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Idle chatter or compelling conversation? The potential of the social media-based #NGSSchat network for supporting science education reform efforts

Joshua M. Rosenberg[1] | **Joshua W. Reid**[2] | **Elizabeth B. Dyer**[2] | **Matthew J. Koehler**[3] | **Christian Fischer**[4] | **Thomas J. McKenna**[5]

[1]University of Tennessee, Knoxville, Tennessee

[2]Middle Tennessee State University, Murfreesboro, Tennessee

[3]Michigan State University, East Lansing, Michigan

[4]University of Tübingen, Tübingen, Germany

[5]Boston University, Boston, Massachusetts

Correspondence
Joshua M. Rosenberg, Department of Theory and Practice in Teacher Education. The University of Tennessee, 420 Claxton Complex, 1122 Volunteer Boulevard, Knoxville, TN 37996.
Email: jmrosenberg@utk.edu

Abstract

The Next Generation Science Standards (NGSS) chat (#NGSSchat) is a social media-based professional network used to discuss topics related to the NGSS in the United States. While successful reforms involve and coordinate the work of multiple stakeholders, recent research points out a striking lack of coordination between the individuals working in different educational roles—to the detriment of intended changes in the system. In this study, we analyzed more than 7,000 posts from individuals participating in #NGSSchat on Twitter ($n = 247$) during 2 years of 1-hr synchronous discussions. We studied the depth and types of conversations that took place, the extent to which the involvement of teachers, administrators, researchers, and organizations was balanced, and what explains participation in the network over time. Using a

Analytic code and information about how to access the data used in this study are available in an Open Science Framework repository: https://osf.io/9ex7k/

mixed-methods approach involving social network analysis, we found that conversations were primarily transactional, or social, and substantive, or providing opportunities for sense-making about the standards or for participants to transform their practice and that individuals from diverse roles participated, with teachers comprising the plurality of those involved. Additionally, researchers, administrators, and teachers were the most active in the network, with no differences in both initiating, or sending, and being the recipients of, or receiving, replies as a part of conversations. Finally, we found that being a teacher or administrator, as well as receiving replies from individuals who were important in the network, were positively related to sustained involvement in the network in the following year. We discuss how #NGSSchat—as a social media-based professional network—demonstrates similar features in other effective networks, and how social media-based networks invite new visions for how to implement ambitious, large-scale changes in science education.

KEYWORDS

learning communities, policy, professional networks, standards, social media, social network analysis

1 | INTRODUCTION

Many large-scale educational reform efforts, such as the Next Generation Science Standards (NGSS) in the United States, are intended to shift classroom practice. The successful implementation of such efforts requires ambitious changes across more than individual classrooms: changes that involve coordinated efforts across educational systems (National Research Council [NRC], 2015). This systems-level perspective recognizes that an exclusive focus on teachers as individual change agents will likely be insufficient to support policy implementation (Coburn, 2001; Penuel, Harris, & DeBarger, 2015). Instead, supporting reform efforts requires capacity-building for multiple stakeholders, such as that of administrators and instructional coaches as well as teachers (Anderson et al., 2018; Lowenhaupt & McNeill, 2019), and the collective participation between (and coordination among) multiple stakeholders (Penuel, Frank, Sun, Kim, & Singleton, 2013.; Stiles, Mundry, & DiRanna, 2017). For example, Stiles et al. (2017) argue that the shifts called for in the NGSS are supported by six *drivers*, or key factors, including: (a) standards; (b) curriculum, instruction, and achievement; (c) policies; (d) stakeholders; (e) funding; and, (f) professional learning. Each of these six drivers cut across different individuals and spheres of the educational system, such as when funding-related decisions require coordination among leaders at the state, district, and school levels.

Despite success in targeting specific stakeholders like teachers or school administrators (Lowenhaupt & McNeill, 2019; Sandoval, Kwako, Modrek, & Kawasaki, 2018), previous large-scale reform efforts in education have struggled to support learning and sustained coordination across stakeholders and components of the educational system (Cobb et al., 2018; Penuel, Fishman, Haugan Cheng, & Sabelli, 2011; Peurach, Cohen, Yurkofsky, & Spillane, 2019; Windschitl, 2006). Research that takes a systems approach to educational reform demonstrates the importance of professional networks for this learning and coordination and has identified the role that networks play in how educational reforms are made sense of and taken up over time (e.g., Coburn, Russell, Kaufman, & Stein, 2012; Penuel, Lin, Marshall, Anderson, & Frank, 2018; Spillane, Kim, & Frank, 2012).

While networks contribute to educational reform efforts, less is known about how these contributions occur. In light of the use of social media for both personal and professional reasons, it is crucial to understand the characteristics of these networks, as they may differ from in-person professional networks in important ways that have the potential for—but also challenges related to supporting—systems-wide reforms.

In this study, we explored the extent to which the #NGSSchat network may contribute to educational reform efforts as a professional network focused on learning and sharing resources about NGSS. This network has regularly met using synchronous Twitter chats to discuss improving science education. Even though #NGSSchat has the potential to exhibit features of networks that support educational reform efforts, we do not yet understand the extent to which it or other, informal, digital technology-based networks in education do. This study, then, examines 2 years of these biweekly chats in terms of their content, interactions between participants, and participants, including how sustained their participation is. This analysis can help shed light on the role of online professional networks as a component of the broader science education digital ecology in which science education policy is being shaped and implemented.

2 | LITERATURE REVIEW

We focus on three features of online professional networks, and #NGSSchat specifically, that have the potential for supporting coordination across educational systems necessary for successful reform implementation:

1. fostering *substantive conversations* (van Bommel, Randahl, Liljekvist, & Ruthven, 2020);
2. being accessible to and foster *balanced participation among educational stakeholders from different professional roles* (Macià & García, 2016; Rosenberg, Greenhalgh, Koehler, Hamilton, & Akcaoglu, 2016; Spillane et al., 2015), instead of involvement dominated by one or two professional roles;
3. *sustaining participation* in online networks (Greenhow, Galvin, & Staudt Willet, 2019).

In the sections below, we explore prior research related to each of the features.

2.1 | Substantive conversations

Participation in conversations is an important form of professional learning and sense-making about educational reforms (Coburn, 2001; Rosebery, Ogonowski, DiSchino, & Warren, 2010;

Rosebery & Warren, 2008), especially when ideas about reforms are situated in the context and problems of practice that practitioners face (Horn & Little, 2010; Penuel et al., 2013) and are carefully facilitated (Andrews-Larson, Wilson, & Larbi-Cherif, 2017). These considerations are important in light of research showing that while some social media-based professional networks are distinguished by conversations that evidence learning (van Bommel et al., 2020), others seem to be more superficial (Staudt Willet, 2019). While there is research on conversations that take place between students in K-12 settings (e.g., Michaels & O'Connor, 2012), and on the role of conversations in face-to-face professional contexts and networks for teachers (Coburn, Choi, & Mata, 2010; Horn, Garner, Chen, & Frank, 2020; Horn & Little, 2010; Little & Horn, 2007), less attention has been given to the *types of conversations* in technology-based professional networks, the first key feature we discuss.

In the context of mathematics and English language learning groups on the social media platform Facebook, van Bommel et al. (2020) explored what subject-specific conversations took place, finding that the majority of conversations provided some opportunity for learning and that a smaller percentage evidenced transformations, or changes, in an individual's knowledge. Van Bommel et al. referred to the former type of conversation as transactional, and the latter as transformational. A *transactional* interaction refers to those in which participation or learning is acknowledged. For instance, they are characterized by an explicit, verbal acknowledgment of something that is shared, or an implicit recognition, such as through a "like" or "favorite" through a social media platform. Differently, *transformational* conversations were longer and were characterized by turns in the conversation that made clear that the individuals—teachers—considered some aspect of planning or teaching differently as a result of what others shared with them.

van Bommel et al. (2020) noted that not only deep (transformational) conversations are important, but also those that are more social in nature. Transformational conversations are not necessarily superior to others for all purposes: Cultivating a sense of belonging, which might be facilitated by transactions, are key goals or parts of professional learning communities (Goode, Margolis, & Chapman, 2014; Putnam & Borko, 2000; Shulman & Sherin, 2004) and digital technology-based networks (Bucher & Fieseler, 2017; Greenhalgh, Rosenberg, & Wolf, 2016; Lantz-Andersson, Lundin, & Selwyn, 2018; Trust, Krutka, & Carpenter, 2016). Doing so might involve social conversations that help individuals to feel recognized and may, therefore, play a role in professional networks, particularly with respect to building and maintaining relationships (Carpenter & Krutka, 2014b; Greenhalgh et al., 2016; Wesely, 2013). Therefore, we view not only transformational conversations as important in dig-based contexts for professional learning but also as an important type of conversation in social media-based contexts for professional learning, particularly when also accompanied by those that are more focused on science education content.

To foster substantive conversations, informal, technology-based professional networks should have specific features, with moderation being one important design element. Moderation is essential for productive conversations to occur (Andrews-Larson et al., 2017) and for individuals to have opportunities to share what they have distinct knowledge about (Farrell, Harrison, & Coburn, 2019). If there are active moderators who provide structure to the participation of those involved in the community, such as by organizing chats with questions related to a common theme (Carpenter & Krutka, 2014a; Greenhalgh, Rosenberg, Staudt Willet, Koehler, & Akcaoglu, 2020). Such moderation is a feature of #NGSSchat, which has been described as being organized around carefully selected topics related to "all things NGSS, from the research that went into the *A Framework K-12 for Science Education* [sic] to examples of

implementation from states and districts already putting the standards into practice" (Shelton & Ende, 2015, p. 3). A benefit of moderation is that while social media-based networks can be facilitated and organized, participants can respond however they choose, perhaps highlighting, for example, issues that emerge in practice that were not anticipated by the authors of reform documents and the standards, which may provide opportunities for collaborative sense-making about the nature of the new science standards (Rosebery et al., 2010). For these reasons, #NGSSchat may support participants to make sense of science education reform efforts; to better understand how they can coordinate their efforts; and how they are changing what they do—as a teacher, administrator, or even researcher—as a result.

2.2 | Balanced participation among multiple stakeholders

In organizations and systems—including those in education (Frank, Zhao, & Borman, 2004)—work is divided between individuals in different roles. For example, when researchers and nonprofit organizations develop curricula, instructional coaches support their teachers, and teachers adapt and shape what they are exposed to in professional development for their practice. While this facilitates specialization—which can be positive for organizations—recent research points out a striking lack of coordination between the individuals working in different roles in education (Cherbow, McKinley, McNeill, & Lowenhaupt, 2020; Coburn & Stein, 2010; Penuel et al., 2011; Peurach et al., 2019)—to the detriment of intended changes in the system (Farrell et al., 2019; Stein & Coburn, 2008). Therefore, networks that support the active participation of stakeholders from multiple roles and interactions among them could play an important role in educational reforms.

Coordination between individuals with different roles reflects a broad vision of the expertise, from a variety of stakeholders, needed to support systems-level reform. By expertise, we refer to a "broad terrain including problem solving and competencies" (Goldring, Huff, Spillane, & Barnes, 2009, p. 198), akin to what Bereiter (2014) described as practical know-how. Expertise, then, is more situated and actionable than just knowledge alone, and concerns what an individual does in their context and is thus different for individuals from different professional roles. This definition of expertise means that what is most important for productive conversations to occur is not that the canonical topics are discussed, but that the conversations are carefully moderated around topics aligned to the focus of the reform effort to provide chances for individuals from different roles to discuss the issues they encounter in their practice.

Balanced participation in terms of the active participation of individuals from different professional roles matters because this has a bearing upon whose expertise, aims, and visions are valued in a network. If, for example, the problems of practice of teachers are not discussed—with conversations solely about researching and evaluating the implementation of the NGSS—then a truly shared understanding of the reform may not be established (Penuel et al., 2011) and trust may not be established among participants (López Turley & Stevens, 2015). This is also important because some voices—especially teachers—have often been ignored when it comes to reform, to the detriment of the success of the reform itself (Coburn, 2001; Windschitl, 2006). As an example, school administrators need to learn about what science teaching and learning should look like in classrooms organized to meet the aims of the NGSS, which requires administrators to learn about ideas for which teachers possess expertise (Lowenhaupt & McNeill, 2019; Marshall, 2018).

Balanced participation among multiple stakeholders invites key challenges in networks of any kind—social media-based or otherwise—one of which is *homophily*, the tendency to

interact with others who share characteristics, is often found in in-person professional networks in education (Spillane et al., 2012; 2015). Researchers, for example, may be more likely to choose to converse primarily with other researchers in the course of their work, and teachers with other teachers. This tendency manifests through what is referred to as the process of *selection*, choosing with whom to connect and interact (Frank, 1998; Frank, Muller, & Mueller, 2013; Spillane et al., 2012; Wilhelm, Chen, Smith, & Frank, 2016). Selection can be viewed as the mechanism through which others' resources and expertise are accessed; those who have this access have *social capital* (Bourdieu, 1980; Portes, 2000). If strong homophily is present in ways that prevent the development of widespread access to others' resources and expertise within a network, then the network may be systematically working better for some rather than others, and it is less likely to support the needed coordination across systems.

Informal, social media-supported professional networks could mitigate individuals' inclination toward homophily (e.g., Lantz-Andersson et al., 2018) because they can involve stakeholders from more roles than are present in many extant professional networks (i.e., those in schools and school districts). Because #NGSSchat is structured around topics that span from the nature and contents of the *Framework for K-12 Science Education* to implementing reforms across states adopting standards at different times (Shelton & Ende, 2015), the conversations that take place through #NGSSchat may be of interest not only to teachers, but also instructional leaders, educational organizations, and other stakeholders. Moreover, because states adopted and adapted the NGSS at different times, it may also be open to individuals from "lead" states, those presently adopting the standards, and those planning to in the future. Moreover, because of the moderation of #NGSSchat by a teacher and an administrator, participants who share these professional roles with them may be more likely to identify with and feel welcomed by the moderators. However, we do not know whether their conversations are limited to the moderators and others in the same role, and so it remains important to understand how balanced participation in this professional network may be.

Finally, both the active participation of stakeholders from multiple roles and interactions among stakeholders may be especially important in and relevant to social media-based networks because of how individuals *identify with* a network or think of a network as being related to oneself or one's work. When identification with an organization or network is low (i.e., when individuals are forced to participate in a group, or otherwise do not perceive themselves to belong in the group), the sharing of ideas and resources from specific, targeted stakeholders with the most expertise can be preferable to shared expertise throughout an organization (Frank, Penuel, & Krause, 2015; Frank, Xu, & Penuel, 2018). But, when identification with the group is high, then a message that balances the voices of multiple people—such as one that could emerge from the contributions of individuals from heterogeneous professional roles with different expertise—may lead to success (Frank et al., 2018). As participation in many social media-based networks is voluntary, most participants do so based upon their interest in and identification with the network to a greater extent than in a traditional—possibly mandated—professional learning opportunity. In this way, participation in #NGSSchat might lead to balanced participation and better coordination between multiple stakeholders working to collectively make sense of the NGSS.

2.3 | Sustainable participation over time

The duration of individuals' participation in reform-related activities is a key consideration for any professional network (Desimone, 2009; Garet, Porter, Desimone, Birman, &

Yoon, 2001). However, this may be especially so for social media-based networks because they are not known for fostering individuals' sustained participation. Duration is important for two reasons. First, it provides sufficient time to be involved in the kinds of conversations that can allow individuals to make sense of the NGSS. Particularly given the complexity of implementing a system-wide reform effort (Stiles et al., 2017) and the multiple foundational documents and ideas (i.e., NRC, 2012; National Research NGSS Lead States, 2013) and those related to specific aspects of the NGSS (NRC, 2014; 2015), it is important for participation in such conversations to not be brief or disconnected. Second, the duration of participation matters because it means that individuals can apply what they have discussed in their practice (Coburn, 2001; Desimone, 2009), whether that be as a teacher, administrator, or even a researcher.

Although the accessibility and flexibility of social media-supported professional networks is a benefit, it also relates to the challenge of how sustainable both the networks themselves and participation in them is over time—a key issue and concern on the part of researchers facing their use (Lantz-Andersson et al., 2018; Veletsianos, 2017; Xing & Gao, 2018). While #NGSSchat has been active since 2012[1] (Shelton & Ende, 2015), and so may demonstrate sustainability itself as a network, the extent to which individuals sustain their participation in a voluntary network such as #NGSSchat—in terms of both how active they are and for how long they remain active—is an important consideration.

The sustained participation of individuals can be affected by many factors, such as having set times (Greenhalgh et al., 2020) and structured conversations (Booth, 2012) and different types of conversations (Bucher & Fieseler, 2017; Greenhalgh et al., 2016; van Bommel et al., 2020). In light of the different types of conversations that might take place, both transactional and transformational conversations may play an important role; transactional conversations may cultivate a sense of belonging among participants, while transformational conversations may provide value through opportunities to either contribute or receive resources. These might matter because they may affect individuals' later #NGSSchat activity. Particularly, a process related to the above-referenced selection processes (which can facilitate access to others' resources and expertise) is *influence*, the process through which access to resources affect individuals' behavior: greater involvement in conversations may relate to sustained participation over time through influence processes. Finally, participation may be different for different individuals. Individuals representing organizations and researchers, for example, might be less likely to sustain their participation than teachers or administrators because of particular, immediate interests. Whereas teachers and administrators might be likely to return to the network year after year. Thus, not only the types of conversations that take place but also the professional role of participants may help to explain who sustained their participation in an informal network such as #NGSSchat over time.

3 | THE PRESENT STUDY OF #NGSSCHAT

To study the characteristics of social media-based professional networks to support science education reform, we make use of a unique dataset, a large collection of tweets from 2 years of activity on #NGSSchat (for the 2014–2015 and 2015–2016 school years).[2] A sample of topics obtained from the #NGSSchat Wikispace website is presented in Table 1; all of the topics are presented in Table S1).

Similar to other chats, each #NGSSchat chat was associated with six questions related to the topic of chat; as Carpenter and Krutka (2014a) explain, in chats that take place via Twitter:

> Moderators generally create the slate of questions or prompts for the chat beforehand. At the outset, they collectively welcome participants to the chat and often ask them to introduce themselves. After that, they periodically ask the predetermined questions and interact spontaneously with participants ... supplementary questions, diversions, and side conversations are common too (p. 14).

These questions asked during chats interrogated different aspects of the topic; for example, for a chat on *the three-dimensional nature of NGSS and what it means for science education*, the six questions aligned with different, particular aspects of the three dimensions of the NGSS (science and engineering practices, disciplinary core ideas, and cross-cutting concepts), as in Table 2.

In #NGSSchat (as in others) the moderators played a critical role, but also welcomed others to participate. In this context, we investigated three particular features of #NGSSchat that stand

TABLE 1 Sample of chat topics for #NGSSchat chats from 2014 and 2015

Year of chat	Topic of chat
2014	Chat focused on moving toward integrating and implementing NGSS, starting with the practices.
2014	Chat focused on the practice of engaging in argument from evidence.
2014	Chat focused on the three-dimensional nature of NGSS and what it means for science education.
2015	Chat focused on the Framework for K-12 Science Education and its implications for the NGSS.
2015	Chat centered on focusing on phenomena in NGSS.

TABLE 2 Questions from one chat arranged in the order in which they were asked during the chat

Order of question	Question
1	The 3D nature of #NGSS is all about making connections. How are you (or how can you) connect the three dimensions? #NGSSchat
2	#NGSS connections exist inside each dimension. How does the scaffolded/banded nature of #NGSS strengthen instruction? #NGSSchat
3	#NGSS is connected to #CCSS in part to help move science from supplement to staple. How do these connections shape your work? #NGSSchat
4	Learners have to see that branches of science are closely intertwined. How are the CCCs successful (or not) at doing this? #NGSSchat
5	How does the NGSS make it easier/harder to connect to other content areas? #NGSSchat (2/2)
6	What steps are you taking (or do you plan to take this year) to help further interweave NGSS into the work that you do? #NGSSchat

out for their potential to support science education reform efforts, with an emphasis on how those characteristics may be afforded—and constrained—by the social media context of the network.

3.1 | RQ #1: What types of conversations are present?

The first characteristic we investigated is the depth of the conversations that took place—in response to moderators as well as between all participants. To consider the depth and types of conversations, we drew upon van Bommel et al.'s (2020) conceptualization of transactional and transformational conversations as well as sense-making conversations, our addition to van Bommel et al. 's coding frame based upon an open coding process (described in the next section). In addition to conversation type, the alignment of conversations (in terms of both the topics selected for chats as well as the questions moderators posed during them) with the tenets of the NGSS is important, as knowing what types of conversations take place provides more information about the kinds of sense-making that may occur during conversations than coding each contribution to a conversation for its alignment with the NGSS. Accordingly, we examined the alignment of both #NGSSchat topics as well as the questions asked by moderators to structure each chat (available in Table S2).

3.2 | RQ #2: Who, in terms of occupational role and NGSS adoption status, has participated in #NGSSchat? What explains greater conversations between individuals in different roles?

Second, we investigated who participated in the network. While moderated, #NGSSchat is also loosely-organized, such that individuals from many professional roles and stages of NGSS adoption may be inclined to join. This feature could provide opportunities for coordination between multiple stakeholders with different kinds and degrees of expertise that are particular to specific roles and professional contexts. Also, we investigated how balanced participation is between individuals; namely, whether individuals from some professional roles participate differently than others, and the extent to which participants are more likely to interact with others in similar roles. Conversations can be considered as a result of selection processes and, therefore, the access to and sharing of individuals' expertise. We emphasize that this process, selection, and the process of influence are methodological and theoretical processes that have been shown to undergird how individuals, organizations, and systems change (Carolan, 2014; Frank, 1998; Frank et al., 2018).

3.3 | RQ #3: What factors are associated with continued participation over time?

Third, we investigated the relationship between participation in the network and interactions during the previous year to better understand what leads individuals to sustain their participation year to year. How #NGSSChat has taken place approximately biweekly for nearly 8 years and may both reflect, and facilitate, sustained participation, which

may provide opportunities for #NGSSchat participants to make sense of the often complex ideas about the NGSS—and to apply what they are exposed to in their practice (whether as a teacher or administrator or a researcher or a representative of a nonprofit organization).

4 | METHODS

We used a mixed methods approach involving social network analysis. Social network analysis is a methodological approach with associated theoretical ideas that are used to understand the nature of social relationships and their effects on outcomes (Carolan, 2014; Wasserman & Faust, 1994). Educational researchers often carry out social network analysis by asking teachers, administrators, and others about their relationships, such as from whom they seek information or with whom they collaborate (e.g., Spillane et al., 2012). Recently, scholars have begun to look at augmenting and conducting analyses with digital sources of information, including data from the digital traces of interactions within social media platforms (e.g., Greenhow et al., 2019; McFarland, Lewis, & Goldberg, 2015), including Twitter (e.g., Fischer, Fishman, & Schoenebeck, 2019; Rosenberg, Greenhalgh, Graves Wolf, & Koehler, 2017), we qualitatively coded individuals' roles and types of conversations. Our mixed methods approach also included and the use of social network analytic models for selection and influence, and qualitative analyses of conversations, individuals' professional roles, and the alignment of chat topics and chat questions with the NGSS.

4.1 | Data sources

The data from this study comes from all tweets over one school year (considered to be from August 1 to July 31) archived by the #NGSSchat moderators on Storify, the platform where the #NGSSchat network chose to self-archive all of the tweets associated with the chats.[3] We focused our primary analysis on the 2014–2015 school year because of the high level of activity this year relative to others. We also chose this year because the 2015–2016 school year that follows it also exhibited high activity and we needed subsequent years of relatively high activity to understand sustained engagement in the network.

The data set from the chats contained 7,456 original tweets. An original tweet is a single post on the Twitter platform and was, at the time of the study, limited to 140 characters. From these original tweets, we identified conversation *threads*, or conversations that took place via *replies*, messages that typically (but not exclusively) began with the screen name of the individual receiving the reply, from one individual to the next. To facilitate the coding, we identified tweets to which any single tweet replied until we identified the longest possible unique thread containing any single tweet. For instance, if Individual 2 replied to a tweet from Individual 1, then these two tweets would be considered a part of one thread. In total, we identified 2,468 such threads (with more than one tweet) and 2,739 other tweets (with no replies) which we considered to be unique threads for the purpose of coding, for a total of 5,207 threads, which we refer to simply as conversations for the remainder of this paper.

These conversations that took place through #NGSSchat were posted by and participated in by 247 unique individuals that posted more than one original tweet; we reasoned that

posting more than one original tweet signified more than superficial use of the hashtag (while still leaving a wide range of degree of involvement). These 247 individuals were active, though some were more so than others: On average, individuals sent 29.83 (median = 10, *SD* = 82.01) original tweets. The large standard deviation suggests that while some individuals are involved to a small to moderate degree, some individuals are highly active (see Figure S1).

4.2 | Measures

We constructed and used measures for the types of conversations that took place through #NGSSchat, the alignment of chat topics and questions, characteristics of individuals, and characteristics of interactions between individuals.

4.2.1 | Types of conversations

The codes for types of conversations (transactional, sense-making, transformational, and off-topic; see Table 3) were developed from recent research by van Bommel et al. (2020) for the depth of the conversations that take place through educational, social media-based platforms. In our initial coding of 200 tweets, we noted that our coding frame fell short in one key respect: While it included codes for *transactional* (exhibiting a simple interaction), *transformational* (exhibiting a change in knowledge or action), and *off-topic* (not related to the focus of the group) conversations, these categories did not seem to capture the *sense-making* (but not transactional, transformational, or off-topic) nature of many of the conversations that we read as a part of our initial coding, or conversations both about the NGSS as well as participants' "ways of understanding" the standards (Rosebery & Warren, 2008). These conversations involved science education and NGSS-related topics and included questions and answers about the NGSS as well as soliciting resources (such as curricular materials). Thus, we added a sense-making code to van Bommel et al.'s (2020) coding frame and then worked to establish the interrater agreement of this expanded coding frame by independently coding the same 100 tweets that were a part of conversations, after which we achieved strong interrater agreement (94% [Cohen's $\kappa = .87$]). Conversations were coded with only one code.

4.2.2 | Alignment of chat topics and questions

To check the alignment of not only the chat topics (Table S1) but also the six questions asked by moderators during them (Table S2), we coded topics and questions (separately) by considering whether each question moderated during a chat was related back to the NGSS or its implementation. Two coders independently coded each question as (1) being aligned to NGSS or (0) not being aligned to NGSS. Interrater reliability for coding chat topics was 100% and interrater reliability for chat topics was 94.8%; all disagreements for chat topics were able to be resolved through discussion. We found that all of the topics and questions were aligned with the tenets and practices of the NGSS.

TABLE 3 The coding frame for the type of conversation

Code	Code description	Example
Transactional Conversation	Affirmations of what was shared introductions; simple posts with content; inviting others to chats or specific conversations; restating in different words or adding a new name for the same thing that was said; may be single tweets (rather than two or more tweets in a conversation).	Participant 1: Need a good data set for students and not sure where to get it? Try @Participant2! It is a fantastic resource! #ngsschat Participant 2: Thank you for your support! Lots of additional materials for science teachers coming soon!
Sense-Making Conversation	Discussions of NGSS- and science education-related content; asking elicitation questions, sharing additional resources, and/or building upon this sharing of resources/ content; must include two or more tweets to be considered as this code.	Participant 1: Sorry to be negative, but easier to say what to avoid. No canned, hokey "engineering" activities not connected to bigger ideas. Participant 2: @Participant 1: Agreed. Too often engineering projects are activity mania. Need to be grounded in science concepts. #NGSSchat
Transformational Conversation	Reflections or exhibitions of an individual's change in knowledge or practice including reporting changes in practice; must include two or more tweets to be considered as this code.	Participant 1: School-based teams and K-12 NGSS exploration teams have been really great in our state to explore progressions #NGSSchat Participant 2: @Participant 1 I'd love to learn more about that. What / who would be the best way to do that? #NGSSchat Participant 1: @Participant 2 I've been leading a couple groups here...email me whenever you like <email address redacted> #NGSSchat
Off-topic Conversation	Not NGSS- or science education-related; including conversations about the mechanics of using Twitter and inside jokes between individuals; and for conversations that are not transactional, sense-making, or transformational	Participant 1: Coherence is so important. How do we express with one voice and one direction? #NGSSchat Participant 2: @Participant 1 I hear #onedirection is looking for a new voice. Can @Participant 3 carry a tune?

4.2.3 | Professional role

To determine the participants' professional role, we first open-coded (see Miles, Huberman, & Saldana, 2014) profiles to develop a coding frame (see Table S3). We then applied this coding frame to the data independently. Each user's self-authored Twitter profile was independently coded by the first two authors for one of five codes for their professional role: teacher, administrator, researcher, organization, and others.[4] Interrater reliability was established by two rounds of coding, each round consisting of a random sample of 20 participants until agreement of 70% (with all disagreements resolved through discussion) was achieved.

4.2.4 | NGSS adoption status

We used the geographical location of each individual in the networks to assign the adoption status of each individual's state as a variable to each individual with this data available. To identify the location of participants, we access the location field from each individual's profile, which has been shown to lead to accurate or approximate results for around 80% of Twitter participants (Greenhalgh, Staudt Willet, Rosenberg, & Koehler, 2018). We then used the Google Maps API to geocode the participants' location. We were able to identify 78% ($n = 193$) of users' locations, with 65% ($n = 168$) able to be assigned to one of the 50 U.S. states. The difference in percentages is due to being unable to assign some locations to states (i.e., for individuals whose locations were found to be outside of the United States or in the United States at the country-level). Next, we assigned each state to one of four levels of a variable for when the state adopted the NGSS (Early NGSS, Late NGSS, Early NGSS-aligned, Late NGSS-aligned, and location missing, or N/A). We considered early NGSS adoption to be the adoption of the NGSS before the 2014–2015 school year, and late NGSS adoption to be their adoption after the 2014–2015 school year but before the 2019–2020 school year. We considered Early NGSS-aligned and Late NGSS-aligned to be the adoption of NGSS-*aligned* standards (but not the official NGSS) for those same periods. Because of the uncertainty inherent to geocoding (Greenhalgh et al., 2018), we used this measure only in a descriptive manner and to understand the distribution of participants' locations, rather than as independent variables in analyses.

4.2.5 | Number of conversations between individuals

To determine how extensive conversations were between individuals, we calculated the number of conversations of each type in which each unique pair of participants were involved. For example, if two participants were involved in three transactional conversations involving the other, then the value for this measure for each of these participants would be three.

4.2.6 | Same professional role

To determine how the extent to which homophily is evidenced through interactions, for every unique pair of participants, we determined whether or not they shared a professional role, and then used this measure in analyses involving interactions between individuals.

4.2.7 | Involvement in conversations with central #NGSSchat participants

To determine the effect of involvement in conversations, we calculated the number of interactions (calculated separately for each of types of conversations) a participant received weighted by the in-degree centrality of the interaction sender during the year of the study. This allows us to account for the role of participation in conversations with more—and more central, and therefore potentially more influential—participants in the network.

4.2.8 | Sustained participation

To determine sustained participation, we calculated the number of tweets an individual sent after the year of the study (August 1, 2015 through July 31, 2016).

4.3 | Data analysis

4.3.1 | Preliminary analyses

To begin to understand the data and to prepare it for subsequent analyses, the conversations were processed into a key social network analysis data type, an edge list. We used the statistical software R (R Core Team, 2020) for these preliminary analyses and subsequent analyses. We then generated a *sociogram*, or a network visualization, based on the edgelist to visualize the conversation network using the *ggraph* R package (Pederson, 2018). We also used the edgelists for the analyses for RQ #3.

4.3.2 | Analysis for RQ #1: What conversations take place through #NGSSchat?

This analysis involved manually coding the conversations that took place through #NGSSchat. To present these results, we summarized the coding quantitatively (through calculating the proportion of tweets that were coded with one of the four codes) and qualitatively (through selecting examples of conversation coded with each of these codes). To describe the frequency of the conversations, we calculated the number of each type of conversation and their proportion of all conversations, and the mean number of tweets present, and professional roles represented within each type of conversation, and the proportion of individuals by professional role participating in one or more of each type of conversation. We note that in the qualitative results, profiles were blinded for publication. We replaced profile names with their role and a number that indicated whether each role was the same individual profile or different for reasons described in the discussion.

4.3.3 | Analysis for RQ #2: Who has participated in #NGSSchat and what explains greater conversations between individuals?

First, for an individual's professional roles, we calculated the number (and proportion) of the #NGSSchat participants for each professional role. We also calculated the mean in-degree centrality for individuals from each role for each conversation type. For NGSS adoption status, we described the number (and proportion) for each and created a map to depict where #NGSSchat participants were from.

We also intended to explain the number of conversations between individuals. While many similar social network analysis models predict the *presence* or *absence* of interaction (Zijlstra, Van Duijn, & Snijders, 2006), other models predict the number of conversations between individuals (e.g., Frank, 2009), which are especially common in social media data. The particular selection model that we used was a multilevel *P2* model (Zijlstra et al., 2006), a cross-classified

multilevel model (Raudenbush & Bryk, 2002) with a count dependent variable. These models are intended to explain the number of times two #NGSSchat participants interacted through a Poisson dependent variable distribution while accounting for senders' (or receivers') tendency to send (or receive) replies as a part of conversations. The coefficients are Incident Rate Ratio (Gelman & Hill, 2006), which is similar to an odds ratio; both result from exponentiating the raw coefficients output from the model, which are natural log-odds units ($\log_e$). To specify the models, we used the *brms* R package (Bürkner, 2017).[5] The independent variables used for sending or receiving replies as a part of each of the four types of conversations included which professional role the individual was a member of, separately for senders and receivers of each type of conversation. The other role served as the reference group; we also conducted post hoc for group-wise differences. Last, we added a homogeneity variable for whether individuals were from the same professional role. We interpreted the coefficients and average marginal effects (*AME*s; which represent the effect not in terms of the Incident Rate Ratio, but in terms of the scale of the dependent variable) as well as their standard errors (and *p*-values) to determine the magnitude, direction, and statistical significance of the effects.

4.3.4 | Analysis for RQ #3: What factors are associated with sustained participation?

For this analysis, we sought to understand how sustained participation might be a product of *who* conversed with one's tweets during the 2014–2015 school year that is the focus of this study. A GLM model was used to predict sustained participation measured as the number of original tweets each individual sent to #NGSSchat in the 2015–2016 school year. Independent variables included each individual's professional role (with, like for the analysis for RQ #3, the other role serving as the reference group, with post hoc tests for group-wise differences) and a term representing involvement in each of the types of conversations. Because the dependent variable represents a count (or rate), we again specified a Poisson dependent variable distribution. The term for involvement in conversations was intended to capture not only how many conversations (considered separately for each of the conversation types) an individual participated in, but, how conversations may matter more when sent by influential individuals. Accordingly, these terms involved determining the number of times every other individual interacted with each individual and then multiplying that number by a centrality measure (in-degree centrality). Thus, these terms were intended to account for participating in conversations in which one received replies from central individuals, who may have a greater influence on others' sustained participation. Finally, these multiplied terms were summed to create a total value for conversations for each individual. Like in the analysis for RQ #2, we interpreted the Incident Rate Ratios as well as their Average Marginal Effects, as well as their standard errors (and *p*-values) to determine the magnitude, direction, and statistical significance of the effects.

5 | RESULTS

5.1 | Preliminary analyses

In this analysis, we aimed to visually explore between whom conversations that took place through #NGSSchat involved. The network visualizations for conversations we created are

presented in Figure 1. Wider edges, or lines, depict a greater number of particular types of conversations between individuals; larger nodes, circles, depict individuals with a greater centrality in the network. From these, we can see that transactional conversations are characterized by a dense structure, wherein many individuals receive replies from central individuals, particularly, an administrator who received very many replies as a part of transactional conversations (see the triangle near the center of the figure) and teacher (circle). Sense-making conversations were also dense but appeared to evidence greater conversations between individuals other than those who were highly central to the network, as shown by more connections among different nodes. Transformative and off-topic conversations were both much less dense, particularly for transformative conversations, which appeared to take place between a few individuals; in addition to being less dense, off-topic conversations were very infrequent (and so were not included in Figure 1). The visualizations also show preliminary evidence that participation in the different conversation types includes individuals from different roles (i.e., shows heterogeneity), and that most of the roles appear to be both sending and receiving replies.

5.2 | Results for RQ #1: The types of conversations that take place through #NGSSchat

The coding resulted in descriptive statistics about the conversation types. Regarding the relative frequency of the different conversations, transactional (n = 3,584; 68.8% of all

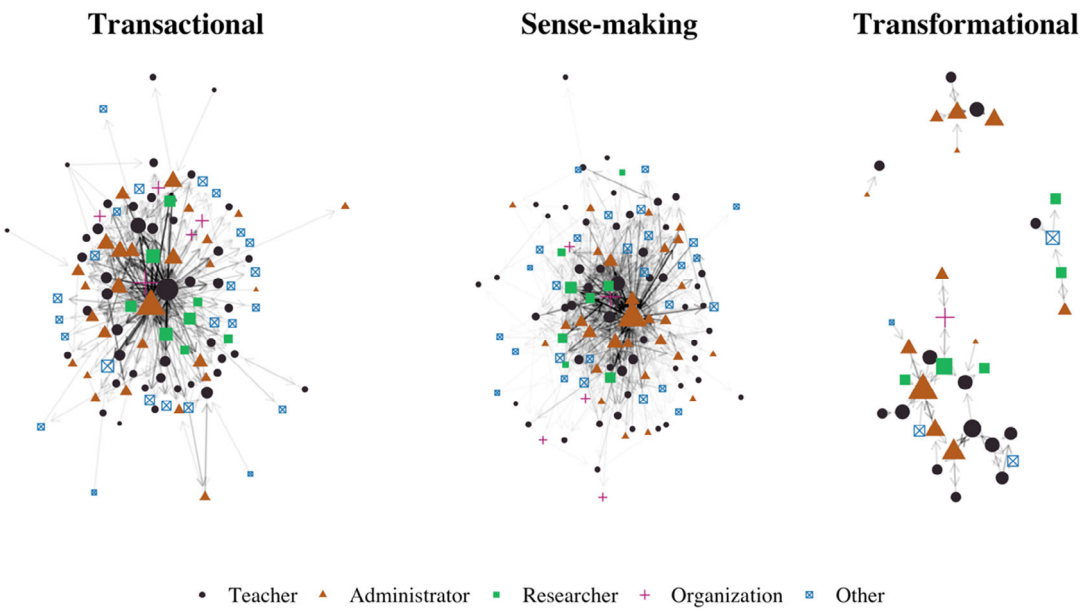

FIGURE 1 Network visualizations for each type of conversation (transactional, sense-making, and transformational). *Notes:* The width of the edges, or lines, depict the number of interactions between participants. The size of the nodes, or shapes, depict the in-degree centrality of the participants. To facilitate interpretation, only the individuals who posted 10 or more original tweets to #NGSSchat during the year of the study. Off-topic conversations were very infrequent and so were not included here. In subsequent analyses, off-topic conversations were not used and substantive and transformative and conversations were combined; see the Results for RQ#1 for a description of why [Color figure can be viewed at wileyonlinelibrary.com]

conversations), and sense-making (1,597; 30.6%) conversations were the most common; these collectively comprised a large proportion of all of the conversations. A much smaller proportion ($n = 17$; 0.3%) of conversations were transformative,[6] with a smaller number still off-topic (8; 0.1%), which, while described here, were not included in subsequent analyses.

For conversations with more than a single tweet (i.e., holding aside the conversations coded as transactional that were single tweets without replies), sense-making conversations were the most common (64.7% of conversations with more than one tweet), followed by transactional (34.2%) and then transformational (0.7%) conversations. As we discuss later, we think that these sense-making conversations—characterized by the discussion of NGSS- and science education-related content—are important because they allow participants to make sense of the NGSS and their and others' roles in implementing the NGSS. We note that while transactional interactions are both frequent and more social in nature than those that are sense-making (or transformative), they may have an important role to play, especially regarding individuals' sustained participation in the network over time.

The coding also provided a context for us to select representative examples. Transactional conversations were frequently brief affirmations of answers or posts, as in the following conversation:

> Teacher 1: Thanks @Administrator 1 @Administrator 2 for all that you do! #NGSSchat
> Administrator 1: @Teacher 1 @Administrator 1 It's amazing to learn with my #NGSSchat PLN! Going to Chicago?

While many transactional conversations referenced science education content, the conversations were more social than sense-making in nature:

> Researcher 1: A3: Drawing on @Researcher 2's work, we organize sequences into cascades of practices anchored to phenomena: http://t.co/u3QIcI8JlC #NGSSchat
> Researcher 2 reply to Researcher 1: @Researcher 1 Thanks for the online fist bump! #NGSSchat

Other conversations were primarily social but were still related to NGSS-related activities

> Administrator 1: Amazing to think that first “met” @Administrator 2 on Twitter over 2 years ago, now co-coordinators of NGSS@NSTA curation work! #ngsschat
> Administrator 2 reply to Administrator 1: @Administrator 1 We've come a long way in 3 years:) #NGSSchat
> Administrator 1 reply to Administrator 2: @Administrator 2 Three years?! Have I already lost count?! #ngsschat

Last, some transactional conversations were not replied to, or were unreciprocated, as with the following:

> Administrator 1: Personally, I love @Other 1's “designing easy inquiries” as a way to develop mental models: http://t.co/N3wt8GSuTx #ngsschat

Sense-making conversations—as noted above—demonstrated involvement with one another's ideas or the science education content, as in the following, which emphasized the importance of the cross-cutting concepts, one of the three dimensions of the NGSS (NGSS Lead States):

> Administrator 1: I'm really going to work on the CCC ideas! How to help people embrace and use them. #NGSSchat
> Researcher 1 reply to Administrator 1: @Administrator 1 Awesome. If you get exciting projects going, please try to loop in researchers. We need to study the CCCs! #NGSSchat

These sense-making conversations also evidence engagement with broader ideas related to implementing policies related to the NGSS:

> Organization 1: A4: Doing great work in WI on standards-based report cards for #science, but still need more work on it #ngsschat
> Administrator 1 reply to Organization 1: @Organization 1 Would love to take a look at where you're going with that if you can share.
> Organization 1 reply to Administrator 1: @Administrator 1 I'll share widely and post on #ngsschat as we get something formal put together
> Administrator 2 reply to Organization 1: @Organization 1 @Administrator 2 This is awesome, I look forward to seeing what you put together. #NGSSchat

Transformative conversations—different from those which were considered to be sense-making—demonstrated some type of change in one's knowledge, as in the following discussion of how an administrator, in response to an answer to a question posted by an organization, was coming to recognize the importance of technology-based networks for implementing the NGSS:

> Organization 1: A1: Capacity for #ngss implementation will only be reached with the creation of/use of networks and taking advantage of technology. #NGSSchat
> Administrator 1 reply to Organization 1: @Organization 1 I agree with the necessity for maximizing tech, but can you clarify what kind of networks you mean? #ngsschat
> Organization 1 reply to Administrator 1: @Administrator 1 I mean that we cannot succeed if we work individually. We must collaborate in existing & new pers./prof. networks. #NGSSchat
> Administrator 1 reply to Organization 1: @Organization 1 I was guessing that was what you meant - the more I get into this, the more I see how much a support network is critical #ngsschat

Other transformative conversations concerned individuals' statements about intending to change one's practice by accessing a new resource, as in the following conversation between two teachers and three administrators about the rigor of NGSS-aligned chemistry courses, and the interest of teachers to access materials related to a new course an administrator was developing:

> Administrator 1: Some teachers I know are willing to change their instruction for “regular” chem, but not “honors” chem...thoughts? #NGSSchat

> Teacher 1 reply to Administrator 1: @Administrator 1 this goes back to the fear that #NGSS isn't rigorous enough 4 college readiness. Many still think coverage = rigor #NGSSchat
> Administrator 2 reply to Teacher 1: @Teacher 1 @Administrator 1 Happy to share a chem course I've been working on. Shows depth. #NGSSchat
> Administrator 3 reply to Administrator 2: @Administrator 2 @Teacher 1 @Administrator 1 Something like that would answer chem Ts questions. NGSS leaves some feeling marginalized #NGSSchat
> Administrator 2 reply to Administrator 3: @Administrator 3 @Teacher 1 @Administrator 1 Working now on a set of YouTube type Vs to explain bonding, gas laws, and inst. seq. #NGSSchat
> Teacher 2 reply to Administrator 2: @Administrator 2 @Teacher 1 @Administrator 2 I would love to see this! #NGSSchat
> Administrator 2 reply to Teacher 2: @Teacher 2 @Teacher 1 @Administrator 2 Email me. #NGSSchat

Last, off-topic conversations were the most infrequent but consisted of conversations not related to the #NGSSchat or NGSS content. For instance, the following conversation is not related to the chat nor NGSS content:

> Administrator 1: I'm always amazed how quickly @Administrator 2 and @Administrator 3 can type in welcome response tweets #NGSSchat
> Administrator 3 Reply to Individual 1: @Administrator 1 @Administrator 2 We have clones. #NGSSchat

Finally, as Table 4 illustrates, while a small proportion of conversations were transformative, they, followed by those coded as sense-making, were longer and involved more participants and more participants from distinct professional roles. Concomitantly, we also found that most participants were involved in one or more transactional (175; 71.9%); and sense-making (205; 83.0%) conversations, while fewer (though still a substantial proportion) participated in transformative (36; 14.6%) conversations.

TABLE 4 Descriptive statistics for the different types of conversations

Measure	Transactional conversation *M* (*SD*)	Sense-making conversation *M* (*SD*)	Transformative conversation *M* (*SD*)
M length (*SD*)	2.22 (0.925)	3.27 (2.41)	5.29 (2.78)
n individuals participated in at least one (%)	205 (70.85%)	205 (82.99%)	36 (14.57%)
M individuals participated (*SD*)	1.96 (0.53)	2.33 (1.11)	3.24 (0.97)
M professional roles participated (*SD*)	1.65 (0.56)	1.82 (0.77)	2.18 (0.52)

Notes: Off-topic conversations were not included on the basis of their infrequency ($n = 7$, 0.01% of all conversations)

Collectively, these results point to how sense-making and transactional conversations exhibit greater involvement from individuals, while transformative conversations—though common—were less frequent than those types. Transformative and off-topic conversations were found to be very rare, yet, still, more than 10% of individuals were involved in at least one transformative conversation.

5.3 | Results for RQ #2: #NGSSchat participants' role and NGSS adoption status

The analysis for professional roles coding revealed teachers as the plurality within the network (37.90%; $n = 94$) followed by those in the other professional role (28.62%; $n = 71$), administrators (21.3%; $n = 53$), researchers (6.9%; $n = 17$), and organizations (5.%; $n = 13$). This variation shows that although teachers are the largest group of individuals using #NGSSchat, substantial heterogeneity in their roles was evidenced.

The analysis of NGSS adoption status showed that 47.6% of individuals ($n = 80$) were from states which adopted the NGSS (or NGSS-like standards) early (before the 2015–2016 school year); 40.4% ($n = 68$) from those who adopted the standards late (during and after the 2015–2016 school year); and 11.9% ($n = 20$) were from states that did not adopt the NGSS. Figure 2 illustrates these differences and suggests that individuals participating in #NGSSchat did so from across the United States, without clear geographical clustering.

5.4 | Results for RQ #2: Conversations between #NGSSchat participants

This analysis provides insight into who initiated (or sent) and who received replies based on their professional role. Overall, we found that individuals in different professional roles sent and received replies at different rates, and individuals had a slight tendency to interact more with others in the same professional role.

Because of the relatively small number of transformative conversations, we carried out analyses for who sent and received replies as a part of transformative conversations combined with sense-making conversations, and with transformative conversations independent of this other type of conversation. Because none of the coefficients were found to reach the criterion for statistical significance in the analyses with only transformative conversations —and the direction, magnitude, and statistical significance of the effects for sense-making did not change when the transformative conversations were included with sense-making conversations—we chose to combine these types of conversations in these analyses, and to refer to this combined value as sense-making conversations for brevity. Table 5 presents the results.

Conversations were *sent* to different extents depending on the individual's professional role. To interpret this table, consider an individual who is a researcher and is otherwise similar to other individuals. Values greater than one indicate that an additional conversation is sent or received is *more* likely; values less than one indicate that an additional conversation is less likely. The coefficient associated with the association of being a researcher on sending transactional replies is positive and statistically significant. Because the Incident Rate Ratio value of 4.86 is interpreted as a rate, it can be interpreted as increasing the count of conversations sent by researchers at this rate (accounting for the effects of other variables). Also, we note that

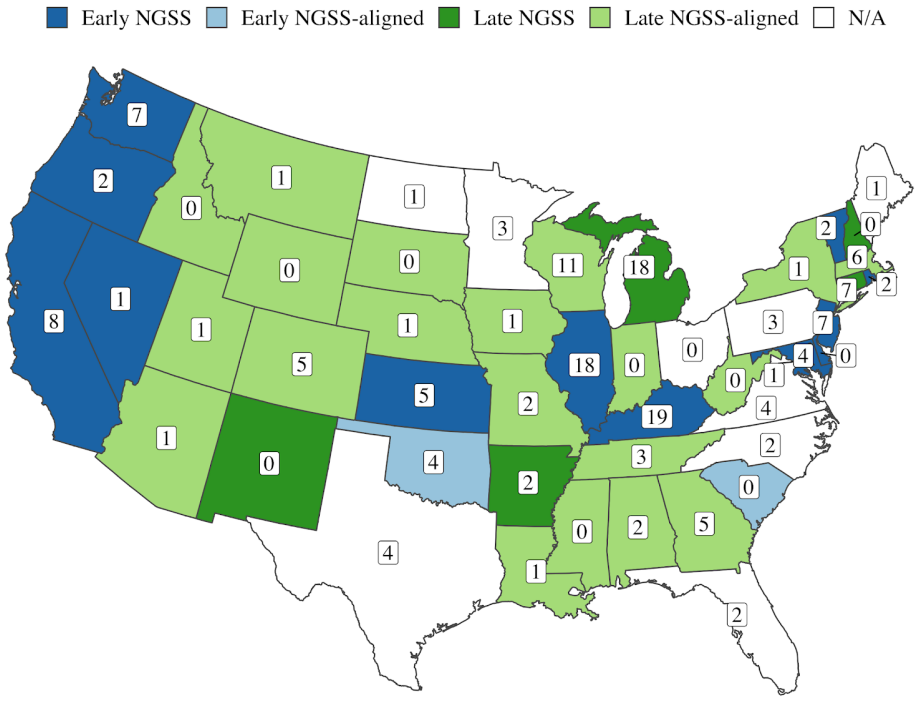

FIGURE 2 Number of #NGSSchat participants by U.S. state and state's adoption status. *Notes:* Early NGSS denotes a state's adoption of the NGSS before the 2014–2015 school year and Late NGSS denotes a state's adoption of the NGSS after the 2014–2015 school year but before the 2019–2020 school year. Early-NGSS-aligned and Late NGSS-aligned denote the adoption of NGSS-aligned standards (but not the official NGSS) for the same periods. No individuals were from Alaska, Hawaii, or other United States territories, and two individuals were from locations outside of the United States. N/A indicates that the state had note adopted the NGSS or NGSS-aligned standards before the 2019–2020 school year [Color figure can be viewed at wileyonlinelibrary.com]

while the reference group is the "Other" professional role, this comparison is less helpful than the pairwise comparisons between groups, which show how the effect of belonging to any one professional role differs from the others (Table S5).

Conversation replies were *sent* to a different extent depending on the individual's professional role. Administrators stood out for their high rate of sending, or initiating, replies as a part of both transactional and substantive conversations to a greater extent than those in the other role. While researchers were even more likely to send transactional conversations than administrators, individuals from both these professional roles as well as teachers were not found to be different from one another in terms of their rate of sending replies, with organizations being associated with slightly lower participation (Table S5); the observed differences were with those in the other role which served as the reference group.

Replies were also *received* to different extents depending on the individual's role. Researchers and administrators stood out for their high rate of receiving replies in both transactional and substantive conversations, while teachers received more transactional—but not substantive—replies than those in the other role. As for sending replies, there were not any statistically significant differences between these roles (Table S5). These findings suggest that one professional role is not privileged over others when it comes to participating in conversations, as long as participants' role is either as a teacher, administrator, researcher, or an organization,

TABLE 5 Selection models for sending and receiving replies through conversations

Type of variable	Independent variables	Transactional conversations incidence rate ratio	Substantive conversations incidence rate ratio
	(Intercept)	0.00	0.00
Sender professional role	Administrator[a]	3.85**	2.45***
	Organization	1.61	0.67
	Researcher[a]	4.86**	2.01+
	Teacher[a]	2.84**	1.44
Receiver professional role	Administrator[a]	2.34**	2.41***
	Organization[a]	1.97*	1.09
	Researcher[a]	3.67***	2.28*
	Teacher[a]	1.88**	1.30
Dyad-level variable	Same professional role	1.12	1.09***
Random effects	Sender (*SD*)	4.71	5.15
	Receiver (*SD*)	2.74	4.75

Notes: The other professional role served as the reference group for the other roles. Superscripts indicate groups with effects that were found to not be different based on post hoc tests (see Table S3). Substantive conversations represent the combined number of sense-making and transformative conversations.
$+p < .10$; $*p < .05$; $**p < .01$; $***p < .001$.

with implications for how #NGSSchat may provide access to expertise to those participating in it, as we later discuss.

Finally, we found that individuals demonstrated a small tendency to converse with others with whom they shared the same professional role, though this tendency was small relative to the effects of professional roles and the sender and receiver random effects: Individuals who share a professional role were 9% more likely to have an additional conversation. Transactional conversations did not exhibit this homophily tendency: Conversations were found to be equally likely between individuals from different professional roles as those between individuals from the same professional role. Transactional conversations may reflect a more accessible type of interaction for those from different professional roles than substantive conversations, and individuals may converse more substantively because they share more similar concerns, questions, or interests.

We note that these rates are relative to the intercept, which has a very small magnitude. The Incident Rate Ratio of 4.86 for the effect of a researcher sending a reply as a part of a transactional conversation is multiplied by the Incident Rate Ratio for the intercept to yield a rate of 0.003, less than a one in 100 predicted chance of a researcher sending a reply to any other individual. If the receiver is also a researcher (Incident Rate Ratio: 3.67), then the rate increases to 0.013. In other words, for any two researchers in the network, their rate of conversing transactionally is 0.013, or a 1.13% chance. Thus, these effects are small in magnitude. In this context, we also note the random effects in the output. In the output, these present the standard deviation of the individual sender and receiver random effects, which model the effects specific to each #NGSSchat participant. Their standard deviation is large in magnitude: 4.71 for senders and 2.74 for receivers. The inspection of the estimates for the random effects shows that a few

individuals seem to have a very large effect: Simply being one of these individuals increases the rate of sending replies to any other individual by those amounts, leading to predicted differences in the rates of sending replies as a part of transactional conversations, for examples, for the individuals with the largest estimates by as much as 0.15. Thus, what this model shows—overall—is that while professional roles do matter (and are associated with statistically significant differences in the rate of sending and receiving replies), the differences appear to be driven by a relatively small number of highly influential individuals.

5.5 | Results for RQ #3: Factors associated with sustained participation

This analysis provides insight into what sustains the participation of #NGSSchat participants over time, which we operationalized as the number of original tweets sent in the year following the study, regardless of the types of conversations in which individuals participated. Like for RQ #3, we combined sense-making and transformational conversations, and refer to this combined value as substantive conversations for brevity. The coefficients in Table 6 are interpreted as an Incident Rate Ratio, because the dependent variable is a count variable, like for RQ #2. For example, the coefficient associated with being an administrator is associated with an Incident Rate Ratio of 1.55, indicating that administrators are 55% more likely to send an additional original tweet in the year following the study than in the other role (see the measures). As for the previous results, we direct attention to the pairwise comparisons from post hoc tests (see Table S6), which show how the effect of belonging to any one professional group differs from that for belonging to the others.

We found notable differences in sustained participation based on the professional role to which each individual belonged. In particular, the effects associated with professional roles were also statistically significantly different from one another except for that between administrators and teachers (Table S6). For these analyses, the Average Marginal Effect represents the effect of a one-unit change in the independent variable in terms of the number of original

TABLE 6 Results for influence models predicting sustained participation in #NGSSchat

Independent variables	Sustained participation incidence rate ratio	Sustained participation average marginal effect
(Intercept)	8.34	2.12
Involvement in transactional conversations	1.83***	14.85***
Involvement in substantive conversations	1.45***	9.01***
Administrator[a]	1.79***	16.80***
Organization[b]	0.20***	−16.91***
Researcher[c]	0.66***	−7.19***
Teacher[d]	1.90***	19.06***

Notes: The other professional role served as the reference group for the other roles. Superscripts indicate groups with effects that were found to not be different based on post hoc tests (see Table S4). Substantive conversations represent the combined number of sense-making and transformative conversations.
$+p < .10$; $*p < .05$; $**p < .01$; $***p < .001$.

tweets in the year following the study. For example, a one-standard-deviation increase (because these variables were standardized) in involvement in transactional conversations was on average, associated with 14.85 more tweets the following year. Teachers, especially, stood out as being more likely to participate in the year following the study, being more likely than those in the other role (with an Average Marginal Effect of 19.06 relative to those in the other role[7]) to post additional tweets in the year following the year of the study, and, according to post hoc tests, were more likely than any of the other three roles to post an additional tweet. Administrators, too, were likely to sustain their participation (relative to those in the other role [*AME*: 16.80], as well as researchers [*AME*: 24.00] and organizations [*AME*: 33.71]). Researchers (*AME*: −7.197)—and especially organizations (*AME*: −16.99)—were found to be less likely to continue to be involved in #NGSSchat in the following year compared to teachers, administrators, and researchers. In short, the two groups who are most likely to work in schools—teachers and administrators—were found to be more likely to exhibit sustained participation.

Finally, and importantly, we found differences based upon involvement in transactional and substantive conversations or the number of such conversations in which individuals participated. We note that this involvement captures not only how many conversations an individual was exposed to, but also who was participating in them (based on the centrality of the individual sending the reply as a part of a conversation). Thus, involvement was calculated in a way that was intended to capture the total effect of receiving replies—and, potentially, expertise—over time. We focus on the AMEs to help us to understand the difference in sustained participation on the scale of the dependent variable. The effect of involvement in conversations can be interpreted in terms of a one-standard-deviation increase in the independent variable: individuals posted 14.85 additional tweets in the year following the year of the study for a one-unit increase in such involvement in transactional conversations, and 9.01 additional tweets for every one-unit increase in involvement in transactional conversations. Therefore, not only one's professional role, but also how one participates in the network matters, with involvement in transactional and substantive conversations both relating to sustained participation, but with a stronger effect for involvement in transactional conversations.

6 | DISCUSSION

We sought to understand how the social media-based professional network #NGSSchat connected diverse stakeholders that are integral to implementing NGSS reforms and allowed for substantive interactions. Overall, we found (a) transactional, sense-making, and transformative, conversations took place through #NGSSchat; (b) participation among teachers, administrators, and researchers sent and received replies in conversations at similar rates; and (c) receiving greater transactional and substantive (which included both sense-making and transformational) conversation replies from central participants in the network was associated with individual's sustained participation in the year following the year of the study. We discuss these key findings followed by implications for policy, research, practice, and recommendations for future research.

6.1 | Key findings for the nature of the conversations taking place through #NGSSchat

#NGSSchat provides an example of how social media-based networks can allow for substantive conversations around education reform—in this case, an ambitious science education

transformation effort. We found that conversations that we considered to be sense-making or focused on NGSS or science education topics or problems, were commonplace: there were 1,597 unique sense-making conversations, comprising nearly one-third of all of the conversations that took place through #NGSSchat. Considering only those conversation threads with two or more tweets (and so not considering posts that received no replies), sense-making conversations comprised nearly two-thirds of the conversations. In addition to being frequent, the vast majority of participants were a part of these substantive conversations; 205 of the 247 participants (or 83%) were involved in one or more sense-making conversations. In light of the importance of conversations, especially those that are situated in the context and problems of practice stakeholders—especially teachers—face (Coburn, 2001; Horn et al., 2020; Horn & Little, 2010; Penuel et al., 2013), for professional sense-making about reforms, the high proportion of sense-making conversations may be a critical part of why individuals value #NGSSchat—and for supporting the balanced involvement and sustained participation we discuss later.

We believe that the alignment of the chat questions with the tenets and practices of the NGSS likely was an important support for these substantive (sense-making or transformational) conversations. Many of the questions that moderators asked to structure #NGSSchat chats called on participants to engage in substantive interactions about NGSS (see Table 1 for example questions). Additionally, the high proportion of sense-making conversations suggests an especially notable use (and role for) social media. Instead of simply an avenue for transmission of information from moderators to participants (Staudt Willet, 2019)—which is likely insufficient to support substantive conversations—#NGSSchat appears to provide opportunities for sense-making conversations for many of its participants. Moreover, due to the strong alignment between the chat questions and NGSS, this sensemaking is likely to be productive. Last, because social media can provide opportunities for individuals to participate in conversations that they otherwise would or could not (Lantz-Andersson et al., 2019; Krutka, Carpenter, & Trust, 2016), these conversations may be especially valuable to participants who are beginning to make sense of how the NGSS might relate to (and inform) efforts to improve science teaching and learning in their state, district, or school.

In addition to the importance of sense-making conversations, past research argues that conversations are more productive when they are carefully facilitated (Andrews-Larson et al., 2017)—like those that take place through #NGSSchat are—and when they help those involved to align ideas about reforms with stakeholders' practice (Borko, 2004; Horn & Little, 2010), as sense-making conversations, especially those that involve multiple stakeholders, may afford. Given how #NGSSchat was designed, and the frequency of sense-making conversations, we argue that an important part of the value of social media-based networks such as #NGSSchat is the open and varied conversations can take place. We think this is the case even when ideas that question (or diverge from) the NGSS are discussed, as such conversations can still provide opportunities to collaboratively make sense of their and others' ideas about the changes called for in reform efforts (Rosebery et al., 2010). Just as science education researchers have argued for valuing sensemaking in science classrooms, not simply correctness (Haverly, Calabrese Barton, Schwarz, & Braaten, 2020; Schwarz, Passmore, & Reiser, 2017)—and as policy scholars have argued in the context of instructional shifts (Coburn, 2001; Windschitl, 2006), there is value in providing opportunities for sensemaking about reforms among educators and other stakeholders in science education.

We also note that while many of the other conversations that took place were transactional, very few conversations were off-topic, or unrelated to the NGSS. While not sense-making (or transformative), transactional conversations, which we found were often more

social, may help participants to build a sense of belonging and community that is important for networks in any setting (Shulman & Sherin, 2004), but is perhaps valued in informal networks (Bucher & Fieseler, 2017; Fischer et al., 2019; Lantz-Andersson et al., 2018; Trust et al., 2016). In other words, social conversations matter, too, as we discuss further in the context of the next set of key findings. In summary of key findings from this study about substantive conversations, while we cannot say to what extent these conversations are representative of all informal networks, including others in science education, these findings suggest that the substantive conversations taking place through #NGSSchat may support stakeholders from a variety of roles to make sense of their practice in light of the broad changes called for in the NGSS.

6.2 | Key findings for the extent of the involvement of multiple stakeholders

Individuals from a variety of professional roles and states at different stages of adopting the NGSS participated in #NGSSchat, even in the 2014–2015 and 2015–2016 years when fewer states had adopted the standards than at present. Participation in #NGSSchat was from individuals from a variety of professional roles, particularly teachers, who made up more than one-third of the 247 participants, but also administrators (20% of participants) and researchers (7% of participants). This heterogeneity of professional roles was significant given past research that highlights how challenging it is for educational stakeholders in different roles to coordinate their work in schools, districts, and Universities (Coburn & Stein, 2010; Peurach et al., 2019; Penuel et al., 2013). Moreover, this heterogeneity is important in that stakeholders from multiple roles could see themselves as active participants because of the involvement of others with whom they share a key (in this context) personal characteristic, their professional role; in other words, homophily could contribute to not only researchers and administrators, but also teachers to choose to be involved in this network (Spillane et al., 2012).

That individuals from different roles were involved may mean that potential access to resources that can drive reform efforts may exist (Cobb et al., 2018; Stiles et al., 2017). Importantly, that many teachers were involved may also mean that conversations are likely to provide opportunities to develop an understanding of NGSS at the classroom level, an important feature of conversations for individuals in any role, but perhaps especially so for teachers (Horn & Little, 2010). Finally, we note that the inclusion of multiple stakeholders may relate to and expand the relevance of the findings related to the presence of substantive conversations: because conversations were varied in nature (from sense-making to more transactional and social) and that nearly two-fifths of participants were teachers, it could be that #NGSSchat served as a welcoming community for teachers, who chose to participate both because it advanced their professional goals (i.e., to learn more about the NGSS) and their desire to interact with others interested in changing their practice and the practice of others. In this context, we note that informal networks like #NGSSchat may be especially useful for supporting teachers to feel like they can take (calculated) risks in their practice—tasks that may be difficult to take in the setting of one's school or district, for example (Krutka et al., 2016). Informal networks may also help participants who are not teachers to better understand the realities of classrooms in relation to large-scale reforms.

In terms of balanced participation, we found that three roles were especially prominent in terms of both initiating, or sending, and being the recipients of, or receiving, replies as a part of conversations. These three roles were researchers, administrators, and teachers. That

individuals from these roles were prominent where it comes to being involved in conversations suggests that multiple stakeholders not only participate in #NGSSchat but, also, that the resources particular to them and their professional role may be available to others, which supports reform stakeholders to develop a shared understanding (Penuel et al., 2011) and trust (López Turley & Stevens, 2015), both of which can be uncommon—especially in collaborations between researchers and practitioners (Coburn, 2001; Farrell et al., 2019; Windschitl, 2006). That teachers both send and receive replies at comparable rates to administrators and researchers in this network is notable, as we discuss more as a key implication.

6.3 | Key findings about the sustainability of participation in #NGSSchat over time

Finally, how long individuals participate in professional learning opportunities is important (Desimone, 2009; Garet et al., 2001); this consideration may be especially important in informal networks in which individuals voluntarily choose to participate (or to stop; Lantz-Andersson et al., 2018; Veletsianos, 2017). We found that teachers and administrators were more likely to actively participate in #NGSSchat in the subsequent year, while researchers and organizations were not likely to sustain their involvement. Additionally, how exposed individuals were to both transactional and substantive conversations (accounting for how central participants in them were) was associated with greater sustained participation. Specifically—and in line with past research on participation in the education-wide hashtag #edchat (Xing & Gao, 2018)—we found that involvement in more transactional and substantive conversations predicted greater sustained participation, but that the relationship between involvement in transactional conversations and sustained participation was even greater than that for substantive conversations. If involvement in transactional conversations can support individuals to feel like they belong (e.g., Lantz-Andersson et al., 2018), perhaps this sense of belonging and community—in combination with involvement in the substantive conversations that provide access to resources—is what causes individuals (particularly teachers, given the high proportion of participants who were teachers and the findings showing that they, especially, are likely to sustain their participation) choose to continue to participate in #NGSSchat over multiple years.

6.4 | Implications

6.4.1 | Implications for research

#NGSSchat was found to support not only deep conversations but also conversations of a variety of types. Moreover, it invites stakeholders from a variety of professional roles, and, importantly, seems to afford uncommon access (Coburn & Stein, 2010) to them: For a researcher to access the insights of teachers, some who are leaders (and pioneers) concerning science teaching and learning in their schools, districts, and states, or for an administrator to pose questions or share concerns with researchers, some who served on the committee to write the *Framework for K-12 Science Education* (NRC, 2012), is uncommon, and so highlights one of the unique affordances of social media, the resources (Carpenter & Krutka, 2014b) and professional networks (Trust et al., 2016) can provide access to. Particularly for the NGSS—a nationwide reform effort present in all but six states (representing more than 70% of U.S. students) as of the time of

this writing (National Science Teachers Association, 2020)—networks such as #NGSSchat may allow resources and professional networks to be more widespread and geographically distributed than they would be were such technology-based networks unavailable. In this context, establishing not only the potential of #NGSSchat and other networks to support reform efforts, but also to investigate how their use may have shaped the particular ways in which this reform effort has developed and been implemented in practice.

Key characteristics collectively distinguish #NGSSchat from other social media-based and informal professional networks (e.g., Greenhow et al., 2019; Lantz-Andersson et al., 2019): (a) the presence of different types of conversations, (b) access to stakeholders from different roles and balanced participation, as well as (c) the sustained participation of participants (especially administrators and teachers). While past research about professional networks and social media in education have pointed out their independent benefits, #NGSSchat seems to demonstrate how the characteristics we explored might work together to support a nationwide reform effort. Consequently, another implication of this study concerns what those who are supporting other networks (including face-to-face networks) might do differently in light of the roles of networks like #NGSSchat that are supported not by geographic proximity, but, rather, an affinity between individuals (Gee, 2004; Rosenberg et al., 2016) and their collective participation in conversations about the NGSS and science education (Garet et al., 2001). In particular, such networks may profitably incorporate multiple stakeholders and provide them with opportunities to interact on more equal grounds—whether that be through social media or carefully designed questions (such as those used by the moderators of #NGSSchat to structure the chats) to interact in any setting. In this way, #NGSSchat suggests new visions for how to address a persistent challenge for those seeking to reform education (Coburn, 2001; Peurach et al., 2019), implementing changes in complex systems that require the collective participation of multiple stakeholders.

6.4.2 | Implications for practice

These findings may have implications for science teachers and science teacher educators. In light of the way #NGSSchat has been used, we think researchers and teacher educators should consider the potential in social media to support sensemaking about the NGSS and other science education topics, questions, and issues in an open and accessible way. Moreover, we think that researchers and teacher educators could see benefits to participating in these networks, as doing so provides the opportunity for science teacher educators to contribute to and shape the conversation about science teaching and learning and how to improve science education, whether in the United States or in other countries around the world, where similar networks often already-exist or could be developed and supported. Last, we think that social media-based networks may be useful alongside professional development efforts for teachers and others, as doing so may leverage some of the affordances on such networks alongside the affordances of face-to-face professional learning communities, which might be better tailored to local issues.

6.4.3 | Methodological implications

While the use of social network analysis in science education research is growing (e.g., Fortus et al., 2019; Navy, Nixon, Luft, & Jurkiewicz, 2020), it remains limited, and much of the

research on technology- and social media-based networks is primarily descriptive (Macià & García, 2016). While descriptive uses of social network analysis are valuable, if researchers wish to design or impact social networks, a focus upon social network processes may be particularly important—including selection processes to interrogate who interacts with whom and influence processes to understand how involvement in interactions or relationships matter. In this study, we explored #NGSSchat with methods more commonly used to study face-to-face networks (Coburn et al., 2010; Frank et al., 2013; Horn et al., 2020; Spillane et al., 2012) that allowed us to understand how balanced the participation of individuals was and how participants' interactions affected their involvement in the subsequent year.

6.5 | Limitations and recommendations for future research

Analyzing a digital network such as #NGSSchat on Twitter has strengths as well as weaknesses—and limitations—relative to face-to-face networks. There are things that we could do with the data we had, such as look back at #NGSSchat during a time in which many states were adopting the standards, and to gain insights into the conversation taking place, the participants involved in them and their participation, and even—using longitudinal data—their sustained participation. While the longitudinal data set was a strength of this study, it also presented limitations. By accessing tweets that were archived through the Storify platform, we knew that some tweets may not have been archived, which may have led to a biased selection of tweets (in favor of those with more conversations). However, additional analyses revealed that most of the original data from the chats were archived and therefore accessed and used in this study, while most of the data from the non-chat time were not available (Borchers et al., 2020).

Second, while we focused on professional roles and geographical locations, heterogeneity in the voices of participants could concern much more. Particularly noteworthy is the absence of any measures about individuals—including their grade level and their identity—in our analyses. This is important because it may speak not only to how #NGSSchat functions as a network, but now inclusive and representative of a network it may be, a key question pointed out in a recent review of digital networks (Lantz-Andersson et al., 2018). Future research may address this limitation by considering the merits of research methods other than social network analysis (e.g., surveys) to gauge how representative #NGSSchat is of the broader science education domain, and to make suggestions for how to improve the network.

Finally, we note that the authors are familiar with the #NGSSchat network. While we are not the organizers for the chat and were not involved in its creation, one of us has led one of the chats, and others have participated in chats, including chats that were analyzed in this study. This familiarity was important as it helped us to recognize potentially positive aspects of the network; it also gave us particular insight into the specific individuals who served as moderators and participants in these chats. However, this position could also be a negative, as it was concomitant with an affinity toward the network and its potential benefits, and so we were careful to frame this study theoretically and to carry out the analyses without aiming for specific results (or levels of statistical significance). Lastly, we note that this positionality was related to our decision to anonymize example tweets and to carefully share data. An issue with Twitter data is that while it is in the public domain, many #NGSSchat participants posted without thinking that their post would be used for research—and, they may not have participated had they known their activity would be used for such purposes (Fiesler & Proferes, 2018). Accordingly, we chose to anonymize the example tweets we included and share the analytic code[8] associated with this study, but not

the data, which we stated that we will share upon request. We recommend to other researchers studying #NGSSchat or other educational networks to consider this, as well, especially when familiar with the network and therefore inclined to share about it.

7 | CONCLUSION

#NGSSchat demonstrates similarities and distinctive features relative to other face-to-face and social media-based networks, and while few networks possess the same characteristics as #NGSSchat, other contexts are likely emerging where science education stakeholders can find common ground to shape its future. Such new—often digital—contexts—especially those that foster substantive conversation, balanced involvement, and sustained participation—should, we think, be sought out, scrutinized, and supported, as they can suggest new visions for how to implement ambitious change efforts in complex educational systems.

ORCID

Joshua M. Rosenberg https://orcid.org/0000-0003-2170-0447
Elizabeth B. Dyer https://orcid.org/0000-0002-4124-7654

ENDNOTES

[1] The #NGSSchat network remains active at the time of writing this article.

[2] We have confidence that this dataset represents most of the chat activity that took place during the 2 years of activity we studied, having validated how comprehensive our dataset was through the use of Twitter's Application Programming interface (see Borchers, Rosenberg, & Fischer, 2020).

[3] Tweets were archived by #NGSSchat organizers on the following website: http://www.ngsspln.com/ngsschat.html. We accessed the data via the Wikispaces website that the #NGSSchat used to post links to the Storify pages for each chat. We then used the Application Programming Interface from Storify to access the URLs for each of the tweets. Next, we used the rtweet R package (Kearney, 2019) to access additional data on the tweets. Finally, because rtweet (nor the Twitter API) does not provide information about who retweeted or favorited a tweet, we used web-scraping to access this information.

[4] Although those in the other role were not coded as belonging to one of the other four roles, they were still, in general, stakeholders in the NGSS, such as parents or those involved in education, but in an unclear capacity.

[5] Particularly for complex multi-level models (such as *p2* models), typical estimation approaches can be challenging to use. The *brms* package uses MCMC estimation, which can aid in the estimation of such models. Another advantage of the use of MCMC is that with typical GLMs, there is a violation of the assumption that the variance and mean of the outcome are equal: MCMC accommodates the uncertainty due to this. We followed Kruschke's (2014) guidelines for checking the representativeness, accuracy, and efficiency of the estimation process.

[6] We chose to combine conversations coded as transformative with those coded as sense-making for the conceptual and practical reasons we describe in the results for RQ #3.

[7] The Average Marginal Effect for individuals in the other group, which accounts for involvement in transactional and transformational conversations, was 0.11.

[8] https://osf.io/9ex7k/

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SUPPORTING INFORMATION

Additional supporting information may be found online in the Supporting Information section at the end of this article.

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