoes are more

hazardous or less hazardous than others. And most of them were good experiences.

Speaking to the power of direct interactions such as those just described, a scientist who participated in the human genetic engineering chat explained why he believes they are so meaningful. He observed, “Follow up questions to me are kind of where the depth of learning or the depth of that cognitive basis of what you better remember, I think that’s where it stems from, so I like it.”

Leveraging the power of direct interactions, several scientists referenced specific strategies that they employed to engage with students. These interactions were sometimes efforts to correct misconceptions and, at other times, simply a means to follow up on an interesting or otherwise compelling tweet. Describing their strategy for interacting with students directly, a scientist explained, “I would engage...directly with the students who would answer and try to, correct...misconceptions on the side. I don’t know how effective that was but, you know, several wrote me back and asked follow up questions.” Other strategies necessitated patience, and allowed scientists to be selective in their responses. As one scientist described:

I was able to sort of watch the conversation go by and kind of pick out an individual person and say alright, this is a new question, it might get lost in the crowd and I’m going to respond directly to that person.

Explaining a similar predisposition for selectivity, another scientist, a participant in the black holes chat, conveyed his approach to interacting directly with students:

Once in awhile you’re tempted to respond to the really cool questions or something that hasn’t been asked before. But then I figured everyone else is going

to be on top of that, so I think it did allow me to – like at least stepping back a little bit, allowed me to sort of pick out a few students that I thought I would just interact with personally. And it seemed to work pretty well.

While there were many direct interactions between scientists and students over the course of the four #scistuchats I followed, numerous scientists expressed disappointment because they had imagined even greater numbers of direct exchanges with students, both during and after the chats. In the words of one scientist, “I was hoping that some of the conversations that I started on the side with students would have continued, [but] they really haven’t.” He elaborated further, stating, “It would be nice to figure out a way to take a couple of students who did follow me after the #scistuchat and sort of have them start sort of interacting with me on Twitter or vice versa so I can interact with them about science.” Other scientists expected more direct interactions during the actual chats. One scientist in the volcanoes chat lamented:

I will admit that I was a little bit surprised that there weren’t quite as many kids asking questions as I expected there to be. I think I had seen previous chats where there seemed to be more active participation, but I’m not sure if that’s true or not. I don’t have any numbers on that. And I’m not sure whether it was just the nature of the subject or what.

Elaborating further on her disappointment, this scientist spoke directly to many of the features that make Twitter such a dynamic medium. She explained:

I anticipated a little bit more in the way of follow-up questions because Twitter is such a brief medium. You make some statement and typically that just generates a lot more questions when you make these very brief statements. And I

was a little surprised that I didn't wind up having a lengthier conversation back and forth with some people with follow-up questions and getting a chance to respond.

Students. Students expressed deep appreciation for the dynamic nature of #scistuchat. The many positive comments related to this sub-theme included sentiments like “[being] able to talk to scientists who have the information there, or to other students who may know, that was very interesting to me and appealing. That’s why I liked it,” as well as “You could ask scientists certain questions if you weren’t sure about something...and then that would start a conversation...” One student put it even more bluntly when, explaining why they enjoyed #scistuchat, they stated, “Because it’s really boring to do book work. With #scistuchat you just get other people’s opinions.” Although perhaps overly simplistic, and a bit gruff, the spirit of the quote is unambiguous—#scistuchat is a dynamic, participant-dependent experience.

Beyond broad generalizations, students’ understanding of the dynamic nature of #scistuchat seemed to especially focus on two distinct aspects: 1. the accessibility of the scientists; and 2. the diverse and immediate responses to questions that were shared over the course of a given chat. With regard to the accessibility of scientists, many students enjoyed the fact that scientists who otherwise seemed distant, literally and figuratively, were suddenly just keystrokes away. Speaking directly to this aspect of #scistuchat, one student explained:

The scientists are so accessible in a way. Like they’re keystrokes away when [normally] you wouldn’t know how to get in contact with one of them. And it’s

cool that you can learn from them as it's happening, instead of being in a correspondence that takes weeks to get a reply. Twitter's right there.

Another student conveyed a similar sentiment and one shared by many students, "The things that I liked were, for example, the scientists would answer to us like in a fast fashion. We didn't have to wait for them to read them and then answer it. They would answer almost immediately."

Interestingly, while the accessibility of the scientists and speed of the interactions was viewed positively by many students, and many perceived the experience as democratic in nature (see student-focused sub-theme above), some students found it took time to acclimate to these interactions. As one student described:

I thought it was kind of neat when someone would respond to my tweet. At first I got really scared. I'm like oh, what's this person doing, I don't know you. But then it became kind of cool to think of an answer and respond.

In addition to the accessibility of the scientists and the immediacy of the interactions, students also expressed gratitude for the diversity of perspectives and responses that each #scistuchat generates. The potential for a given tweet to spawn multiple responses, from scientists, other students and teachers alike, clearly resonated with students. This reality was addressed in detail by the following student:

Even if you're not participating in someone else's conversation, it's interesting to watch people like go back and forth. Especially when scientists get into it, it's fun. So even if you're not participating, it's interesting to watch other people comment back and forth with each other and delve off from things. Especially when scientists comment, it's really cool, like they're paying attention to it to

such a degree that you would think that they wouldn't really pay attention to you, but it's really interesting when they put their input in.

Expressing similar sentiment, another student shared, "Yeah. And especially that they could all be right and it was different – like you actually got to...you don't copy others' answers but you might build off other people's answers. And being able to see...other ideas was really interesting."

Several students alluded to the presence of disagreements, or occasional differences in perspectives and takeaways, as a positive outcome of bringing together diverse participants. As one student pointed out, "I liked the different perspectives because a lot of people didn't agree and asked each other questions on what they posted and stuff...you didn't get to see just one side of what they were talking about." Another student, referring to outcomes realized by students, specifically, explained, "Because if they're learning something else...and the students want to talk to each other about what they've learned, maybe if they're learned something different, that's still good too because then you can compare or contrast."

The content and frequency of student reflections about the dynamic nature of #scistuchat paint a clear picture of their appreciation for this unique feature. This appreciation led one student to exclaim, "The fact that you could, only for an hour, go for questions addressed to a specific topic is great because you have that sensation, you have that awesome sensation for more. You want to go to #scistuchat again."

Teachers. Unlike scientists and students, who spoke directly to the dynamic experience of #scistuchat, teachers spoke more generally in this regard, primarily referencing the social nature of the chat instead. Importantly, there seemed to be

consensus on the part of educators that, while students recognized and appreciated the social and dynamic aspects of the chat, students still were challenged by the notion of using Twitter for educational purposes. This “challenging of perceptions” is a sub-theme that will be explored in greater detail near the end of this chapter. For some teachers, however, #scistuchat was dynamic in the sense that it offered them opportunities to interact with scientists and other educators. Thus, the dynamic nature of #scistuchat extended beyond two-way interactions involving only students and scientists. The dynamic nature of the chat both for the students (through the eyes of the teachers) and for the teachers themselves is explored below.

As a Twitter chat, #scistuchat is necessarily a collaborative experience. Given any interest in the tweets of others, or inclination to ask a question of or offer a response to another participant, the experience is also inherently social. Teachers recognized this social dimension and, considering the chat through the lens of their students, cited it as an important and appealing factor in the eyes of their students. As one educator who visited this theme often explained:

They’re teenage students. And the idea of them interacting with other teenagers or people their age is pretty engaging to them. It’s like a real life interaction. If you tell your students, hey, guys, you know what, we’re going to visit the science fair at school, they get excited because they’re going to get to see other students or get to see what is the school like in other buildings. In my opinion, that was the one motivator—the social interaction. And then the learning—the learning they might get.

This educator felt so strongly regarding the “pull” of social interaction that he placed learning as a clear runner-up in terms of student motivations to participate. He later spoke to this idea directly, stating:

What appeals to them the most is the social interaction. That’s my opinion. Of course the learning is a part, but I think what motivates them is the fact that they get to interact through social media with other students.

Other teachers, who spoke more generally about their students’ affinity for social interaction, still recognized it as a powerful motivator. Validating the perspective of the student who earlier mentioned the boredom that they experience with pencil and paper learning, one teacher stated, “...the experience of learning it that way or applying it this way was totally different and was totally engaging.” Another teacher expressed similar observations, and noted the challenges she observes in students grappling to understand the value of Twitter as a learning tool. In her words, “...they love that interaction, that ability to talk to people instantly, share photos, those kinds of things...they know how to use it to socialize but they don’t know how to use it for learning purposes.”

In addition to recognizing #scistuchat as being a dynamic experience for their students, several teachers experienced the dynamic nature of a chat first-hand, through direct interactions with scientists and other teachers. When asked about what aspects of #scistuchat they found engaging or appealing, one teacher promptly responded, “Just flat out the interaction with somebody in the field.” Elaborating on her position she further explained:

I just find it a great experience, even for me, just to get to interact with some of those post-doctoral scientists. You get some of the doctoral students, some of the

professors, some of the people just in the field. And just getting that interaction and finding out some of the stuff that you don't necessarily have time to learn on your own.

The same teacher spoke at length about the professional benefits of participating in #scistuchat. After giving a presentation about her participation in the chat, she had a number of follow-up conversations with teachers in attendance. She spoke to the power #scistuchat can have in connecting fellow educators:

The other thing that's incredible about #scistuchat is it also puts educators together. So when they go out, it's kind of like the ripples in education, that they can then share their own experience and their students' experience with other teachers and that can help their own classrooms. And it's very personalized.

Prior to presenting her #scistuchat experiences to other educators, this particular teacher had already experienced, firsthand, the power of directly interacting within the dynamic environment of #scistuchat. Below, she recounts her own serendipitous encounter during an earlier #scistuchat:

And so at #scistuchat I met Dr. Alan Marnett who is a neuroscientist in a former life at MIT, the Learning Institute, who was studying the brain. And since I teach Anatomy, I was like completely wowed with that. And so we had a conversation that continued on after #scistuchat and basically said hey, let's see if there's any way we can work together.

What started as a chance encounter within #scistuchat has since blossomed into a collaborative partnership, ultimately directly impacting the learning experiences of this particular teacher's students. In her words:

We scaffolded in the use of video as a thinking product that the students create to communicate their thinking and then also utilizing his platform. And so that work is ongoing. So because of that chance meeting at #scistuchat, which is to me hilarious, I now have a classroom partner.

Teachers considered #scistuchat to be a dynamic experience both for their students and, in some cases, for themselves, too. Considering the experiences of their students, teachers spoke broadly about the overall social nature of the chat. Additionally, several teachers capitalized on the dynamic nature of the chat to further their own learning and, in one case, to initiate what has become a close partnership.

Scientific interactions. #Scistuchat focuses on a different science topic each month and, thus, generates discussions that are necessarily science-related. This study focused on four chats that took place between February and May 2014. The topics of these #scistuchats, respectively, included: black holes, human genetic engineering, green chemistry and volcanoes. As the creator and organizer of #scistuchat noted earlier in these findings, student moderators create the questions that ultimately guide the flow of each chat. See Appendix E to view the complete list of questions posed by moderators in each of the four chats that comprised this study. As an example, Figure 3 presents a collage of the moderated questions that were posed during the black holes chat, each in the form of a screenshot as it would have appeared during the actual chat.

Scientists. Participating scientists spoke most frequently, and most deeply, about the scientific nature of the interactions within #scistuchat. Whereas students and teachers were more likely to discuss scientific ideas tangentially related to the #scistuchat topics, scientists often directly referenced very specific, science-focused elements of their

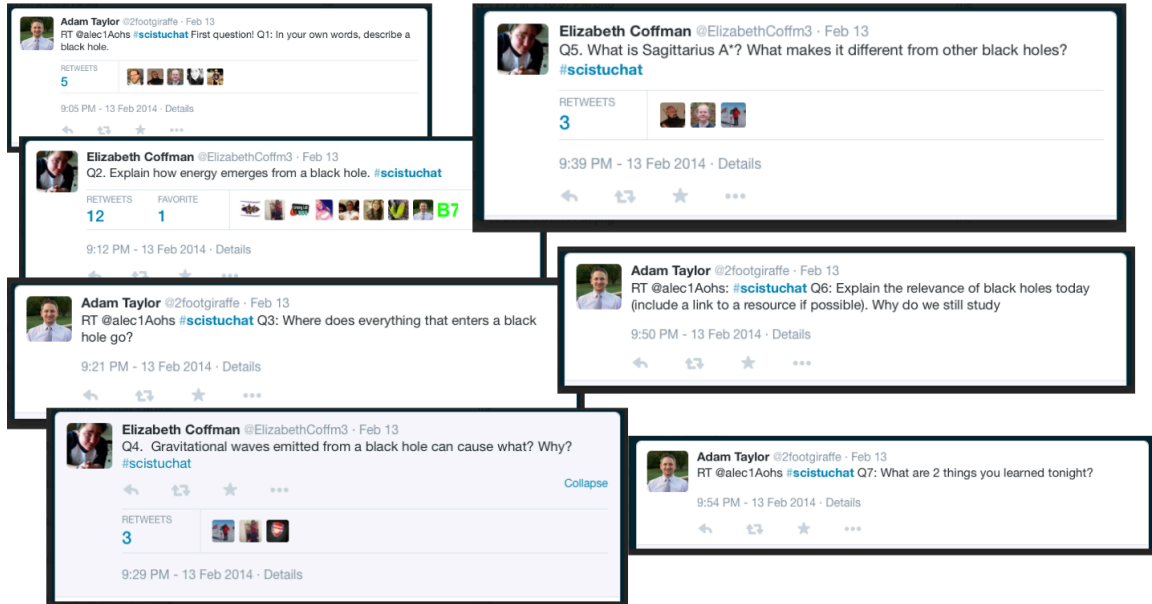


Figure 3. Collage of tweeted questions from black holes chat as they were seen by participants.

interactions. Specifically, scientists frequently cited the nature of the questions asked, the societal implications of the science involved, and the prevalence of misconceptions as important dimensions of the scientific nature of their #scistuchat interactions. Due to the depth with which each of these dimensions is discussed below, an additional layer of headings has been added within this “Scientists” section to help clarify important points of transition between ideas.

Types and quality of questions. An important component of scientists’ interactions with students during #scistuchat centered on the types of questions they were asked. Students’ questions provided scientists with information about their background and familiarity with the topics, possible sources from which they had gained their understanding (or misunderstanding), and a sense of their interest in the topics discussed. Interestingly, scientists who participated in the same chat sometimes had differing

opinions of one or more of these measures. In the black holes chat, for example, one scientist recollected:

The questions that the high school students asked seemed to be more about the content rather than process, so I wasn't really sure how to go ahead and say, well this is *how* we know that there's a black hole in the center of the Milky Way.

Another scientist who participated in the same chat shared what is, in essence, a completely different perception of students' questions. Speaking to why he enjoyed the student questions he received, he explained, "the reason I liked the questions, I think, was because they were getting at *how* do we know this as opposed to, you know, what do we know." At first glance, this discrepancy between accounts seems hard to square.

However, given the dynamic, student-focused nature of the chat (see sub-themes above), two scientists may have completely different experiences based on the specific questions they were asked and the students with whom they interacted. Furthermore, every scientist enters the chat with certain expectations and associations, both of which can influence how one perceives the questions asked.

In the same black holes chat, other instances of differing perspectives among scientists occurred. For example, some scientists found the questions to be very basic. One noted, "If you already know a little bit about what's going on then you might be frustrated by the very low level of a lot of the questions." Another scientist reflected:

It seemed like they really had no idea of what a black hole was, which I think is a good thing. I would much rather science that rich be targeted to people who are interested rather than just to people who are supposed to be good at it.

However, other scientists in the same chat were at least mildly impressed by the questions they encountered. As one scientist shared:

It was interesting to see that this isn't the standard stuff you would get from going to a Wikipedia page on black holes and reading it and then having questions about it. A lot of them are going to: What did Stephen Hawking say in the news a few weeks ago?

Another scientist also felt that the quality of the questions was high, enough so that they felt having experts available to respond was important. He stated:

A number of the questions that they asked I think were not easy ones to just find out the answer by using Google. So I think that that connection to scientists is very valuable in that respect because there's a lot of things that people are curious about that aren't necessarily in textbooks, or easy to find in a textbook, and yet are a great way to engage the public and get them more excited about science.

Because of the depth of scientists' responses, the above discussion regarding the quality of questions was drawn specifically from the black holes chat. However, across all chats, discussion of questions posed during #scistuchat was a common talking point for scientists. Furthermore, variability in scientists' perceptions of the questions was also recurring. A scientist from the human genetic engineering chat, for example, came away thoroughly impressed by a student's questions, stating:

I was like, wow. It was a conversation with a student that I wouldn't have in – okay, I didn't think that a person under – not even an undergrad in a science class would even be thinking about this, and here you're thinking about it. Awesome.

While on the other end of the spectrum, a scientist from the volcanoes chat expressed disappointment at the lack of frequent, engaging questions, sharing, “I guess I expected more questions and there just weren’t all that many. And that was a little surprising. So I felt like I had to supply content rather than respond to questions.”

Ultimately, scientists’ perceptions of the quality of the questions asked during a given #scistuchat depended on their specific exchanges with students and others, both within and outside of the moderated framework. In most cases, the spectrum of questions encountered was broad. In the words of one scientist, “So there were a lot of questions, and variance, on sort of what I would consider the target of the questions. Like whether it made no sense at all or was actually insightful was quite large.”

Societal implications. A second important dimension of the scientific nature of #scistuchat interactions involved the notion of societal implications. Scientists repeatedly referenced their own interest in, as well as students probing of, the societal and personal implications of the science being discussed. This was particularly true for the human genetic engineering and green chemistry chats. Speaking to this appealing aspect of #scistuchat, one scientist from the human genetic engineering chat shared:

The other aspect I like about it, too, is you can’t abstract science or just take it out of societal issues. Like you can’t separate society from science. And I think it’s really good to have kids that are not just in one area but in several different places at a time, that can comment on the societal implications of what their science is in that way. And I think these kids are going to be the ones that end up voting, right? In a very short amount of time. And even if they don’t end up having a science

career, they're realizing it's more than just we can do this, but should we or how do we best.

Another scientist who participated in the same chat explained how, in some ways, what was once science fiction is now our reality. He explained:

We're living in a time where the things that we may have seen on a TV show or a series like Star Trek or some of the other scientific programming are actually here. And that's something that I think, even from an ethical standpoint, young people should be thinking about that. What's the implications for you...to consume genetically modified foods?

Further expressing the important role he sees #scistuchat playing in helping to shape students' understanding of science, and its role in their lives, the same scientist explained why it's important for students to continually ask "What's next?" In his words:

I think it's critical for students to maintain their interest...Oh, there's gene therapy for cancer, but what else can we do with gene therapy?...So piquing their interest in things that they don't know about, something that's relevant and happening today, or happening within the school year, that you give information on, that's something that they can use to help shape their perspective.

In the green chemistry chat, the focus of the societal connections was different, but present none-the-less. In this chat, economic factors, questions arising from personal experiences, and uncertainty around the goals and processes of green chemistry were prevalent. Regarding economics in particular, one scientist shared, "I think one of the biggest things were talking about how, in order to make green (chemistry) useful, it has to lead to green for corporations. Right? So there is the whole economic aspect."

Other scientists described interactions in which students were curious about the role of chemicals in something they consume every day—food. One scientist detailed her interactions, explaining:

So it was one person that did ask me directly a question and it was about chemicals that are concerning because of their toxicity. She wanted to know why they're used, like what their purpose is... Like chemicals have a lot of different purposes and they can be in there for a bunch of different purposes and their toxicity is something completely different and so we kind of went back and forth on what it was...so I found that actually really rewarding to get, to answer a question that this one person had on their mind.

Elaborating on her appreciation for the question, the same scientist shared:

I was just very glad that it was such an honest question, just concerned with these news stories, basically, that I hear about additives in everything is toxic, why are they there? I thought that that was a very smart question and without making it be very chemically intensive...it wasn't asking about the chemistry, just about the purpose of additives and if they're toxic, why are they there in the first place. I thought that that was a good question to ask instead of jumping to the idea of let's get them out of there immediately.

Rounding out the discussion of societal connections in the green chemistry chat, scientists shared how important they felt it was for students to be exposed to the primary goals and processes of green chemistry. For example, one scientist noted how common it is for green chemistry to be understood solely as being water-based, and how such a narrow understanding can be problematic. This scientist explained:

The other thing that I thought that was really interesting that got talked about was the fact that a lot of people see green chemistry as being water based. But if something is water based, it's just easy to take your refuse and flush it down the drain, whereas if it's in some other solvent you have to do other things to properly remove that into the environment and things like that. With water, it's easy to just pour it on out. And that's not necessarily the most green thing to do.

Another scientist, sharing how important she felt it was to discuss basic principles of green chemistry, stated:

I do feel that some of the guiding principles for green chemistry were really talked about and what that means, and how you apply green and think about green and how you make green real and get people to pick up on green. I think there are lots of those things that did go on there.

Although direct, societal level questions and implications were discussed less in interviews with the scientists who participated in the black holes and volcanoes chats, opportunities to consider such issues were provided. For example, as seen in Figure 4, questions in each of these chats offered participants potential avenues to explore connections between their topics and current, societal-level implications.

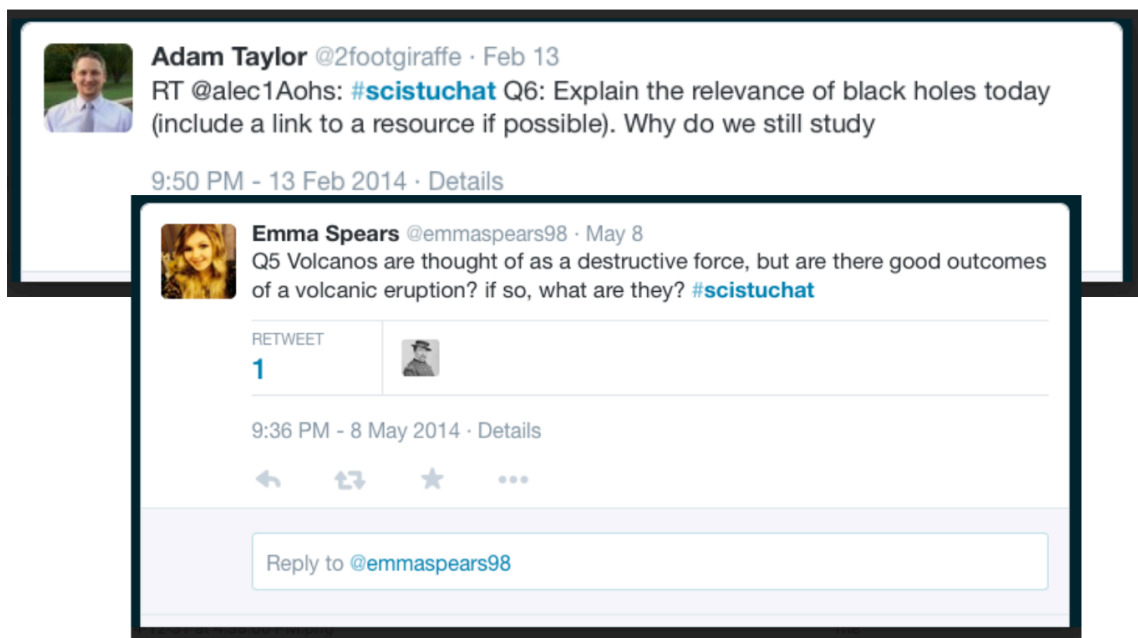


Figure 4. Opportunities in black holes and volcanoes chats to consider societal implications

Misconceptions. In addition to the types and quality of the questions and the societal implications of the science behind the topics discussed, scientists also frequently alluded to misconceptions as a prevalent aspect of their interactions in #scistuchat. Although these misconceptions were often discussed generally, the frequency with which they occurred, as well as the effort exerted in attempting to address them, clearly held meaning for the scientists involved.

As experts in their fields, scientists have a keen eye for the nuances of the science involved in their areas of study. Thus, not surprisingly, in an open forum in which individuals of varying technical backgrounds—most very limited at that—freely pose and respond to questions, misconceptions are likely. Indeed, scientists across all chats spoke to the variety of misconceptions and inaccuracies they encountered throughout their chat experiences. While most of these instances occurred on the part of students, some actually were shared by scientists. In virtually all cases, scientists attempted to politely

correct or redirect offending statements, even when this involved their more science-minded peers.

Scientists spoke often, and typically in general terms, about the misconceptions shared by students. They recognized that #scistuchat is not a forum where in-depth explanations can occur, nor is it an event where one has the time to engage in substantive discussions and still attend to the moderated questions. Scientists also shared how they managed addressing these instances, if they chose to at all. Sharing how he attempted to address misconceptions, a scientist from the black holes chat explained:

I would engage, try to engage directly with the students who would answer and try to, correct this, the misconceptions on the side. I don't know how effective that was but you know, several wrote me back and asked follow up questions and so it's always fun to do that.

Another scientist from the same chat shared his recognition of inaccuracies being tweeted, as well as how he responded to these occurrences. In his words:

I saw a number of answers from teachers or non-scientists or other students that I was like, ohhh, I wouldn't say that. But you just keep going and you just say the best, positive things you can say in that situation.

Speaking to a similar challenge of trying to be technically accurate on the one hand, and deciding how to respond to instances of misconceptions on the other, a scientist from the volcanoes chat offered the following account:

I mean even just in the nature of the way the questions are thrown out there, that anyone can answer without much filter on quality or source of the answer, can sometimes be a little frustrating. Because I'm trying to make sure that what I'm

saying is technically accurate, and then there's about a half dozen other answers that are ranking from also accurate to a little less so...I was trying not to respond, not to be too much of a grader, to correct everything that was going out there because, of course, it's a collective sort of experience rather than a specific Q&A for experts...just getting the flow of that was challenging.

One scientist even recounted a situation in which she critiqued the position of a student and that student, days later, responded. She explained:

He said something that – it wasn't incorrect but it was possibly misleading and I sort of modified a little bit. Actually, it was the day after or two days after that he came back and said oh, yeah, you're right. I probably should have said X, Y Z instead. So that was pretty cool, I thought. He took it gracefully.

While misconceptions on the part of students were most frequently cited, scientists did discuss instances in which they noticed an inaccuracy on the part of another scientist or, in some cases, instances in which they, themselves, were corrected. As one scientist shared, "I was pleased to see that scientists who were answering this weren't afraid to correct each other; that they weren't afraid to say like, okay, that's actually some good information but there's additional good information."

An example of this played out during the human genetic engineering chat, and was recounted by an interview participant. Speaking to the importance of evidence-based responses and, ultimately, settling points of debate, a scientist shared her perspective on a question she tackled with a student and another scientist during, and after, #scistuchat (see Figure 5). Addressing the origin of the exchange she explained:

I posted a comment about genetic engineering, specifically about sterility of stuff, because our resources here had said that that was a primary concern. We had a visiting scholar who talked about sterility being a big issue. So in our lessons here, we were talking about sterility with an example he had given us, as well as gene flow. And so when that came up, I commented about it.

Because her post caught the attention of another scientist, as well as a student, they began to debate the related science. In her words:

We talked about some of the issues around those for a bit and actually it was really nice because we were talking about this with a student as well, and we could look back at those issues and actually correct each other, which was good...I think it's really good because it shows the students the process of science.

Expanding on the notion of the process of science, and the role of evidence in this case specifically, the scientist went on to share:

So you bring up evidence and if the evidence doesn't stand up, you can see. You have to follow the evidence and I think that's a really good point and I've seen it happen a couple of times in the other [chats] where someone will say something like well, I found this and like, well, there's an updated source here. And it's kind of good to show them that scientists are people, too....So none of us wants to be wrong, of course, but like correcting is what makes the most sense...So that actually happened...and I think we actually arrived at a solution the next day—maybe—for sure by 24 hours later.



Figure 5. Conclusion of discussion of sterility that started the previous day during the human genetic engineering chat.

Students. During the interview process, students spoke infrequently about the scientific content encountered, or science-based interactions engaged in, while participating in the chats. Perhaps due to the nature of the interview questions, or perhaps a reflection of the relative insignificance of the science content compared to other elements of their experience, students addressed the scientific dimension of their experience drastically less than did scientists.

In some ways, this might be expected. Unlike scientists, who have a deep understanding of scientific content, students often bring very little subject-specific background knowledge with them to the chats. As a result, it would be hard for them to have an inherent understanding of the quality of questions and potential societal implications, or to be able to even recognize potential misconceptions. However, one

could argue that not having a scientific background might predispose students to be especially struck by the content encountered, as well as by the societal implications discussed, and, as a result, expect that such take-aways would be common talking points in sharing their experience. Regardless, students' discussion of scientific elements of their experience largely centered on a shifting of their understanding of scientists as people, and the work that they do. Although these perspectives could have been discussed here, I believe that they were a better fit for the "Learning" sub-theme within the parent theme of "Outcomes" that follows. Please see that section for a more thorough exploration of students' evolving understanding of scientists and the nature of their work.

Teachers. Across all chats, teachers appreciated the scientific nature of the interactions. However, what resonated with each individual teacher often varied, sometimes focusing on how exposure to scientific ideas impacted their students and sometimes on how such interactions impacted them, and their own practice, directly. In this section, I will focus on the curricular benefits and challenges articulated by teachers attempting to provide an interactive experience for their students outside of the classroom and school day. For a fuller discussion of the individual benefits realized by teachers as a result of their #scistuchat interactions, please see the "Learning" sub-theme of the parent theme "Outcomes" that follows. Here, as with the case of students, specific learning outcomes associated with direct, science-focused interactions are discussed in detail.

Most often, teachers spoke to what they hoped were curricular benefits for their students. Because #scistuchat is topic-based, with foci that often do not align seamlessly with typical high school science curricula, teachers must look to unveil for students universal themes that span individual units of study. In the Next Generation Science

Standards (NGSS), these ideas are known as cross-cutting concepts. As described in *A Framework for K-12 Science Education* (2011), crosscutting concepts are purported to “provide students with connections and intellectual tools that are related across the differing areas of disciplinary content and can enrich their application of practices and their understanding of core ideas” (p. 233). Speaking to the curricular benefits of #scistuchat, and the black holes chat specifically, one teacher stated:

I think it’s great because...principles in physics, they’re universal. You apply velocity everywhere. You apply acceleration everywhere. You apply time everywhere. So the fact that I could get to tell them something like – well, so you see black holes, remember all the physics we learned in tenth grade, well that’s going to apply here. I think that was pretty great, and kids were impressed by that.

Elaborating further on the advantages offered, the same teacher explained:

So the advantage about the classes I teach is that they are connected, especially physics. I always tell students, look, guys, what we learn today we’re going to apply a few months from now, so physics is a continuing study. Everything is related. In fact, scientists – they are breaking their backs in trying to find a formula that unifies all of physics together.

Another teacher, from the volcanoes chat, discussed embracing the challenge of tying certain #scistuchat topics to her science classes. Referencing an earlier chat focused on the topic of bioluminescence, this teacher spoke directly to the value she sees in fostering opportunities for her students to encounter crosscutting concepts. In her words:

From the classroom standpoint, there were some topics in #scistuchat that were really outside of the realm of my subject matter that I was teaching. So I felt like

there was value in students—like in anatomy—being able to connect the topic of bioluminescence to something that we were doing, because that means that the students have the ability to connect something – to think about those big science ideas and make connections between things in science that at first look might seem somewhat unrelated. And so if they can see a relationship, that is a really deep understanding of that core science idea. So I liked the challenge.

Discussing in more detail her willingness to accept the challenge of finding unifying themes and patterns, the same teacher explained:

It didn't put me off if [the creator of #scistuchat] had a topic that I would say oh well that's not an anatomy topic, I can't do that #scistuchat. So I embraced that challenge of how can my students look at our subject matter through that lens... sometimes it was just seeing homeostasis or seeing the way structure and function related in that particular subject matter.

Expanded, authentic audience. A fourth sub-theme within the “Nature of Interactions” parent theme centered on participants’ perceptions of #scistuchat as offering an expanded, authentic audience. Because #scistuchat requires only the use of a hashtag as a prerequisite for participation, prospective participants can easily join the discussion. Moreover, because the hashtag is science-specific and, thus, likely to be frequented by and shared among science-minded individuals, the resulting audience for #scistuchat typically shares similar interests and expertise.

Beyond an authentic audience of science-minded participants who share a common interest in the science topic being discussed, #scistuchat also offers an expanded audience, both in terms of numbers and participant demographics. Twitter chats are

structured to leverage the power of the media to support discussion among greater numbers of individuals than would typically be feasible in a shared physical setting. #Scistuchat regularly supports discussion among dozens of participants. Furthermore, in addition to numbers of participants, #scistuchat also brings together diverse individuals who would not easily, if ever, be able to share the same physical space otherwise. Because barriers to participation are low, and convenience high (to be discussed later in “formal vs. informal sub-theme), #scistuchat is able to bring together individuals who vary widely with regard to age, education, prior knowledge of the science topic, geographic location and, in some cases, even cultural and linguistic backgrounds.

The accessibility of the chat, the shared interest among participants, and the elimination of many traditional, persistent challenges related to space, geography and time, provides #scistuchat participants with an expanded, authentic audience that is unique and diverse. As described below, participants recognized this phenomenon as a strength of the experience and, through the eyes of students and teachers in particular, a unique opportunity to expand one’s voice.

Scientists. Scientists spoke to the notion of an expanded, authentic audience in ways that were not as specific as students and teachers. Many recognized and put words to the global nature of the experience, sharing statements such as “It was cool to see that there were people basically from all over the world. There were people from Honduras and Australia and so it was fun to feel like it was global,” and “Yea, it was like chatting with people all over the world, while taking a break from exercising, but it was really cool. A neat experience.”

Another scientist, a participant in the volcanoes chat, recognized both the global nature of the event as well as the high degree of intellectual curiosity evident in students' questions—a dimension of an expanded, authentic audience other scientists echoed. In his words:

It was definitely an interesting experience because there were people from all over the globe asking questions and some of them...had follow-up questions to the answers and they were definitely being intellectually curious, which I think is a good thing.

Similarly, other scientists noted the curiosity of participants as a refreshing and distinctive feature of an authentic audience. As one scientist explained:

I think there was probably a little more interest in that than I expected. There were more people who were just interested in the topic than I thought. I thought it was going to be a little smaller. And so it was nice to get the number of reactions and to see other people being able to react with people asking them things.

Many additional thoughts were shared by scientists regarding the curiosity of the audience, and the role that this played in creating an authentic science discussion. These thoughts ranged from highlights of experiences, as in the case of the scientist who shared, “The best for me was we got a lot of questions from students who seemed like they really had questions that were motivated by their own curiosity,” to instances of surprise, as the following scientist noted while speaking about the specificity of their discipline, “I think it is certainly really surprising to see how many science interested people there are, especially about pretty specific topics.” Summing up the sentiment of many fellow scientists, a participant noted, “And it’s exciting to see that they are out there, in a sense.

The general public is there and very interested, or at least this particular subset of it was very interested in scientific questions. So that's heartening."

Another scientist shared the impact communicating with an engaged audience had on her and, specifically, her appreciation for her own work. Speaking to the idea of a motivated and engaged audience, this scientist explained:

And I think it's also sort of a nice reward in a lot of ways. Because what I do every day, like it gets mundane, and it's not as cool as it could be, and then when I meet someone that's actually interested in what I'm doing, and every time I come on, there's always some kid that's like you study sex, wow, I didn't know you could do that. And I'm like I guess that is cool. I think it's a good way to remind me that this is a student that's engaging with me that doesn't have to. It's not about the grade, it's not about anything else; they legitimately find this interesting.

In addition to speaking to the palpable curiosity displayed by students, many scientists also expressed interest in and excitement about the nature of the audience's questions. Having a window into the thoughts and questions of this particular slice of the public, outside of those with whom they work professionally, seemed to offer scientists welcomed and appreciated insight. In reference to the nature of students' questions, one scientist from the black holes chat shared these thoughts:

It was really interesting for me to see what sort of place they were approaching their questions from. It was pretty clear that a lot of them had done some research on the internet and had gotten some – you call it science by press release – so

they'd gotten some of the latest like ah, this famous person says this thing, can you say something about that.

Another scientist shared the reasons he welcomed the questions of an expanded, authentic audience, particularly considering the unique and somewhat siloed nature of his work. As he explained:

It was definitely interesting to see, especially if you teach volcanology and then you write about it on the blog like I do. It's interesting to see what aspects of it people are most interested in. Because if you're fully submerged in it like I am, the sorts of questions that I probably find most interesting might be different than what somebody who just thinks about it every once in awhile, or is just starting to think about it, might find interesting.

Students. Whereas scientists spoke widely and in more general terms about the audience afforded by #scistuchat, students repeatedly addressed two primary dimensions of this sub-theme, both closely aligned with the name of the sub-theme: 1. the global nature of the chat (i.e., expanded audience) and 2. the sense that real people—actual scientists, even—were reading their tweets (i.e., authentic audience).

Students were quick to point out the fact that participants in the chats were often separated by hundreds if not thousands of miles, sometimes even tweeting from other countries. In the words of one student, “whoever came up with [#scistuchat] was really smart because I'd never have thought of having a chat where people could communicate with different places. I really did like it.” Other students, expressing similar wonderment at the ability of the chat to bring together individuals from different places, spoke quantitatively about the distances involved and the fact that different countries could even

participate. One noted, “I can’t think of any other way you could do that. To be able to talk with scientists who maybe live thousands of miles away.” Another noted, “I thought it was surprising that there were so many people that joined in, like not just scientists, but like a bunch of students—from other schools. I feel like it’s also people from other countries, too.”

Students who participated from outside the United States, and whose first language is not English, were uniquely influenced by the expanded, authentic nature of the #scistuchat audience. For these students specifically, having an international audience of primarily native English speakers resulted in them paying special attention to the grammar of the tweets that they were sending in English. As one native Spanish speaking student explained:

At first, I don't think we could be considered to be nervous, but we were like careful with our English writing because as you know our native language is Spanish, right. And English is a language that we've been learning from a long time ago, but we still make many mistakes. So I think that was one of the things that could make us be careful when writing or asking questions.

During the course of the interview, several other students echoed the previous student’s attention to grammar in their tweets. One shared, “I was scared about my writing because I’m not perfect at typing, or perfect English,” while another said “Same as the others, I was nervous at the start...I was nervous because of my writing, which is not perfect.”

Students also spoke to the benefits, and novelty, of having diverse participants interacting in real-time. Speaking specifically to the benefits of diversity, one student explained, “For me it’s knowing that you could have a lot of different people from

different areas come in and build a conversation about different types of things that you can learn about.” Another student shared, “I liked how they ask one question but you hear so many different answers from just one question. I found that really interesting.”

Lastly, students were distinctly aware that what they said during #scistuchat, as reflected in their tweets, was read by real people (including, importantly, real scientists) in real-time. From a teacher’s perspective, there is perhaps no better indicator that students perceive an authentic audience than when they express healthy trepidation at the prospect of such interactions. Speaking to this perception of a “real” audience, one student revealed, “Especially with scientists there. Like what if you mess up and they like tell you something, it’s pretty scary.” Other students elaborated on the idea of tweeting to real people, outside of their school and classes, in real-time. As one student shared:

That’s what I was nervous about, like saying something that is wrong and that someone would see it, because normally with homework it’s just your teacher [who] sees it. So it’s kind of just putting your work out there a little bit more.

Another student expressed their similar initial reservations, but ultimately came to appreciate the authentic nature of the #scistuchat audience. In her words:

And you can also know that people are looking at your tweet, which is a little nerve racking at first, but you get used to it and it kind of makes you feel appreciated because people are reading your stuff.

Students’ understood #scistuchat as a forum in which their voices and perspectives reached an audience well beyond what they were used to in a typical classroom setting. Many students recounted competing sensations of uncertainty and excitement leading up to their participation in this unique learning opportunity.

Ultimately, the majority of students in this study found their interactions with an expanded, authentic audience to be meaningful and overwhelmingly positive.

Teachers. As with students, teachers viewed #scistuchat as an opportunity to connect their students (and themselves) with an authentic and potentially global audience. Perhaps the most prominent sentiment expressed by teachers was their desire to “expand the walls of their classrooms.” Teachers aiming to expand the classroom through the use of digital technologies is not new or unique. However, doing so successfully and in a forum as geographically and demographically diverse as #scistuchat is notable, especially considering that the experience happens outside of the school day. Teachers repeatedly expressed satisfaction in this regard, offering statements such as “I think that this experience of interacting with so many schools, so many scientists was really, really, really great for the kids” and “we leverage media as a way for us to communicate our thinking to an audience beyond the four walls of our classroom.” One teacher spoke to global collaboration being a specific goal of they held for their students, they explained:

I guess another thing for me that’s appealing is the global collaboration...One of my goals this year is to really get them to globally collaborate, which is why I’ve been trying to get them every month to do some kind of webquest or web conference with some other school, so I think this is just another extension for them to gain that collaboration.

Teachers also recognized what students noted previously. Participating in #scistuchat provides an audience for students that is greater in number, and fundamentally more authentic, than can be achieved in a traditional classroom setting. Teachers’ perceptions of the impact of such an expanded, authentic audience mirrored, in

many ways, those of their students. In describing changes in her students that one teacher noticed throughout the course of a semester, the following teacher spoke to the synergistic influence of interacting with a broader audience via #scistuchat, her student's classroom use of Twitter, and a video initiative. Tying her observations to the notion of a 21st century learner, she explained:

We think that when they write and turn in their paper to us, that that is us hearing their voice, but they don't look at it that way...So I think that that has been the biggest takeaway...they carry themselves with a totally different confidence than they did at the beginning of the semester. And I think it's a lot of different things, but it's definitely that focus on sharing their voice through Twitter and through the video that I think is a really important preparation for what a good deal of interaction in the 21 century is.

Recounting his students' feedback from the black holes #scistuchat, the teacher of the native Spanish speakers shared a similar insight:

And they told me, yes, Mr., the thing is that the blog posts, sometimes we just do them for the sake of the bonus points, you know. And we know that you're the only one that's going to probably read it. But these tweets, we knew that people from the USA were going to read and students from over there were going to read them, so we put a lot more effort into writing with the correct grammar. We double-checked. They actually told me they proofread their tweets which I think was a great sign to take away from this chat.

#Scistuchat offers participants an unusual opportunity to interact with individuals from across the country and, in some cases, across the globe. Beyond connecting

individuals across vast geographic distances, #scistuchat also brings together participants who otherwise have few opportunities to interact directly. Due to many factors, scientists—including graduate students, professors, writers and those working in the field and from the bench—rarely are able to engage directly with high school students. When they do, many of the same factors that make it difficult to arrange meetings in the first place (e.g., time, schedules, proximity) similarly restrict the time and degree of interaction they are able to accommodate. Recognizing these challenges, scientists, students and teachers spoke to an expanded, authentic audience as a unique dimension of the #scistuchat experience. Although the effect of such an audience was perceived in subtly different ways by each participant group, the overwhelming consensus was that this was a positive outcome of the experience.

Scientists as experts. The last sub-theme that I identified within the broader “Nature of Interactions” theme addresses the role of scientists as experts in #scistuchat. Scientists were perceived by participants in my study, especially students, as defacto experts. Thus, scientists’ responses to moderated questions, as well their responses to direct interactions outside of moderated questions, held considerable weight in the eyes of others involved. Students, in particular, perceived scientists as informed authorities on a given #scistuchat topic and held their scientific opinions in very high regard. Scientists rarely referred to themselves as experts but, interestingly, frequently used the term when referring to other participating scientists. Additionally, scientists often shared connections they had with other scientists, either in-person or virtually, participating in a given month’s #scistuchat. Teachers alluded to the expertise of scientists as a distinctive feature of #scistuchat, but were not as descriptive, collectively, as students when they articulated

the impact scientists' expertise had on them or their students. The exception to this statement came from teachers who participated in the black holes chat. These individuals did speak directly to what they believed was the power of having scientists with so much expertise interacting with students. Regardless of how scientists' expertise was perceived, the notion of scientists as experts pervaded discussions of #scistuchat and, I believe, is an important factor in the nature of the interactions that occurred within the chats.

Scientists. The term "scientist" is used with significant latitude within the confines of #scistuchat. The generous definition of the term, in this setting, enables participation by individuals who fall along a broad spectrum of scientific involvement. As a result, participating scientists in a given chat may, in fact, be practicing scientists working directly in the field or laboratory, Ph.D. candidates and post-doctoral fellows studying a variety of related research questions, or professors, writers and others interested in that month's topic. A common trait that seems to be shared by all scientists, regardless of their title, position or educational background, is their interest in and commitment to science communication. The simple fact that they are on Twitter for science purposes is a testament to their willingness to explore non-conventional means of science communication, as well as a selective factor predisposing them to participation in such a forum. As a scientist who participated in the black holes chat pointed out:

The ones who showed up...are already self-selected. The ones who are interested in communication, who are interested in sharing what they know with each other, with the community and with anyone who's interested in the general public. And so I thought there was, among the professionals who showed up, this good-natured positive, vibe coming from them.

Scientists did not often refer to themselves as experts, but frequently did do so when discussing their fellow scientists. As one scientist, noting highlights of his #scistuchat experience, explained, “And the other thing that makes it worthwhile is this community of diverse experts who show up and can offer something valuable with respect to those questions.” Another scientist seconded this opinion in sharing his perception of the expertise of scientists on Twitter. He noted, “there’s such a breadth of expertise on Twitter with people who are willing and able and excited about talking about science.”

Several times, scientists in my study referenced fellow #scistuchat participants as being notable, specifically for their contributions to a particular field or because of their positional authority. For example, one scientist in the human genetic engineering chat shared his perspective on the participation of the head of a national science association. This scientist explained:

The former head of the American Association of Biochemistry was participating in #scistuchat – that’s a big deal... There are people in biochemistry that have never had an interaction with the former head of the Biochemistry Society. So it is a monumental acknowledgment when there are students... and educators that have an opportunity to interact with someone on that level, and especially on a policy level. That is a big deal.

When asked about the quality of the science being shared, as well as the caliber of those sharing the science, many scientists spoke highly of their peers and referenced professional connections as a measure of the expertise of these individuals. A scientist from the green chemistry chat noted, “Certainly from the scientist end, there are people

whom I know both from Twitter and from real life who were involved in it and so I think that's a good thing." Another scientist, a volcanoes chat participant, explained his connections to and confidence in the reputability of the other scientists. In her words:

I remember there were a lot of people on Twitter who are personal friends of mine who are members of the Planetary Science and who work and do research in the sciences. So I knew...several of these people already, and had seen them on Twitter. So I knew that they did have the expertise that they were sharing.

Lastly, a fellow scientist echoed the sentiments of those above, while also pointing out the benefits of simultaneous participation by experts with varying foci. In his words:

There were definitely other people that I know through geology that were taking part in it that were answering questions that were centered on some of their expertise that is slightly different than mine. So there are a lot of reputable people that have good answers at the same time.

Students. Students were unequivocal in their characterization of #scistuchat scientists as experts. For reasons including how #scistuchat is billed to students by classroom teachers, a recognition of the unique and specialized work many participating scientists engage in directly in their respective fields, and the impact of what are often clear differences in age and educational achievement, scientists are perceived by students as possessing distinct and significant levels of expertise. Students repeatedly shared the value they place on the participation of scientists, with comments running the gamut from "I think we learned a lot from the experience and just all talking to actual scientists and getting more knowledge based on the topic" to "I read a lot of the things [scientists] said, like when someone said oh I'm a scientist, I played special attention to that."

Students expressed confidence in both the authenticity and accuracy of the tweets scientists shared. A student in the black holes chat explained why she placed so much value on the responses of scientists:

It was an interesting experience because we got to meet people who...knew what they were telling us...they were people who studied them, and it was cool to talk with them because they knew the topic.

Echoing the previous quote, another student in the same chat explained, “It was great...we have the opportunity to ask questions to people that truly know about the subject and [spend] their whole life on that.”

Other students, across each of the four chats, shared similar opinions of scientists, often placing special emphasis on their perceptions of the accuracy of scientists’ responses. One student explained, “The positive thing of this was that we were talking to professionals, teachers and scientists. That was really great. And we had the correct answers and not a random answer.” Another student noted, “For me personally, I felt it was very helpful because I could talk to scientists who may have more information about a certain subject than somebody else would.” In addition to reflecting on the accuracy of scientists’ tweets, many students noted the extent to which interactions with scientists caused them to appreciate the layers of complexity that characterize many scientific topics. One student, in particular, spoke to the wonderment she sometimes felt while participating:

When I talk to the scientist...I think they’re going to have just like a simple answer or whatever, but actually they...tell me a whole bunch of different stuff. Like what? I’ve never heard of such a thing before, but knowing I can learn

all that information and see how much they give to what they do, it catches my interest.

In addressing their interactions with scientists, and their perceptions of scientists as authorities on the topics being discussed, the perspectives of two students stand out.

With regard to the excitement of engaging with real scientists, one student explained, “You make your schedule around it so it’s like, I can’t do that because I’m doing #scistuchat tonight or something...you look forward to talking to the scientists.”

Considering the expertise of scientists, particularly contrasted against a typical classroom experience, another student recounted, “It was good how you get to talk to people that actually work in certain fields and not just learn about it in a classroom.”

Teachers. As mentioned previously, teachers alluded to the expertise of participating scientists throughout the course of the interviews. References to “valuable opportunities,” to “real scientists” and to “direct interactions with scientists” pervaded discussions of #scistuchat. However, on the whole, teachers did not speak directly to scientists’ expertise, nor the impact that they believed the presence of such expertise had on their students, to the extent that students and scientists did. More often, in the case of teachers, discussions of expertise consisted of passing references or led directly to a discussion of what they themselves had learned as opposed to more student-centered outcomes (see the “Learning” sub-theme below for a more detailed discussion). Thus, while I believe that teachers recognized and appreciated the expertise of scientists, in most cases they did not relate this appreciation directly back to their students’ experiences.

Teachers who participated in the black holes chat, specifically, did speak directly to the expertise of scientists, as well as the degree to which they believed such expertise impacted their students. These two teachers referenced the expertise of scientists in both general and specific ways. General references to the experiences of their students included statements such as, “They really liked it. To be able to go on there and connect with an expert and get the answers that they wanted,” and “I think it’s wonderful that they get to ask their own questions and then they get an immediate response from an expert.” Following up on these general sentiments, the teachers elaborated on their perceptions of the significance of experts participating. While sharing why they believed scientists were willing to participate in #scistuchat, one of these teachers explained:

Scientists like astrophysicists or physicists – whenever they get an opportunity to get to talk to young minds, they love it, they want to do it. They love opportunities in which they can influence young minds. So that’s why they’re willing to be there. That’s why they want to answer your questions.

Another teacher spoke more directly to the impact on student learning. He asserted:

You know what determines if you’re going to learn something or not. If you read it from a book it’s going to be different than if you actually go and experience how it is done or in this particular case, the fact that a scientist replied to you through Twitter.

While considering the significance of students’ interactions with scientists in more specific terms, a teacher who participated in the black holes chat recounted one of his student’s experiences in the chat and their subsequent discussion of the event. He shared:

At the end, I noticed one of my students, she made a question to the scientist. I think his name was “@StartsWithABang.” So then when I saw the physicist reply back to her and they had like a mini conversation, it wasn’t a chat, I went to look at this guy’s bio and I noticed that he was an astrophysicist. He was a columnist from NASA. And I go and tell her, did you know you just had a conversation with a columnist from NASA? This guy’s an astrophysicist. And she was impressed.

Elaborating further on the significance of the direct interaction between his student and the scientist, the teacher explained:

I believe that me telling this girl – this guy who answered this question for you, he is an astrophysicist with this amount of experience and he writes a column for a NASA magazine – I think that whatever she asks the scientist and this scientist answers her back, that is going to stick to her for a long time.

Scientists, students and teachers all either alluded to or, in most cases, spoke directly to the power of having scientists with deep, specialized expertise interacting with curious students eager to learn more about a specific topic. A teacher in the black holes chat shared a perspective with which I believe all stakeholders would agree, and one that summarizes the influential role scientific expertise plays, among others, in shaping the nature of interactions within #scistuchat:

I think it’s good that they have these spheres of learning firsthand from people that know what they’re talking about, because one thing that I liked about it was that some of the questions [students] made to the scientists, they would make

them to me. And I would tell them, you know what, I really don't know. In fact, I am a science teacher. I am not an astrophysicist.

Summary. #Scistuchat is, at its core, a discussion. Like face-to-face discussions, the course of a given month's #scistuchat is driven by personal motivations, curiosities and perceptions and, although occurring within a framework of moderated questions, evolves organically and encourages concurrent discussions among participants. As such, a given participant's #scistuchat experience is constantly and profoundly shaped by the nature of the interactions they experience over the course of a chat. Within this study, distinctive features of these interactions included the fact that they were student-focused, dynamic, driven by scientific interests, shared among an expanded and authentic audience, and included the specialized expertise of scientists from myriad scientific spheres.

Outcomes

Unlike many educational tools, experiences, and initiatives, #scistuchat does not purport to raise student achievement nor promise certain learning outcomes. In fact, on the #scistuchat homepage, the event is described simply as "A Twitter Chat for High School Students to Talk to Scientists" with those interested encouraged to "Join the discussion between high school students, scientists, science educators, and general science thinkers sharing around current science topics." Despite its general billing and avoidance of purported benefits, it is reasonable to question what outcomes are realized through participation in #scistuchat. Over the course of my research, drawing on direct observations of chats in real-time, analysis of exchanged tweets after-the-fact, and interviews with participants, several sub-themes emerged as relevant and important

outcomes of participation. These sub-themes—including 1. learning; 2. affective impact; and 3. effectiveness—reflect participants’ perspectives on the larger impacts of their participation.

Learning. Like all Twitter chats, #scistuchat is moderated by individuals who pose specific questions, monitor responses and ensure that the overall flow of the chat is smooth. As described in the “Scientific” sub-theme within the broader “Nature of Interactions” theme above, the questions of every #scistuchat are science-based and center on the given month’s topic. Not surprisingly, the focus of the interactions during #scistuchat are also science-based. Importantly, however, increased knowledge of science content, particularly as it related to the given month’s topic, was rarely referenced as an outcome by students and was a point of uncertainty for numerous scientists in this study. There was no a clear consensus among teachers regarding the notion of learning either. Some expressed satisfaction with the learning they personally realized, while others pointed to the importance of learning in relation to student outcomes. Notably, the most prevalent thread within this sub-theme was the role #scistuchat played in challenging and often transforming students’ perceptions of scientists.

Scientists. While scientists referenced learning as an outcome of their participation in #scistuchat, the spectrum of responses related to this idea varied widely, with some focused on personal learning and others referencing possible learning outcomes for students. When speaking about their own personal learning, scientists’ responses typically involved instances where their own learning of science content increased or instances where they learned more about their audiences. Illustrating the former, one scientist explained “Well, I mean, from the technical viewpoint, there was

the latest research on the mass threshold that a star takes to form a black hole, and I learned something about that.” Speaking to the latter, scientists offered statements such as “It helps me maybe focus my own thinking about it a little more in terms of what do people want to know,” and “One thing that was cool to learn was just sort of what kinds of questions are on people’s minds about black holes in particular.”

When explored through the lenses of scientists, the notion of learning related to #scistuchat generated many more questions than answers. In essence, due to the brevity of tweets and the pace of the chat, many scientists questioned whether or not meaningful student learning was truly possible. As one scientist skeptically pondered, “In terms of thinking about how people learn, I honestly don’t know if these students will necessarily remember anything about black holes or that there’s enough weight there to sort of dislodge whatever misconceptions they might bring to the table.”

This perspective was echoed by scientists across several of the chats, particularly those who participated in the green chemistry chat. There, given the complex nature of the chemistry, scientists expressed hesitation at the prospect of lasting student learning. As one of the scientists from the chat explained:

I’m not entirely sure that the students walked away with a clear understanding that it is a defined field and that it crosses into so many different sectors. Towards the end I feel like there was a conversation about – like jobs or [or whether it is] a separate field...the reality is it’s intended to just be better chemistry all the way through. So...I posted something about the job opportunities, trying to get that out there to them...I guess I’m not entirely sure what it was that the students got out of it – right? You know?

Continuing with this train of thought, the same scientist shared her interest in knowing more about what students took away from the experience:

I'd have to ask the students what they got out of it. Because it wasn't for me.

It was for them. So I didn't learn anything from it... That's so not true. I did learn things from it. I mean I learned the format of how to do a chat in Twitter. And I learned – I learned that the tool itself could be really cool. I just think there has to be that debrief with your students. I'm sure that is what the giraffe guy – @2footgiraffe – I'm pretty sure that's what he does. Like I think he goes back to his students afterwards and then gleans, okay, what is it that we learned from this. So I guess I'm just like, oh, I'd be kind of curious – because I do – I think there is a little time at the end [of the chat] for what did you learn.

Addressing the specific, chronological nature of chemistry content, another scientist who participated in the green chemistry chat explained:

At that age, you have only the most limited idea of what regular chemistry is and [#scistuchat] is necessarily here's what it was, here's what the challenges are, and here's how we're fixing it. If you don't have that first box, which for the most part, when you're talking about green chemistry, is organic chemistry, which is the second year college course, most places, it's really hard to teach concepts. So if you can, fantastic, but what I try to do... is just try to get across that it is out there so that hopefully they're further receptive in their futures.

This notion of providing students with an introduction to a given science topic, as opposed to deepening a base of knowledge, was a common refrain among scientists. This is likely a byproduct of the inherent limitations of Twitter chats, as well as a reflection of

scientists' deep appreciation for the subtleties and complexities of their particular fields. While many scientists expressed appreciation for the degree of engagement they encountered, and hopes of having increased students' interest in the topics, they also voiced skepticism regarding the degree of lasting learning that resulted. As one scientist noted, "I think it's important to introduce that type of concept thoroughly in high school, even though it's not like the science of actually how you do this, because they haven't learned a lot of the background chemistry that's needed" and, as a result, pointed out that, "I don't know if it was necessarily the science of green chemistry but it was the cause of green chemistry that was very valuable." Reflecting this position, another scientist from the same chat explained:

I didn't know that [genetic and metabolic engineering inside living organisms] existed until graduate school, and my mind was blown and that's what I wanted to do. So if you can just introduce that there are these things out there, please forgive me that I do not have the fortitude or vocabulary maybe to explain it in this particular context of an hour, 140 characters, very different audience threads going every which way, but know it's out there and hopefully you will want to learn about it and take the time to find the resources or I can provide the links to resources for it.

Students. Unlike scientists, students were more consistent in their discussion of what they learned by participating in #scistuchat. Namely, *during interviews*, students repeatedly articulated a shift in their perceptions of scientists as a distinct outcome of their experience. This finding is *inconsistent*, however, with students' tweeted responses to a concluding #scistuchat question that was posed near the end of each chat that was

part of this study. In other words, while students consistently cited an evolving understanding of scientists as a key point of learning during interviews, when asked what they had learned in the context of the actual chats, their tweeted responses did not identify the same outcomes. This discrepancy between learning initially shared during the chats and that subsequently discussed during interviews is explored in more detail below.

Near the conclusion of each of the four #scistuchats that comprised this study, moderators posed a question in which participants were asked what they learned during the course of the evening's chat. Although this question often felt lost due to the lack of participant attentiveness that characterized the last few minutes of the #scistuchat hour, numerous students in every chat did respond. As can be seen in Figure 4, in virtually every case, analysis of the tweets in which students shared their learning revealed responses directly related to the science topic. Although points of learning shared by students during the actual chats were often general in nature, with some even clear attempts at being humorous, virtually all centered on the topic of discussion. Thus, it was surprising to find such little reference to the same science-related learning during subsequent focus-group interviews.

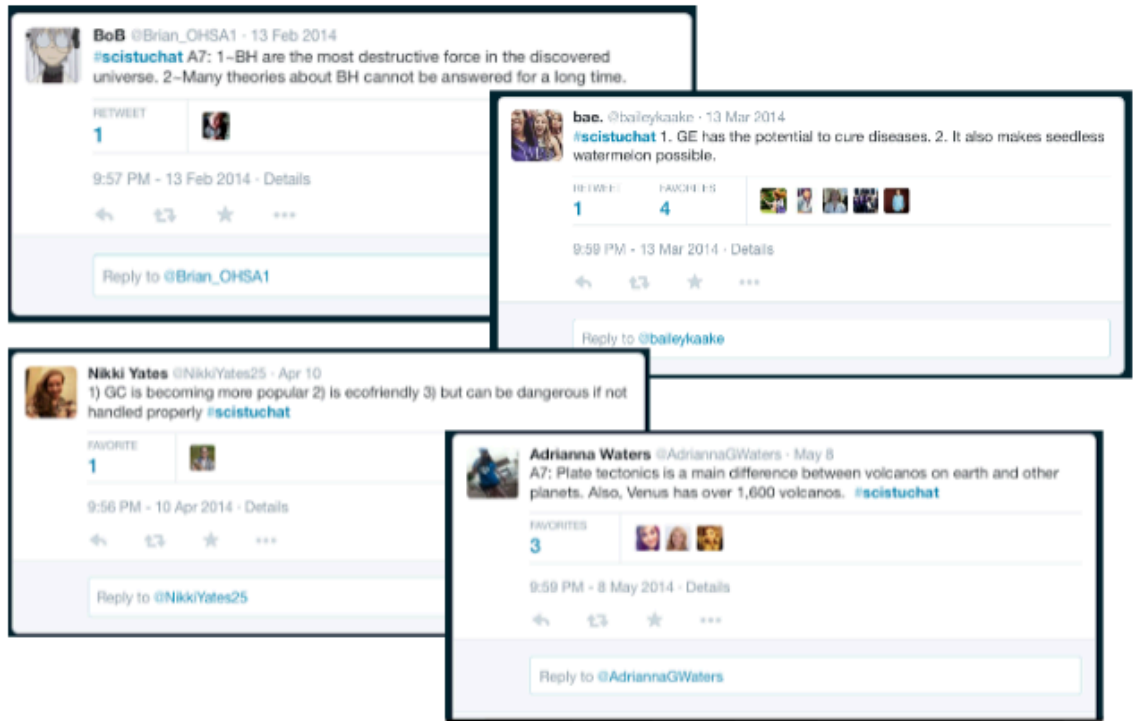


Figure 6. Examples of students’ tweets, shared near the conclusion of their respective #scistuchats, addressing what they learned through the course of the chat.

During numerous focus group interviews with students from each of the four #scistuchats that comprised this study, the most frequently cited takeaway was not content-focused, as expressed during the actual chat, but instead concerned students’ evolving understanding of scientists as people. When students did mention science-specific learning, most did so in passing and only in general terms. For example, when describing science-related outcomes, students shared statements such as “we learned so many things, that black holes have been in the universe many years and that black holes can make matter turn into energy,” and “I didn’t know a whole lot about the green chemistry aspect so it was kind of cool just to see like it’s actually a thing and it’s up and coming and it’s going somewhere.”

Students across all chats were quick to reference the ways in which their perceptions of scientists had been influenced as a result of their shared #scistuchat experience. As mentioned previously, I expected to hear students describe science-specific, content-focused phenomena as primary points of learning. Instead, students repeatedly shared a humanizing effect their participation had on their perceptions of scientists. This phenomenon was addressed across the board by students and, in all cases, was viewed as a positive outcome. Students described their evolving understanding of scientists in much the same way, offering statements like the following:

My perspective of scientists used to be mainly they were like people who just went to work, did science and were done with it, like we are at school most of the time. But there are the ones that go and go on Twitter and try to further other people's knowledge of science...I didn't expect scientists to be that way.

Numerous students alluded to their previously held conceptions of scientists as aloof and standoffish, as one student described:

I kind of always thought that scientists were like uppity uppity and they didn't like want to talk to students, like why would they want to talk to me. I'm just a high school kid. And like following some of the scientists from #scistuchat and talking to them on the chat, it made them seem like more down to earth. Oh hey, he's a person just like me. The only thing different about them is that they went to college and got a degree and I haven't done that yet.

Echoing this sentiment, another student shared an equally blunt assessment of her previously held view of scientists and, importantly, how her perception has since changed:

I always thought scientists were like kind of mean, like they seem like people like who are all to themselves and they only talk to each other. But it seems different because you have older scientists who have been doing this for a while and they seem like, not at the same level, but they have the same goal as people like me who are just in high school. I found that interesting, and really comforting, and I definitely don't think scientists are like that anymore.

Even a student who shared that his perception of scientists hadn't really changed pointed out, in the same sentence, a new realization related to how scientists conduct themselves. He explained, "My concept of the people who study all this remains almost the same, now I know that they truly enjoy to explain what they know and they want to share that information with everybody."

Ultimately, students seemed to take a different path when speaking about what they learned during #scistuchat, as compared to their tweeted points of learning within the confines of the chat. In the case of the former, students frequently referenced transformed perceptions of scientists as a significant learning outcome. Offering a tweet-length perspective, one student summed up in a few short words the consensus of many others, "I see scientists as like real people and not just like scary professionals."

Teachers. As was often the case in this study, the teachers' discussion of the #scistuchat experience vacillated between a focus on their own perspectives and those of their students. This was particularly evident with regard to outcomes, generally, and to this sub-theme of learning, specifically, as opportunities to discuss current science with experts in the field has potential benefits for both. With regard to this learning sub-theme, specifically, teachers discussed leveraging the #scistuchat forum as a way to connect their

students with real scientists in real-time, and as a means to further their own understanding of current science related to #scistuchat topics.

Teachers frequently voiced skepticism about the extent to which participating in #scistuchat resulted in significant content-specific learning. As one teacher asserted:

I think that the biggest takeaway was not what I learned about black holes in a one-hour Twitter chat. I would think the amount of knowledge these kids took – when you said, for example...okay, guys, tomorrow we have a test about what you learned about black holes on Twitter – I think that in my students' case, it was they learned more from the video that they saw previous to the chat.

This teacher elaborated on his position, explaining his perspective on the flow and dynamics of the chat:

The amount of learning that you can get, I think, is the appropriate to the amount of learning that you should get from a Twitter chat...I really don't expect for my students to become professionals at a topic after a one-hour Twitter chat when 30 or 35 percent of it was hey, how are you or I'm from Honduras, oh, you're from the States.

While recognizing the limitations of the chat from a content perspective, teachers none-the-less felt that #scistuchat offered opportunities for students to learn about the nature of scientists and their work. Explaining the motivation behind having his students participate, one teacher shared, "My big thing is that science doesn't just happen in class. They need to see it around them, they need to see it from other people besides me, so that was my hope," as well as "helping [students] get to know some scientists and that they're

not all white guys with white jackets on.” Another teacher, a participant in the volcanoes chat, also spoke to this scientist stereotype. She noted:

Maybe some students don’t see themselves as scientists. They think of scientists in white coats working in labs but I think by communicating with scientists on Twitter...they see they’re kind of just like them but that they have much higher degrees and they can obtain that. So I think it kind of makes it a more attainable goal for them.

Sharing specifics regarding the benefits offered by #scistuchat, the same teacher explained:

It’s my belief that science needs to be learned through experience; students need to act and think like scientists. So #scistuchat is a great opportunity for them to see how scientists act and think, by interacting with them, and it also gives them a chance to do that.

Interestingly, a teacher in the green chemistry chat also addressed the idea of stereotypes, speaking not only about the scientist stereotype, but also to the two-way power of the chat in challenging the assumptions held by all participants. In her words:

I think for the scientist, it makes students seem less stereotypical. And I think you break the stereotypes of both groups because you tend to [say] – oh, let’s keep them at arms length away, with the way they fit this mold – oh, they’re high schoolers, they’re this mold. And then you discover, no, the mold really isn’t the way it is.

In addition to opportunities for students to interact directly with scientists, and the potential for each to understand the other in more meaningful ways, teachers also pointed

to exposure to current science as a learning outcome for their students. Although mentioned to a lesser extent, teachers cited the metaphorical chasm between science discussed in the classroom and that happening outside the classroom, as well as the persistent, temporal lag between when science happens and when it actually makes its way into the classroom, as an issue addressed by #scistuchat. Explaining this additional learning outcome, one teacher shared:

Well I've always known that you have to stay up to date on the science and really try to connect kids to the news about what's happening in the science world. And I think this is one of those ways to really enhance that for students, and to keep them up-to-date and form connections with scientists outside of the classroom and beyond newspaper articles, somebody they can actually chat with.

Echoing the comments of the previous individual, another teacher-participant from another chat spoke to the power of #scistuchat in bringing real-world science to her students. She posited:

I think it's definitely a way to make science more relevant for students until they get more real world. I think they can see what's going on outside of the school in the science field and what's going on in our world so I think in that way it's definitely kind of bringing the outside world in.

While teachers found that #scistuchat had learning benefits for their students, they also discussed benefits that they, themselves, realized through participating in the chats. Most often, the learning teachers articulated centered on science content and direct connections to practicing scientists. Teachers repeatedly referenced having learned “about some different types of research they're doing and they're currently working on”

and, as a result, “looking forward to future chats because I know that there are many things I can learn, especially from people who are specialists in these areas.” Speaking about the multidimensional benefits of her participation in #scistuchat in greater detail, one teacher explained:

One of the things that #scistuchat has allowed me to do, because I’m interacting with a scientist on #scistuchat, is follow them on Twitter...science is constantly changing so it allows me to keep up to date. Also to have a lens into their research and that particular world that I’m a little bit removed from now since I haven’t been an undergraduate major in science for quite some time. So that’s refreshing. And then there’s also the curation of those resources that by following them that I can use in the classroom that are real science examples of some of the things that the students are exposed to.

It was not uncommon for teachers to reference their time away from their own formal education as a challenge addressed by interacting with scientists currently working in a specific field. Reflecting on this phenomenon, a teacher who participated in the green chemistry chat pointed out:

The green chemistry one was interesting in terms of putting some of...the newer stuff that I haven’t had a chance to [study] in awhile...Learning some of that actually helped put some of what I teach in context or into a more current context.

This same teacher, recounting a prior #scistuchat on the human brain, offered a detailed window into the learning she realized through direct interactions with scientists. In her words: “Just being able to discuss how our understanding of neurons and the nervous

system has changed with some of the information that the doctoral students or post docs shared was huge.” Elaborating on the impact of these interactions, she explained:

I can’t read...scientific journals like I did when I was at school getting a degree. And now you’re having this interaction, kind of a colleague-to-colleague, and discovering all this stuff. There’s this new stuff here and this new stuff there. The whole thing with stem cells and the brain. We still have active stem cells in the brain. This is really what they think is now behind learning and the plasticity of the brain and things like that. That’s certainly not in any books...we’re 7 years behind the curve learning about some things.

The question “What learning results from participation in #scistuchat?” is one that is not answered easily. Scientists, students and teachers pointed to a variety of learning outcomes that at times diverged and, at other times, overlapped. Highly dependent on the participant, these points of learning ranged from a better understanding of their audience in the case of scientists, to challenging scientist stereotypes in the case of students, to a two-pronged outcome for teachers in which their students exposure to scientists practicing real science occurred simultaneously with their own gaining of content-specific knowledge from experts in the field.

Affective impact. Participants in #scistuchat, particularly students and teachers, spoke often of the chat’s ability to magnify student “voice.” The notion of voice—a somewhat abstract conceptualization in which one’s thoughts, perspectives and emotions are recognized and validated, typically in a setting, or among an audience, beyond one’s peers—was a thread that ran throughout participant interviews. In many ways completely different than more cognitive-based outcomes, these emotionally-tied, participation-based

student outcomes were significant in the eyes of participants, especially students and teachers.

Scientists. Scientists, on the whole, rarely referred to affective outcomes for either themselves or the students and teachers. However, the scientists who did speak to this affective dimension of the chat most often did so when addressing a sense of empowerment and comfort asking questions that they hoped students gained. The significance of asking personally-driven questions, irrespective of how they might be perceived by others, was a theme revisited often by scientists. In one case, sharing a perspective that is as much student-centered as it is affective-specific, one scientist explained why he thinks #scistuchat empowers students to ask questions. As he explained:

It's good for them to have that conversation and not have a one-sided conversation that's just dominated and dismissive. And I think that's the advantage, to have students be empowered and ask the questions. That's what I like about #scistuchat. It's not just the typical situation where there's an expert and the expert that's going on and on pontificating about whatever it is they're doing.

Another scientist, speaking again to a desire to have students feel empowered to ask questions, specifically addressed the ubiquitous notion of “stupid” questions. He stated:

I think you keep students interested, engaged, if you keep students asking questions...and not afraid of asking what a lot of people call stupid questions. Once they get over that, they realize that there actually aren't stupid questions.

That's valuable and it doesn't necessarily just apply to science. That's really just applicable always and so hopefully that skill is communicated through #scistuchat.

Following up on his hopes of dispelling the notion of stupid questions, the same scientist offered a specific example of a question he was asked by a student during the human genetic engineering chat. In his response, he also speaks to the personal cost of not asking the same question when he was in high school:

I know one of the people I was talking to, he asked a question, are there programs in college for bioengineering or for human engineering, genetic engineering? And being on this side of the fence, it's like of course there are. That's a true question. Most people don't know it. I mean, I went to a school where we exported students mostly to junior college. I had no idea about different classes outside of the ones I had taken. I went in as a literature major because that was the closest thing to English. I had no idea that there was psychology. I didn't know that that could be a major. I didn't know that statistics could be something you studied as a focus...if I had I asked that question, I wouldn't have wasted a couple of years in college.

Yet another scientist addressed their perceptions of #scistuchat as a space in which students are encouraged to be vulnerable and to ask questions. In her words:

If you're a student in science, you're always afraid of feeling stupid. And maybe that's a professor's thing, too. They feel the same thing but they just hide it better...Because it's informal...I guess you don't feel as vulnerable at that point

to show that hey, I don't know how to do this – help. And I think it's a good way to be able to just ask.

Students. A majority of the students interviewed felt strongly that #scistuchat offered a unique forum within which they could express themselves in a manner that felt fundamentally different than face-to-face interactions in class. Moreover, students often alluded to a freeing effect #scistuchat has on individuals who may otherwise be shy, introverted or feel as though their voice is marginalized or unrecognized for a variety of reasons. Lastly, numerous students spoke to a sense of increased confidence in themselves as science learners and as consumers of science.

Students described the environment of #scistuchat as one not only of novelty but, often after a short period of adjustment, as one in which they felt comfortable in ways that they found surprising. A sense of freedom—to respond, to ask uninhibited questions, to interact—was a common talking point among many students in the focus group interviews. Speaking to this effect, one student shared a summary of her journey from fearful to engaged participant. As she explained:

I feel like it made me open up a little bit more, too— like I wasn't as afraid. At first I was afraid to answer something wrong, but then I realized that even if you do answer something wrong, you can correct it... You're not Google. You're not a walking encyclopedia... It helped me correct my mistakes, too, if I made a mistake. I think it really helped me open up to answer things more... before I was always afraid of like raising my hand to get something wrong. But now I'm not as afraid and I'm a little more confident, and I try to bring in more of my inner knowledge and not just stuff that I've memorized from other science classes.

Having experienced a similar sense of contentment while participating in #scistuchat, two additional students attempted to pinpoint the genesis of their comfort. Expressing similar sentiments, each compared and contrasted their in-person interactions with those they experienced online in #scistuchat. As the first noted, “And me personally, I feel more comfortable knowing that I can just type it...I don’t know, I just feel different answering the question in person than responding through the internet.” Sharing a parallel perspective, the second student explained, “It’s more...comfortable. You can’t see [them], they can’t see your expression...I don’t know, I just feel like, I could say more online than I could in person because then I’d like feel awkward or something.”

While some students describe a general sense of comfort interacting in #scistuchat, others cited the digitally-mediated, interactive experience as one well-suited for individuals who find verbal participation challenging for a host of reasons. Some students spoke to this effect from personal experience, while others cited instances in which they observed this phenomenon play out for a classmate. Offering a first-hand account of this effect, one student described her own experience in this way:

I kind of learned to speak like, to actually answer stuff, because I’m kind of shy...In class, I don’t like raising my hand even if I know the answer. But with #scistuchat, I just felt different because I didn’t know the people and I was kind of scared, but at the same time I...had freedom. So it helps me to be able to express my thoughts more.

Another student also described “coming out of her shell,” and learning to interact more freely and confidently. She shared:

There are a lot of people and not all people are like really outgoing. They're shy. It's not their personality. And I feel like it's helped a lot of people, especially me, come out of their shell kind of and be able to talk with people more.

Some students, echoing those who offered first-hand accounts, shared how they believe a Twitter chat like #scistuchat can offer an outlet for individuals hesitant to share openly in a traditional classroom setting. One student shared, "So some people who are maybe hesitant to do so in person might feel like it's easier to speak through Twitter." Another student offered her take on the benefits #scistuchat might afford to individuals less inclined to class-wide discussion and participation. She explained:

For those people that don't really just talk a lot, they [are] just shy and they just sit around most of the time, they could actually connect with other people when they get on Twitter and actually they talk. Well, they're not really talking, but they can understand if they're actually learning something because they're interacting with other people.

Perhaps the most powerful affective outcomes expressed by students, regardless of how they felt about in-class vs. digital communication, involved stronger connections to and confidence with the field of science. Expressing newfound self-efficacy, students spoke movingly of their evolving confidence in themselves as science learners and as active consumers and communicators of science. As one student, speaking about the outcomes of his participation in #scistuchat, shared:

I think it certainly makes me feel better about myself because I felt, beforehand, I was just maybe a little smarter than average when it came to science, but... didn't feel like I was smart enough to be able to actually talk and converse with

scientists. But with #scistuchat you're actually doing that and it made me feel good about myself.

Another student, referring to how he believes #scistuchat will connect to future science experiences, as well as his overall interest in science, noted:

It made me feel like, in the future, I can take science and be able to connect it to #scistuchat and be more interested...I think it's changed [me] because I now find science interesting and that changed my view on a lot of things.

Speaking directly to the notion of student voice, the following students expressed an increased sense of confidence and, in one case, a realization of the fact that many scientists can and want to help students reach their goals. The first student shared, "I feel smarter in science. I never thought I was really good at science, but I feel like it made me feel smarter and to actually care about what I have to say." The second student, speaking to both voice and the willingness of scientists to help, asserted:

I feel like I can accomplish things a lot easier now because people care about what I say and I can see what they say. And a lot of people can actually help you a lot. I heard this one girl she actually got a lot of help from another scientist. And that can benefit me...I feel like I can become more easily – what's the word? – I feel like I can become more of a scientist easier with the help of other actual scientists with their knowledge.

Summing up the perspectives of many students, and the meaningfulness of Twitter as a tool for learning, one student articulated the affective impact of engaging with real scientists in real-time via #scistuchat. In her words, "So I feel more like

professional because of interacting with professionals, and especially because we're using Twitter and not as a social media but more as a learning tool."

Teachers. Teachers discussed what they saw as affective impacts on their students in ways that mirrored the points-of-emphasis shared by students. Similarly, teachers frequently alluded to a recognition of student voice, as well as to the ways in which direct interactions with scientists resulted in greater self-confidence for their students.

Like their students, teachers perceived #scistuchat as a forum in which student voice was valued. Often speaking directly to the notion of voice, teachers shared opinions such as "my students have been talking about their voice and how they would like to be heard and how #Scistuchat has helped them do that" and "one of the benefits of Twitter in the classroom is to give every student a voice...I've got several students that's happened with." Other teachers were more specific in connecting the experiences of their students to an increased sense of empowerment and confidence. Addressing the take-aways her students left #scistuchat having realized, one teacher shared "they felt like it was empowering to share their voice. So I think that's something that, maybe as educators, that we overlook."

Not every teacher identified "student voice" so explicitly when speaking of their students' participation in #scistuchat. However, even in these instances, the perceived significance of students interacting directly with others, as well as having their opinions and questions reach a broader audience, was unequivocal. As an example, one teacher shared his experience with a particularly quiet student. In the case of this student, #scistuchat provided a means for him to engage with and, most importantly, share ideas

and questions around science. Recounting this student's experience in #scistuchat, his teacher explained:

I think the first time he participated all he did was retweet the questions...he's been in it probably four or five times now and the last two times...he's had like 30 or 40 tweets, where he's been responding and asking questions and saying oh I understand that, that makes sense now, or sharing a website, and this particular student in class is extremely quiet. Hardly ever talks to anybody. So it was good to see that at least he appears to be interested in what's being covered in the discussion.

Related to student voice, but more directly tied to the experience of interacting with scientists in #scistuchat, teachers frequently referred to their students' increased sense of empowerment. Speaking to the value of an expanded, authentic audience and real scientists with unique expertise, teachers' comments specifically focused on the confidence students gained through their participation. One teacher asserted:

They come in very confident. They're proud of themselves that they participated in #scistuchat and they think that...they have something worth sharing, that their voice is important because scientists talk to them and listen to them. It's kind of a world that I think that they look at as kind of beyond them, that they're not part of that world. And #scistuchat shows them that they are part of that world. We say all the time everybody's really a scientist. And so I think that to an extent, they feel like there's some truth to that through that experience. That it makes it real. They say things like this scientist retweeted me and this scientist said this to me and they're very lifted by that.

Another teacher shared a similar perspective, again noting students' increased sense of confidence and comfort as a result of communicating with experts. In her words:

Students can interact and they have that back and forth dialogue, and I think it makes the students feel more comfortable in that realm in talking with an expert. They're not so far beyond their reach that they can't ask them a question so I think it opens up that avenue.

One of the teacher's above elaborated on specific types of interactions her students experienced within the chat—being retweeted and having their tweets publicly praised—that she felt were especially meaningful to her students. She detailed the following examples:

Now outside of the classroom site, the students were very empowered by having that place where they could share what they knew and they could interact with others. So for example, they would always come in the next day. And I retweet them all the time and it's not really all that cool. But they would walk in the next day and they would be like Adam Taylor retweeted me, did you see that? Or did you see that I talked to a brain scientist for 10 minutes? And it really made them feel like they had something to say and something to share. And when the scientists would ask them questions that they answered back and gave classroom examples...people would say back to them, wow, that is really smart or I can't believe you know that...That chat allows kids to connect, but that also gives them confidence and they then feel special and empowered.

Effectiveness of #scistuchat. In addition to the learning and affective outcomes realized by #scistuchat participants, another prevalent outcome-related topic centered on

the overall effectiveness of the chat. The home page of the chat encourages interested individuals to “Join the discussion between high school students, scientists, science educators, and general science thinkers sharing around current science topics.” Not surprisingly, the nature of such discussions, and the extent to which the design of #scistuchat effectively fostered them, was an inevitable topic of conversation among scientists, students and teachers alike. The following discussion of #scistuchat effectiveness explores the common outcomes referenced by participants that did not fit well within the previous sub-themes of learning or affective impact, but which still had significance in the eyes of participants. In all cases, the discussion centers on participant-generated outcomes that tie back to the chat’s objective of bringing together interested stakeholders in a discussion of current science topics.

Scientists. Throughout the course of my interviews with scientists, references to participation rates, as well as to #scistuchat as a potential doorway to deeper and more meaningful engagement with science, were two recurring outcome-based, effectiveness-related topics of discussion.

At its most basic level, discussion of the effectiveness of #scistuchat among scientists focused on the degree of participation and interaction that occurred within a given month’s chat. Scientists often shared perceptions of how many tweets were being sent and received throughout the chats as well as perceived response rates to student questions. Considering such measures, scientists shared a variety of observations like the following, “I think it was very successful. I think students who participated, who asked their questions, who had their questions accepted by the moderator and tweeted out, I think every one of those got a response from multiple scientists” and, moreover, that

“many of the others who just sort of tweeted questions into the void of the twitterverse, they got answers as well, or at least responses as well.” Other scientists offered similar testimonials to the participation they observed in their respective chats, offering statements such as “I felt that it was effective in getting scientists answering and engaging and communicating” and “It seemed like it did a great job. It’s a type of interaction that I would not have otherwise had except through some account like that.”

While many scientists offered broad observations of participation and response rates, some scientists spoke to specific aspects of the experience that they believed predisposed the rates of participation to be high. One scientist, a participant in the volcanoes chat, offered a detailed account of her perspective:

The scientists who participate in #scistuchat are already generally quite familiar with the medium of Twitter and have learned how to use it effectively and generally are the kind of people who enjoying...reaching out to people on Twitter. And so I think it’s a really great way of taking advantage of that resource and...making a space where it’s okay for students who might be a little trepidatious about approaching these people outside of that context to say okay, it really is okay; you can ask whatever question you want in this context.

Offering even further details about why the forum might be conducive to student questions, she proposed:

And then because there’s more than one expert that’s participating in it, there may be more than one way of approaching an answer to the question. I think a lot of the problems with having student Q&A’s is that students’ questions may not be well formed a lot of the time. And it’s not so much that it’s a dumb question; it’s

just that it's not quite organized in a way that makes it easy to answer. And so the more people you have participating, the more chances there are that somebody will come up with a creative way to answer that question that...encourages them to ask questions again in the future.

Although recounting rates of participation and response in the chats was common among scientists, many looked beyond this basic measure and spoke to the potential the chat has to foster longer term interest in and connections to science. These scientists frequently spoke to the value of the science that was shared and to their belief that #scistuchat has the potential to lead students to more in-depth engagement with science, as a result of interacting directly with scientists from the field and in the lab. Speaking to the value of the science that was shared during the black holes chat, one scientist posited:

To me valuable science is something that, especially in this context, is something that gets students more excited about an area of science and makes them want to continue to pursue it, maybe get a little bit more motivated even just do their homework for their science classes. Ideally, to think again about the value of pursuing a career in science...I think the opportunity to actually interact with scientists is a very important part of that because most people seem to feel more comfortable pursuing careers when they have met people in those careers and realized that it actually is a profession that people can do.

Another scientist shared how she viewed the basic nature of the science that was shared during the green chemistry chat—what she terms “trans-science”—as a positive. As she explains, by presenting her field of study at a more readily understandable,

conceptual level for high school students, the more detailed science of the topic can be left for future study. She stated:

I actually find the trans-science more interpretable in some ways because it didn't delve too deeply into the science. I have seen other science accounts break down the chemistry behind things, but in terms of just teaching about what green chemistry is as a concept, I absolutely think that it was valuable.

Echoing this perspective, another scientist from the same chat shared her take on the science that was shared:

I do feel that some of the guiding principles for green chemistry were really talked about, [including] what that means and how you apply green and think about green and how you make green real and get people to pick up on green.

Speaking specifically to the idea of leaving room for future engagement, another scientist described the effectiveness of the chat, despite the fact that it might generate more questions than answers. She asserted:

So I think that it's a great platform for that, for starting to ask questions, and totally okay that if you leave the Twitter chat and still have questions that haven't been answered. Your teachers admit when they don't know all the answers. And scientists – scientists have a hard time with that one. So, yeah. I think that it can for sure be a great tool to spark good conversations definitely about complex issues that there is no one silver bullet right answer for.

Although many scientists felt that #scistuchat was effective, particularly when viewed through the lenses of response rates and as a potential precursor to more in-depth study, they were not without questions. Foreshadowing some of the perspectives of

students to come, one scientist shared the numerous questions he had regarding the overall effectiveness of #scistuchat. His interest in knowing more about the impact of the experience on students led him to ask:

I think that the one thing that I would want to track if I were watching this is to see how engaged the student users are outside of #scistuchat...Are they more willing to contact scientists that they interact with on #scistuchat? How much goes on outside of that hour time period on Thursday evenings? Do they reach out outside of that? I think that's the one thing that I would be interested in seeing.

Students. Students mentioned participation and response rates in passing, offering statements such as “I made like, I believe like, eleven questions and every one was answered” and “I was pretty satisfied with their answers.” More often, they spoke of an enhanced interest in science and direct interactions with experts as being two primary measures of #scistuchat’s effectiveness. To a lesser extent, but still referenced with moderate frequency, students also referred to an increase in their use of Twitter.

During interviews, students were spirited when discussing the impact that #scistuchat had on their interest in science. Thus, while the learning outcomes students realized through participating in #scistuchat might be ambiguous and focused more on perceptions of scientists rather than content (see “learning” sub-theme above), their belief in the effectiveness of the experience was undeniable. Students across all chats identified an increased interest in science as a notable outcome and as a valid indicator of the chat’s effectiveness. Feedback to this effect ranged from succinct references such as “I’ve always liked science and #scistuchat made it better” and “I feel like I could remember it a little bit better. I actually learned it more than just memorizing it” to more descriptive

accounts of the impact of the chat. For example, one student spoke to the influence #scistuchat had on the attention she gives to science. In her words:

Due to #scistuchat, I'm starting to pay attention more to science type stuff because, I guess you could say, before I had like the wrong idea about certain things or whatever, but now with #scistuchat I'm starting to pay attention a little bit more.

Another student also realized greater interest in science. As she described:

I definitely think I'm more interested in science now... When you do science in school, it's nothing like, oh, you can continue doing after you leave high school or college or whatever, unless you go into the sciences. I know [now] that I can still continue to learn and participate and stuff like that.

Further attesting to the influence of the chat on students' interest in science, another student from a different chat noted, "I never was interested in science before now, and now I find a lot of interesting subjects about random things and that, and I put a lot more thinking to it and a lot more learning with it." Lastly, the following student not only spoke to an increased interest in science—as evidenced by their consideration of science as a field of study in college—but also to the importance of interacting directly with scientists in the field. This student explained:

I think it helped a lot because you could actually talk to people in the field. I have actually thought about studying science when I get to college. I'm not really sure what subject or degree or whatever I should go for yet, but #scistuchat I think in the future will help me figure that out.

Related to sentiments shared in the discussion of the sub-theme “Expanded, Authentic Audience,” many students referenced the ability to connect directly to scientists, in real-time, as an indicator of effectiveness. Addressing this idea, one student explained how he liked the fact that they could converse with “older” scientists. As he explained:

I think it’s really effective, because I liked having many conversations with people I didn’t know, who were older than me... Whether it was indirect, like you had the same question, or whether you were directly having the conversation with them.

Another student also felt that having access to scientists with specific expertise resulted in a richer learning experience. Addressing the notion of effectiveness, she stated:

I thought it was cool because like usually you only have the opinions of people in your class and stuff, so you got to hear opinions of other scientists and their theories and their ideas and stuff. Learn more, I don’t know, kind of broadening it a bit so you got to hear other people’s ideas and theories and I liked that.

Although mentioned with less frequency than enhanced interest in science and direct interactions with scientists, an increased use of Twitter for science and educational purposes was referenced as a third measure of the chat’s effectiveness. Although students did not directly address all of the questions posed by the scientist at the conclusion of the “Scientists” subsection above, they were clear in describing their increased use of Twitter. One student shared, “Now I am using it more often. I like to follow the accounts that give facts about science and biology, chemistry and all that.” Another student noted, “Well, after we did the chat, I started using it more and I follow other science classes and

so when [the classroom teacher] published cool things like that, you just learn more little things every day.” Yet another student described her slight increase in her use of Twitter, as well as her subsequent use of the tool to communicate across the globe. As she explained:

I am not that active on Twitter, but the times that we have...something interesting to say, I will tweet it. And I have been in touch by Twitter with some girls from Australia. We did a project in physics in connection with them.

Teachers. Teachers’ perspectives on the effectiveness of #scistuchat, in all cases, centered on the impact the experience had on their students. Unlike other sub-themes, in this case, teachers did not discuss effectiveness in terms of their own personal outcomes. Their opinions on the effectiveness of #scistuchat blended aspects of both the scientists and the students. Like scientists, teachers identified #scistuchat’s potential for providing a doorway to deeper and more involved learning opportunities as a distinctive, effectiveness-related outcome. Like students, teachers cited the unique ability to engage directly with experts throughout the course of a chat as a second notable and effectiveness-related attribute.

The role of #scistuchat as an introductory forum to scientific ideas, as well as a direct connection to active scientists and their related practices, was referenced by teachers as an important gateway for students. Speaking to this potential, one teacher asserted, “I think it’s the beginning steps...it cracks the door open for something further.” Elaborating on this statement, the teacher referenced another Twitter-based science initiative, Real Scientists (@realscientists). Self-described as “a rotational twitter account,” @realscientists purports to provide followers with opportunities to “get a feel

for what scientists are actually doing locked away in those labs” and to “check out all the things you can do with a science degree.” Comparing the unique access provided by both #scistuchat and @realscientists, she explained:

Yeah, the Real Scientist account on Twitter, it actually has rotating scientists that participate and will run a week-long question/answer thing. And I think also what #scistuchat has done is open that door for those opportunities that may not have existed otherwise.

Sharing a similar perspective, another teacher explained her thinking behind designating #scistuchat as a doorway to further opportunities. In her words:

I think it’s a doorway to a deeper connection that can be had if the class/students/teacher continues to nurture that connection and encourage it. So it’s definitely a big step. It’s having the doorway opened to a very closed world prior to that. I can’t think of any other experience that I’ve ever provided for my students that’s anything like that.

Related to the utility of the chat as a means for connecting individuals who would otherwise have little opportunity or motivation to do so, teachers referenced the conversations between their students and scientists, and the potential take-aways these held, as meaningful outcomes. One teacher recounted her students’ first experience in #scistuchat, and a particularly notable exchange between one of her student and a participating scientist:

The very first one I...participated in, there was a student from our school that was basically going back and forth with a scientist about her college degree and what

field she should go into, what should she major in and minor in, so I think it definitely achieved that goal.

Reiterating the significance she places on the accessibility of the scientists, the same teacher stated:

I think the main takeaway here is just having these great accessible scientists, and how students can directly ask questions about...their future careers and interest more in their field. So I just think the accessibility with scientists probably the main thing that I have enjoyed about it.

Another teacher spoke at length about the accessibility of scientists, how it can impact students and why it should be considered a testament to the effectiveness of #scistuchat. Addressing the latter, she explained:

I think it's really effective to have the interaction with the people whose job it is [to pursue] these ideas. And I think that from that standpoint it is helpful for them to run into actual scientists and see that there's no real one-size-fits-all for that definition.

Speaking to value of connections initiated through Twitter, and in a forum such as #scistuchat, this same teacher detailed the unique possibilities to be realized. She asserted:

I think it goes back to the quote I mentioned earlier about the fact that the world really isn't that big and that it is small enough that you can make a connection on Twitter that becomes – it becomes a valuable part of your growth...you feel you've made this connection with someone that you can now ask questions to, that you put a face to. Even though Twitter's faceless, still you put a face to

what's going on and to somebody who's doing something, and like I said, in terms of students, if there's a field that they're interested in and they're able to date that connection with a scientist who says yeah, I'm here in Chicago, come visit the lab. Where else could I do that besides Twitter?

Elaborating even further, this teacher drew an analogy between the possibilities #scistuchat offers and an annual face-to-face visit in her classroom involving a former student and current scientist. In her words:

I've been fortunate enough in the past to be able to bring in a former student who is pursuing forensic anthropology...and they always get a kick out of it, not because he's a former student, not because he went here, but because he's doing this all the time now...And it just gives them that connection to...a job as a scientist – I'm actually doing this and this is what we do and this is why this was helpful and different things like that, kind of giving them that reminder that there is more than just today and do these things – you can – you may have thought you were going this route but there's this cool little deviation to your career path that would let you do this. That to me is what #scistuchat potentially offers to my students.

Summary. Outcomes related to #scistuchat touched several domains, including learning, affective impacts and overall effectiveness of the experience. In one of the most interesting findings of this study, learning—most pronounced for students—centered primarily on perceptions of scientists and their work, and not on science content related to a given month's topic. In addition to this unexpected finding regarding learning, affective impacts related to the magnification of student voice and students' increased

confidence as science learners, as well as considerable overlap among participants concerning the effectiveness of having real scientists interacting with students, were noteworthy points of emphasis.

Limitations / Challenges

Thus far, this discussion of findings has included an analysis of the “Nature of Interactions” within #scistuchat, as well as an exploration of associated “Outcomes.” These themes, and their related sub-themes, are critical dimensions of #scistuchat and were discussed frequently and, in most cases, positively by scientists, students and teachers alike. This third theme, “Limitations / Challenges,” was also prevalent and one that revealed some of the inherent and logistical shortcomings of the #scistuchat experience.

A defining characteristic of Twitter is its 140 character limit. Within the context of a Twitter chat, and in #scistuchat specifically, this inherent trait of Twitter inevitably shapes the interactions and the take-aways that participants realize. As described above, the advantages gained include interactions that are dynamic and that occur in real-time among an expanded, authentic audience. However, in gaining these unique attributes, the chat also sacrifices in other areas. Participants in this study referenced the pace of #scistuchat, the difficulty some participants had adhering to the chat’s protocol, and the 140 character limit as challenging aspects of their participation.

Pace. Twitter chats are typically fast-paced events. The inherent brevity of tweets dictates that interactions using the medium usually consist of bursts of exchanged tweets. This can be challenging to follow even with small numbers of participants. Twitter chats, with participants numbering in the dozens, are especially difficult to follow. If one is

unaccustomed to Twitter in general, and doesn't leverage some of the tools available to assist in managing the numbers of tweets exchanged in a chat (e.g., TweetDeck, HootSuite, etc.), this task can be overwhelming. Thus, it is not surprising that the breakneck pace of most chats was cited as a challenging aspect of #scistuchat.

Scientists. Scientists spoke most frequently to, and elaborated most on, the challenges presented by the pace of #scistuchat. There was a general consensus among all scientists that the pace of the chat was rapid. Opinions such as, “there was just so much going on and it was really hard to follow any one thing” and “at the time, it just felt quite frantic” abounded. Others described the pace even more dramatically, sharing perspectives such as “after the first five, ten minutes it’s just madness,” and “I expected it to be a little less everywhere all at once.” However, given the inevitability of this reality, scientists spent considerable more time sharing strategies they used to cope with the pace, as well as the frequent realization that keeping up, in a literal sense, was futile.

A common outcome of scientists attempting to manage the quick pace of the chat was simply to abandon trying to keep up with every tweet and, instead, focus on the quality of their interactions. They often arrived at this position during the actual chat. As a participant in the black holes chat shared, “Once I managed to disconnect from the fire hose, I was like okay, now I can take a couple of minutes to compose something and that’s okay.” Similarly, other scientists noted, “So I then adopted a strategy where I just accepted that I was going to miss some stuff” and “I definitely felt like I was missing big chunks of it while I was trying to make sure that I was giving appropriate answers.”

Submitting to the pace rather than to struggling to keep up is often necessary, especially for scientists, as they are faced with the challenge of responding to both

moderated questions as well as questions directed at them by individual students or teachers. Speaking to this reality, one scientist explained:

It's sort of this weird balance you have to strike because on the one hand, you have people tweeting under this hashtag and everything's coming up in real time. And on the other hand, you have people tweeting at you or responding to you and interacting with you. And you can't have both of those things going at once in the same window.

Although such competing interactions *can* actually be placed on one screen through the use of a Twitter chat tool, the challenge of managing interactions is considerable.

Regardless of the approach taken, most scientists identified the pace of the chat as a significant challenge and, in the words of a green chemistry participant, one that “really does force you to think fast and try to be right as fast as possible.”

Several scientists identified specific strategies they used to manage the pace of the chat. Speaking both to the realization that he couldn't see everything, as well as to a specific multi-computer strategy, one scientist explained:

I guess the biggest surprise was the pace of it and that how difficult it was to just sort of keep up with everything that was going on. And then I realized that well it's just not possible, it's not even possible so don't even worry about that. Just sort of jump in when you can and do what you can...I use three different computers and, as an active participant, I'm getting pinged with questions or retweeting what I wrote and I'm trying to be as helpful to the students as possible.

Another scientist found a very large monitor to be helpful. She explained:

I did it on the big 24 inch Mac in my lab so I had lots of space. My notifications in one window, the actual feeds of the moderators in another, and then a general hashtag search in another so I didn't have to toggle through as much, but you could use Tweetdeck for that, too.

Other scientists focused their attention less on the hardware they used and more on the management of their accounts. Addressing this idea directly, a scientist described his strategy:

I would write an answer to somebody and then I would just clear the cache and wait for the next thing, wait for something new to come up that then I could respond to. So once I got that strategy down, it was much more manageable and I sort of let go of the idea that I was responsible for following everything.

While the pace of the chat can be problematic from an account management standpoint, it also has implications for the rate at which information is propagated. The dynamic, fast-paced nature of the chats can result in unprecedented rates of sharing. When information is scientifically accurate, this is rarely a problem. However, when information is inaccurate, such widespread and fast-paced distribution can be problematic. While instances of inaccurate information being favorited or retweeted rapidly within #scistuchat were limited, they did occur. An illustration of this phenomenon occurred during the green chemistry chat. What follows is a scientist's account of the frustration she experienced in trying to lasso the incorrect representation of the word "biomimetic," a term specific to her field of study. See figure 5 to view a portion of the exchanges within the actual chat.

The thing that really frustrated me during, actually, both bioengineering and a more specific example for green chemistry, is how quickly, if any error happens on the part of the scientists or audience, how quickly it gets dispersed...they were discussing biomimetic, and these people were like, what is that? Somehow, whoever typed it, either didn't know or just typo'ed it to bio-minmamic or even, I think at one point it might have been bio-ematic, like you're throwing up biology, and it got retweeted and retweeted and I was just like, replying to everyone, the term is biomimetic, like mimicry, or imitating bio, the term...I was getting hoarse with my fingers, please stop...I didn't want to be like a brat about it but it's also my field, so I'm a little sensitive. I do a lot of biomimetic chemistry and it's like, it makes so much more sense if you know the right word.

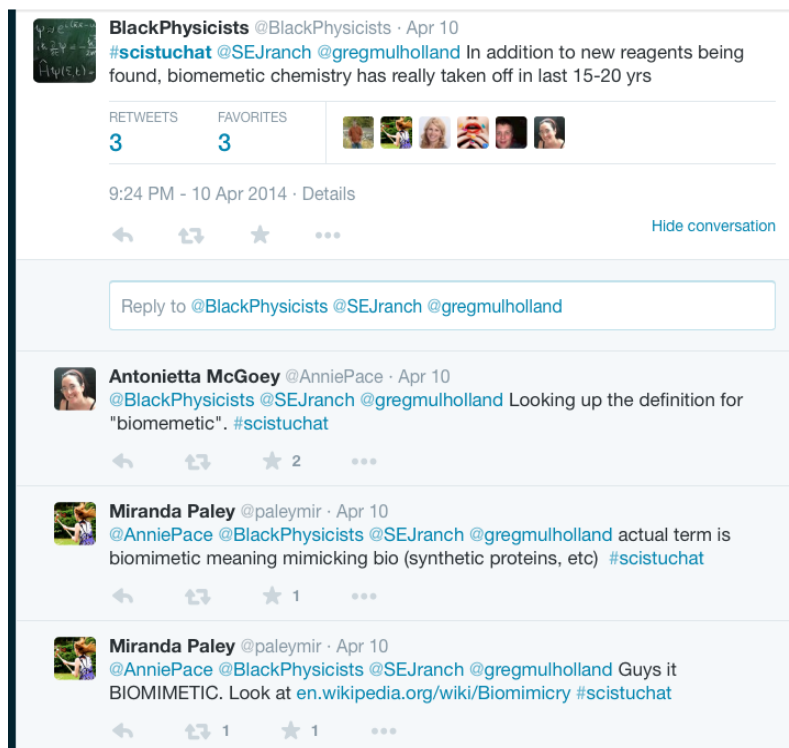


Figure 7. The pace of #scistuchat can result in information, or misinformation, being spread quickly. Here a scientist attempts to clarify the correct spelling of a term.

Students. Unlike scientists, and even their own teachers, student references to the pace of #scistuchat as a limitation or challenge were infrequent. In fact, across each of the “Limitations / Challenges” sub-themes, students referenced these areas of challenge much more infrequently, if at all, as compared to scientists and teachers. While the pace of the chat was the most commonly expressed limitation or challenge among students, a majority of those who addressed this area were actually non-native English speakers. Even though bilingual, the limited opportunities to engage with native-English speakers, particularly in the context of a fast-paced Twitter chat, disproportionately affected these students. Regardless, students spoke to the challenge of the pace in general terms, offering perspectives such as “The fact that the tweets were pretty fast, and trying to read the answer, that was kind of hard” and “The challenges that I find is that with the posts going so quickly, you might be looking for an answer but it might be missed because they’re so fast.”

Other students recognized the difficulty of keeping up but, at the same time, perceived the pace of the chat as a positive feature of the experience. As one student shared, “It’s a little confusing how fast it goes, but at the same time it is kind of neat.” Another student similarly struggled with the pace of the conversation, yet was careful to point out that this was part of the fun of the experience. In his words:

Something that I thought was challenging was that the conversation was so fast, there were too many tweets flowing in. So, at least me, I wasn't able to read every single tweet that everyone wrote. It was too fast, the conversation. But I really enjoyed it and I had a good time.

Teachers. Teacher descriptions of the pace of #scistuchat were mainly based on feedback from, or on their perceptions of, their students. Teachers' feedback about the impact of the pace (again, described through the eyes of their students) ranged from mild to moderate, with some on the mild end even sharing positive associations with the pace, while those on the moderate end referenced missed content as a casualty. One teacher who fell along the mild end of the spectrum shared her students' feedback:

They said they have to constantly be refreshing, kind of going back and looking at things. They mentioned that, but I think maybe they're more used to that as part of Twitter. They didn't seem like incredibly discouraged by it, but they did mention it.

Another teacher from a different chat noted his students' appreciation for the chat. Like the previous teacher's students, his students felt the challenge of the pace, but did not see it as solely a negative. As he described:

At the end, some students were saying – I can't believe this – they said Mr., we think one hour is too little time. So time went pretty fast for them. Well, then one student said something that really impressed me. He said hey you know, I think one hour is fine... That's what makes them fun and makes me want for more.

Although no teacher cited the pace of the chats as a *major* obstacle to their students' experience, several felt the fast-paced nature had at least a moderately negative impact. Citing students' lack of experience with Twitter chats as a contributing factor, and missed content a consequence for many, several teachers shared how they perceived the pace affected their students. Speaking directly to her students' lack of familiarity with Twitter, one teacher explained:

A lot of them haven't done those kind of things before. A lot of them aren't even on Twitter actively, and so they are not used to how fast those chats go and it's hard for them to follow along and keep track of what's going on. They think that they have to engage with every single person, when that's really not a possibility when you have a chat that's flying that fast.

Another teacher referenced her own first encounter with a Twitter chat and, even though her students did not openly identify pace as a challenge, she inferred that they, too, were likely overwhelmed. In her words:

Some don't necessarily feel comfortable in the Twitter chat because after the first two or three [tweets], if you're staying with it, all of a sudden there's like 15 tweets that have gone by...I don't think anybody's outright said they felt overwhelmed, but I know I was the first time, so I suspect that's also part of it.

Other teachers referenced missed content as a downfall of the pace of #scistuchat.

With students' attention divided—responding to questions from moderators, asking questions directly to scientists, clicking on links shared within tweets, remembering to include the #scistuchat hashtag—these teachers felt that there was no way one or more areas could receive the attention of their students. As one teacher explained, “with Twitter in general, it's very fast moving and that would be the only negatives and a lot of things seem to be missed.” Another teacher from a different chat offered a similar perspective. She stated:

I think some of the moderators do a great job of it, retweeting the questions, but I still think that it's kind of fast-paced. And I think that...students are still learning things, but I think that probably...they're missing a lot of what's going on.

Organization. A Twitter chat typically brings together individuals who, for a variety of reasons, could not otherwise meet and share the same physical space. Although chat participants often share similar interests, there are no formal prerequisites for participation beyond a functioning Twitter account. Thus, participants' familiarity with Twitter, prior experiences participating in chats, attention to chat-specific protocols, and general focus on the task at hand all function to affect the overall flow and feel of the chat. In the case of #scistuchat, where different populations of individuals are gathering in a unique digital forum, the variability of these factors, and their impact on the chat as a whole, can be especially pronounced.

Interestingly, in this study, scientists cited the organizational and procedural challenges associated with their participation in the chat far more than did students or teachers. In particular, individuals' adherence to the chat's protocol and role ambiguity were the two areas of challenge most often discussed.

Recognizing that participants come to #scistuchat with varying Twitter backgrounds and skill-sets, the organizer of the chat offers a five minute video tutorial on the #scistuchat homepage. The format of the discussion is also described in writing. For reference purposes, I have shared this description of the format of #scistuchat below. On the homepage, the discussion format is laid out as follows:

1. We will have a series of questions for students and scientists to answer. The format will be as follows.
 - a. Questions will be posed-
 - i. Q1 What is DNA?
 - b. Student and scientist responses -
 - i. A1 DNA is a blue print of the body.
 - ii. A1 DNA is made of nucleotides

- c. Students and scientists are encouraged to Retweet questions before they start writing their reply, this will help more people see the question.
2. The questions will get deeper and will begin with Q1, Q2, Q3. Responses to questions should start with A1 A2 A3 depending on the question. Eventually the questions will lead us into our focus question
 - a. If DNA can tell you when you are going to die, would you want to know.
3. The focus question will start us on the path of ethics behind using DNA to decide whether or not to hire people or insure them.
4. We need to encourage students to ask thoughtful questions and to address someone specific.
 - a. Questions by students put out the whole group are less likely to be addressed. Thus resulting in frustrated students.
5. We want to encourage students to talk to each other and the scientists

Scientists. Scientists, to a much greater degree than students or teachers, described organizational issues associated with their #scistuchat experience as a noteworthy limitation. The most significant aspect they discussed was participants' lack of adherence to the delineated protocol (shared above). Also significant, but to a lesser extent, they expressed difficulty in being able to always understand participants' roles (e.g., moderator, students, teachers).

While observing the chats in this study in real-time, the lack of adherence to the protocol was easy to spot. Usually involving students, these instances included errors like asking individual questions randomly to all participants and labeling individual questions with Q1, Q2, etc., which should be limited to moderators. Not surprisingly, given that most of the scientists described having viewed the discussion format resources or previously participated in #scistuchat, they found these violations of the protocol challenging to work through. These procedural transgressions were perhaps most evident in the black holes chat. Describing these instances, a scientist in this chat explained:

Supposedly there are moderators, but first of all students seemed to be tweeting directly to me or just tweeting to no one...I was confused as to whether or not I was supposed to answer those or only answer the moderators' tweets. And then there was supposed to be some numbering system. And it didn't really seem to work. Like I saw Q1, Q2, Q3. So I was trying to answer A1, A2, A3. But then there was another Q1. So...it seemed to be a little disorganized.

One scientist who participated in the human genetic engineering chat, and is a regular #scistuchat participant, stated, "Well, I feel like the most recent one was the least well organized that I've seen. It seemed a lot more haphazard." Elaborating further, she explained:

Several people were asking questions at once. I think part of it might be that it is expanding in its scope as to how many students are actually there...the students who are regularly there know the format and those who join in – I'm excited that they are like, oh, my God, scientists! But jumping in on some of those questions sort of detracts from some of the main educational objectives [and] some of the questions that were already sort of prescreened.

Having experienced the challenges noted by the scientists above, a participant in the green chemistry chat offered a recommendation for possibly addressing some of these issues. She proposed:

Maybe opening and then closing discussion to Q1, Q2, Q3 might give it a little bit more defined kind of progression and feel...the first question obviously is what is green chemistry and 25, well, 45 answers appears in the first 30 seconds or so, so people don't necessarily need to still be answering that question 30 minutes

in... they're still going to have people sort of not catch that or filter and pass, but a kind of beginning, middle and end might help.

In addition to the challenges related to protocol, scientists also expressed confusion over participants' roles as a detractor from their #scistuchat experience. Speaking to a recommendation they would offer to improve the chat, one scientist explained how she felt that students were not clear regarding who the actual scientists participating in the chat were. In her words:

Maybe that's easier said than done, but more organized in the sense of more clearly having...certain people who are definitely the scientists and that all the students know who the scientists are at the beginning. It wasn't really clear to me that the students knew who the scientists were.

Other scientists shared how they, themselves, had trouble understanding who the students were. They offered perspectives like the following, "I'll be honest with you, it's hard to keep track of who is a student and who isn't." In addition to feeling as though students and scientists had a hard time recognizing each other, scientists occasionally expressed confusion regarding who, exactly, was moderating the chats. As one scientist shared, "And I guess I wasn't 100 percent sure. I thought I know who was the moderator but then I wasn't 100 percent sure about that, so I didn't know who I was supposed to respond to." Another scientist was even more blunt in his assessment: "This may just be a personal thing...when people were imitating the moderators...I just needed to figure out what was going on. And then once I did figure out what was going on, it was annoying."

Students. Students, surprisingly, had very little to say about challenges

related to the organization of #scistuchat. Perhaps because they are so focused on their own questions and interactions, and because the pace of the chat is so fast, students did not seem to recognize the same challenges that were so prominently encountered by scientists. The only area that students spoke to, with any degree of genuine concern, was that of moderator ambiguity. Like scientists, some students found that when others posed questions prefaced with Q1, Q2, etc., the practice not only violated the chat's protocol, it also added a layer of confusion to an already fast-paced, challenging event. In the words of one student (and supported with um-hums from her classmates):

There are people who do ask questions during #scistuchat, which is fine. However, we do have moderators who are the ones that ask the main questions and sometimes somebody else will try to do what the moderator is supposed to do and ask a question a certain way. And I kind of would change it to where everyone knows that the moderator is supposed to ask the main questions and, for the separate questions, you ask a scientist.

Teachers. Like students, teachers did not identify organizational challenges associated with #scistuchat as especially notable. One teacher spoke to the somewhat unique aspect of the #scistuchat protocol that encourages students to ask a scientist specific questions by “mentioning” them in their tweets, as opposed to simply posing questions to all participants in the chat. He explained:

Because that's one of the rules. If you have a question for a scientist, mention that scientist, which is not typical. The typical structure of Twitter chat... is one moderator that moderates the question and everybody contributes to that question.

And if you have a question, you make a question to the whole community of chatters.

Sharing his efforts to make this norm of #scistuchat clear to his students, this teacher offered how he attempted to guide his students. “So I told them the first thing you have to do is identify the scientists. If you have a question, mention that scientist. Go mention the scientist. And that’s what they did.” Interestingly, although the teacher recognized this practice of mentioning a scientist when asking questions, and shared the expectation directly with his students, looking back through the archives of the chat they participated in, not all of his students took this approach during the actual chat.

In my interview with the creator of #scistuchat, a science teacher and participant in my study, he spoke to the same issue of moderator confusion identified by scientists and some of the students. He explained, “Recently there’s been confusion and people have thought if they want to ask their own questions, they have to include Q1, Q2 as well, when that’s only supposed to be for the official moderators.” Explaining his role and, specifically, his efforts to address issues around the organization and flow of #scistuchat, he offered the following account:

Currently my role is more of helping remind students or scientists how the discussion runs. I start sending out...the protocol. Here’s the video about how to participate and so on and so forth. So that’s what I do during the actual chat, is just kind of organize that and then I send them background. I try to answer questions when I can or guide questions or remind people to use the hashtag or whatever. Then I also gently guide the moderators. Usually once we get them started, they’re good to go.

140-character limit. Tweets are limited to 140 characters. Any part of a tweet—whether it be text, a URL, a photograph, a video, or other people’s Twitter handles—uses characters. As a result, tweets force users to condense thoughts and to communicate ideas as succinctly as possible. For most individuals, communicating via tweets is an exercise that, at least to start, resides outside of their regular communication patterns. For people new to tweeting, and new to participating in chats, these unique communication demands can be difficult to adapt to. Even for seasoned Twitter users, the act of composing a meaningful tweet, especially within the context of a fast-paced, real-time chat, can be challenging. Participants in #scistuchat identified Twitter’s character limit as a challenge to their participation. As with the previous sub-theme of “Organization,” scientists far outweighed students and teachers in terms of the frequency with which they mentioned the character limit, as well as the degree to which they discussed its impact.

Scientists. Twitter’s 140-character limit was mentioned regularly by scientists as a limitation of #scistuchat. The general consensus was that the inherent limitations of Twitter made communicating science within the context of #scistuchat difficult to do, when compared with other more traditional forms of communicating (e.g., face-to-face conversation, blog, email). Statements such as “I think that the format is maybe a little bit limiting because you don’t really have that in-depth a conversation” and “Twitter is what it is. It’s hard to get across big ideas in as few characters as you’re allowed,” abounded. This phenomenon can be particularly challenging if one tends to be loquacious. As one scientist who characterized herself as verbose noted:

Once you start providing examples, you run out of space real quick. I’m a kind of verbose person so Twitter is always hard for me. I feel like I waste so

much more time deleting tweets back down to get them under 140 characters than I would have ever spent writing on them in the first place. So sometimes I'll get questions and I'm like, oohhh.

When further probed, scientists expressed concern that they were unable to convey exactly what they had hoped and that, as a consequence, they were not sure what the take-aways were for their audience. Articulating a sense of restriction, one scientist shared, "I felt like during #scistuchat, that something was holding me back. Because I was like alright, I want to respond to this question. Now how do I do it in a way that's going to be short...but also interesting."

A scientist in another chat noted a similar challenge in attempting to craft tweets that would resonate with the audience of #scistuchat. In his words:

I don't know whether it's talking with kids or whether it's from using Twitter as a medium itself with the 140-character bursts, you really have to think about how to put a statement that you might want to say and do it in such a way that...what you want to say can't mean anything else. There has to be one meaning to what you're saying and you need to get your point across.

While reflecting on their attempts to communicate specific science ideas in #scistuchat, numerous scientists wondered aloud how, if at all, their intended points were received by their audience. Not surprisingly, most lamented the lack of space and the fleeting nature of the interactions. Speaking about tweets composed of text only, one scientist explained:

The three tweets that I did which were just character tweets, I'm not sure...how much they got out of that because I could have really gone into like a huge amount of detail. I'm not sure if my point came across.

Another scientist reflected on the nature of their response to a specific question, and their desire to have covered it in more depth. She shared:

For example, that's a rich question that gets at a lot of sort of fundamental physical concepts that I think you can develop. I'm not sure it got developed as far as I would have liked to, like for example, in a classroom. I would have loved to spend 10 minutes talking about that. And it didn't ever really go very far with any individual person.

One scientist's point summed up the feelings of many. He stated, "I don't feel there's a lot of depth or refinement. A lot gets thrown out and very little gets developed."

While the 140-character limit clearly presented a challenge to participating scientists, the ability to include links—to websites, videos, images and blog posts—provided a means to expound. Although not used by all scientists, this strategy of linking to other resources was referenced regularly throughout my interviews. Reflecting on her first #scistuchat, one scientist shared how she would approach subsequent chats and, specifically, how she would anticipate potential links to share. In her words:

If I did it again, I'd be more effective if I prepared a little bit, if I had some links that I could immediately drop into a tweet, or if I even thought a little bit about what are the likely questions they'll come up with and maybe think about how I can express things concisely.

Other scientists capitalized on the ability to add links to their tweets during the chats they participated in. Explaining her rationale for including links, one scientist shared:

Usually I try to find, in terms of links, either a popular press article from *Scientific American* or one of the ones that's sort of a more reputable blog or a video, because I think that the students tend to click on--videos, or the, I guess the sexier presentations of science more.

Another scientist shared an instance in which they were able to include a link, in the form of a visual graphic, as part of a reply to a specific student question. Speaking to the power of a visual, as illustrated in Figure 6, he explained:

So when someone asked that, I was able to just give a tweet and respond with that image. I felt like that was kind of noteworthy because now some people are going to see this, and maybe having this graphic explaining it is going to help a lot more than you can in just words. Because honestly, it's fairly sophisticated theoretical physics...they say a picture is worth a thousand words. Well, I hope it's worth at least a thousand characters because you can say a lot more with that than you can in just a tweet.

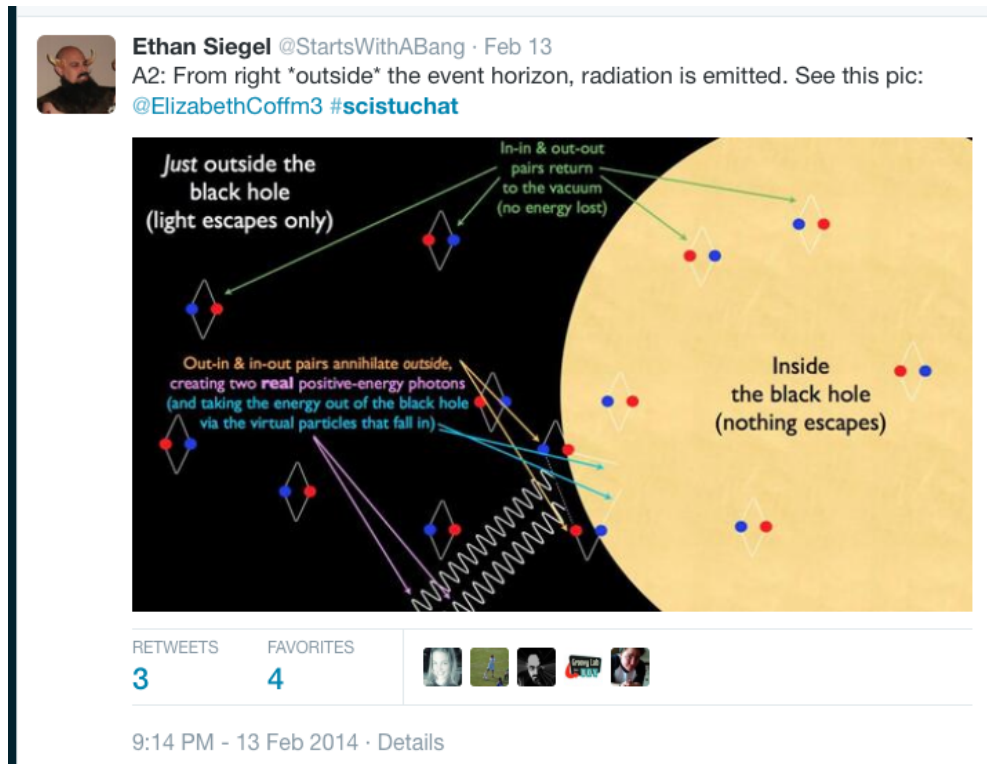


Figure 8. Graphic shared by scientist during black holes chat. Including visuals in a tweet allows one to convey greater detail than can be included in just 140 characters.

Students. Students did not reference Twitter’s 140-character limit as a limitation or challenge to their participation in #scistuchat to the same extent as their scientist counterparts did. However, students in the black holes and volcanoes chats did speak directly to this restrictive feature, as well as the impact that it had on their participation. One student in the black holes chat recounted how their participation in #scistuchat was their first time ever using Twitter. Reflecting on the challenge of writing concise tweets, she explained:

I hadn’t done Twitter before. It was my first time like ever on it so you could only type a little bit. Because I wrote these big things and I could only send like a little part of it. That was the only thing I had a hard time with.

Other students, participants in the volcanoes chat, offered more detailed accounts of the challenges they, and their peers, faced in trying to work within a 140-character limit. As one student explained:

With Twitter, you can only have so many characters to state your answer. And sometimes people go overboard and...they can't fit their entire response on the one tweet. So it can be difficult to make a summary of your response and put it all into one tweet, which I've found difficult before and I've had to get rid of a few words.

Another student from the same chat spoke to both the challenge of a character limit and the usefulness of links as a means to explore a topic more deeply. In her words:

One of the strengths I found in Twitter was, like she said, you can attach links to it. I think that's really interesting because you can look at the answer and then you can look further into the answer that someone else had. And also I think Twitter provides kind of a challenge because it has that limit on words. And for some people that's not much a challenge because they don't use many words. But I like words. I like talking. And so answering questions in Twitter is a challenge because I have to state my answer in like the limit. And I think that's really interesting to see how that works out.

Teachers. Interestingly, teachers made few, if any, references to Twitter's 140-character limit as a significant obstacle to their or their student's #scistuchat experience. Perhaps due to a focus on other factors, or the legitimate possibility that the limitation of characters was truly not a significant barrier to their participation, the absence of this concern on the part of teachers was notable.

Summary. Scientists, students and teachers recognized certain limitations and challenges associated with their participation in #scistuchat, including the pace with which at chat occurred, the organization and flow of the chat, and the 140-character limit per tweet. Scientists' awareness of these limitations and challenges, as well as the depth of their discussion, was greater than that of students or teachers.

Formal vs. Informal Learning

The fourth and final parent theme specifically related to #scistuchat explores the notion of formal vs. informal learning. Aspects of #scistuchat enable it to be considered as both a formal and an informal learning experience, depending on the vantage point from which it's considered. Formal learning is typically associated with "in-school" learning experiences, and often occurs within a teacher or standards-driven framework. Informal learning, on the other hand, is typically associated with out-of-school learning experiences and often with no direct reference to "learning." These endeavors are driven primarily by the motivations and interests of the individual, and have less-defined parameters, rules, goals and objectives.

Characteristics of #scistuchat consistent with formal learning experiences include the fact that virtually all students learn of the chat through their high school science classes, participation by some students can impact their science grade, and that the chat itself has a defined format and timeframe. Aspects of #scistuchat consistent with informal learning include the fact that participation happens in the evening outside of the school setting, participants can come and go within the chat as they please, and interactions within and outside of the moderated series of questions are encouraged. In exploring participants' perceptions of the formality of #scistuchat, several areas emerged as

important. These dimensions, including a sense of freedom, the fact that #scistuchat occurs outside of the school day, and the convenience afforded by the medium and the time of day, are all discussed in more detail below. Each of these characteristics ultimately makes #scistuchat decidedly informal in the eyes of participants in this study.

Freedom. The notion of freedom was a common thread in virtually all interviewees' comments related to the formal vs. informal nature of #scistuchat. Whether directly comparing and contrasting #scistuchat with in-school experiences, referencing an ability to pursue individual lines of inquiry, or entering and leaving the chat when and how convenient, participants repeatedly spoke to a sense of freedom as a pervasive and distinctively informal dimension of their experience.

Scientists. Scientists recognized the open nature of the chat, both in terms of who was able to participate and the direction of the conversations. They frequently alluded to these freedoms in general terms and, in multiple cases, drew analogies to more directly illustrate their perceptions of this dimension of the chat.

When asked about their perceptions of #scistuchat as either a formal or informal learning experience, scientists most often described it as being more informal than not. Reasons for leaning towards an informal categorization were variable, but often centered on the notion of freedom. One scientist reflected:

And so I think [#scistuchat] does provide a way for participants to, if something in particular intrigues them...go follow that. They can just leave the chat and go do whatever they want, or they can mark it for future reference and go check it out later and just follow up on whatever is of specific interest to them.

Lastly, another scientist explained:

One of the nice things about #scistuchat and on Twitter in general when you do a chat like that, and I'm of course extrapolating here, but it's that you don't have a moderator necessarily in between everything.

Sometimes scientists directly addressed the rigidness confines of traditional learning experiences and their measures of assessment. Speaking to the benefits of interacting via social media, one scientist shared her perception of the freedom gained when compared to a more traditional setting. She stated, "You really can't have that [freedom] in the absence of social media because any other avenue is structured. There's a long, tedious, structured process." Other scientists, sharing a similar perspective, contrasted #scistuchat against what she perceived as an educational backdrop with misplaced priorities. One shared, "I don't think those kinds of engagement or learning are supposed to be rigid. I think it's informal and I think it's impractical to think we're going to be able to fit it into a box." Lastly, a third scientist noted the uniform, standardized approach to evaluating students, and the benefits he believed #scistuchat possesses in comparison. In his words:

Having a conversation versus a standardized test is – that's two different things.

And there's something you have in the conversation that you can't elaborate on a standardized test, because if it's multiple choice, you've got to pick the correct choice.

Several scientists used insightful analogies to illustrate the informal and open nature of #scistuchat. The following analogies offer two particularly helpful windows into scientists' perceptions of #scistuchat experience. One scientist drew an analogy between #scistuchat and parties. In he words:

If I can visualize [#scistuchat] off Twitter, I can visualize what would be happening in real life, actual people, it would be much more like a party than it is a lecture...people break off into smaller groups, people deal with smaller things, and everyone's experience is a little different. So a party itself is inherently chaotic. There's no way to control it while you're at a party. Same thing, there's no way you can control it in the Twitter format we're in.

Another scientist described #scistuchat as a “question fair.” In his mind:

It would be like a question fair, similar to a job fair. You take the school bus of people who are interested in whatever the topic is, you drive them into like a multipurpose room, and then you let them free. And then some people talk, other people...break off into little cliques...some scientists are talking to each other, but very generally you have people in their little niche tables, so I'd say like a job fair except with questions. A question fair that would probably be the best way to describe it.

Students. Students recognized #scistuchat is being fundamentally different than many of their in-school experiences. In their eyes, school is a place characterized by rules, assignments, and structure—generally not an environment that embraces freedom. In contrast, students described #scistuchat as an experience in which they felt free to engage in whatever way that seemed appropriate to them at the time. In the words of one student (supported with sounds of agreement from his peers), “I think all of us wanted to do it for like learning and seeing how it goes. Just get exposed to it, and if they like it they can continue, but if they don't they can just stop.” Another student from a different

school shared how her participation, like that of a fellow interview participant, stemmed from her intrinsic interest, and not the promise of extra credit. She shared:

That's the same thing with me. Like I had the extra credit but I wasn't too worried about it. I kind of just did it because I wanted to. I think that might be the reason some kids in our class did, but they weren't the ones that participated as much. Like the ones who really actively participated were the ones that were interested in it.

Other students, participants in the volcanoes chat, offered a similar perspective. They directly contrasted their experiences in a traditional school setting with their experience in #scistuchat. In the words of one student:

I wasn't like dreading doing it...I think it made me feel more grown up, I guess. Because in school, they almost hold your hand in everything that you do. I felt like we really could voice our opinion on an answer and put our knowledge into it and get a response back...Normally the message is don't talk to anybody about the questions. It's not like – I don't think it's like copying off someone. You build off each other's answers.

Another student who participated in the same chat explained how impactful #scistuchat has been on their thinking about science, specifically pointing out how different the experience was compared to school. She shared:

I think if you told me last year I was going to spend an hour of my free time doing science, I probably would have thought you were crazy. But it's not how I would associate most things of science, because it's just different. You do stuff on your own. It didn't feel like school.

Teachers. All of the teachers I interviewed described #scistuchat as being considerably more informal than formal. As one teacher explained, “I present it to students as informal...informal in a good way. I told them, guys, if you want to join, go ahead join. If you don’t want to join, it’s okay.” When asked to provide rationale for why they classified #scistuchat as informal, other teachers offered similar reasons. One teacher-participant in the black holes chat shared this explanation:

I don’t require them to do it, and maybe if I required them, I would say...this is the topic we’re talking about and you all need to go on there and do it and then we’ll come back in and discuss it...I’d do some activities that are related to it or something like that. I think that would be more formal, but outside of the classroom, and there’s no one like really me pushing to do it and making them do it, I would say that’s more informal.

Another teacher shared a very similar sentiment:

To me it’s informal because there’s not a set goal at the end. You’re not going to do this, this and this so that this is the outcome. The outcome is much more ephemeral, much more undefined. It’s a general let’s just learn a little more about this topic, which almost allows it to be very self-paced, very on your own terms...You don’t have to go from A to B to C to D, and then we’re going to talk about this topic. If you want to go in 10 directions, there’s probably somebody here that can help you with whatever direction you’re going in. And so I think it leans itself more towards that idea of just, I’m interested and so I want to learn more, which very much I think falls into kind of that informal kind of learning environment.

Elaborating further on the role she plays during the chat, and how that role differs in #scistuchat compared to her classroom, she stated:

I want them (students) to just kind of interact with everybody else because it is outside of class time. It is now a completely different conversation. And so I actually don't deal with them in that traditional sense of okay, I'm still your teacher online. No, this is a digital thing; this is an opportunity to talk to everybody. I kind of give them the parent reminder – this is a reflection of you. It's a digital footprint type idea... Now you're in this microcosm with people that if you are pursuing science, they might remember this conversation, both good and bad.

Lastly, in describing #scistuchat, including why she believes that it is an informal experience, a teacher from the volcanoes chat offered the following account:

The way I describe it to other people is it's very organic. There are questions thrown out, but the spirit of it is for students to interact with scientists and interact with each other and to have conversations, not to contain them into just a Q&A format, but to have those conversations and explore interests. So even if there's a topic and a framework, I would consider it more informal in that it's about the interaction.

With an understanding of why teachers considered #scistuchat to be an informal learning experience, it was interesting to explore whether or not they deemed this a positive or negative characteristic of the chat and why. All teachers perceived the freedom #scistuchat offers students, in their eyes a key aspect of its informal nature, as distinctly positive. As one teacher described:

I would say one of the advantages for informal is that they're making the choice for themselves and those kids that are really, really interested in it aren't wasting my time on, like, I don't know, negative interactions in the classroom when they don't want to participate. But students, if they're in that informal realm, they can make their choice and if they want to do it, they'll do it, and they'll extend their learning, but I don't have to do anything to make that happen.

Another teacher describes how she believes #scistuchat is a more engaging experience than many of their students' in-school opportunities:

That informal setting, I think, is more engaging when it comes to learning.

Whatever is learned, whatever reply the scientists gave to them, I think the ahhh factor – you know what I mean – they say ohhhhh, so that's how it is.

Speaking to the benefit of students being able to pursue their own questions, another teacher pointed to science-based interactions motivated by personal interest, as a primary advantage. In his words:

Somebody asked, can we ask our own question? And I'm like, of course. I don't care if you get off topic. I don't care if you go a different direction, as long as you're talking science with a scientist. And I really can't try to control that anyway. I mean if they want to talk about other things, that's fine. They're having communications and I'm happy.

Elaborating further, the same teacher explained his desire to have his students' chat experience be distinctly different than school. He stated:

I think of it as basically unrelated to school...A lot of the topics aren't even in any of the curriculums I teach. So I want it to be informal and I want it to be off topic

just so they can explore another aspect of their world, or of science, or of popular scientific issues.

Out-of-school. Because #scistuchat takes place on a weekday, once a month, at 9:00pm EST, it occurs entirely outside of the school day for any participating students and teachers in the United States. For students, the fact that #scistuchat takes place well outside the confines of their school day, yet remains associated with their science class, challenges their conceptions of what constitutes science learning. In this second sub-theme of the “Formal vs. Informal” parent theme, students’ voices are represented almost exclusively. Across all four #scistuchats, students in each focus group alluded to grappling with the idea of a science learning experience residing so clearly outside the boundaries of school, as traditionally defined.

Scientists. Scientists, because they have so little direct connection with high school science classes, and are not tied in any way to a typical school day or schedule, did not speak to the idea of #scistuchat occurring outside of school to any significant degree.

Students. Across all chats, students described the novelty of participating in an event outside of school that focused on a science topic. For many, their notion of learning, specifically applied to instances outside of the traditional framework of school, was also challenged. Yet, in all cases, students spoke positively about their experiences as participants in #scistuchat. Reflecting the challenge of categorizing the #scistuchat experience and, in particular, the difficulty of teasing out the subtleties between learning inside and outside of school, one student attempted to describe how rare it was to learn outside of the classroom. He stated, “Learning outside of school, that doesn’t happen

very often, at least for me, so #scistuchat, being able to learn outside...I mean, I'm trying to think of how to phrase it for you.”

The challenge of how to phrase their thinking around the role #scistuchat played in their learning of science, as well as the significance of this happening outside of the school day, was a frequent sticky point for students during focus group interviews. Despite the challenges of articulating their experiences, interesting perspectives emerged on the positive influence an informal experience can have on students' learning. For example, as one student-participant in the black holes chat shared:

Well, it was nice not being so formal. But with astronomy, you don't think about a whole lot outside of school all the time, but it was cool to be able to think about it outside because you kind of thought of things usually you wouldn't come up with while you're sitting in class and stuff like that. It was kind of cool. I liked it.

Another student who participated in the same chat shared a similar perspective:

I've always really liked science. It's one of my favorite subjects, and so being able to learn outside of school is cool because you usually don't think about it at all outside of school...But I feel to do it outside of that, you gotta kind of apply it more to stuff around you and things like that. I don't know if you could apply black holes to all things, but the whole communicating with other people about it and learning other people's ideas is cool.

Many students reflected on the blurring of lines between in-school and out-of-school learning and, in particular, on the realization that learning can happen well beyond formal schooling. For example, as a student in the human genetic engineering chat noted:

Well people tend to, like, close off learning after they leave school. So it's like, oh this is my learning time and then after I leave school I can do whatever. But to know that you are still in the process of learning, like you're never going to learn everything so it's like, you kind of, I don't know how to phrase it, you kind of get to see that not everyone is in school, but they keep learning. So why can't you keep learning while you're not in school? Because I mean scientists, that's what they do for a living. They just inform people and learn more while they're informing people.

Another student described his excitement in realizing that learning can happen outside of school. He shared:

You would think that only school is the only place you can learn that. I mean some people will try to drill that into your brain, but to be able to still learn even when you're not in school, to be able to talk to scientists and everything, that feeling is unlike anything I can think of right now.

Student-participants also spoke to the unique nature of engaging in science learning at night. Notably, several mentioned their participation in the chat positively influencing their overall approach to school. One student shared:

I describe it as a positive learning experience because it could be used as a motivator to stay in the news at school. Like usually when I leave school, my brain just kind of goes off of school. But #scistuchat brought me back to school at home, so that could be used as a motivator to actually do schoolwork.

A student from the green chemistry chat explained how it took some time to adjust to #scistuchat and realize all of the ways in which it connected to her classwork. In her words:

It didn't really seem school related to me, not really at first. It was just kind of like, okay, I'm going to get on Twitter and then I'm going to go tweet with this hashtag. But then, once I got into it, like we pulled topics from what we've learned in class and it got easier to communicate as I thought more about what we got in class, then it became more school related as time went on.

Lastly, students in the volcanoes chat also reflected on the non-school feel of participating in a science-focused event at night. Contrasting her chat experience with her more formal in-school experiences, one student asserted:

I think we enjoyed it more because, after sitting through two classes, you don't want to learn any more. But then you go home and you're like – well, I get to be on that then, and I'm still learning and it's a different experience. Instead of just sitting in a classroom with textbooks around you. You just feel different.

Teachers. On the whole, teachers did not speak in depth about the out-of-school nature of #scistuchat with regularity. However, the idea of out-of-school engagement with science was addressed on occasion. In these instances, teachers articulated the reality that learning for today's students does not have to be confined to the classroom or to a textbook. For example, contrasting traditional book learning with the ability to connect with actual experts from the field, one teacher shared:

Hey, we're going to learn about the nervous system. Mr., what page? No, no, no, we're going to go to Twitter, tonight, 8 p.m. Go in and you're going to join

scientists and neurologists and scientists who know about this better than the teacher. So I think that's great.

The same teacher shared how such an informal experience can free students from focusing solely on grades and, instead, focus on their own true questions as well as on the quality of their interactions. He explained:

I mean learning is no longer bound to school only. Kids can learn anytime, anything, anywhere. So the fact that this is not in school, the fact that this is a kind of informal learning, the fact that they are not going to be quizzed about it – the first thing they ask is, is this going to be on a quiz – I think that is the factor that makes the learning more significant.

Another teacher from a different chat explained how a primary goal of theirs was “just helping students know that they can talk to scientists and science is everywhere and it doesn't have to be only in the classroom.”

Convenience. #Scistuchat offers unique access points that many participants in this study deemed convenient. The fact that #scistuchat occurs at 9:00pm EST, that participants do not have to be in a shared physical setting, and that participation can occur via a variety of electronic devices, enables participants to engage in the chat despite often residing in extremely disparate circumstances. Although most often perceived as convenient, the ability for #scistuchat to reach so deeply, and so easily, into people's schedules was seen by some as having the potential to be intrusive. In interviews with scientists, students and teachers, the variety of settings in which participants resided during the chats was especially notable, as was the array of devices used to participate. As with other “Formal vs. Informal Learning” sub-themes, students discussed instances

of the chat's convenience more frequently and in greater depth than did scientists and teachers.

Scientists. Participating scientists did so across a variety of settings, while juggling commitments ranging from rock climbing to putting their children to bed. In considering #scistuchat through a lens of convenience, the vast majority perceived its evening timing and the ability to use a range of devices as positive. Speaking to this dimension of convenience, one scientist put forth an argument for why participation, in her mind, is so easy. She explained:

It's really hard to be able to commit to doing something ahead of time. And if you can just tell someone, oh, it's going to be on Twitter, you can do it from your phone or whatever. I don't have a smartphone so I usually use my computer, but I know friends that, they tweet all the time, they're on their phones or whatever, they can do it from wherever they are. It's not dependent on their travel schedule, either. So everybody's always going somewhere. So you can just say, well it doesn't matter that you're in Ohio this week or in California or in Hawaii. Just at that time, be online and you're golden. So I think that that really helps grab a lot of people because it's like, look, it's an hour, you don't have to organize it yourself, there are tons of kids that you can reach...It's just so easy to do. Like, there's no reason not to.

Attesting to the convenience described above, another scientist from a different chat explained how she simply took a break from rock climbing with colleagues, one of whom also participated in the chat. She shared:

We were actually rock climbing at the time. Yeah, I had to take a break to be part of the chat, so she helped me at first with the first few questions, but then she went back to the rock climbing while I answered the rest.

Given the convenience and the ability to participate across a variety of settings, including home, it was not surprising to hear scientists share instances when they were forced to balance participation in the chat with their personal lives. Multiple scientists shared the challenge of participating while maintaining family commitments, such as dinner and putting children to bed. Regarding the latter, specifically, one scientist recounted:

I kind of had to go back and forth because about that time is also bedtime for our 2-year-old. He tends to be a little later than the average 2-year-old in terms of bedtime. So there I had to kind of depart for 5 or 10 minutes...I had to leave behind everything that happened in between and come back to it. So I was trying to pay as much attention as I could but it's hard to just sit there and focus on it at that time of the evening if you're not someone who doesn't have any other distractions.

Students. Students participated across settings more diverse than either scientists or teachers, and utilized the widest of variety of digital devices. Because participating students span several grades (typically 9-12) and are often involved in numerous extracurricular activities or forms of employment, the settings in which they accessed #scistuchat varied widely. Students in this study participated in settings as varied as Buffalo Wild Wings, tutoring jobs and play practice. One student described her experience participating while out to eat at a restaurant, “Well, when I did it, I was at

Buffalo Wild Wings. It was just weird because usually I'm not using my phone a lot when I'm eating out or anything. But I don't know, it was kind of cool." Another student participated with a classmate while both were attending their play practice (see Figure 9).

In her words:

For me, I was doing it at play practice. And there was another girl in my play practice that's also in our astronomy class, so she was participating at the same time as me and we could talk about it as well, which was kind of cool. It was cool not being at school, outside of the classroom and everything like that.

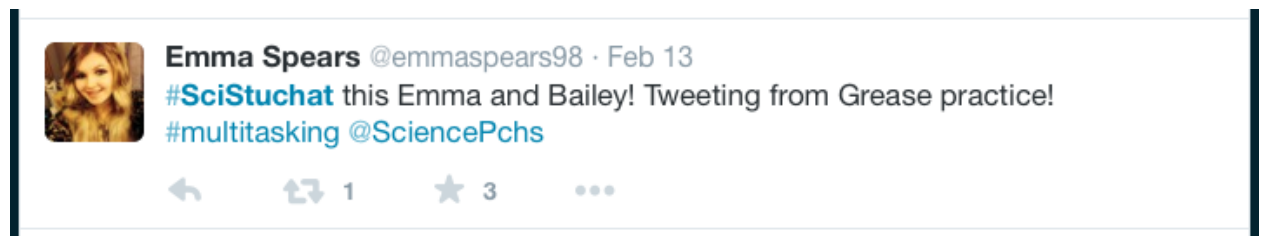


Figure 9. Student participating in #scistuchat from play practice.

Attesting to the flexibility that #scistuchat affords, other students chimed into the chat while on break from various forms of employment. As one student shared:

Sometimes I do it on my break at work, so it's like, I jump in a conversation, and then I'll have to look all the way back to see what they're talking about and to see specifically what question they're answering, because you can kind of get lost.

Another student described participating both while at work and in the midst of tutoring other students. As she explained:

And to me [participation in #scistuchat] varies because sometimes I have work and sometimes I don't. And then if I don't have work, I tutor kids in math so I'm on my phone, because I tell them that I have to do a school thing and to like excuse me for a minute. But yeah, it's usually like on my break or something.

In addition to the varied settings across which they participate, students also utilize the greatest array of devices to participate. While many scientists and teachers discussed working on their desktop or laptop computers, students utilized a far greater assortment of devices. In addition to desktops and laptops, frequently used devices included iPads, smartphones, and iPods. Speaking to the convenience of using her cell phone, one student shared:

I sometimes use my laptop, but most of the time I used my cell phone. I think that was really convenient, too, because if you had other homework, you had to bring all your stuff everywhere...[with #scistuchat] you don't have to stop and drop everything you're doing. You can be out at a restaurant waiting for food and you can be doing it. One time we went out to eat and I just did it while we were waiting. So I thought that was really convenient to not have to bring all your stuff.

Echoing the previous student's perspective, the following student also benefited from accessing the chat via her cell phone. In her words:

For me, I'm usually at home but then sometimes, if it's on a Thursday, I usually have concerts, school concerts, and they're always on Thursdays...so as soon as that's over with, I just take out my phone...okay, sorry I'm late but I'm here.

Other students spoke to the value of being mobile while participating, even if just in their own house. As one student described, "When I participated, I'm always in my

house on my cell phone. And I like using my cell phone because if I wasn't finished – I could leave and still have it with me.” Another student described the convenience afforded by using her iPod touch, and her ability to roam throughout her house while participating. Reflecting on how she participated, she shared:

I just had my iPod touch. I'm not a fancy gadget person. But I did use it and I could be downstairs with it and I'd be upstairs on my bed or like anything I want to do. It was different than bringing other homework because I didn't feel stressed, like I was weighed down with paper and books. I just had this small thing in my hand to use.

Teachers. Teachers addressed the convenience of #scistuchat to the smallest extent and, when they did, they tended to touch on the drawbacks that such convenient participation can entail. For example, despite his own attempts to participate in the chat while in the midst of another obligation, one teacher stressed how he encouraged his students not to sacrifice family dinners to participate. Regarding his own attempts to participate, the teacher stated, “Well, I'll be honest. I was kind of – you know, I try to conceal my phone during the meeting I was trying to – get in on some of the conversations.” However, pointing out that some of his students had shared their efforts to participate while at the dinner table, the same teacher offered his reaction. He explained, “Oh, yeah. I've had students who have been at dinner on their phone trying to tweet. And I'm like okay, no, no, no. No, no, no. Eat with your family. Tweet after you're done.”

Teachers also recognized that the convenience of being able to participate so easily from home inevitably intrudes on their valuable out-of-school time. Speaking to

the commitment involved in participating, as well as the weariness that can result, one teacher explained:

Sometimes it's nice for my workday to be done by a specified time. And instead, I've extended my day another two or three hours. Because usually it's an hour chat, which I think it's amazing how fast the hour can go by but if I'd gone to work at say 7 or 7:30 now I'm on until 8 and I'm literally on the job until 8 p.m., that makes for a very, very long day. So I would say the biggest barrier for me is just making sure I end my day, especially if I'm going to do #scistuchat, ending my day early enough that I have a break between my day and doing #scistuchat. So that I don't feel like I'm on duty for that 12-hour day because it does tend to become weary.

Summary. The consensus of participants in this study was that #scistuchat represents a distinctly informal science learning opportunity. For students, in particular, the informal nature of the chat rested on three pillars, including a sense of freedom, the chat's out-of-school time frame, and the overall convenience of the experience and avenues for participation. While scientists and teachers were less inclined to reference the chat's out-of-school timing and overall convenience as factors that resonated deeply with them, like students, they did cite the sense of freedom that the chat embodies as a defining characteristic of its informal nature.

Twitter and Professional Practice

Beyond #scistuchat, Twitter is used by scientists and teachers as part of their professional practice. For most, #scistuchat represents just one outlet of their Twitter use. In the case of scientists, #scistuchat may literally have been a one-time event. Given that

scientists and teachers use Twitter in varied ways outside of #scistuchat, a secondary focus of this study was to explore the role that Twitter plays in the professional lives of these individuals.

Scientists and teachers use Twitter in myriad ways as a professional tool. A defining characteristic of their Twitter use, regardless of their Twitter history or professional work, is that it is highly personalized. Even when their motivations for using Twitter are shared, how and when they use Twitter can vary widely. The utility of Twitter as a professional tool for scientists and educators is discussed, separately, as two sub-themes below. The role Twitter plays for scientists as a vehicle for science outreach and communication is also discussed as a sub-theme.

Twitter as a professional tool for scientists. Scientists in this study were, overall, frequent users of Twitter. When discussing how they use Twitter outside of #scistuchat and in their professional lives, scientists consistently spoke to three distinct areas: 1. connecting with other colleagues; 2. sharing and receiving feedback; and, 3. leveraging Twitter to follow and live-tweet professional conferences. Each of these areas is explored in more detail below.

Connections. Overwhelmingly, scientists referenced Twitter's ability to connect them with others as its most advantageous feature, and one that they used often in their professional lives. Virtually every scientist mentioned, in some way, Twitter's ability to connect them to others. The perspectives ranged from "one of the nice things about Twitter is just connecting with people around the world, I've connected with people from all walks of life and other scientists and science writers and so forth. So it creates these great connections" to "It's more of a conversation than I've ever had with my colleagues,

sort of about who we are and what we're doing. And it gives you depth, I think, to your interactions with people." In addition to a strong general consensus that Twitter is a valuable networking tool, scientists also spoke to specific benefits realized in this regard. Namely, they expanded their personal network of contacts by initiating interactions with individuals via Twitter, and they engaging in dialogue with like-minded researchers, professors and academics, often across otherwise insurmountable distances.

One of the primary professional benefits of using Twitter, specifically related to making connections, was its usefulness as a means for initiating conversations with individuals outside of one's current set of contacts. It was not uncommon to hear scientists describe fortuitous encounters with other individuals who share similar interests. As one scientist shared, "So sometimes I start engaging with a scientist, who I haven't talked to before, so that's an important thing for me. To feel that Twitter, in terms of what I do, is more of an outreach, networking tool than anything." Similarly, another scientist noted, "There's a lot of professional astronomers that I have met based on Twitter and so it's a professional sort of thing as well."

While fortuitous encounters were not unusual, other scientists shared how they have used Twitter in more purposeful, even calculated, ways to engage with others they had never met in person. Using the networking power of Twitter, for example, one scientist shared how he has initiated interactions with people he did not know:

I've followed links from Twitter user to Twitter user to locate people who I may not have met before. So it does help to meet people on Twitter and then interact with them later. Although I don't know if I meet more people on Twitter or if I meet more people at conferences – I'm not really sure.

Speaking to even more intentional outreach efforts, one scientist described her use of Twitter to explore potential research partnerships. She explained:

I've used it to get in contact with other people that I want to work with, which – at first I kind of laughed at myself because I was like, you're really using Twitter? But these are people that actively tweet. And so it was just an easy way for me to like sort of test the waters and see what they're like as an individual. And actually I did a mock interview two weeks ago at the University of Georgia. I got paid to go down there and do that and someone said, hey, I know you from Twitter...

In some cases, scientists' initiation of interactions via Twitter can lead to more than just occasional, fleeting exchanges. For example, the following scientist shared his experience in connecting with a well-known science writer via Twitter:

This is such a great way to get in contact and communicate with random professional contacts whom you might not have otherwise. So I do involve myself in science communication a little bit. So through that I've had lots of interaction with Debra Blum who wrote *The Poisoner's Handbook* and has a blog on Wired, and is a Pulitzer Prize winning journalist, all of that stuff. And it's gotten to the point through conversing with her several times, she wrote the other day to wish my wife a happy Mother's Day. So weird things like that. Just going from this completely professional thing to a little bit more than that. It's such a great avenue for doing that. And so I have given myself lots of introductions through Twitter, so that's helpful.

For scientists, a second benefit of using Twitter professionally was engaging in dialogue with like-minded researchers, professors and academics. Like the use of Twitter

to connect with new individuals, scientists' use of Twitter for subject-specific and, at times, highly academic purposes spanned all chats. Speaking to the power of Twitter in this regard, a scientist from the human genetic engineering chat shared:

I've met a lot of people through Twitter and have a lot of interactions through Twitter to where I've built my knowledge base of active professors, active institutions, places where I know that if I went to a conference, a handful of scientists I already know will be there. So in terms of networking and outreach, I think Twitter is just a dominating force.

Other scientists leverage Twitter as a way to stay up to speed on the newest developments in their fields. For example, as one scientist from the black holes chat explained:

I would say the biggest professional thing I use it for is – I follow and am followed by a bunch of professional astrophysicists and sometimes I can engage with them a little bit or listen to their conversations to find out what they're talking about, what they're thinking about, what's going on in the world.

A scientist from the volcanoes chat shared a similar use of Twitter, noting "I follow and interact with a lot of professional colleagues, a lot of astronomers and planetary scientists and other people in the business. And we have conversations all the time about the latest news and what's going on."

Lastly, like many scientists, two who participated in the human genetic engineering and green chemistry chats, respectively, shared how they use Twitter as a resource for working within their particular areas of study. Speaking to their mostly academic use of Twitter, one scientist shared:

I mean academics in a broad sense, because that tends to be who I associate with on Twitter a lot. But most of those people tend to fall into behavioral biology. So I say broadly because there have been people who have solved my issue that are working in another field. But they're like hey, it sounds like this problem – but it's usually, I guess, academics that happen to be on Twitter.

Another scientist shared the focus of her work and how she utilizes Twitter to expand those with whom she engages. In her words:

My research is very specialized and it's highly unlikely that I am interacting on Twitter with people who share my specialization. I probably have 3 or 4 people who I follow and who follow me who we could have a really in-depth conversation on very esoteric things on our research. But for going more broadly than that, there's a lot – I do research with proteins and so I can talk to biologists about my research and have questions about how one of my proteins may or may not have evolved or – and it's a way to sort of expand the type of people that you talk to within your own research. I think that's probably the best way at it.

Feedback. A second professional benefit of Twitter that scientists articulated frequently, in addition to its power as a networking tool, was its unique ability to function as a feedback mechanism. Because one can use Twitter very narrowly, interacting with just an individual or two with specialized knowledge and interests, or very broadly, such as sending tweets out to all of one's followers, the audience for a given tweet can be purposeful. Scientists in this study leveraged their access to an expanded audience through Twitter to receive feedback on an assortment of professional-related endeavors, with feedback on their writing and on issues encountered in their own research being

most prevalent. Drawing an analogy to his own science department, one scientist from the volcanoes chat explained, “I tend to look at Twitter as an extension of the geology department, where you can just stick your head out the door and ask a question and see what sort of answers you get.”

Scientists most frequently referenced receiving feedback on their writing as an important aspect of their Twitter use. Scientists who participated in this study represented professors, graduate students, and practicing scientists and, collectively, they often wrote for grants, blogs, and journals. To them, receiving feedback on their writing is meaningful as they work towards achieving their professional goals. Speaking directly to the process of writing and receiving feedback, one scientist shared:

I’ve seen people use it pretty well to share their papers to get feedback on things. Like there are a couple of venues where you can post drafts of papers and then you have a link and you can send it out to all your followers going hey, read this and tell me what you think. And I’ve seen people do that and they’ve gotten tons and tons of feedback, which I think is actually really good for sharing a lot of the stuff...I think of science as a process, so it’s not just the end product of what comes out and what we know now, but it’s how we got that knowledge and it’s instrumental in actually forming a lot of that.

Sharing a personal experience in which he tweeted a portion of a grant application and received extensive feedback, one scientist from the human genetic engineering chat described the potential of a single tweet:

Pretty much I just tweeted it...my follower account isn’t necessarily the largest but the amount of scientists that do follow me are fairly popular scientists and

awardees, or are sub-awardees, so I think when we all talk science, when we have to kind of get together and do science, it's not hard to get ahold of these people. It really takes just one to tweet in science and I think that's a time when it only took one tweet.

Reflecting on this experience, the same scientist shared:

Seeing a professional community come together for someone who really doesn't matter right now – my grant, whether I win it or lose it, has no affect on everyone else, particularly in the Twitter sites community – but their outreach, just being able to know that there's a resource like that out there is extremely valuable...So seeing that, wanting to give back too, I want to provide as much sustenance as I can.

Other scientists, too, shared how feedback from followers on the writing process had benefited them. For example, referencing the benefits of a diverse audience, one scientist explained:

And that's the other cool advantage, from a science perspective, if I write an abstract, I can find somebody to read that abstract that's completely out of my area. I can get somebody that's in meteorology to read that abstract and they can tell me whether it makes any sense or not and if it's readable. They may not understand the concepts because they're not in my area, but if it's readable, then that matters.

Reflecting on the overall benefits of an engaged audience, particularly in the case of Twitter, where feedback can be virtually instantaneous, a scientist from the volcanoes chat shared:

I like to receive feedback about what I do. I don't like just putting blogs out there and sort of firing and forgetting. I like to receive comments on them, discussion, or just sort of up votes or that kind of thing. Twitter is a medium that really makes it easy to get a pretty instantaneous feedback on whether people find what you write valuable or not.

In addition to feedback on their writing, receiving feedback on questions pertaining to their research was also cited by scientists as particularly helpful. Because Twitter can connect individuals with specialized interests and expertise, examples of feedback benefitting research are often very specific, with the benefits perhaps being hard to appreciate from an outsider's perspective. For example, one scientist shared an example of cross-Atlantic communication regarding tanks of stickleback and the regulation of light. In their words:

I was setting up my tanks of stickleback. And there's a person who works on stickleback in the UK. And I had gotten everything set up and my summer field season was going great and I was like – I just made a comment like, wow, 100 nesters this week and that's like unheard of. And so one of the people in the UK sent me a message – how did you get that to happen? And so I just described my tank really quick and she was like, our lights. And I'm like, yeah, what's your light set at. And she was like dadaddaadada. And I was like no, no, no. So we were able to kind of talk to that problem and then sort of fix something that you wouldn't even think to really – I mean that's how I met her was talking about random stickleback stuff.

Even when the question at hand was purely statistical, scientists found their audience to be helpful. As one scientist shared:

I've also used [Twitter] to sort of sit down amongst the people that follow me or that I follow. I'd be like, okay, I have this issue can you help me solve it. So a couple of times it's been useful when I've needed some random statistical test that I have no idea about. Somebody knows about it. I'm like, really?

Conferences. The last of the three areas cited by scientists as being especially meaningful applications of Twitter involves the role it can play in providing greater access to content shared during professional conferences. Often, particularly with those who participated in the black holes and volcanoes chats, scientists referenced using Twitter either to share about a conference that they were attending or to follow tweets from a conference that they were unable to attend. Called live-tweeting, this practice enables others to follow the main ideas and, in many cases, side conversations originating from within the actual room where a presentation is occurring. Remembering their introduction to the practice of live-tweeting conference presentations via Twitter, one scientist recollected:

I had heard that people had started tweeting at previous conferences and I was like, you know, I want to check this out and see what it's about. And it was exciting and fun to see that yeah, people are in sessions and tweeting what's happening in a session. So I was able to learn some stuff even though I hadn't been able to go to that session. Or they were calling attention to especially good posters. Or they were using it to sort of, hey, everybody who's interested in talking about this topic let's meet up at this location. So that was fun and exciting.

It made me feel connected to the community that otherwise would have been more anonymous.

Whereas the previous scientist had been at the conference she was following via Twitter, the following scientist described his experience following conferences from afar. He explained:

I think one of the more interesting uses of [Twitter] that I've found is that many of my colleagues, when they attend conferences, will tweet the main results...and then it's nice to be able to just follow all of the newest, a lot of the snippets of what's happening at the conference...a nice way to hear some of the latest news in my field without actually being at the conference. It's certainly not a perfect way of conveying all of the richness of what's happening, but I can at least hear some interesting results.

Reflecting on the quality of the tweets shared during what was, at the time, a very recent experience with live-tweeting, the same scientist recalled:

The level of tweeting was good, and high enough that I took something away from this meeting. So when people who were at this meeting came back to Arizona the following week, I was able to ask them more specific quality questions.

Two scientist-participants from the volcanoes chat also shared their experiences live-tweeting conferences, including the benefits they believe the practice holds. In one scientist's words:

Every time I go to a conference, I wind up participating in a chat throughout that

conference...and typically there are several other tracks going on and other friends are going on Twitter, mostly professional scientists, are also tweeting from their rooms. And then we may engage in conversation about what's going on in the different sessions, ask questions of each other of what this or that meant or whether they followed this particular protocol or whatever. And so there is a conversation that takes place on Twitter. It happens a lot during conferences.

Another scientist from the same chat described how he and others, who are members of a section of the American Geophysical Union (AGU), leverage Twitter to share information from meetings with a wider audience. He explained:

One of the things that we started doing in the last year was we started a Twitter account so that when people are at meetings, if they want to, they can – we can give them the account information and they can tweet about interesting things that they see or are hearing at the meeting.

Reflecting on the value of this practice, he stated:

I think that's been one good way that you can get information that's happening at meetings that a lot of people either can't afford to go to, wouldn't go to because they're not geologists or, just for timing reasons, couldn't get out there – to get that science information out there. And I think people have been really impressed with that ability to get even little snippets – what's the important conclusion or surprising thing there at the meeting.

Scientists use Twitter for a variety of professional purposes, including connecting with others, giving and obtaining feedback on their work, and both sending and following conference-related tweets. Considering this breadth of applications, it is not surprising

that how one uses Twitter, similarly, does not look the same from person to person. In fact, how one engages with Twitter, as well as manages their account, often is directly correlated with the benefits they realize. Recognizing this, many scientists take a strategic approach to their use of Twitter. As one scientist stated, “I carefully prune my Twitter feed in order to follow people who tweet about things that I find particularly interesting. And it’s a wide range of topics.” Regarding the differing ways one might engage with Twitter, another scientist thoughtfully pointed out:

I think if you just immerse yourself in the Twitter community, you realize that it’s not just about tweeting out a few papers from Frontiers or it’s not just about retweeting links from one place, it’s a whole thing. Sometimes you’re just the retweeter for the week or sometimes you’re just replying to people, you’re not actually tweeting things to have tweets. You’re just tweeting as replies. It varies...I could send one tweet out to the world, but I’ll have like 50 tweets out of single people, whereas the next day I could send out 50 tweets and no one replies.

Summing up the sentiments of many, one scientist, reflecting on the multidimensionality of Twitter and the demands required for its use, asserted, “of all the social media platforms that I use, it’s the one really that I feel like I get more out of than I put into it.”

Science communication + outreach. Based on their experiences using Twitter as a medium for communicating about science, including their participation in #scistuchat, it is not surprising that scientists spoke frequently about the value of Twitter as science communication tool. Drawing on their familiarity with Twitter, and their own experiences communicating science to a wider audience, scientists shared readily about

Twitter's potential as a means for communicating with increasingly connected public stakeholders.

Science communication. Science is communicated via more diverse media than ever before. In an age where mobile technologies and social media continue to expand, and in which the digitization of society continually creeps forward, it was interesting to explore the perspectives of scientists regarding the role Twitter plays in communicating science within a complex, digital landscape. What became clear was that, as a science communication tool, Twitter holds promise across a range of settings and is ideal under certain circumstances. Specifically, scientists spoke to three reasons why it is a compelling science communication tool: 1. its ability to support real-time interactions; 2. its power to engage and pique interest; and, 3. its ability to link to many other forms of media.

Real-time interactions. Perhaps more than any other feature, scientists referenced the real-time interactions afforded by Twitter as a significant advantage, especially when compared to more traditional forms of media. As one scientist shared:

That's one of the things that I think is so great about Twitter is the immediacy of the ability to interact with anybody, whether they be experts, members of the public, amateurs – it's such an immediate medium for interaction with all kinds of people.

Another scientist expressed his belief that Twitter is at its best when it is used to engage in dialogue about a shared event happening in real-time. In his words:

It's a really interesting tool to see when something happens in real time; where people are trying to process an event that's happening right now, or like going

back to the #scistuchat example, where you have a bunch of people doing something right now. I think that [is] where it's actually at its peak, because you can kind of have everybody focused on a single topic and you can deal with specific questions as they come up and people are on this topic following this thread.

Following up on his assertion, the same scientist described an example from the night before in which a segment of Twitter lit up at the possibility of a gamma ray burst. He recounted:

Last night – I don't know if you follow this – NASA has an orbiting observatory that looks for gamma ray bursts. And then last night it detected one and so all of the astronomers and astrophysicists who were on there were going crazy with everyone trying to type one single detail into a tweet that was particularly interesting. It was actually enough for me to write a Facebook post citing most of these tweets with the information and with some background on the instrument that they weren't providing. But the details were good, accurate and I did like six of them to get an article to put it together.

More than providing unidirectional, real-time updates, Twitter also supports two-way communications between individuals with shared interests. Importantly, these communications can also occur in real-time. Speaking to the significance of this dynamic quality, one scientist stressed the significance of amateur and citizen scientists being able to contribute to scientific pursuits via Twitter alongside experts. In her words:

I think it's a great way to have a public conversation among all different kinds of parties about space science. And I think you have your experts, but even the

experts are only expert in a tiny slice of – a little silo of science. And so they have questions to ask other experts. So there's conversations between experts. There are conversations between experts and journalists. There are conversations that log all of these and very expert amateurs. So you have people like amateur astronomers who take astounding photos of other planets and they'll be the first ones to notice new storms on Jupiter or outbursts in a comet and they'll post a photo on Twitter and then the astronomers are oooh, that's pretty cool, let me go turn my gigantic telescope toward that object. And then you have members of the public who get to observe this whole conversation and, if they have a question, something that they don't understand, they can pipe up. And the nice thing about Twitter is that if the question...does not meaningfully add to the conversation or if the question is not worded in a polite way or something like that, then the person who receives it can simply ignore it and it doesn't become part of a conversation. Whereas if it was a question that makes people say aha, that's a good question, I think more people have this question, then you can amplify it and respond to it and it becomes part of the outreach. And so even the people who are not experts are taking a role and shaping the conversation by priming the conversation and they can amplify the questions and the responses get amplified.

Engage + pique interest. In addition to real-time interactions, scientists pointed to Twitter's ability to engage diverse audiences, and to pique interests, as an advantage it possesses as a science communication tool. In part stemming from its sometimes claustrophobic 140-character limit, and in part a product of users' creativity in working within such confines, scientists believed in the power of a single tweet to grab the

attention of those holding even a mild interest in a given science topic. Considering the notion of a science Twitter community, one scientist shared, “it’s a strange community, but the science community on twitter is extremely helpful, extremely engaging. They’re interested in promoting science from all angles.” This commitment to sharing science from all angles means that, regardless of one’s scientific interest, there is probably a host of related individuals or organizations tweeting relevant science content. Because of this, as one scientist noted, the likelihood of one encountering interesting tweets from which to pursue deeper science is high. In their words, “it’s definitely a good gateway or way to get your feet wet in terms of getting into other science or deeper science, links to blogs, links out to events or programs.”

Space science, and astronomy in particular, represents a branch of science containing an incredibly abundant and engaged Twitter population. NASA, alone, has dozens of active Twitter accounts providing real-time progress updates, technical updates and timely alerts for upcoming missions and events. Scientists, writers and bloggers active in this arena often are keenly aware of the interest-piquing power of tweets. In this study, numerous scientists working within this field shared their perspective on why communicating about space science can be so conducive to Twitter. Sharing their focus on generating tweets that pique interest, one scientist stressed how live events can be especially engaging. She explained:

And so there certainly is content that fits very comfortably within a tweet. And then there is other content – I think most of the time I use Twitter for... piquing people’s interest... when there are special live events taking place is when I use it for the ability to give rapid-fire updates on evolving situations.

Perhaps the most common events eliciting rapid-fire tweet updates are tweeted involves space launches. Describing how tweets compliment the nature of launches, one scientist shared, “For something like a launch, where literally all you have to say is the spacecraft is now on internal power, Twitter is great for that and you have plenty of room to share that kind of information.”

Beyond just launches, however, Twitter also complements space science due to the broad, overarching goals of many related missions. As one scientist described:

One of the things that I like about planetary science in particular...is that it's very easy to explain to people what a lot of the questions are. The questions that are motivating space research are fairly simple ones. Was Mars ever like Earth, for instance, is one of the motivating questions for space science, and that's a very easy question to ask; it's a very hard question to answer. So there are certain aspects of planetary science that can be communicated very effectively. However, you cannot give all of the various caveats and explain all of the limitations to, observations that have been made or anything. For that you need a much lengthier discussion.

Offering a perspective that I think speaks to the essence of Twitter's ability to pique interests, as well as one that reflects the consensus of scientists in this study, the following scientist posited:

I think that there's a large number of ways you can do interaction with people online. Twitter, of course, has as its strength and its weakness the brevity of the medium. And so the people who use it effectively tend to be people who use

Twitter to either incite a conversation or incite an interest that then somebody will want to go dig deeper and follow up.

Links. The third and final reason Twitter was cited as being a compelling science communication tool by scientists in this study involved its ability to link to many other forms of media. With the 140-character limitation of Twitter, the ability to supplement tweets with additional links, visuals and movies was critical in the minds of scientists. In the words of one scientist, “I see Twitter as more of a launching pad for links to other things, kind of a – sort of like a Grand Central Station where all these different avenues come together and people can learn more.”

Elaborating on their use of links, the value seen by scientists connected to both the advantages of real-time interactions and the interest-piquing qualities of tweets. In the case of the former, one scientist described how links can be shared in real-time, explored by interested recipients and then followed up on when convenient. In his words:

But still you have links from Twitter. So you can make a statement; you provide a link to a lengthier discussion. And then people will go and read that and then they’ll discuss it. They’ll ask questions of you on Twitter. And then you can have that discussion. So Twitter is... a medium for a conversation but it’s not all that’s happening. I think that it’s only a part of the conversations happening on the internet and to have longer – to make longer statements you just link away to something else and the people who are participating in the conversation will go read that and then come back and talk.

Regarding connections between links and the spurring of readers to further pursue an area of interest, another scientist discussed his purposeful use of links:

I think that the most effective use of Twitter for sharing science is to share links to articles and information that have more detail. Many of my tweets are, oh, here's this interesting new result. Here's an article about it. Or that sort of information sharing. The 140 character limit is not a problem for that.

Explaining how such a practice can lead readers to further pursue areas of interest, he noted, "I'll post some brief statement with a link that takes you to an image that will have more explanation and links from there to more explanations so people can just go down a rabbit hole from any one tweet."

Science Outreach. For scientists, a significant draw to using Twitter for science communication also rested on its tremendous outreach potential. Scientists frequently noted how appealing the potential reach of Twitter was, especially when compared to more traditional forms of outreach. Statements such as "there's sharing possible at all levels and I think it's perhaps most exciting to actually reach people in a fairly non-intrusive way" and "I think it's really helped gain me a wider audience for things that I write and people who read my blog posts and read my books and so forth," abounded. One scientist put the potential in more quantitative terms, describing his wonderment at the extensive reach of Twitter. In his words:

And so that's a wider advantage of Twitter, that basically 140 characters that can go to 10 or hundreds of millions of people and you never know who's going to respond to it. When I tracked – I found a few programs that tell me how many people retweeted something or how many people mathematically were in the region, it's like oh, this past week I technically had a reach of 100,000 people. I don't know 100,000 people and I don't know if they even care what I was

tweeting. But the fact is that if there's 100,000 people out there, there may be somebody that will say oh, this is interesting, let me ask this guy another question. And usually – oh, wait a minute, I didn't think about that; that's a perspective on it...and as a scientist we're really narrow in our pursuit of whatever our project is. For me, I do well or better in science when I'm thinking about the bigger picture, not to my niche of experiments in a particular project, but when I can zoom out and see on a macro level.

Of course, such reach capabilities have been exploited by many, for years, to share science with phenomenal numbers of followers. A scientist who participated in the black holes chat referenced attending a conference at which Neil deGrasse Tyson, an active Twitter user with over 3.4 million followers, spoke. Tyson exhorted attendees to leverage technology to communicate their science to the public. As she recounted:

He talked a lot about using Twitter for outreach purposes. And his argument was that science is in the public mind maybe more now than ever before. Like it's kind of in the culture and people are talking about it and there are meetings about it and people are kind of looking for this information. And so his argument was that we as scientists have this opportunity enabled by technology to reach a larger audience than ever before. And he was basically calling for people to do more with this.

Noting her own take-aways from Tyson's talk, the same scientist shared how she set her mind to engaging in more purposeful science outreach.

And it occurred to me after Tyson's talk that Twitter could potentially be a way for me to do outreach in a more proactive way. To say look, I'm going to put stuff

out there that I think is interesting that the community might be interested in, or that I think would be cool to share, especially my local community. So instead of just waiting for somebody to call me, I can maybe start to be a resource for the local news media or whoever, especially locally, but maybe not exclusively. But being a little bit more in control of what I give to the public. And especially now that I have tenure, I'd like to do more of this.

Expressing a similar commitment to outreach, and speaking to the unique advantages of digital outreach efforts specifically, a scientist from the human genetic engineering chat explained:

We can leverage digital media more, because it is sort of a more convenient thing. Like we're doing as much as we can with our physical time and being able to be physically present in schools around here and all that, but we can reach a much bigger audience than we're trying to just by trying some more digital platforms.

The potential to share science with an increasingly diverse public was a thread that tied together some scientists' motivations to actively engaging in science outreach.

As one scientist shared:

One of the things I'm really concerned with is the representation of women and minorities in science, which is a serious problem. And you know, I'm sitting here thinking like how do I – how do I connect with students of color?

Explaining how Twitter, in part, helps her reach out to some of these underrepresented populations, she explained, "One of the things I'm hoping is that...the diversification of platforms allows me to diversify my audience as well." Summing up her thoughts on the importance of diversity, she considered the younger generation of scientists in her field,

stating, "...the concern about diverse audiences is going to be more of a concern for the younger generation of astronomers because they see that the sort of old boys network is not really reflective of the current society or the way that they want to be engaging with the community."

Another scientist who shared a similar appreciation for the virtues of diversity, both in terms of scientists and their audience, explained how he saw Twitter as promising on this front. Speaking specifically to the personal benefits he experienced, he noted:

And the other thing that happens is, as a scientist, I get to interact with other scientists from both genders – I should say people who consider themselves different things gender wise – a wide range of genders, a wide range of ethnicities, a wide range of political perspectives, religions, and science. And so now I have this connectivity with people that I wouldn't actually know unless we happened to be in the same place at the same conference in the same session and happened to say something to each other

The same scientist shared how he not only encourages scientists from groups traditionally underrepresented to engage with social media, but also how he founded an organization with the mission of "increasing interest in STEM within African American communities through media advocacy." Regarding the former, he stated "And so from the Twitter perspective, I actually have begun to encourage other scientists in general, but especially scientists from groups that are considered to be underrepresented in science to engage in social media." Regarding the latter, he explained:

One of the things that developed out of my Twitter conversations with other scientists is I helped found an organization – The National Science & Technology

News Service. You can look that up...NSTNS.org. What we noticed in a lot of underserved communities is the news coverage doesn't talk about the science. If it's health-related, it doesn't talk about the science. And one of the ways of actually effectively communicating the science sometimes is having – the messenger is important.

Twitter as a professional tool for educators. The professional benefits of using Twitter by educators can be summed up with one word—access. Although there was overlap in what they accessed and how, teachers, like scientists, used Twitter in highly individualized ways. These included using Twitter for personal interactions among two or three individuals concerning specific questions and issues, interactions in large forums—Twitter chats—where scores of educators can gather to discuss a common topic, and using Twitter as a research tool to curate contacts and resources and, in some cases, to work collaboratively on new initiatives.

The most common refrain among teachers when describing the utility of Twitter as a professional tool centered on the instant access to resources. Often referencing personal learning networks (PLN), teachers enthusiastically touted the on-demand nature of Twitter. As one teacher shared, “Most of my PLN is right there on Twitter, and the best thing about it is that it's right there at the tip of my fingers.” Delving deeper into its convenience, the same teacher explained:

So for me as a teacher, that's the biggest takeaway from Twitter. I mean the resource is available right there. And sometimes you're like, hey, I need this. And sometimes you don't even know what you need until you see it. Yeah, I could use this for this and this and that. So I think that's great.

Another teacher, too, spoke directly to the immediate, networked nature of Twitter. In his words:

In my opinion, Twitter's the quickest way to connect with anybody. Once you have a login, I mean that's it. You don't have to worry about finding people. You can just do a quick Twitter search in the Twitter search bar and instantly you're connected with whatever idea you want to pursue.

Having established that Twitter provides teachers with a convenient, real-time network that allows interactions to be initiated with ease, a natural follow-up question is to wonder, "What exactly what do teachers use Twitter to communicate about?" How, and for what purposes, teachers leverage Twitter is where the personalization of the medium shines. For some, Twitter provides valuable opportunities to interact with an individual or two who share similar interests or questions. For others, Twitter enables them to engage in chats with dozens of other educators from across the country, in real-time. Still others use Twitter as a research tool, exploring the tweets, interactions and followers of others as a way to discover and to cull valuable resources and contacts. And, of course, many educators use Twitter for all of these purposes, and more, depending on their needs and the time that they have.

Perhaps one of Twitter's greatest benefits for educators is that it is so populated by educators. Spanning grades K-12, thousands of classroom teachers are active users of Twitter and, importantly, readily willing to share. As a consequence, teachers can engage with other teachers quietly, even privately, in one-on-one conversations, or be part of chats in which dozens of teachers with similar interests gather to learn from each other.

Teachers shared numerous instances when direct, small-scale interactions over Twitter benefited them professionally. Discussing her specific experiences, one teacher shared:

I think Twitter has allowed me at least glimpses of people who are willing to share and have done this. And this is what they did and this is how well it worked and this is how it didn't work...then sometimes I can have those specific conversations to some extent with those people about this, and this is what we're going to do and this is what they got out of it. And I can ask substantive questions. Maybe have some of my erroneous thinking clarified or rectified so that I'm not making that same mistake again.

Sharing even more detail of how she uses Twitter for her own professional development, and how her appreciation for the tool has grown over time, the same teacher explained:

As I ended up getting some more specific questions in terms of what I wanted to learn and what I wanted to ask, and as you just interacted with people over time, it became much more useful...being able to get that different feedback from everybody in different locations and actually having a shared experience with somebody in a different state that you don't necessarily share here is helpful. I ran into this – I wonder if you guys do this – we're doing this and somebody – oh, yeah, I did this...And it's more the people that I have found that I've been able to develop that rapport with and have interactions with and know will answer my questions. That to some extent is a huge influence in my Twitter use.

Detailing a specific and recent illustration of Twitter functioning in such a way, this teacher described how she turned to Twitter for support in her first year teaching AP chemistry. She stated:

I'm new to AP chemistry and this is only my second time teaching the course. So I would actually say, as soon as I ended up taking this on, my Twitter focus ended up going straight to those people, in terms of chemistry, AP chemistry, that had experience, simply to buffer my inexperience and to get feedback from and/or just kind of lurk and follow and learn from some of what they share. So as I get more familiar with AP chem, I think it'll broaden back out again, as it was my first year or so using it.

While Twitter can be used for direct interactions around specific questions, as described above, it can also be used to bring together large numbers of educators interested in discussing a common topic. These Twitter chats occur across virtually all subject areas, and are often refined in focus. Numerous teacher-participants in this study were active participants in Twitter chats and, in some cases, even acted as organizers and moderators of well established and highly regarded science chats. In the example below, a teacher shares her motivations for helping to establish and facilitate these unique forms of professional development. Speaking to her interest in helping support the learning and empowerment of other educators, this teacher explained:

One of the things that is a passion of mine is for me to grow so my students can grow – we can grow together. But I also want to grow other teachers and help them feel empowered and that they can be leaders in their field and they can address the things about education that we as educators feel need to be fixed to put the students front and center to meet their needs.

Translating her interest into action, this educator worked with a curriculum director close to the development and unveiling of the Next Generation Science Standards (NGSS) to

revitalize a chat—#NGSSchat—that had gone dormant for a period of time. Together, they run the twice monthly #NGSSchat that, at the time of this writing, had “60 or 70 educators as part of that group that participate.”

Beyond direct interactions with others, whether individualized in nature or on the scale of Twitter chats, Twitter was also used as a research tool by some educators. When used in this way, individuals simply leverage the information every Twitter public account provides to learn more about resources that might be useful in one’s own classroom and to one’s own practice. For many, simply participating in #scistuchat leads to the exploration of the backgrounds, tweets and those followed by participating scientists and fellow educators. As one teacher described:

So I approached Twitter as a researcher, to be honest. So when somebody would follow me or I would follow them, I would go and find out what I could about them to see what it would be that I could learn from them and with them.

With educators actively exploring the backgrounds and interests of others, and with interactions on Twitter as simple as a few keystrokes, it is not surprising that partnerships and collaborations often result. In fact, in this study, two of the participating teachers have teamed up to couple their passion for cooperative learning via technology with their interest in assisting other educators in realizing the benefits of such an approach in their own classrooms. Together they have founded “Connect Think Learn,” an initiative grounded in the belief that:

Connected classrooms break down the four walls, creating countless opportunities to grow student appreciation and understanding of science, while providing

opportunities for developing the 21st Century Skills of critical and creative thinking, collaboration and communication.

As a testament to the value of Twitter, their website maintains, “Twitter is the doorway to connecting yourself, but more importantly it is the foundation of your PLN. The connections made on Twitter can lead to collaboration through Google and other platforms.” Numerous video tutorials are also offered to help teachers and their students get started using Twitter. Additionally, these teachers have also teamed up to present their work at various NSTA conferences and start an initiative to pair science teachers who are aspiring Twitter users with science teachers who are veteran, savvy Twitter users. As one of the teachers leading these collaborative endeavors explained:

“We’ve done several sessions at NSTA and we are planning them out in such a way that not only do we tell people about Twitter and how to use it, but we can actually, we want to get them connected...but these people we’re going to connect them with proficient Twitter users who are also science teachers, and also bring in the NGSS”

Summary. As a tool to complement and extend the professional practices of scientists and teachers, Twitter offers a highly personalized vehicle for facilitating meaningful interactions, often in real-time, across traditionally limiting factors such as distance, time and expense. Although used in different ways, sometimes highly variable even among those with shared professions, Twitter none-the-less offered unique contributions to the practices of its users and, importantly, to the learning and awareness of their audiences.

Twitter as an Educational Tool

Like the potential it holds as a professional tool, the use of Twitter as an educational tool holds promise and its potential is worthy of analysis. The first four sections of this “Findings” chapter discussed themes specific to the use of Twitter in #scistuchat. However, the exploration of participants’ perceptions of Twitter as an educational tool below, like the preceding theme in which its utility as a professional tool was discussed, focuses on applications outside of #scistuchat. Specifically, the role of Twitter in the science classroom (literally and figuratively) is considered through the lenses of scientists, students and teachers. Exploration of this theme then concludes with a discussion of perceptions related to the use of Twitter for learning about and communicating science.

The purposeful, guided use of Twitter by high school science students for learning and communicating science is an unusual practice. At a time when many schools and districts have placed an outright ban on social media, students and teachers who have access, and who use Twitter thoughtfully, provide an interesting case study for exploring the worthiness and viability of such endeavors. Thus, just as their perspectives pertaining to #scistuchat were valuable, so too are their reflections on the broader, more general uses of Twitter for science purposes.

Twitter in the science classroom. In addition to #scistuchat, Twitter was part of participating students’ in-school science experiences in all cases. Thus, all students, and their teachers, had invested time in engaging with Twitter for a variety of science purposes outside of #scistuchat. Although how Twitter was used in these cases again varied widely, certain commonalities existed across all settings, with some applications

demanding more time, being more purposeful and, thus, more notable than others. In what follows, scientists, students and teachers share their experiences with, and perceptions of, Twitter as a learning and communication tool in the science classroom.

Scientists. Despite not being directly connected to high school students or high school science classrooms, scientists were asked to share their perceptions of Twitter as a tool for learning and communicating science in a high school classroom. This question was posed to scientists as a way to triangulate and round out the perspectives on this important consideration. Furthermore, when interviewed, many of these scientists were either current graduate students in the sciences, working in science classes in higher education settings, or were teaching professors.

Scientists responded thoughtfully regarding their perceptions of the appropriateness and value of embracing Twitter in a high school science class. While they did not have direct experiences from which to draw, collectively they offered several agreed-upon conclusions. Namely, that Twitter would likely lead to more engagement; that although Twitter could play a positive role in students' science experiences, it was not a necessary addition; and, that there could be potential negatives associated with its adoption.

Increased engagement. Scientists across all chats expressed a common sentiment that Twitter in the science classroom would likely lead to more engaged students. For several reasons, including the fact that it could provide a personalized jumping-off point and that it could act as a fundamental tweak to the traditional classroom experience, scientists felt that embracing Twitter presented worthwhile potential. Speaking to the various ways in which Twitter might be used in a classroom, one scientist stated, "And

all this would translate well into education, ways to sort of personalize the experience or connect with people or ideas that you would never come into contact with otherwise.”

Other scientists, too, viewed the ability of Twitter to connect students with scientists whose work they were interested in as a promising outcome. As one individual shared, “Providing contact for people who wouldn’t otherwise necessarily have contact with scientists, I think there’s a real potential there.” Going one step further, a scientist shared how these connections might lead to students exploring potential careers or fields of study. In his words:

One immediate advantage that I can see is something I mentioned earlier, it might be the ability to connect students at that grade level with professions...Twitter provides a great way for students, especially if they don’t have any friends or relatives who are scientists, to still connect with some and realize that real people have these jobs, or at least real Twitter accounts have these jobs.

Other scientists pointed out that students might experience deeper engagement with science if Twitter was part of their in-school science experience. Because they felt it would introduce a more dynamic element to traditional classroom pedagogy, numerous scientists believed a greater number of students might be reached. Directly addressing this idea, one scientist shared:

I hear from a lot of people that their students just kind of are there. And it shows me that maybe if they’re not excited it’s because maybe the pedagogy might need a little bit of tweaking, and if this is a way that you can reach students, do it.

Another scientist stated:

I definitely think it's interesting, too. I mean, new technology always brings new ways to do things, so I think it's an interesting way of looking at it. Whether or not it's better or worse, I don't know, but as a supplementary, definitely. I think some people might just get it through Twitter better than in a classroom. That's a possibility.

Although they did not always connect their thoughts directly to the notion of a pedagogical shift, other scientists also expressed a sense of promise in Twitter's potential to increase student engagement. As one scientist shared:

I know a number of teachers who have used Twitter just like they would use any social media tool, to sort of get students engaged in a different fashion, get students working to combine these aspects of science and social. And I think Twitter is good for that.

Yet another teacher, while expressing a similar perspective, wondered the degree to which such an impact might already be happening. In their words:

So maybe this conversation through Twitter might be helpful to engage and spark some conversations in class. I imagine it's already happening but I'm just not – I don't see any of the data or the analytics, so I'm not really sure on how many people.

Lastly, when considering engagement, another scientist immediately tied it to having an awareness of the most up-to-date information available. In their words, "So that's where you're getting the most up-to-date scientific information you can. So of course if that's where it's being released, that's where we should be pointing students to find information."

Possibility vs. necessity. When asked to consider the role of Twitter in a science classroom, many scientists were careful to draw a distinction between what the role that it *could* play and whether or not that role was *necessary*. In general, even when scientists were describing some of Twitter's distinct advantages, they were deliberate in expressing that such benefits were not synonymous with being necessities. As one scientist explained:

I don't think it should be used, but I certainly don't think it should be avoided. I think that people are going to use social media whether you want them to or not and to embrace that as a possible valuable resource is...so much more rewarding than to say you're not allowed to use this.

Clarifying her position in response to this question, another scientist shared:

When I said that I don't think it should be used, it isn't that it doesn't belong, like in the classroom, social media, I don't mean that. I think it has a place in a classroom...I just meant that it doesn't, in my opinion, need to be like incorporated into every teacher's curriculum and not every teacher has to embrace it...I think a lot of people could benefit from it.

Several scientists articulated the view that Twitter was particularly valuable for engaging with other professionals, but still a worthwhile tool to consider for classroom use, as noted here:

I think my answer would be it can, but I...think it's one out of potentially a lot of tools that you could use in an educational setting. It has some advantages that probably didn't exist very well when I was in school, which is – in this case, if I had a question to ask to a professional geologist, I wouldn't have any idea what I

would have done because I had no means to do that, whereas now, if I was in high school, I could absolutely do that through such means. So that's a big advantage.

Again speaking to belief that Twitter is just one of many tools at the disposal of classroom teachers, one scientist posited:

But you know, a high school science teacher who doesn't want to use that isn't necessarily at a disadvantage in as much as they're able to present their information in a way that's accessible. It's one potential tool. If somebody has a question, I think I'd be happy to answer it...That it's one way of doing things but it's a potentially good way to reach people who are cued in those subjects, already know them, but it's not necessarily the only one and it's not a mandatory thing, I'd say. It's one out of a number of options to access people.

Concerns. Numerous scientists expressed concerns related to the prospect of high school science students being encouraged to use Twitter for classroom purposes. These concerns ranged from distractible students to fears of books taking a backseat to other more instantly gratifying sources of information.

Articulating the tension between good and evil that many scientists also recognized, one individual shared:

For me in particular, to be just totally honest, I think a face-to-face conversation conveys a lot more. I think having a thoughtfully crafted reply rather than an off-the-cuff one sentence is going to be a lot better. But this way, it's something that's fast, instant gratification and accessible – and accessible to more people. So there are pros and cons with it. And I totally think yes, there is a place for this.

Another scientist spoke to the distractibility factor, explaining:

When you have students going on the internet and for a class assignment, you're going to have a few curious students who would have chosen to participate in something like that if they were given the opportunity. And that's great. But you're also going to have students who don't engage or engage in a distracting or destructive of – you know, undesirable fashion. So yeah, you get that, too...although honestly, I don't know that that's any worse than any other day in any other class that you have that as well.

Continuing with the theme of distractions, another scientist was even more blunt in her assessment of the role Twitter, and other forms of social media, should play in the science classroom. She declared:

I don't think you want to be encouraging students to be logging onto Facebook, Twitter, everything else, because even if they can be educational tools, that's not how we were designed and there will always be other distractions available via these media. You can say "log on to Twitter and go, add this hashtag and don't check any other feed." Do you really believe that's going to happen? My five years have said, and before that, all four years of being an undergrad and four years of being a high school student, I wouldn't have listened to that. I'm not going to be high and mighty and pretend I'm perfect. I get distracted today by social media for my work. I think it can be used. I don't think it should be invited if you can avoid it.

Lastly, one scientist expressed sincere concern over the prospect of social media, and other technology-centric applications, supplanting the experience of learning through reading physical, bound books. He explained, "If a student already is into books or if a

student can't possibly be convinced to learn through books and articles, then it's an alternative. But I really don't want to see generations grow up without books and articles." Later in the interview, circling back to the importance of books, he again reiterated:

Once again, going back to the whole idea of books and articles...I think it could be something fun that's extra, but I think a good teacher should introduce students to classic science books or new science books or science fiction.

Students. Students in this study all used Twitter as part of their science classes for purposes beyond #scistuchat. This section captures the perspectives of students regarding how they have used Twitter for science purposes outside of #scistuchat, often as an element of their actual in-school classroom experiences. Students described both direct applications of Twitter in their respective classrooms, as well as the benefits that they believe Twitter holds as a complement to their high school science experiences. For organizational purposes, and to facilitate the comparison of sometimes disparate uses, how Twitter was used across classrooms is described according to the specific chat for which students were interviewed.

Black holes students. Twitter was used by students in their classrooms in a variety of ways, ranging from tweeting article summaries to regular use of "professional" Twitter accounts. Students interviewed from the black holes chat described periodic, in-class instances in which their teacher poses questions on the board that must be answered via Twitter. As one student shared:

In our case, Mr. puts up a presentation and pretends to have some icons so that we can have fun between the stations. He always puts up cell phone icons. That

means that we have to tweet about what he is talking about. If it is something about genetics, and he puts the icon of cell phones next to it, the slide, we have to tweet something productive about genetics. And it's kind of fun, and it's kind of a distraction for students to not get bored.

Other students from the same chat described how they have Twitter accounts for their classes that enable them to share content across classes. As one student described:

Yeah, we have a science class Twitter account, and so other classes can tweet to it and so the things that they're learning, we're learning about too, just by reading it. So whenever we're making telescopes, I'll take a picture of a diagram of my telescope that I planned out and I'll post it on Twitter.

A fellow interviewee explained how taking pictures and posting them to Twitter also allows teachers to follow their work, even when she's not actually in the classroom or school. In her words:

When we're working on projects, like when Mrs. is gone, we take pictures of them and post them on there and she can see how we're doing and stuff like that. You can also see how everyone else is doing and things like that.

Notable comments from students related to their use of Twitter in their science classrooms included excitement at the viral nature of the medium, and a belief that, while not necessarily the case for all students, Twitter can be used responsibly. Concerning the viral nature of Twitter, a student shared:

I think that it is a good way of sharing information and learning because it is a very viral, social...a very viral, social world. Because, for example, if you were to

tweet something about science and use a hashtag that was for some reason at that time trending, you will probably get several retweets, right?

Piggybacking on this comment, another student contrasted their use of blogs in their science class with their use of Twitter.

We have something in our classroom that we call blog posting, right, but I like Twitter better than blog posting because I believe that Twitter is more viral, more people can get to see your tweets than will get to see your blog post.

Some students alluded to concerns around the responsible use of Twitter and, specifically, how not all students can necessarily handle such responsibility. In one student's words, "I think if the students were using it responsibly, it could be a good learning tool, but some students can't handle the responsibility and pay attention...so it just depends on people that are using it." Another student in the same focus-group emphasized that those who cannot handle the responsibility should not prohibit the use of Twitter by those who can. As she pointed out:

I think there is good and bad, for like everything. No matter what it is that you're using to learn, there's gonna be like people who are going to misuse it, but it's better to like focus on the positive. It's like let the people who are responsible enough to be able to use it correctly, use it.

Human genetic engineering students. Students who participated in the human genetic engineering chat explained how a primary, in-class use of Twitter in their science classes involved a constant backchannel. This backchannel enables students to tweet questions and notes throughout the course of a class, and is visible to all other students in the room. In the words of one student:

Well every class period that we're in here, we usually get on Twitter and have conversations with the class account so Mr. will give us a certain topic or something. And we'll be posting about what the topic is and stuff, so that people in class get to read what we're learning and we get to see what they're learning even though we're just sitting down, and we don't actually have to talk to each other to be able to know what is going through our mind.

Sharing an additional benefit of the backchannel, another student noted:

It helps because it's kind of like taking notes, so there maybe something that he said that you didn't catch but someone else did, and you get to see it on the screen and then you're like oh, well I didn't think of that but yea, that's cool too.

Because some students use their own personal Twitter accounts, tweeting science-related tweets at random times during the day can cause some students' followers to question the reasons behind such seemingly unusual tweets. As one student explained:

Actually, people always ask me what I'm tweeting about because you're tweeting in the morning. What was all of that about? And I'm just like oh well, it's for class. Or in the afternoon they'll send me a tweet and be like, what are you talking about or something, and I'm like you should join the conversation. We're talking about so and so or something.

Green chemistry students. Student-participants in the green chemistry chat used Twitter in their science classroom the least of any of the student focus groups. In addition to #scistuchat, the only other science-related application of Twitter they used for their science class involved an instance in which their teacher asked them to summarize

science articles using Twitter. The article summaries, shared as tweets, were then posted to a teacher-generated hashtag specific to their science class.

Although they did not have much experience using Twitter as part of their science classes, these students did offer potential uses of Twitter in classroom settings. Speaking to the fact that many students are already on social media during the day, one student suggested trying to conduct part or all of class via Twitter. In their words:

Considering that most people are on their devices, probably checking out Twitter, in the middle of the day, instead of like teachers taking their devices or whatever, they could actually take advantage of the fact that they're using Twitter and maybe teach a class, one day, on Twitter.

Explaining how such a class might work, another student noted, "Yea like, kind of like how #scistuchat is a hashtag...so create a hashtag and make it the for the whole class."

Reinforcing a point he made earlier, a student reiterated his belief in the engaging nature of Twitter, stating "I think it really is useful because it helps kids pay attention more, instead of sitting through teacher lectures, you could be engaged in Twitter. Like I said before, that's pretty much what kids are doing throughout the day."

Volcanoes students. Students who participated in the volcanoes chat were unique in that they have what their science class refers to as "professional" Twitter accounts. These science-specific Twitter accounts are designed to be used for science purposes and to give students opportunities to build a professional-like presence on Twitter. In the students' words, "We have professional Twitter accounts that we can tweet to if we're just answering questions in class or if we're doing a project" and "I think Twitter – the

professional Twitter, in general, is something different to have, like on an application, like something that makes you stand out more just from having that professional side.”

While these students tweeted frequently as part of their science class, including tweeting regularly with another school in a different state, an even more notable example of their Twitter use involved a collaborative project with fourth grade students in a local elementary school. As one student explained, “Recently we had a project that involved invertebrates and we tweeted to fourth graders, talking about our invertebrates. And it was a lot of fun.” This project, to be described more in the next section by the teacher who helped to create and lead it, involved the high school students sharing science-based ideas with the elementary students over several weeks prior to a culminating “Invertebrate Olympics,” which brought all the students together in the same physical space.

These high school students also shared reasons why they believe that Twitter is a helpful addition to their science classes. For example, like other students who participated in the other chats, they, too, cited the engaging nature of Twitter as a positive. As one student shared:

When a teacher says take out your tweeting devices and tweet the answer to this question...It’s a lot more exciting than like opening a book to page 192. And that gets people excited about learning, like whether they actually enjoy it or whether they’re just doing it for a good grade. And then people who might not necessarily pay attention in school normally might be captivated by this new way of learning just because their more familiar with it. It’s just a lot more fun and allowing

people to interact in a different way. And it breaks the standard that people thought that they found in school.

Another student, in describing how Twitter can help facilitate students sharing their opinions, explained:

But on Twitter we're not really – we're not nervous about what we think and we'll just state what we think about the question. And I think it helps a lot with other people answering questions because we can – what we call piggyback from our notes, and learn even more from what their response was.

Students also spoke to the perceptions of risk involved. Echoing the perspectives of previous students, one student shared:

I believe in any new experience or activity you use there's going to be at least one risk. And it doesn't matter if there's a risk. What matters is if the benefits outweigh the risk...I mean I see where some people might feel that way but I think for the most part, the benefits of using Twitter for science would outweigh anyone thinking I don't want to use it.

Lastly, a student offered her take on why Twitter, and other forms of social media, should be part of the classroom experience. In her words:

I think it should be used in school more because like technology is evolving so we have to adapt to it for us to use it. And even teenagers should use social media so that they'll be comfortable with it; they'll know how to use it. So using it as a learning tool would probably make it easier to learn the material.

Teachers. Teachers whose students participated in #scistuchat also used Twitter in their classrooms. Because they developed, implemented and have reflected on their

uses of Twitter in the classroom for learning and communicating science, their discussion of these efforts was rich. In many cases, what students might have described in one or two sentences, teachers discussed in paragraphs. As was the case in the student examples above, for organizational purposes and to facilitate the comparison of sometimes disparate uses, how Twitter was used across classrooms is described according to the specific chat for which teachers were interviewed.

Black Holes. Two teacher-participants from the black holes chat were interviewed. While both used Twitter with students in their science classrooms, one teacher, in particular, described more applications than the other. Each teacher's efforts is described separately below, with the efforts of the individual who used Twitter in more diverse ways explored first. Because each instance in which Twitter was used in the classroom was described in detail, and would be too cumbersome to explore thoroughly in this section, only the highlights of each are shared below.

One of the teacher-participants in the black holes chat had used Twitter in a multitude of ways in his classroom. With most of his students having Twitter accounts for science purposes, he explained "I have three hashtags, one for every class I teach, which they are supposed to tweet productive stuff." However, beyond simply expecting students to tweet interesting stuff, this teacher had explored numerous ways to leverage the power of Twitter with his students, and described several more that were in the works. First, he had used Twitter as a means to have a shared review session outside of school. He noted that he simply shared with his students a day and time they could opt to participate. As a second example, he described how he has used Twitter's hashtag function for student presentations. In his words:

What I did once, and now I could try it internationally, but what we did once is we made presentations and in those presentations every team had to come up with their own hashtag. So every team would have a hashtag and this hashtag was to be used by the audience, by their classmates to make comments, to make questions during their recitation. It was a bit scary, I would say, because the idea of having students with their cell phones while their classes are presented is that it's scary when you think about it, right? But it worked pretty well. The kids were engaged; they liked it...it was exciting.

This same teacher also described a then current project in which his students were using Twitter to update their progress in a projectile motion project. In his words:

I have this project going on on Thursday. It's for physics. And students are reporting their progress through a hashtag. And they have been reporting. They're putting up pictures. They're building so many things to launch objects, 2-dimensional projectiles, and they have been reporting their progress through that. So they take a picture, they put it up on Instagram and they share on Twitter or they put it directly on Twitter and that's how they've been reporting.

As a last example of a current or past effort to integrate Twitter into the classroom, this teacher shared how he uses Twitter to provide fun, competitive games for his students. He explained:

Another way I have used Twitter is for contests. Who answers the questions first. I send out a question and they have to reply to it on Twitter. So they have to use the hashtag, and they find it really exciting, when I refresh the stream and...then you can see who would be first.

Considering *future* ways he might incorporate Twitter, this teacher offered numerous ideas, ranging from shared TV viewing experiences to providing interactive feature to the traditional science fair. Regarding the former, he explained:

This just started...what I propose to students, is well, okay guys, Thursday you have to propose a show – a show from the History Channel, Animal Planet, something that is relevant that you think we might find interesting...At the end of the week, we're going to have a few show proposals, then we're going to vote for one show, and at the time of the show, we're all going to be watching and we're going to have a discussion through Twitter with a particular hashtag.

Explaining his rationale, he noted, “NBC, ABC – every show has a hashtag. And they expect people to go and discuss about what’s going on in the show. And they do....People like to interact. So I said why can’t we use that for something more productive.”

Hoping to continue to capitalize on the power of hashtags, he also shared what he hoped would be successful future uses of Twitter related to his science classes. As a way to further enhance his students’ presentations, mentioned earlier, he explained:

I have broadcasted my students’ presentations live through Ustream, so for the future I have classes, okay, the next time you present and I share the lengthier presentation, I’m also going to share a link to your Twitter hashtag...so that people can go and comment and share and watch the presentations.

Regarding the use of hashtags for his school’s science fair, he shared “Next year we have science fair. And then what I’m planning to do is I have every project with their own hashtag so that people who come visit can make comments through Twitter.”

The second teacher-participant in the black holes chat had fewer direct experiences with Twitter in her classroom. As her students mentioned earlier, her classes have a specific Twitter account, with students having the option of tweeting to the class hashtag. As an example of the connective power of Twitter, this teacher described how one of her students took the initiative to reach out to a scientist via Twitter. As she described:

I have a student that was doing a project on Astrobiology for keyboarding class and so she went on and was like Mrs., do you think we could find some scientists on Twitter. I was like, oh yeah...there's a website that has 100 scientists on Twitter, so we will have to find one. And so they went on there and did that, so that's how she found the connection to go on Twitter and talk to scientists. And they did, they responded and that was pretty cool.

Considering potential future uses, this teacher offered two unique possibilities. First, she shared plans to model a virtual competition between schools after a popular TV show. In her words:

So Cutthroat Kitchen is like, they're cooking like normal, they're given a recipe, they have to try to make it...then he throws out like random sabotage things...so we're going to do that, like Cutthroat Water Propelled Rockets, as a virtual competition with some schools.

Explaining the importance of sabotage, and the role Twitter might play, she continued:

They know what they need to do, but it's that sabotage, kind of like the Apollo missions where they had to design that thing with only these certain supplies that they had to make it back to Earth. So it's kind of like that. It's really getting

them to think outside of the box and to design and critically think about those kinds of things...We're going to have a hashtag that they'll follow and they can talk back and forth to those teams and post pictures, ask those other teams, hey how's that glue stick working, those kinds of things.

As another potential future use of Twitter with her students, this teacher explained how she had recently reached out to a university to explore the possibility of having her students connect via Twitter with science teachers-in-training. As she explained:

Actually I sent an email to one of our higher education science educators... my students have been talking about their voice and how they would like to be heard and how #scistuchat had helped them do that. So I emailed her and I was like, hey, what do you think about possibly having a hashtag that, for kind of an informal chat that just goes on randomly between your future elementary science teachers and my science students, so they can kind of see how we're using Twitter in the classroom, how we're globally collaborating, how we're giving students voice and hopefully preparing them to come into the classroom. Because recently, in December, I ended with my first student teacher and I noticed that that was kind of a gap that he had and that wasn't something, when I talked to him, they had been discussing in their practicum programs or any of their education classes.

Human genetic engineering. The teacher-participant I interviewed for the human genetic engineering chat was a veteran Twitter user and one who believed strongly in the ability of Twitter to connect scientists and students. With many of his students having Twitter accounts, his primary use of Twitter in his science classes centered on

contributions to a class backchannel, a place where, using a specific hashtag, students' thoughts and questions can accumulate over the course of class or unit. As he described:

When I'm doing the 10, 15-minute lecture, I like to have the students tweeting about it...have them back-channeling the discussion...it doesn't happen every day, just because of timing or whatever issues are going on, plus I like to mix it up.

Logistically, backchanneling can work in his because, as he noted, "I've got two projectors I run in my class. One for our activities and lecture and whatever, and then another one dedicated to the backchannel, either using today's meet or Twitter. Usually, we only use twitter now." Explaining the usefulness of this practice, he shared:

Students have started using it to take notes and so...they have an additional resource for the information they can refer back to later. They can do a hashtag, they can go to their own tweets, or to the kids in the classroom and so that's been good. It also has raised engagement in class while we're using it, because it's funny, the kids who can't have accounts because their parents won't let them, or they don't remember their information to login or whatever, they have to take notes on paper and no one wants to be the one taking notes on paper.

Although he felt that the backchannel was a meaningful dimension to his class, this teacher felt that Twitter's ability to connect him and his students directly to scientists was even more exciting. To illustrate the power of this networking capacity, he shared an example in which he reached out to scientists who study amphibians and, because a scientist responded quickly, he was able to include that scientist's voice directly into their class discussion. In his words:

One time last year we were talking about amphibians in class and we were tweeting about it and I sent out an all call on Twitter saying hey, if there's any amphibian scientists out there who have a minute to join us, and we had one join us and was able to answer questions while we were talking about it in class.

Excited by the potential for students to have the same kinds of interactions, he explained:

So students would be able to do that on their own as well. If they're given homework and they're given questions and they're having trouble, then they can get a scientist to help them...if they're helping with the homework and they're actually doing the math themselves, I don't care. If they're talking, I'm happy.

Overall, this teacher ultimately pointed to the potential of Twitter as a means through which students could develop their own PLNs as perhaps the greatest advantage to using it in his science classes. He explained:

So a student with an account can start building their own personal learning network. References, resources, they can do a lot with it. They can organize the people they want to connect with. They can make Twitter lists. I've had students start making Twitter lists for the scientists they follow and then those lists are also shareable so it's easier for me to keep track of who's doing what.

Green chemistry. One teacher was interviewed regarding her participation in the green chemistry chat. It is important to note that her particular students were not interviewed, however. Like the previous teacher, this teacher primarily uses Twitter as a backchannel for classroom activities. In her case, however, her students backchannel almost exclusively when watching videos. Sharing how her use of Twitter in her classroom ended up with such a specific focus, this teacher explained:

As much as I would like to have it grow – for me, when I first started using Twitter, I wanted it to be a science literacy tool. So I wanted my students sharing articles. I wanted them commenting on stuff in class. I wanted to have that backchannel in class. But it becomes one more thing to do. And I didn't really want it to be one more thing.

Detailing how such video backchanneling plays out during class, as well as the benefits that this practice affords, she explained:

They have to have [Twitter account] for my class...anytime we do videos or anything related within class, it's a complete Twitter back channel that is our discussion while the video occurs. And so that let's me see that yes, they are paying attention, yes, they are picking up on some of the things I want them to pick up on. If they have questions...I can immediately answer it without stopping the video sometimes. Sometimes I will stop the video and we'll just talk, make sure everybody has seen whatever this one question was or something like that. So I use it strictly for that.

Volcanoes. Two of the teachers interviewed were participants in the volcanoes chat. One of these teachers, whose students were interviewed separately for the green chemistry chat, only used Twitter for a small number of instances when her students summarized science readings and tagged these summarizing tweets with a class hashtag (see “green chemistry students” section above). The second teacher used Twitter on perhaps the widest scale of any of the teachers interviewed. It is her integration of Twitter as part of her science classes that is described in the remainder of this section.

A defining feature of this this teacher's use of Twitter with her students is her students' creation of "professional" Twitter accounts, accounts purposefully designed and solely dedicated to science learning and communication. The impetus for such accounts actually grew out of close dialogue between the teacher and her students during a prior year. As the teacher explained:

The way that I have distilled down what my role is in education is to partner with students for us to learn together. And so the students asked me when we knew we were going to be a BYOD school the next year if I would research how Twitter could be used in the classroom. And so my first response back was, well, everything that I think we do in the classroom is around thinking. And they said well we're confident that you can find a way that we can think with Twitter. So I love a challenge. I didn't know anything at all about Twitter. What I knew about Twitter I looked at from a social standpoint just because I wasn't on Twitter. I had never even seen a tweet. I didn't know what a hashtag was. I called it a pound sign. So I joined and just followed a couple of people and watched them tweet and looked at the resources they would tweet out, for at least a month.

Seeing how others were using Twitter, and exploring and realizing the utility of the tool for own professional practice, this teacher none-the-less wanted to be cautious of simply using Twitter for the sake of using it. She explained:

So I joined Twitter last summer with the goal of trying to figure out how I could leverage that, and pretty much everything that I do is around student thinking. I much more concentrate on the how and the practice, as I feel like kids learn the

content through that proficiency of skill. So I wanted to utilize technology, but it had to be about that. It wasn't just going to be bells and whistles.

Her consideration also involved dialogue with her students and, before long, it became clear that creating professional Twitter accounts could be a meaningful approach to using Twitter in the classroom. As she described:

The students and I started talking about the need to have a professional learning network even as a high school student, where we could connect to other – to scientists, other teachers and other students. So that's when we decided that we would create professional Twitters and that we would talk about what kind of picture we would use and what we would write on our timeline.

With such a purposeful adoption of Twitter, it is not surprising that this teacher's use of Twitter has also been well thought out and refined. Students in her classes are always encouraged to support claims, even in tweets, with evidence. As she explained:

We concentrate on this even in Twitter and even when they're in #scistuchat, and it's a work in progress so it's better at the end of the semester than at the beginning, that they need to communicate a point with evidence. And so a lot of times that evidence is some kind of link or picture or a classroom example. So again, acting and thinking like a scientist.

Elaborating on the significance of evidence-based claims, and how these play out when using Twitter, specifically, she stated:

Our basic framework is claim/evidence/reasoning. ... We couldn't really do the reasoning part but the evidence part we could still do and that's where their thinking came in, besides the claim, I mean that's thinking. And then their

creativity, because a lot of times they would find – and not just any old data representation or picture from the internet, but something that really, really strongly supported that claim that they wrote, or they might take a picture in class or they would start documenting things in class as we went because they didn't know if they were going to need to use that picture later on as evidence...And so we shared that through our class hashtag and then we also have a shared hash tag that we use often with another classroom....And then we store it by the hashtag, often, so we can turn it into a PDF so we can save that as an artifact of our thinking.

While the claim/evidence/reasoning approach has allowed this teacher's students to engage with other students and scientists throughout the world, one of their most recent and exciting projects included using Twitter to interact with fourth grade students in their own town. A partnership was formed between this teacher and a local fourth grade teacher to inject new energy into a standing event referred to as the Invertebrate Olympics. Following introductions between high school students and the fourth graders via Google Hangout, Twitter was used to foster ongoing dialogue. As the teacher described:

And then from there we communicated via Twitter. So the fourth graders, we communicated with the parents and they set up Twitter handles for the whole group. There were eight fourth graders in a group and they all shared a handle and then the parents had access to that. And then on my end, my students had their own Twitter accounts...

The collaboration culminated with all of the involved students, along with the public, coming together in a large gymnasium for the actual Invertebrate Olympics. As she described:

We used social media. We videoed the event. The students all tweeted and shared the experience that way...And then we tweeted out the video from the live event to share with the public. Because we invited the public to our event. There were lots and lots of people there. So it was a really great exercise for the students to see a way that they could use social media and Twitter not just to connect to scientists...but with people that they'd seen in Google Hangout a few times but...didn't get to ever meet...In this case it culminated in that we took buses over there and they sat with each other all day and just captured the pictures of the high school students with the elementary students that they'd been corresponding with for two months. It was just amazing. They were all so excited to see each other.

Challenging perceptions. When discussing the benefits of their participation in #scistuchat, as well as other current and prospective use of Twitter for educational purposes, scientists, students and teachers all repeatedly referenced encountering misperceptions of Twitter. Specifically, scientists shared how they often encounter misperceptions of Twitter in their interactions with colleagues. Students referenced their *own* perceptions of Twitter being challenged. And teachers discussed how, given the misperceptions that they encounter, providing students opportunities to engage with Twitter in new and different ways will lead, ideally, to greater understanding, independence, and empowerment.

Scientists. Scientists in each of the chats shared similar accounts of encountering surprise from colleagues and others upon learning that they use Twitter as a professional and educational resource. Sharing an instance not uncommon among their Twitter-using colleagues, one scientist shared:

When I tell people about Twitter, a lot of people are really impressed and it's kind of surprising, because like Facebook, so many people use it. Twitter...they just think it's really scary or really high tech or they haven't figured it out.

Another scientist shared their plans for assisting colleagues in setting up their own Twitter accounts. In this scientist's words:

I have heard from many of them that they want to start using it, they just don't know how. So I'm actually going to teach them, hopefully, how to use Twitter but they want to start using it because they've heard me talk about how useful it can be. How it can really be a resource instead of just "I had a sandwich for lunch and I'm still hungry." It is valuable.

Scientists in a different chat also touched on the perceptions of their colleagues, as well as how they believe that the use of Twitter among scientists will become increasingly commonplace. As one individual noted:

Every time that I start something like this, I always am skeptical. But every time that I have, it seems to have ended up being much more beneficial than I expected. So I think this is, again, getting over that hump that this is just a fad type thing, to something that is actually useful for science communication. The more people I talk to...at least in my community, the more they buy into it.

Another scientist in the same chat offered a similar perspective, explaining:

I think the people that are interested in it will make their way out to social media and the people who aren't will continue to do what they do. But I think it will become more and more the norm as of course the older people retire and younger people replace them, where it will just seem commonplace that you will want to be talking to a broader community all the time.

Students. Reflecting on their use of Twitter, both in #scistuchat and for other class-related purposes, students across all chats echoed virtually the same message—that their own perceptions of Twitter had fundamentally changed. Specifically, students explained how they had a newfound appreciation for the power of Twitter as an educational resource. Below are quotes from students who participated in each chat. They are shared here to illustrate the fidelity of the conclusion that a powerful take-away for students was the shift in their perceptions of Twitter as an educational tool.

Two student-participants in the black holes chat share these reflections, “The thing I liked most was that I learned about Twitter, that there’s just so many ways to learn from it. I thought it was like just a social media thing but there’s a learning side to it.” and “Being in a chat that has information on science, like #scistuchat...I found out that you can use Twitter to learn instead of just following tweets.”

Students from the human genetic engineering chat also pointed to an evolution in their perceptions of Twitter an important outcome of their experiences. One student noted, “One major takeaway for me was that you can use social media to learn. It’s not just communicating with people about entertainment or whatever. You can actually join together and actually talk about something that you can learn from.” Another student from the same chat shared:

To me it kind of changed my perspective of how I see Twitter and social media, because people usually use it to say, oh I'm eating this or like posting about their life, and I kind of saw it in that way. But now that we've been using #scistuchat, it's more like an educational way and you can see how not everyone uses it in the same way.

Like their counterparts in the black holes and human genetic engineering chats, students who participated in the green chemistry chat also conveyed a new appreciation for the utility of Twitter. As one student shared, "Before #scistuchat I thought that Twitter was just another social media network. Then we did #scistuchat and I learned that it can be used for a lot more...It can be used for learning things and teaching new things." Another student shared a virtually identical take-away, noting, "Well, being on #Scistuchat has made me aware that Twitter can be used for more than just social media. I have explored some science-related topics which I wouldn't have done before #scistuchat."

Lastly, student-participants in the volcanoes chat, like so many other students across the four chats, spoke to the impact of using Twitter for science purposes. Two particularly relevant quotes included, "So I feel more like, professional, because of interacting with professionals and especially because we're using Twitter. And not as a social media but more as a learning tool," and "I think in general social media or Twitter isn't just a social network but a learning tool."

Teachers. Teachers' discussion of perceptions of Twitter centered on their students. When viewed holistically, their comments broke along two distinct lines: 1. students being challenged by the notion of Twitter as a tool for science learning and

communication; and 2. teachers' own beliefs in the power of Twitter as an educational resource that can empower their students to become independent learners as they move through school and life.

Teachers spoke often of what they perceived as their students' lack of familiarity, and even discomfort, with the notion of Twitter having educational value. As one teacher expressed, "They look at Twitter just as a way to connect with their friends and possibly be silly," and that "At first, there was a big hesitation even about tweeting because it's out on the internet and people are going to see them tweeting smart stuff as opposed to social stuff." A teacher from a different chat noted the even more widespread suspicion of Twitter in her community. She explained, "At least where I am, teachers, educators, parents, they don't see social media as something you can learn from. Most of them see it as a distraction."

Understanding how teachers perceive their students' perspectives of Twitter is helpful, as it provides context for better appreciating the rationale behind committing to its use in their classes. This rationale, common among virtually all the teachers in this study, is driven out of a desire to empower students to become more informed, opportunistic learners, aware of the power and perils of social media. Put simply, in the words of one teacher, "The whole goal is really to get them to use social media for learning purposes."

Teachers' efforts to provide opportunities for their students to pursue their own learning was a recurrent theme. Comments such as "I'm very much about students exploring their own learning and gaining their own knowledge, not from somebody like hand feeding it to them or them consuming. I want them to build it on their own" and

“That’s why it’s so important to find a way that they can continue to learn as an adult so they can be critical consumers who make sound decisions,” were expressed regularly. Speaking to his desire to empower students as well as to their misperceptions of Twitter, another teacher shared, “I guess part of it is giving students opportunity to find their own resources for those who want to learn and...to help students know that social media can be used for educational purposes and it can be very powerful.”

Explaining why he believes that the classroom is an acceptable venue for such exposure, a teacher-participant in the human genetic engineering chat bluntly stated:

A lot of kids won’t get that experience unless it’s happening in the classroom.

They won’t learn how to build a positive digital footprint because all they do is post crap on Facebook, or whatever they’re using, that is not relevant to their lives or cannot help them progress...

Piggybacking on the general sentiment of the previous teacher, the following individual offered her own question, followed by a compelling response—one that I believe most teachers in this study would agree with. In her words,

My question is why shouldn't we be leveraging these platforms for education? By embracing tech that is already a part of kids daily lives, we can model life-long learning, empowering students as well as giving them a vehicle to share their thinking.

Summary. As an educational tool, participants in this study used Twitter in a variety of ways. Because all secondary science students and teachers involved in this study used Twitter as part of their in-school science experiences, they offered a unique window into the practical applications of Twitter as an educational tool. Like its use as a

professional tool, the use of Twitter as an educational tool, as well as its degree of influence on students' science experiences, depended heavily on the motivations and creativity of the teachers who embraced it. Moreover, scientists, students and teachers each sensed that their use of Twitter as an educational tool challenged general perceptions regarding the utility of social media. This was especially pronounced among students, who often described their own cognitive dissonance as they began using Twitter for educational purposes.

Chapter 5: Discussion

The purpose of this study was to explore #scistuchat participants' perceptions of Twitter as a tool for learning and communicating science. Drawing on the perspectives of participating scientists, teachers and students, the study sought to answer the following research questions:

- How do participants understand #scistuchat as a digitally-mediated, learning experience?
- How do participants understand #scistuchat as a formal vs. informal science learning experience, particularly as it relates to in-school science learning?
- How do participants use, and perceive, Twitter as a medium for teaching, learning and communicating science outside of the confines of #scistuchat?

Participants in this study recognized #scistuchat as a unique opportunity to engage, across traditional barriers, with other interested stakeholders around a shared science topic. Through direct observation of the chats in real-time, both one-on-one and focus-group interviews, and analysis of archived versions of the chats, distinct themes emerged related to both #scistuchat, specifically, and the broader use of Twitter for teaching and learning in high school science classrooms. Themes specific to #scistuchat considered the nature of participants' interactions, as well as associated outcomes, particularly as they played out within a novel context that challenged traditional conceptions of when, where and how learning takes place. Themes connected to the use of Twitter beyond #scistuchat offered windows into participants' experiences with, and

perceptions of, Twitter as both a professional and educational tool. The following discussion considers my research questions in light of these themes, offering connections to existing literature where possible as well as implications for policy and practice. I also acknowledge the limitations of my study and propose potential avenues for future research.

The #Scistuchat Learning Experience

Although Twitter's utility as an educational tool is the focus of an increasing body of research, studies concerning its use at the K-12 level still lag significantly behind those concerning its use in higher education settings (Junco, Elavsky & Heiberger; 2013, Kassens-Noor; 2012, Lin, Hoffman & Borengasser; 2013, Prestridge; 2014). When encountered in the literature, discussion of Twitter in K-12 settings often assumes the form of short articles exploring the *possibilities* of its integration with students (Lesley, 2014; Morgan, 2014), or its utility for teachers and administrators (Carpenter & Krutka; 2014, NEA; 2013). Although in his review of dissertation research concerning social media (SM), Piotrowski (2015) noted that while "the analysis shows that dissertation research on the implementation of SM for *academic* purposes predominantly reflects applications in college or university settings," there did appear to be an "emerging interest in the nexus of SM and K-12 instruction..." (p.3). Indeed, cases in which Twitter is used directly with students in K-12 settings are few and far between (Hunter & Caraway, 2014; Journell, Ayers & Beeson, 2013)

Uniquely, #scistuchat capitalizes on the connective power of Twitter to bring together scientists, high school students and teachers across vast distances. As such, the range of participants, including their backgrounds and expertise, often varies widely. And

yet, the experience works. Students are intrigued by the idea of interacting with real scientists, who work in exciting fields, scientists enthusiastically embrace the opportunity to share their passions with curious students, and both share an interest in the science topic that is the focus of a given chat. These broad factors function to predispose successful interactions and, thus, often lead to successful chats. However, it is reasonable to wonder if there are more subtle, underlying factors at play that lead many participants to repeatedly participate with such willingness and enthusiasm. My research, unique in that it explores the voices of three participant groups using Twitter—scientists, *students* and teachers—across four separate cases, points to several distinctive features as lynchpins in the appeal and success of #scistuchat.

Students are more likely to excel, and enjoy themselves, when they participate in learning experiences that are student-centered. #Scistuchat is inherently student-centered. From the selection of topics and questions, to the moderation of the chats, to the freedom of students to pursue their own personal questions throughout the course of a chat, #scistuchat is designed to maximize student voice and engagement. Moreover, as participants alluded to, because interacting through Twitter seems to reduce power dynamics that accompany traditional face-to-face interactions between individuals with such differences in educational attainment and life experience, the #scistuchat experience tilts even more in students' favor.

In addition to the overall set-up of the chat and a freer sense of interactions between adolescents and scientists, my research pointed to other factors, too, that functioned as lynchpins in the success of #scistuchat. Namely, again through the eyes of students, #scistuchat provides an expanded, authentic audience and the entire experience

occurs over a medium that is more consistent with students' out-of-school lives. Students are used to interacting with others over social media. #Scistuchat leverages the power of one form of social media—Twitter—to connect students with others in real-time. The fact that other people in this case are large numbers of real scientists, real students and real teachers, and that the interactions among them are organic and unscripted, creates a sense anticipation and excitement. When contrasted against what many students described as their typical school experiences, such real-time interactions among such a diverse and widespread audience, over a medium familiar to students, stood out as a welcomed, novel experience.

Scientists appeared to recognize, implicitly, the student-centered nature of the chat and the important role this factor plays in the keeping the chats as viable and engaging as they are. During interviews, scientists frequently referenced challenges faced during the chats—including students not abiding by protocol, the frenetic pace, and the frequency of scientific misconceptions—that could easily have left them exasperated during the chats or disillusioned in the aftermath. Yet, time and again, scientists exhibited both a tolerance of such challenges and an understanding of the limited scientific background from which many of the students were working. This was evident in watching the chats play out in real-time, as well as in our in-depth conversations about #scistuchat during the interviews. Scientists' appreciation for the spirit of #scistuchat—and the larger goal of fostering student-scientist interactions, even in the face of sometimes repeated distractions—I perceived as a deep recognition of the fundamentally student-centered nature of the chat. They often expressed joy at simply engaging with

students around science ideas, and stressed how much they enjoyed seeing the types of questions that were on participants' minds.

Teachers recognized many of the same student-centered benefits their students mentioned as important, positive aspects of #scistuchat. However, at a more primary level, teachers deserve credit for functioning as the constant intermediary between their students and the chat. Their students' opportunities to be involved in a unique event like #scistuchat resulted directly from their own involvement with Twitter and a unique willingness to support and model the use of social media for science purposes. As the agents ultimately responsible for the delivery of curriculum in a culture driven by test scores and accountability, these teachers demonstrated a commitment to an untested learning opportunity. Doing so required that they relinquish a significant degree of structure and control over their students, instead placing trust in them to represent themselves, their school and their teachers within an exciting, yet experimental digital forum. There is perhaps no other act more student-centered than entrusting students with the freedom to pursue their own questions and drive their own learning.

Ultimately, consideration of the impact of participation in #scistuchat is important. My research suggests that from a learning standpoint, if measured by the degree to which new content was learned or existing knowledge deepened, the benefit of #scistuchat for students is very limited. Based on analysis of archived student tweets and their discussion of their experiences during focus group interviews, a deeper understanding of the science underlying a given topic was not significant or, at the very least, notable in their minds. Of course, learning is multidimensional, and can encompass more than the accumulation of content knowledge. In one of the most interesting findings

of my research, when discussing learning, students repeatedly referenced an evolving understanding of scientists as people—in essence, #scistuchat had a humanizing effect. Thus, coupled with the affective impacts and students’ overwhelmingly positive assessment of the chat’s effectiveness, it could be argued that such outcomes do, in fact, constitute learning—perhaps in ways even more significant than learning content alone.

#Scistuchat—Formal vs. Informal

The teaching and learning of science in schools is often considered formal science education. In contrast, engagement in science-related activities and experiences outside of school (e.g., museums, zoos, TV, radio, video games, etc.) is typically considered informal learning. Many consider school as their primary and, in some cases, only direct experience learning science. However, research suggests that informal encounters with science comprise a significant portion of an individual’s understanding of science (McCallie, 2009; NRC, 2009; NRC, 2010; NSTA, 2012; Phipps, 2010; Tal & Dierking, 2014). In fact, Falk and Dierking (2010) stated “Average Americans spend less than 5 percent of their life in classrooms, and an ever-growing body of evidence demonstrates that most science is learned outside of school” (p. 486).

Concerning the use of digital technologies, specifically, McCallie et al. (2010) noted that they “hold great promise” and that the internet “opens new doors for synchronous and asynchronous interaction, including interactions across vast distances and among small to very large numbers of participants” (p. 36). However, illustrating that much work still needs to be done on this front, social media was one of the topics in the *Diving Deeper, Looking Forward* session of 2014 Advancement in Informal Science Learning (AISL) Principal Investigators Meeting sponsored by the Center for the

Advancement of Informal Science Education (CAISE). Here, it was described as “a (potentially) effective way to reach and engage different audiences,” as “In particular, social media can be a great way to connect the public to scientists who participate in these activities” (CAISE, 2014). Occurring since 2012, #scistuchat is an ongoing example of social media being leveraged to bring students and scientists together in real-time. Thus, this research offers a valuable contribution to the field of informal science education, particularly as it relates to digital technologies and, specifically, social media.

The designation of #scistuchat as an informal science learning experience was not assumed at the start of my research. As one of three research questions framing this study, I was interested in understanding how participants—students and teachers, primarily—understood #scistuchat as a formal vs. informal learning experience, especially when juxtaposed with their in-school, classroom experiences. As described in the “Formal vs. Informal Learning” theme in my “Findings” chapter, the notion of freedom was a thread that ran throughout all participants’ responses when discussing the formality of the #scistuchat experience. It’s this quality in particular that contributes to the informal characterization of #scistuchat.

At its most basic level, participants had the freedom to participate in the chat or not. Participation was not required of any scientist, student or teacher. However, even when one chose to participate, additional encounters with freedom abounded. For example, although adhering to the protocol was expected, participants were free to respond to questions in ways they thought were most effective. Moreover, spontaneous interactions centering on individually driven questions outside of the moderated questions were not only acceptable, they were encouraged. Still other examples of freedom

included the fact that the chat occurred outside of school, which was especially important to students, and that one could be in whatever physical setting they wanted, using whatever device they were most comfortable using, while participating.

With the continual evolution of digital technologies, educational institutions are increasingly expected to personalize educational experiences and opportunities for their students (Atkins et al., 2010; Ed tech, 2015). A direct result of their often informal use, both #scistuchat and the use of Twitter for learning and communicating science outside of #scistuchat offer users the freedom to personalize their experience. A distinctive, general finding of this study was that one's experience within #scistuchat, as well as one's use of Twitter for science purposes outside of the chat, was highly personalized. As is often the case with informal science learning opportunities, what one puts into the experience—influenced by one's knowledge of the topic, motivations for participating, and comfort operating within the framework the activity resides—can vary widely and, as a result, heavily influences the outcomes realized. Twitter, as a pedagogical tool, and #scistuchat, a learning experience that occurs via Twitter, offer promise as means by which students can add a dimension of personalization to their science experience. The fact that such personalization can occur both within and outside of the school day further adds to the possibilities.

Twitter for Science Purposes Beyond #Scistuchat

This study showed that Twitter can be used meaningfully and productively for science purposes beyond #scistuchat. Both as a professional tool for scientists and educators and as an educational tool for teachers and students, Twitter offers these users a wealth of possibilities. While, as described above, instances of direct use of Twitter by K-

12 students in educational settings are sparse, *all* students in this study used Twitter as part of their high school science classes. Students described the numerous ways they used Twitter as part of their classes, ranging from rarely to daily and ranging from single tweets of article summaries to regular use of professional accounts to share science thinking with schools in other states. Perhaps the most striking finding, however, was students' across-the-board descriptions of how their perceptions of Twitter, and of social media in general, had shifted. With near identical consistency, students spoke time and again of a shift in their understanding of social media from that of a purely social forum to one able to be leveraged for learning and academic pursuits.

While students' use of Twitter in school settings is uncommon, Twitter is widely recognized as a valuable professional tool for educators (Ferriter & Provenzano, 2013; McGinnis, 2014; Mieliwocki, 2015; Visser, Evering & Barrett, 2014). Reflecting the trend of Twitter being a foundational component of educators' personal learning networks (PLNs), teachers in this study, too, used Twitter for a variety of professional reasons. With the notion of "access" a common tie among them, teachers consistently spoke of the power of Twitter to connect them with like-minded colleagues who share similar interests. Once again a testament to the personalized use of Twitter, teachers in this study were as likely to use Twitter for individual conversations with other educators regarding specific questions as they were to engage in Twitter chats, where sometimes dozens of educators gather to share their thoughts and experiences around a predefined topic. As part of a two-pronged approach to using Twitter—a professional tool on the one hand and a pedagogical complement to their classroom on the other—teachers' use of Twitter for professional purposes seemed meaningful. For sporadic users, Twitter simply

is there when they need it, with its utility somewhat left to chance. For more frequent users, especially those that nurture their Twitter relationships and actively curate their lists and followers, Twitter acts as a source of constant professional development, interaction with others and, often, inspiration.

As a pedagogical complement to their science classes, teachers again used Twitter in varying ways and to varying degrees. Those who did so most effectively incorporated the perspectives and feedback of their students as they developed ways that Twitter could be leveraged to enhance their students' science experiences. Notably, hashtags were used frequently as a way for students engage in shared dialogue, to provide evidence of their scientific thinking, to backchannel during class, and as a way for teachers to archive class-specific uses, including discussions among students in separate states. In one school, the clarity and intentionality of use was especially evident as both teacher and students referred frequently to their creation of "professional" Twitter accounts. Across all chats, and especially in cases where the clarity of purpose regarding the use of Twitter was high, teachers articulated their efforts to model for students ways that Twitter could be used for learning. Given students' experiences with #scistuchat, complemented by teachers' efforts to model constructive uses of Twitter for academic purposes and to develop in-class opportunities for students to use Twitter to communicate science, it is little wonder why students so unanimously expressed a shift in their perceptions of Twitter.

Scientists in this study used Twitter as a professional tool and, relatedly, as a means for engaging in science communication and outreach. Like their teacher counterparts, scientists encountered #scistuchat through their own use of Twitter. Thus, it

was not surprising that their use of Twitter was already established and multifaceted. Both the presence of scientists in this study on Twitter, as well as their varied uses of Twitter, reflect a larger trend in which scientists are increasingly turning to new media to communicate science (Baker, 2015; Brossard, 2014; Liang et al., 2014; Van Noorden, 2014). Participating scientists used Twitter regularly for professional purposes, including as a tool to connect with other colleagues, to share and receive feedback, and to both follow and live-tweet professional conferences. Like teachers, who personalize the use of Twitter for their individual needs within the field (and sub fields) of education, scientists' use of Twitter reflected similar, personalized applications—in this case, specific to an individual's area of expertise, interest and scientific questions.

Scientists' use of Twitter offered a striking counter to common perceptions of Twitter. While it is common to hear those unfamiliar with Twitter describe it as trivial, quippy, and characterized by what-I-had-for-breakfast kinds of exchanges, scientists' use of Twitter demonstrated its versatility. In their case, Twitter was used first and foremost as a way to communicate with other *scientists* about *science*. Primary among these communications, scientists frequently reached out to other scientists, in many cases using Twitter as the medium for initiating these interactions. Whether following up on serendipitous encounters, purposefully targeting an individual because of his or her expertise, or reaching out to longstanding Twitter colleagues, the interactions turned common perceptions of Twitter on their head. As detailed in the “Twitter as a professional tool for scientists” sub-theme of the broader “Twitter and Professional Practice” parent theme, the focus of these interactions were frequently very science-focused, with topics ranging from how specific proteins “may or may not have evolved”

to cross-Atlantic discussions of experimental Stickleback set-ups stemming from a single tweet that proudly exclaimed “100 nesters this week.”

As mentioned above, scientists’ use of Twitter in this study paralleled that of scientists in other, larger-scale studies. For example, Van Noorden (2014) found that, among scientists who claimed to use social networking sites with regularity, that “Facebook is not widely used professionally” and that “researchers on Twitter are very active and social” (p. 128). Moreover, among scientists who were regular users of Twitter, the most oft-cited uses included following discussions, posting (work) content, discovering peers and commenting on research (p. 129). And, with “Relatively few scientists are taking the opportunities Twitter offers,” this leaves “much network potential untapped” (Baker, 2015, p. 263). Speaking directly to the network potential Baker noted, “Following thought leaders and relevant organizations is an effective, easy way for researchers to learn about important papers, events, funding sources, potential colleagues and job opportunities” (p. 263). Moreover, the scientists in my study, members of the subpopulation of scientists actively using Twitter, realized many of these outcomes, among others.

Scientists use of Twitter as a professional tool had both personal and public dimensions. Thus, in addition to the personal outcomes they realized in their professional lives, scientists also used Twitter to engage in science communication and outreach where the intended audience was broader than scientific colleagues, in many cases involving the public writ large. This is meaningful because, as Liang et al. (2014) noted, there is “value in ‘building buzz’ by utilizing social media as well as legacy mass communication channels to enrich information exchanges between the scientific

community and public audiences” and that “social media can augment the impact of more conventional forms of public communication” (p. 785). In this study, scientists leveraged the real-time nature of Twitter and its ability to easily link to other forms of media to offer what many hoped was a gateway or jumping-off-point for audiences to engage in deeper exploration, once their interest had been piqued. For some, the aims of their outreach efforts were large in scale, as one scientist noted, “we’re doing as much as we can with our physical time...but we can reach a much bigger audience than we’re trying to just by trying some more digital platforms.” For others, importantly, outreach efforts were considered promising and meaningful at the local level. As one scientist shared, “So instead of just waiting for somebody to call me, I can maybe start to be a resource for the local news media or whoever, especially locally.” Regardless of the scale, and mindful of the time and energy required to engage in such efforts, scientists in this study believed that Twitter offered a promising and viable venue to share science with others beyond their colleagues.

Implications for Policy and Practice

The potential implications of this study are numerous and relate to the teaching and learning of science, the potential for expanded opportunities for science communication between scientists and the public, and evolving considerations for institutional review boards (IRB). Below are several notable implications of this work. Specifically, they include alignment with the aims of the *NGSS*, connections to additional sets of national standards, district-based policy ramifications, opportunities to make more permeable the barriers between scientists and the public—including students and teachers, and a brief discussion of IRB-related considerations for similar studies.

In science classrooms committed to the *NGSS*, the use of Twitter as a complement to the existing curriculum, and to current pedagogical practices, could result in greater movement towards students realizing intended outcomes. For example, in “Appendix A - Conceptual Shifts in the *Next Generation Science Standards*,” the first conceptual shift states “Science Education Should Reflect the Interconnected Nature of Science as it is Practiced and Experienced in the Real World” (p. 1). Expounding on the importance of this conceptual shift, in “Appendix C - College and Career Readiness,” it is noted:

Scientists and engineers have always integrated content and practices in their work, but that has not been the case with science instruction. As former president of the National Academy of Sciences, Bruce Alberts, stated, “rather than learning how to think scientifically, students are generally being told about science and asked to remember facts” (Alberts, 2009). Traditional instruction has emphasized lectures, note-taking, reading, and assessment that tested recall, offering little opportunity for in-depth study or research (NRC, 2007). (As cited in *NGSS*, Appendix C, p. 2)

The fact that student outcomes associated with participation in #scistuchat appear to result in an increased sense of science-related self-efficacy, as well as a deeper appreciation for scientists and the nature of their work, suggests that students’ use of Twitter could support classroom activities and practices. It would seem that such a strong commitment to providing students with experiences in which scientific practices (*NGSS*, Appendix F) are the vehicles through which students learn science content, could only be enhanced by opportunities for students to engage in real-time with actual scientists practicing real science.

Beyond the general aims of *NGSS*, this study offers an in-depth look at how students engage with and communicate through a specific form of new media—Twitter. Virtually all national-level learning standards include a dimension specific to how students communicate their learning. For example, in the *NGSS* practice titled, “Obtaining, Evaluating and Communicating Information” (grades 9-12), it is explained that students should “Communicate scientific and/or technical information or ideas (e.g. about phenomena and/or the process of development and the design and performance of a proposed process or system) in multiple formats (including orally, graphically, textually, and mathematically).” In standard W.11-12.6 of the “English Language Arts Standards” in the Common Core State Standards (CCSS), it explains that students should “Use technology, including the Internet, to produce, publish, and update individual or shared writing products in response to ongoing feedback, including new arguments or information.” In the International Society for Technology in Education (ISTE) student standards, “Standard 2: Communication and collaboration” explains: “Students use digital media and environments to communicate and work collaboratively, including at a distance, to support individual learning and to contribute to the learning of others.” Notably, subtopics include: “a. Interact, collaborate, and publish with peers, experts, or others employing a variety of digital environments and media” and “b. Communicate information and ideas effectively to multiple audiences using a variety of media and formats.”

These standards clearly convey the significance of students communicating their thinking, often with considerable flexibility in how that might be accomplished.

#Scistuchat, and the use of Twitter for communicating science in general, places students

in the position of constantly communicating their thinking to a wider, authentic audience. Furthermore, because of its inherently dynamic nature, students are likely to experience instances in which they are engaged in two-way communication, in real-time. These interactions offer authentic, embedded opportunities to practice digital citizenship, an ever-present need in the lives of today's students.

Related to digital citizenship, but expanding into the realms of student privacy, confidentiality and safety, policy implications associated with practices described in this study abound. As a building or district leader in K-12 education, one must grapple with the many potential benefits, as well as the numerous and significant drawbacks, of embracing social media in school settings. As noted in the National Association of Secondary School Principals (NASSP) position statement "Using Mobile and Social Technologies in Schools" (2011), "The rapid growth in the use of social media and mobile devices has created both a crisis and an opportunity for school leaders" (para. 1). Ultimately responsible for articulating a position on this often publicly-contentious issue, leaders are challenged to create policy that is both narrow enough to have consequence, yet broad and flexible enough to be responsive to an ever-evolving landscape. As the NASSP position statement concludes, it is paramount that leadership commit to "engaging students in the creation of responsible-use policies so that they can access social technologies without unreasonable obstacles." As evidence of the obstacles that do exist, even some of the teachers in this study had to lobby heavily, over extended periods of time, to have Twitter be an accepted component of their classroom. And yet, even with sound policy that embraces the promises of social media for educational purposes, resistance can persist. At the ground level, teachers ultimately must lobby and, in many

cases, persuade often skeptical parents to support their adoption of what is still, in many corners, a controversial practice.

Beyond standards, this study has implications for the broader pursuit of greater communication between scientists and the public. Funk, Rainie & Page (2015) found “stark fissures between scientists and citizens on a range of science, engineering and technology issues” and, furthermore, that “both the public and scientists are critical of the quality of science, technology, engineering and math (STEM subjects) in grades K-12” (p. 5). When asked if the public’s limited knowledge about science was a major or minor problem, 84% of scientists in this Pew Poll cited it as a major problem. Clearly, there is room for improved communication among scientists, students, teachers, and the greater public. This study offers a window into one means by which students and scientists engage in dialogue about specific science topics. #Scistuchat, as has already been shared, bills itself as “A Twitter Chat for High School Students to Talk to Scientists” and welcomes those interested to “Join the discussion between high school students, scientist, science educators, and general science thinkers sharing around current science topics.” Given these stated objectives, as well as the findings of this study, #scistuchat offers a promising avenue for opening up dialogue between scientists and other stakeholders. When one considers the use of Twitter for science purposes more broadly, beyond #scistuchat, and considers this practice in the context of the findings of this study, one cannot help but be encouraged by the possibilities.

Lastly, IRB-specific questions encountered during the design and implementation of this study suggest that certain policies concerning the rights and welfare of participants might need revisions to address an increasingly digital, global research landscape.

Numerous times throughout this study I encountered IRB-related questions that did not appear to have clear answers or to fall easily within a decision-making flowchart. For example, by virtue of the simple fact that they were participating in #scistuchat, all chat participants had created Twitter accounts specifically designated as “public”. This meant that their tweets, as well as any information contained within their profile descriptions, was viewable and searchable by anyone. If one is already knowingly tweeting publicly, using a platform that is specifically designed to connect individuals and promote interactions, do traditional measures aimed at ensuring privacy and confidentiality still apply? In my case, I was careful to run this question, and others similar to it, by my advisor and UVM’s IRB. Ultimately, after numerous interactions with UVM’s IRB and amendments to my study, I was granted permission to share content of participants’ accounts and tweets in the manner that is represented in preceding figures and descriptions. I can imagine other studies that explore social media, and whose interactions with participants occur primarily or even entirely via digital means, will likely encounter similar questions and ambiguity. Like K-12 districts and boards challenged with developing policies that are responsive to these technologies—and the iterations and future technologies that are sure to come—institutional review boards must also be prepared for new questions that challenge traditional conceptions of research settings and involve unique and unprecedented connections between researchers and participants.

Limitations

This study has several limitations that are important to note. First, the selection of participants was limited. While I had originally intended to have populations of

participants that reflected as much diversity as possible, the realities of identifying, contacting and securing participants, especially across vast distances and coordinating across multiple time zones, made the process particularly challenging. For example, ideally I would have had student-focus groups comprised of students with balanced gender representation, differences in their overall familiarity and use of Twitter, and differing socioeconomic backgrounds. However, given the logistical challenges of communicating with all students indirectly through their teachers, and the realities of students' busy daily lives, securing enough individuals to have a focus-group became the bottom-line goal. Often, realizing this goal required considerable flexibility and problem-solving on the part of all parties involved. Also, as a related consequence, the numbers of scientists, students and teachers differed over the course of the four #scistuchats.

A second limitation of this study is related to researcher bias. Although I emailed all participants transcripts of their interviews, and welcomed feedback, clarification and follow-up comments, I was unable to follow up with each participant to present my *findings* and to receive their feedback. In an effort to minimize any potential negative effects, I did share my findings (in the form of the themes matrix found in Appendix D) with the creator of #scistuchat and followed up with a personal discussion via Google Hangout. My rationale for doing so was that this individual, who was also a teacher-participant in my study, has by far the greatest understanding of and familiarity with #scistuchat. I was aware that he often receives feedback from scientists, students and teachers and, as a result, would provide a critical lens through which to pass my findings.

Lastly, generalizing the findings of this study beyond the specific cases analyzed is an inherent limitation. Although not an aim of qualitative research, it is not

unreasonable to question the “relevance or applicability of our findings to other similar settings, to transcend the particular in order to understand the general” (Miles et al., 2014, p. 101). While I believe that my efforts at cross-case analysis allowed me to identify findings that cut across individual cases and suggest transferability to other contexts, expecting *identical* findings across similar settings, or even among future #scistuchats, would undoubtedly reveal inconsistencies.

Directions for Future Research

One of my favorite quotes states, “The more you learn the more you realize how little you know.” Not surprisingly, while I learned an enormous amount about participants’ perceptions of Twitter as a tool for learning and communicating science, the process has left me pondering additional questions.

First, there is research that considers students’ conceptions of scientists (Thomas, Henley, & Snell, 2006; Hillman, Bloodsworth, Tilburg, Zeeman & List, 2014). Given the unanimity with which students referenced #scistuchat as impacting their perceptions of scientists in this study, it would be interesting to explore the effect digitally-mediated interactions have on students’ perceptions of scientists. I would also be interested in knowing if such digital interactions impact students’ understanding of STEM practices and careers.

Second, related to the first implication I discussed above, I would be interested to learn more about potentially synergistic effects of integrating digitally-mediated science learning experiences like #scistuchat within a classroom that is consistent with the best practices as described in the *NGSS*. In other words, can #scistuchat, and the use of

Twitter more generally, offer a new and meaningful dimension to a classroom that already embodies the ideals of the *NGSS*?

Third, I would be interested to know to what degree, if any, science students who are provided with opportunities to use Twitter continue to do so. As a teacher whose students use Twitter as part of their science experience, I am always curious to know if my students are taking advantage of the unique possibilities afforded by Twitter to pursue their own curiosities and to extend their own learning. Tracking science students' use of Twitter longitudinally would provide an interesting window into whether or not new habits have been formed, as well as how their use may or may not have evolved over time.

Lastly, although not directly related to this study, I would be very interested to learn more about the benefits organizations realize through their use of Twitter for science outreach purposes. For example, the National Aeronautics and Space Administration (NASA) has Twitter accounts for many of its missions and departments. These accounts are updated very frequently, and give every indication that NASA's commitment to this level of communication must result in some positive benefit(s) realized on their end. I think it would be interesting to understand better the rationale for such dedication to communicating with the public, metrics used to gauge impact, and the players involved in, as well as chain-of-command for, such frequent, science-specific outreach.

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Appendix A: Geographic Locations of #Scistuchat Participants (Feb-May 2014)

February 2014 (Black Holes)	March 2014 (Human Genetic Engineering)	April 2014 (Green Chemistry)	May 2014 (Volcanoes)
Arkansas/USA/Pale Blue Dot	Arkansas/USA/Pale Blue Dot	Altoona, Ia	@LSU @LSU_MNS
Arlington, VA USA	Arlington, VA USA	Arlington, VA USA	Arlington Heights, IL
Atlanta	Ashland, VA	Bay Area	Arlington, VA USA
Australia	Aurora, Nebraska	Bethesda, MD	Aurora, NE
Bergen County, New Jersey	Baltimore, MD	Boston, MA	Austin, TX
Boston	Baton Rouge, LA	Canada	Bar Harbor, Maine, USA
Brasília	Charlotte, NC	Colorado Springs, CO	Bellevue, WA
California	Chicago, IL	Columbia, Mo	Berkeley, California
Columbus, OH	Colorado Springs, CO	Conway, Arkansas. USA	Brighton, UK
Conway, Arkansas. USA	Columbus, Ohio USA	Corvallis, OR	Brooklyn, NY USA
Corydon, IN	Conway, Arkansas. USA	Corydon, IN	Buenos Aires, Argentina
Denver, CO	Corydon, IN	Dublin, Texas	Buffalo, NY
Denver, Colorado	Dallas, Texas	Edmonton, Canada	Charlottesville VA
Des Moines, Iowa	East Lansing, MI	Elizabeth City, North Carolina	Clifton, Virginia
East Lansing, MI	Edmonton, Canada	Florence, KY	Columbia, MO
Ex Vita, Scientia	Elizabeth City, North Carolina	Green Bay, WI	Deep South East Pennsylvania
Florence BCHS	Elizabethtown, Kentucky	Houston, Texas USA	East Sussex UK
Fort Atkinson, WI	Florence, ky	Indianapolis, IN	Florence, KY
Honduras	Frederick, Maryland, USA	Kentucky	Florida
Indiana	GA	Lanesville	Granville, OH
Kansas	Honduras	Lanesville, IN	Guatemala, GT
Kentucky	Honduras, Central America	Los Angeles, California	Herkimer County, NY
La Lima, Honduras	Honolulu, Hawaii	Matamoras, PA	Honduras, cortez, la lima
Lanesville	Indiana	Montana	Hong Kong
Lanesville, IN	La Lima, Honduras	Nashville, TN	Huntington Beach,

			CA
Lansdale, United States	Lanesville, IN	Nebraska :)	Illinois
Los Angeles, California	Logan, UT	New Salisbury, IN	Indiana
LSU	Los Angeles, California	Norman, OK	Indonesia
Melbourne, Australia	LSU	Orange County	Kent, OH
Minneapolis, MN	Minnetonka, MN	Orlando FL	Kentucky
Montana	Montana	Philadelphia, PA	Las Vegas, NV
Nashville, TN	Nashville, TN	Pittsburgh	Los Angeles, California
New Mexico	New York, NY	Portsmouth, NH	Maryland
New York City	New York, US; Tanzania, Africa	Seattle	Mojave, CA
Norwich	Norman, OK	Sonoma County, California	Myrtle Beach, SC
Orlando FL	Ohio	Stanford, CA	Nashville, TN
Oxfordshire	Ontario Canada	Toronto, Ontario	Nebraska
Pasadena, CA	Orange County	ÜT: 27.179819,- 80.236438	New England
Philadelphia	Orlando FL	Vancouver, Canada	New Jersey
Portland, OR	Philadelphia, PA	Washington, DC	New York City
Princeton, United States	Point Pleasant, NJ		Nome, Alaska
Sherbrooke, Voie lactée	Rochester, NY		Northern NJ
Spokane, Wa	San Antonio, TX		nottingham uk
State College, PA	San Diego, CA		Orlando FL
The wilds of Connecticut	Seattle		Ottawa, Canada
Tucson, AZ, USA	St. Louis		Panama
	USA		Pasadena, CA
	USA		Pennsylvania
	ÜT: 40.88714,- 97.58976		Perth, Western Australia
	York, NE		Plymouth University
	서울 (Seoul)		Providence, RI
			Puerto Rico
			Sacramento Area
			Santa Fe, New Mexico USA

			Shelton, CT
			Sydney, Australia
			Taipei, Taiwan
			University of Alaska Fairbanks
			Victoria BC #yyj
			Washington, DC
			York, NE
			噴火の起きるところ

Appendix B: Interview Guides for Scientists, Students and Teachers

Interview Guide for Scientists

- How did you learn about, and ultimately decide to participate in, #scistuchat?
- What aspects of #scistuchat did you find engaging or appealing?
- What challenges, frustrations or barriers did you encounter during #scistuchat?
- What are your biggest takeaways from participating in #scistuchat?
- How might you change #scistuchat if given the chance?
- Are you doing anything now, or do you foresee yourself doing anything in the future, that you wouldn't have done without participating in #scistuchat?
- Were there any tweets that you shared during the chat, or exchanges that you were part of, that you felt were noteworthy? Any that occurred in previous chats?
- Overall, how did your experience in #scistuchat compare with your expectations?
- What, if anything, have you learned about science students through your participation in #scistuchat?
- How effectively did #scistuchat connect you with students?
- Do you feel as though you shared valuable science with a receptive audience during #scistuchat?
- Have you been contacted by any students with direct questions to you...either during or in the aftermath of #scistuchat?
- Has participating in #scistuchat influenced how you think about yourself as a scientist and as a communicator of science?
- How would you characterize yourself as a Twitter user?
- What role does Twitter play in your professional life?
- Can science be communicated accurately and in a meaningful way via Twitter?
- What value, if any, do you believe Twitter holds as a tool for sharing science?
- Do you believe social media, and Twitter specifically, should be a welcomed part of a student's educational experience? Why or why not?

Interview Guide for Focus Groups with Students

- How did you learn about and why did/do you choose to participate in #scistuchat?
- Was there anything you were uncertain about or nervous about leading up to the chat?
- What aspects of #scistuchat do you like and/or find engaging?
- What challenges, frustrations or barriers did you encounter during #scistuchat?
- What are your biggest takeaways from this experience...about the chat, Twitter, science, etc? In other words, what did you learn, if anything?
- How might you change #scistuchat if given the chance?
- Overall, how did your experience(s) in #scistuchat compare with your expectations?
- Are you doing anything now that you wouldn't have done without having participated in #scistuchat?
- Can you describe what it was like to be participating in something science-related outside of school, using Twitter, during the evening? Did it feel like school? Better, worse, other?

- Where were you physically located during the chat and what kind of a device were you using?
- A main goal of #scistuchat is to connect students with scientists...to get them communicating with each other. How effectively did/does #scistuchat connect you with scientists?
- What did you learn about science and/or scientists through your participation in #scistuchat?
- In what ways, if any, does your out-of-school participation in #scistuchat carry over into the classroom, and vice versa?
- Has participating in #scistuchat influenced how you think about yourself as a science learner?
- How do you use Twitter in your personal life?
- Other than #scistuchat, what are some of the ways you use Twitter to learn about or share science in school? Any ways you learn about and share science via Twitter outside of school?
- Thinking outside of the box now, are there other ways beyond what you've already mentioned that you can imagine using Twitter for teaching/learning/sharing science?
- What are the strengths of using Twitter as a tool for learning about science?
- What are the shortcomings of using Twitter as a tool for learning about science?
- Do you believe that Twitter can enhance your science experiences in school? Outside of school?
- Do you believe social media, and Twitter specifically, should be a welcomed part of a student's educational experience? Why/why not?

Interview Guide for Teachers

- How did you first learn about, and then ultimately decide to participate in, #scistuchat?
- How many chats have you been a part of in addition to the volcanoes chat?
- What aspects of #scistuchat do you find appealing or engaging? What aspects do you believe that your students find appealing or engaging?
- Is there a specific incentive for students to participate (extra credit, mandatory, other)?
- Can you describe the role you play during #scistuchat when students participate?
- What challenges, frustrations or barriers do you encounter during #scistuchat? What about from your students' perspectives?
- What are your biggest takeaways from participating in #scistuchat?
- Are there examples of specific tweets or exchanges, related to #scistuchat, that you believe speak to or exemplify its strengths?
- Are you doing anything now that you wouldn't have done without #scistuchat?
- How does #scistuchat fit into your approach to teaching science?
- Science learning can occur in school settings (often called "formal" science learning), outside of school settings (often called "informal" science learning) and be voluntary or required. How would you classify #scistuchat and why?

- In what ways, if any, has students' out-of-school participation in #scistuchat carried over into your classroom and vice versa?
- What have you learned about science and/or scientists through #scistuchat?
- Has #scistuchat influenced how you think about science and/or your approach to teaching science?
- The primary goal of #scistuchat is to connect students and scientists, how effectively has #scistuchat connected you and your students with scientists?
- Please describe a little about your history with Twitter, how you would describe yourself as a Twitter user, and how you use Twitter in your professional life?
- In what ways do you use Twitter for teaching science outside of #scistuchat?
- Can you share what you believe are the strengths and challenges of using Twitter as a tool for teaching/learning science?
- Are there other ways can you imagine using Twitter for teaching science?
- Do you believe social media, and Twitter specifically, should be a welcomed part of a student's educational experience? Why/why not?

Appendix C: Full Codebook

<p>#scistuchat changes #scistuchat description #scistuchat effectiveness #scistuchat expectations #scistuchat future #scistuchat highlight #scistuchat history #scistuchat into classroom #scistuchat learning #scistuchat limitation/challenge #scistuchat motivation #scistuchat nervous #scistuchat outcome #scistuchat pace #scistuchat prior #scistuchat questions #scistuchat roles #scistuchat strategy #scistuchat tweets 'ashamed' 'chaos' 'cocktail party' 'collaborate' 'connections' 'curious' 'evidence' 'fire hose' 'interested' 'responsibility' 'separate learning from a book' 'social interactions' 'takes one tweet' a lot to learn Archive_learning audience careers confidence convenient digital citizenship Diversity dynamic educational future empowering equalizer experts extra credit feedback formative assessment forum for quiet generational global grammar informal internet access Invertebrate Olympics</p>	<p>lifelong learning links literacy live-tweeting/conferences local me-observation ms influence ms/hs recollections network new NGSS outside school parents participant ambiguity perceptions personal interactions perspectives powerful quote researched profiles science accuracy science beliefs/agenda science excitement science literacy science value screenshot? side conversation social media benefits social media in education social media perceptions social media: Ts&Ss societal implications student-scientist interactions student-student interactions teaching philosophy technology in classroom technology overload traditional barriers transcript Twitter + sci comm Twitter as outreach Twitter as professional tool Twitter avoidance Twitter description Twitter highlight Twitter history Twitter in classroom Twitter in education Twitter in society Twitter limitation/challenge Twitter outcome Twitter perceptions Twitter personal account Twitter representation Twitter resume Twitter strategies</p>
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Appendix D: Themes Matrix for Findings

	Quotes below speak to specific sub-themes of the six broader, overarching themes (four of which address #scistuchat, two of which address use of Twitter in general). Quotes reflect themes that emerged across the analysis of four cases—February, March, April and May 2014 #scistuchats. They do not reflect ALL perspectives of ALL participants in these cases.		
	Scientists	Students	Teachers
#Scistuchat			
I. Nature of Interactions			
a. Student-focused interactions	“I think it’s an excellent place to have a conversation because the conversation is not initiated by me...it’s an educator and students raising a conversation about a particular science topic. And they’re in control of the direction of the conversation.”	“I thought it was cool because we weren’t totally sure. They were kind of learning also so it wasn’t just like them lecturing us either. It was us all giving input and stuff like that. I thought it was cool.”	“I just love how down to earth the scientists are and how they’re approachable to students.”
b. Dynamic interactions	“I think Twitter also emboldens people to reply to questions. You ask a question on Twitter, just the ability to have that potential for a real conversation – right? On email you can write something back and you wait a while. There might be a wait. But if I send something off and send something back, sometimes I assume that’s going to be the end of it. And on Twitter, there is more conversation. It is more conversational, just by definition of what it is.”	“The scientists are so accessible in a way. Like they’re keystrokes away when [normally], like you wouldn’t know how to get in contact with one of them. And it’s cool that you can learn from them as it’s happening, instead of being in a correspondence that takes weeks to get a reply. Twitter’s right there.”	“They love that interaction, that ability to talk to people instantly, share photos, those kinds of things but they know how to use it to socialize but they don’t know how to use it for learning purposes.”
c. Scientific interactions	“I think these kids are going to be the ones that end up voting, right? In a very short amount of time. And even if they don’t end up having a science	“I didn’t know a whole lot about the green chemistry aspect so it was kind of cool just to see like it’s actually a thing and it’s up and coming and it’s going somewhere.”	“I think it’s great because...principles in physics, they’re universal. You apply velocity everywhere. You apply acceleration

	career, they're realizing it's more than just we can do this, but should we or how do we best. And I think those are all good reasons about it."		everywhere. You apply time everywhere. So the fact that I could get to tell them something like – well, so you see black holes, remember all the physics we learned in tenth grade, well that's going to apply here. I think that was pretty great, and kids got impressed by that."
d. Expanded, authentic audience	"It was cool to see that there were people basically from all over the world. There were people from Honduras and Australia and so it was fun to feel like it was global – really a global effort."	"That's what I was nervous about, like saying something that is wrong and that someone would see it, because normally with homework it's just...your teacher who sees it. So it's kind of just putting your work out there a little bit more."	"So the students and I, we leverage media as a way for us to communicate our thinking to an audience beyond the four walls of our classroom."
e. Scientists as experts	"There were definitely other people that I know through geology that were taking part in it that were answering questions that were centered on some of their expertise that is slightly different than mine. So there's a lot of reputable people that have good answers at the same time."	"It was good how you get to talk to people that actually work in certain fields and not just learn about it in a classroom."	"You know what determines if you're going to learn something or not. If you read it from a book it's going to be different than if you actually go and experience how it is done or in this particular case, the fact that a scientist replied to you through Twitter."
II. Outcomes			
a. Learning	"At that age, you have only the most limited idea of what regular chemistry is and [#scistuchat] is necessarily here's what it was, here's what the challenges are, and here's how we're fixing it. If you don't have that first box, which for the most	"I kind of always thought that scientists were like uppity uppity and they didn't like want to talk to students, like why would they want to talk to me. I'm just a high school kid. And like following some of the scientists from #Scistuchat and talking to them on the	"My big thing is that science doesn't just happen in class. They need to see it around them, they need to see it from other people besides me, and so that was my hope."

	<p>part, when you're talking about green chemistry, is organic chemistry, which is the second year college course, most places, it's really hard to teach concepts. So if you can, fantastic, but what I try to do...is just try to get across that it is out there so that hopefully they're further receptive in their futures."</p>	<p>chat, it made them seem like more down to earth. Oh hey, he's a person just like me. The only thing different about them is that they went to college and got a degree and I haven't done that yet."</p>	
b. Affective impact	<p>"If you're a student in science, you're always afraid of feeling stupid. And maybe that's a professor's thing, too, they feel the same thing but they just hide it better...Because it's informal...I guess you don't feel as vulnerable at that point to show that hey, I don't know how to do this – help. And I think it's a good way to be able to just ask."</p>	<p>"I think it certainly makes me feel better about myself because I felt beforehand I was just maybe a little smarter than average when it came to science, but didn't feel like I was smart enough to be able to actually talk and converse with scientists, but with #scistuchat you're actually doing that and it made me feel good about myself."</p>	<p>"It's kind of a world that I think that they look at as kind of beyond them, that they're not part of that world. And #scistuchat shows them that they are part of that world. We say all the time everybody's really a scientist. And so I think that to an extent, they feel like there's some truth to that through that experience. That it makes it real. They say things like this scientist retweeted me and this scientist said this to me and they're very lifted by that."</p>
c. Effectiveness of #scistuchat	<p>"It's a great platform for that, for starting to ask questions, and totally okay that if you leave the Twitter chat and still have questions that haven't been answered, your teachers admit when they don't know all the answers. And...scientists have a hard time with that one. So yeah. I think that it can for sure be a great tool to spark good conversations definitely about complex issues that there is no one silver bullet right answer for."</p>	<p>"I definitely think I'm more interested in science now...When you do science in school, it's nothing like, oh, you can continue doing after you leave high school or college or whatever, unless you go into the sciences. I know [now] that I can still continue to learn and participate and stuff like that."</p>	<p>"I think it's really effective to have the interaction with the people whose job it is that are pursuing these ideas. And I think that from that standpoint it is helpful for them to run into actual scientists and see that there's no real one-size-fits-all for that definition."</p>

III. Limitations / Challenges			
a. Pace	<p>“Once I managed to disconnect from the fire hose, I was like okay, now I can take a couple of minutes to compose something and that is okay.”</p>	<p>“The challenge that I find is that with the posts going so quickly, you might be looking for an answer but it might be missed because they’re so fast.”</p>	<p>“I think some of the moderators do a great job of it, retweeting the questions, but I still think that it’s kind of fast-paced. And I think that...students are still learning things, but I think that probably...they’re missing a lot of what’s going on.”</p>
b. Organization	<p>“Supposedly there are moderators, but first of all students seemed to be tweeting directly to me or just tweeting to no one...I was confused as to whether or not I was supposed to answer those or only answer the moderators’ tweets. And then there was supposed to be some numbering system. And it didn’t really seem to work. Like I saw Q1, Q2, Q3. So I was trying to answer A1, A2, A3. But then there was another Q1. So...it seemed to be a little disorganized.”</p>	<p>“There are people who do ask questions during #scistuchat, which is fine. However, we do have moderators who are the ones that ask the main questions and sometimes somebody else will try to do what the moderator is supposed to do and ask a question a certain way.”</p>	<p>“If you have a question for a scientist, mention that scientist, which is not typical. The typical structure of Twitter chat...is one moderator that moderates the question and everybody contributes to that question. And if you have a question, you make a question to the whole community of chatters.”</p>
c. 140-character limit	<p>“Once you start providing examples, you run out of space real quick. I’m a kind of verbose person so Twitter is always hard for me. I feel like I waste so much more time deleting tweets back down to get them under 140 characters than I would have ever spent writing on them in the first place. So sometimes I’ll get</p>	<p>“With Twitter, you can only have so many characters to state your answer. And sometimes people go overboard and...they can’t fit their entire response on the one tweet. So it can be difficult to make a summary of your response and put it all into one tweet, which I’ve found difficult before and I’ve had to get rid of a few words.”</p>	<p>Not applicable</p>

	questions and I'm like, ooohhh."		
IV. Formal vs. Informal Learning			
a. Freedom	"And so I think [#scistuchat] does provide a way for participants to, if something in particular intrigues them...go follow that. They can just leave the chat and go do whatever they want, or they can mark it for future reference and go check it out later and just follow up on whatever is of specific interest to them."	"I think if you told me last year I was going to spend an hour of my free time doing science, I probably would have thought you were crazy. But it's not how I would associate most things of science, because it's just different. You do stuff on your own. It didn't feel like school."	"The way I describe it to other people is it's very organic. There are questions thrown out, but the spirit of it is for students to interact with scientists and interact with each other and to have conversations, not to contain them into just a Q&A format, but to have those conversations and explore interests."
b. Out-of-school	Not applicable	"Because it didn't really seem school related to me, not really at first. It was just kind of like, okay, I'm going to get on Twitter and then I'm going to go tweet with this hashtag but then once I got into it, like we pulled topics from what we've learned in class and it got easier to communicate as I thought more about what we got in class, then it became more school related as time went on."	"Hey, we're going to learn about the nervous system. Mr., what page? No, no, no, we're going to go to Twitter, tonight, 8 p.m. Go in and you're going to join scientists and neurologists and scientists who know about this better than the teacher. So I think that's great."
c. Convenience	"It's really hard to be able to commit to doing something ahead of time. And if you can just tell someone, oh, it's going to be on Twitter, you can do it from your phone or whatever...I know friends that, they tweet all the time, they're on their phones or whatever, they can do it from wherever	"For me, I was doing it at play practice. And there was another girl in my play practice that's also in our astronomy class, so she was participating at the same time as me and we could talk about it as well, which was kind of cool. It was cool not being at school, outside of the classroom and everything like that."	"Well, I'll be honest. I was kind of – you know, I try to conceal my phone during the meeting. I was trying to – get in on some of the conversations."

	they are. It's not dependent on their travel schedule...So I think that that really helps grab a lot of people because it's like, look, it's an hour, you don't have to organize it yourself, there's tons of kids that you can reach"		
Twitter			
V. Twitter and Professional Practice			
a. Twitter as a professional tool for scientists	"I've met a lot of people through Twitter and have a lot of interactions through Twitter to where I've built my knowledge base of active professors, active institutions, places where I know that if I went to a conference, a handful of scientists I already know will be there. So in terms of networking and outreach, I think Twitter is just a dominating force."	Not applicable	Not applicable
b. Science communication + outreach	"We can leverage digital media more, because it is sort of a more convenient thing. Like we're doing as much as we can with our physical time and being able to be physically present in schools around here and all that, but we can reach a much bigger audience than we're trying to just by trying some more digital platforms."	Not applicable	Not applicable
c. Twitter as a professional tool for			"I think Twitter has allowed me at least

educators	Not applicable	Not applicable	glimpses of people who are willing to share and have done this. And this is what they did and this is how well it worked and this is how it didn't work...And I can ask substantive questions. Maybe have some of my erroneous thinking clarified or rectified so that I'm not making that same mistake again."
VI. Twitter as an Educational Tool			
a. Twitter in the science classroom	"And all of this would translate well into education – ways to sort of personalize the experience or connect with people or ideas that you would never come into contact with otherwise."	"It's a lot more exciting than like opening a book to page 192. And that gets people excited about learning, like whether they actually enjoy it or whether they're just doing it for a good grade. And then people who might not necessarily pay attention in school normally might be captivated by this new way of learning just because their more familiar with it. It's just a lot more fun and allowing people to interact in a different way. And it breaks the standard that people thought that they found in school."	"The students and I started talking about the need to have a professional learning network even as a high school student, where we could connect to other – to scientists, other teachers and other students."
b. Challenging perceptions	"Every time that I start something like this, I always am skeptical. But every time that I have, it seems to have ended up being much more beneficial than I expected. So I think this is, again, getting over that hump that this is just a fad type thing, to something that is actually useful for science communication. The more people I talk to...at least in my community, the more they buy into it."	"To me it kind of changed my perspective of how I see Twitter and social media, because people usually use it to say, oh I'm eating this or like posting about their life, and I kind of saw it in that way. But now that we've been using #scistuchat, it's more like an educational way and you can see how not everyone uses it in the same way."	"My question is why shouldn't we be leveraging these platforms for education? By embracing tech that is already a part of kids daily lives, we can model life-long learning, empowering students as well as giving them a vehicle to share their thinking."

Appendix E: Moderated Questions (verbatim) from each #Scistuchat

Black Holes (February 2014):

- Q1: In your own words, describe a black hole.
- Q2: Explain how energy emerges from a black hole
- Q3: Where does everything that enters a black hole go?
- Q4: Gravitational waves from a black hole can cause what? Why?
- Q5: What is Sagittarius A? What makes it different than other black holes?
- Q6: Explain the relevance of black holes today (include a link to a resource if possible). Why do we still study?
- Q7: What are 2 things you learned tonight?

Human Genetic Engineering (March 2014):

- Q1) What does "Human Genetic Engineering" mean to you?
- Q2) If genetic engineering could eliminate all illnesses would it be worth it? What would be some of the consequences?
- Q3) If genetic engineering is allowed, do you believe that there should be limits to what we can alter? Explain.
- Q4) What would unintended personal, social, or even cultural consequences be?
- Q5) Is human genetic engineering safe and effective?
- Q6) Could genetic engineering be used to COMPLETELY eradicate inheritable diseases (i.e. sickle-cell, muscular dystrophy)?
- Q7) Could a negative issue ever arise regarding a contrast between an artificial and a natural gene?
- Q8) Hey all, TELL US 2 THINGS YOU LEARNED TONIGHT

Green Chemistry (April 2014):

- Q1 What is Green Chemistry?
- Q2 How does green chemistry help the environment?
- Q3 Is it better for big businesses to use a certain type of lightbulb? Which/Why?
- Q4 Are there any ways that green chemistry could "harm" the environment? If so, how?
- Q5 RT @Akennedy_7 How fast is the field of "green chemistry" growing?
- Q6 RT @baileykaake Is green chemistry an actual field or does it just overlap with all other fields of chemistry?
- Q7 Alright everyone What are the 3 things you learned tonight?

Volcanoes (May 2014):

- Q1: What are the most active volcanoes?
- Q2: How do you know when a volcano is not going to erupt anymore?
- Q3: Why are volcanoes called active even when there is no eruption? is there a site that explains this? Please share
- Q4: Volcanos are thought of as a destructive force, but are there good outcomes of a volcanic eruption? If so, what are they?
- Q5: Scientists have studied volcanoes on other planets for many years. How do u think these volcanos differ from those on earth?
- Q7 Please share 2 things you learned tonight.