Research in Science Education (2022) 52:1–20
https://doi.org/10.1007/s11165-019-09911-y

Social Media Interaction as Informal Science Learning: a Comparison of Message Design in Two Niches

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Published online: 10 January 2020

Abstract
Social media provides science learners opportunities to interact with content-specific messages. However, most science-specific social media content is designed to disseminate information instead of encouraging dialog. In this novel, ex post facto exploratory study of a science social media community, we sought to understand the relationships among community member interaction, design elements of messages, and post type on two digital niches (i.e., Facebook and Twitter). Framed by the theory of symbolic interactionism, we conducted a content analysis of 1370 messages that were systematically created by an informal science learning project and found that usage frequency of messaging elements varied by niche; interaction within each niche differed, varying by messaging element; and differential interaction was found to be associated with post types within Facebook only. This study suggests a pathway for developing and examining social media as an educational component of informal science learning.

Keywords Social media · Informal science learning · Twitter · Facebook · Content analysis

Introduction

Social media allow for rapid-fire, potentially continuous communication among people with diverse backgrounds, interests, and experiences, which can lead to exchanges of information, formulation of new ideas, and other forms of social learning (Daume and Galaz 2016). As such, social media platforms that include communication about science (e.g., Twitter, Facebook, and Instagram) are effectively functioning as informal science learning spaces, a concept more traditionally associated with in-person venues such as museums, aquaria, and zoos, or education-specific online environments such as massive open online courses (MOOCs) (Falk and Storksdieck 2010). There has been

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some debate regarding the scientific merit of meaning-making that occurs in such online spaces, with Marsh (2018) arguing that such spaces operate to provide only social support, not scientific knowledge gain. However, if people and institutions use social media with the focus on sharing and communicating about scientific practice, such spaces can be viewed as informal learning environments (Russo et al. 2009).

Social media efforts by entities that promote informal science learning have historically emphasized a one-way, disseminatory practice of content communication in lieu of a more dialogic, educative approach; one where learners connect, collaborate, and discuss in order to build knowledge socially (Lundgren and Crippen, 2019; Fauville et al. 2015). Currently, more traditional informal learning spaces (i.e., museums, science centers, aquaria, zoos), are undertaking efforts to utilize social media, but the approach tends to be practitioner-focused, emphasizing mass messaging or didactic marketing (Drotner and Schrøder 2013), or focused entirely on art or cultural institutions, not science centers or institutions (e.g., Budge 2017; Gerrard et al. 2017). Indeed, the American Alliance of Museums (AAM) and the Association of Science and Technology Centers (ASTC) both have applied the basics of marketing to social media in order to develop effective strategies for bringing in the same populations, but this approach is misaligned with the educative mission of these institutions and falls short of expanding the audience to those traditionally underserved (Lundgren and Crippen, 2019).

In their practice, informal science educators operate with an explicit intent to communicate, using messages to provide information, as well as to seed or support chains of interaction among individuals that are intended to result in the construction of meaning (Martin et al. 2016). This practice applies to traditional forms of face-to-face interaction as well as emergent digital forms such as online courses, forums, email exchanges, or social media messaging. For face-to-face contexts, a plethora of evaluation methods exist for gauging visitor engagement with such practice (Barriault 2010; Essex and Haxton 2018). However, there currently is no standard method for evaluating or benchmarking best practice for messaging as it applies to informal science learning in digital social environments like social media.

Social media messaging has an educative potential, offering the possibility for new or sustained science-related discourse. Currently, social media messaging often takes the form of marketing, a one-way customer-oriented form of communication intended to improve or maintain satisfaction (Vaynerchuk 2013), which differs from an educational goal and likely failing to capitalize on any potential for learning. Such practice is more prone to presenting science as a collection of unrelated facts or a body of knowledge to be learned instead of as a practice-based participatory human endeavor. Illustrating science as practice is an embodiment of a situated perspective on learning that positions science education as an explicit attempt to engage people in what scientists do: authentic, epistemic practice (Crippen et al. 2016, Fauville 2017). Messages and message elements that illustrate and support a visual practice-based view of science are conjectured to facilitate social interaction among diverse members of a community within a digital niche (Wenger et al. 2009).

In this ex post facto study, we investigate this conjecture via the interactions that members of an informal science education community had with social media messages that were systematically produced by researchers on The FOSSILProject, a project funded by the National Science Foundation, a US government agency which provides nearly eight billion dollars in funding to scientific research in the USA (NSF Budget Requests, https://www.nsf.gov/about/budget/). The FOSSIL Project project, which was funded from 2014 to 2019, focused on building knowledge and relationships that centered on paleontology (i.e., the study of fossils). Social media messages were part of a long-term campaign to use social learning strategies to build a diverse community around the authentic practice of paleontology, a field-based natural science. With the goal of sustaining engagement beyond a single message, researchers merged best practices from a variety of fields to create quality messages, including graphic design principles, marketing-specific messaging strategies, and educative design. These messages were then deployed on Facebook and Twitter, two distinct digital niches upon which community members interact. To evaluate the response to the message, we investigated the following research questions:

- Which elements, when included as part of a social media message, led to interaction within an informal science education community?
- Which forms of paleontological practice, when illustrated via social media messages, led to interaction within an informal science education community?
- How are the message-specific interactions of an informal science education community influenced by the social media environment?

Theoretical Framework

This study is grounded in the symbolic interactionist tradition, a perspective focused on the development of people through their interrelated and reciprocal relationship with transformations of their communities through communication (Charon 2009). Meaning-making is the process of how people interpret discourse, situations, or events based on their previous knowledge and experience (Zittoun and Brinkmann 2012). Symbolic interactionism, which draws upon this understanding of the process, is a set of ideas for studying the interplay of individuals and community where structure and significance are created among people who, over time, produce shared meaning for certain symbols and actions, which in turn are representations of their understanding of particular events. Such interactions create and transform collections of people into communities via an evolving and dynamic process of mutual coordination and role taking (Crable 2009). Ideas, when symbolized for communication, become objects for interaction, which in turn come to define a social reality for those within the community (Stryker and Vryan 2003).

Communication within a community involves messaging, the purposeful exchange of information, which includes the use of symbols with some degree of representational significance for its members (Littlejohn and Foss 2011). In a social situation, people use these symbols and their expectations to define and organize their behavior. Thus, a community's response to different forms and types of messages is indicative of the implied meaning of those messages to the group, as these interactions represent the ongoing negotiation of norms, values, roles, rules, and shared understanding (Crossley 2011).

Science learning is inherently such a symbolic social process, one that occurs throughout a person's lifetime in all manner of contexts (Bell et al. 2009). Considering the relatively small part of a person's life that is spent in the formal social space of school (~8–15%), the remaining time offers great potential for learning, especially if it can occur in informal social spaces that are based upon digital access, connections, and interaction (Falk and Dierking 2013). Wenger et al. (2009) define such spaces as digital habitats, collections of individual niches where people are connected in their interest in science through conventions such as posting, following, liking, hashtagging, or commenting. Within each niche of a digital habitat, the collection of individuals represents a community of informal science learners whose practice is influenced by the affordances of the environment (Gibson 1986). Thus, our capacity to understand and support learning within these niches is based upon our knowledge of the participants, the nature of their culture, and social interactions as well as the environmental conditions provided by each niche.

Each social media niche affords interaction in different ways through their design and use of conventions with a single message from one participant serving as the origin for all interaction. Within these social learning niches, individuals, groups, or organizations are provided the opportunity to contribute to an ever-developing social world via interaction. Subsequently, constructive dialog would involve the chaining of messages into turns of discourse. In this way, individual messages serve as potential starting points or seeds for subsequent lines of educative discourse (Michaels et al. 2008). The capacity of a message for generating subsequent interaction is indicative of its social learning potential. Elements of the message, such as hashtags, URLs, and mentions, are intended as symbols for people to infer, then interact with in order to build meaning socially.

Related Empirical Studies

There is a dearth of research that examines the meaning-making process that can occur on social media, particularly as it relates to science. Existing studies include Lewis et al. (2010) work involving a designed social media application, which provides heuristics for interpreting the process on such platforms and Hargittai et al. (2018), who describe young adults' engagement with science on social media, finding that platform-specificity and the nature of content accounted for participant interactions. Although meaning-making has been explored deeply in formal learning environments (Mortimer and Scott 2003), few examples involve or highlight this process in informal spaces. Even when digital environments are examined to determine the forms of meaning-making (e.g., Hoban et al. 2015), studies emphasize the relationship between digital environments and that of a formal classroom. Here, we break from this tradition by examining social media as a stand-alone interest-driven educational environment without the necessity of status (i.e., student, teacher, etc.) or that any interaction or the meaning-making process must be related to the formalities of the educational system (i.e., a classroom, program or degree pathway).

Other science-specific research has explored the role for social media as a professional development resource for educators (Carpenter and Krutka 2014, 2015; Visser et al. 2014) as well as students (Warren 2016). In a similar manner, scientists are becoming more cognizant of their social media presence, with many working towards utilizing it to network with others. Studies concerning scientists' use of social media indicate that it can be used effectively for "inreach" (reaching other scientists) as well as "outreach" (reaching general populations) (Collins et al. 2016; Côté and Darling 2018), which results in best practices for growing a personal online science network (McClain 2017). Guidelines for scientists and educators provide a missing and necessary voice for the community, but, there is too little focus on dialogic communication, instead preferencing didactic dissemination of information.

Some studies address design elements and post types within social media messages. These studies indicate that there is interest in discovering best practices for communicating with people about science within social media niches; however, empirical evidence is lacking. For instance, researchers recently examined space science-related social media, determining that messages received high engagement when they included visual elements such as photos and the text associated with such images involved authentic, personalized language (Hwong et al. 2017). Similarly, a case study of Facebook groups interested in environmental-based citizen science found that utilizing motivational post types (i.e., those with rewards or incentives) were important in increasing participation (Cardoso et al. 2016, p. 239). Science communication and science education were melded in a recent content analysis of New York Times articles about genetics, in which it was determined that such articles could help educate members of the public, providing evidence that science communication can be done in an educative fashion (Shea 2015).

Interaction on social media can indicate the success of messaging or discourse strategies as well as outreach projects. Each social media niche measures interaction differently based upon the tools that they provide users, but each reports these interactions as a level of engagement or engagement rate. This metric, which is reported to social media account administrators, is an amalgamation of the number of newsfeeds a social media post is served to as well as the number of clicks, shares, comments, retweets, likes, or other actions on a post (Bugeaud et al. 2016). For example, every year, non-profit sectors that include cultural, education, environmental, health, international, rights (i.e., social justice and change), and wildlife/animal welfare sectors are studied to determine benchmark engagement rates with each sector's messages. Bugeaud et al. (2016) determined that these sectors had an overall engagement rate on Facebook of 5.4% (5.3% for education specifically) and an overall Twitter engagement rate of 1.6% (2.0% for education specifically). Understanding and delineating the purposeful exchange of information, including the ways in which engagement rates (as a measure of interaction) are influenced by content, specifically, content that highlights scientific practice, is the goal of the current study.

Methodology

Science Context

This research is couched within the scientific discipline of paleontology, which is the study of past ecologies and evolution of species on Earth through the collection, preparation, curation, and digitization of fossils (Crippen et al. 2016). Collection involves field work in which paleontologists visit sites (i.e., locations) that are known or suspected to have fossils. Onsite, these scientists use tools to extricate fossil specimens from the ground and then package them so they can be taken to laboratories and studied. In the laboratory, paleontologists prepare fossils, which entails cleaning off sediment, using specialized tools to remove encasing rock, and observing them in order to determine how they related to other fossils in a collection, or stabilizing them for exhibition in a museum. Curation is a technique by which paleontologists add taxonomic information to fossils, which is cataloged and stored via analog or digital means. Digitizing fossils involves complex photography or scanning techniques, such as photogrammetry, and utilizing 3D printing technologies to ensure that fossil specimens are accessible. While there is ample evidence describing paleontological practice as it occurs in the real world (Lundgren and Crippen 2019; Crippen et al. 2016; Catalani 2014; Twitchett et al. 2017), it also occurs in digital niches (Bex, Lundgren and Crippen 2019; Ludgren et al. 2018; Crippen et al. 2016; Lam et al. 2019). Digital practice reflects and enhances real-world practice by emphasizing novel enactment as well as inclusion of diverse members from across the continuum of expertise.

Study Context

This ex post facto study explored an informal science learning project's initial two-year social media campaign on Twitter and Facebook (May 2014-Dec 2016). The project's focus was to build connections in the field of paleontology. For the use of social media, this involved a tailored plan for various niches. Twitter and Facebook were two such niches that also afforded the potential for studying the development of people through their interrelated and reciprocal relationships (Hayes et al. 2016). Background on the project was provided within each niche via the biography section for the account, which on Twitter stated "Based at the Florida Museum of Natural History of the University of Florida, the FOSSIL Project promotes paleontology, outreach, education, and collaboration." Further information was provided via a link to the official website. The community for both niches, which involved those that followed or liked the project's page or interacted with its content, included people with an interest in paleontology, such as professional scientists, educators who were interested in using paleontology in formal or informal learning environments, and amateur paleontologists (i.e., citizen scientists with interest in paleontology), as well as people who bought and sold fossils to make a living (i.e., commercial collectors). From the analytic reports provided by Facebook and Twitter (i.e., insights), we determined that the majority of community members were from the USA and between the ages of 18 and 65, with an equal number of people identified as women and men.

During the campaign, project staff, including the first author, developed and implemented a social media plan—a method for identifying and using community interests in the construction of original content messages and the subsequent continuous review of responses to these messages in order to maximize reach and engagement—as defined by metrics in the analytics reports. The plan was intended to promote social paleontology as a practice-based open and collaborative exchange of ideas related to the collection, preparation, curation, and study of fossils (Crippen et al. 2016). The plan included guidance on the language to use for posts (i.e., reduced jargon and variable sentence patterns), specifications for creating graphics (e.g., less than 50% text coupled with high-quality pictures of people conducting fieldwork), and a regular posting schedule (e.g., every Tuesday at 11 AM), which was managed by a software system (Lundgren and Crippen 2017).

The individual engagement rate for all posts, which was only made available to administrators for a limited time, was downloaded in monthly increments and rudimentarily examined at the individual post level to inform small changes to the plan as part of an agile strategy (Bugeaud et al. 2016). Messages were constructed so as to be unique to each niche and tailored based upon the plan. Over the two-year duration of the campaign, the Facebook community grew from 417 to 3270 page likers (+ 2853; 684%), while the Twitter community grew from 149 to 1166 followers (+ 1017; 683%).

All data were originally collected for internal project use as part of the social media plan and this study was subsequently undertaken as a more robust and systematic way to address questions related to the educative potential of social media messaging for informal science education. The second and third authors were not involved in the development of the social media plan; their insight allowed for the data to be viewed consistently through the theoretical framework, which strengthened the manuscript and ensured that any bias from the first author did not unduly influence interpretation of the data. The research was approved and found to be exempt under University of Florida institutional review board, protocol number IRB201601751.

Study Design

In line with our theoretical framework, this study sought to determine the aspects of social media messaging that supported participation in (i.e., like or share posts) or contribution to (i.e., comment on posts) social paleontology within each niche during the campaign. As such, it represents a description of how individuals built meaning communally by interacting with content via liking, sharing, or commenting on posts. Our analysis involved content-based message elements, specifically, hashtags, mentions, and website URLs as well as a categorical framework for practice-based post types. Data included 1370 messages over a two-and-a-half-year period that were posted to Facebook and Twitter and the subsequent level of interaction that each generated (i.e., engagement rate). Message element and message type were treated as distinct independent variables and engagement rate (as reported by Facebook and Twitter for each post) served as the dependent variable. Though calculated slightly differently due to the conventions of each niche, engagement rate represents a similar construct and is computed by dividing the total number of engagements (likes, comments, shares, clicks) by the total number of members a message reached (Bugeaud et al. 2016). We view the reported engagement rate as a social behavior that is an expression of shared meaning-making (Charon 2009).

Data analysis occurred in two stages that aligned with the first two research questions: the effect of messaging elements then that of paleontological practice-based post types. Each stage involved a separate content analysis of the messages (Krippendorff 2012). In the first stage, all messages were classified and tallied based upon the inclusion of combinations of the three specific elements that have been shown to increase messaging engagement: hashtags, a strategy for aggregating new content for a topic (e.g., adding #science to a post); mentions, which is a strategy for calling attention to specific users (e.g., adding @username), and URLs, a strategy for adding additional, external information to a post (Naveed et al. 2011; Suh et al. 2010). Hashtags, a metadata technique that allows users to organize information around a certain topic/s, as well as including URLs, have been shown to predict Twitter message popularity (Petrovic et al. 2011), whereas messages with mentions have been shown to lead to increased citations of pre-prints of peer-reviewed work (Shuai et al. 2012).

In the second stage, messages were additionally coded holistically without regard for use of message elements using the paleontological practice-based post type (P3T) framework (Crippen et al. 2016; Lundgren and Crippen 2017, Bex, Lundgren and Crippen 2019). This framework, based upon established digital forms of paleontological practice, involves four categories (i.e., information, news, opportunity, and research) that delimit posts based upon the intent of the message (Fig. 1). A constant comparative method was used by two researchers for the initial coding, then a three-person team independently coded the data and held weekly meetings in which all codes were discussed to consensus (Lincoln and Guba 1985). Using a randomly selected 10% sample of the coded messages, the process was determined to have a significant level of agreement among coders ($\kappa = 0.70$). After data cleaning, including the removal of outliers, 759 Facebook messages and 554 Twitter messages were included.

The average engagement rate for each category was compared. The statistical software IBM SPSS Statistics 24 (IBM 2016) was used to conduct a one-way analysis of variance (ANOVA) to determine overall statistical differences among the average engagement rates within each niche for both design elements and post types. Post hoc comparisons were then conducted using Gabriel's test, which is used to test differences between pairs of means (Gabriel 1969). All averages are compared to the benchmark rate for the non-profit education sector as determined by Bugeaud et al. (2016) (i.e., 5.3% for Facebook, 2.0% for Twitter). Benchmark

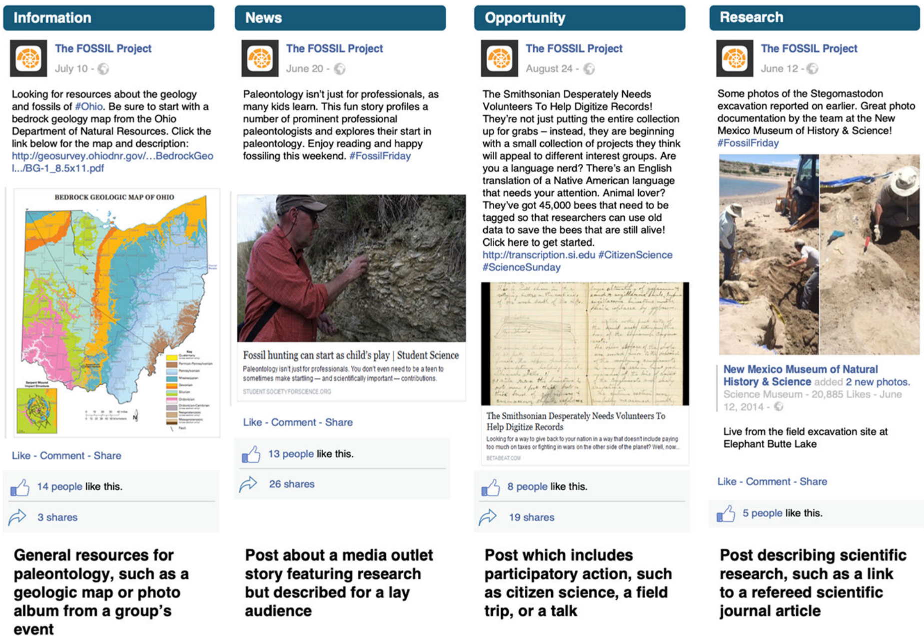

Fig. 1 Descriptions associated with the P3T framework with example posts

rates for each niche are computed in a slightly different fashions; prior research has demonstrated that the population of users for each niche are not necessarily the same (Perrin 2015; Zhao et al. 2016); thus, a direct statistical comparison of Facebook and Twitter was not possible or warranted. Furthermore, we follow the assumption that different social media niches harness different messaging elements as well as appeal to different populations. The relative effectiveness of elements and post types for each niche are compared descriptively across niches.

Results

Our study was primarily concerned with understanding how people within a digital niche were individually engaging with social media messages in order to build communal learning about the scientific discipline of paleontology. We explored namely hashtags, mentions, and URLs, the most commonly utilized range of markers, which allowed us to develop an understanding of the social worlds found in the niches of Twitter and Facebook. The categorization of messages led to three main findings: (a) some messaging elements were used frequently while others more scantily, (b) engagement rates differed by niche and message element, and (c) post types resulted in differential interaction within one niche but not the other. We acknowledge that some of our findings may seem self-explanatory or have been at the center of discussions by science communication practitioners (e.g., Hines and Warring 2019); however, to our knowledge, this research is the first attempt at pairing theoretical understandings of the social world with empirical evidence about social media messaging elements.

Messaging Elements and Interactions

Message design elements included hashtags, mentions, and URLs (Fig. 2). The combined use of these elements resulted in eight different categories (e.g., hashtag only, hashtag and URL, etc.). On Twitter, the following types of posts surpassed the benchmark engagement rate of 2.0%, posts with hashtags and URLs (2.4%); hashtags, mentions, and URLs (2.3%); mentions only (2.1%); URLs only (2.1%); and mentions and URLs (2.0%). In contrast, on average, no Facebook posts, regardless of combination of elements, surpassed the benchmark engagement rate of 5.0%. However, some individual messages within the categories did exceed the average rate. Specifically, messages with hashtags only (4.9%) were close to the benchmark rate.

The use of message elements varied by niche (Table 1). On Facebook, the following were the most-used message elements: the combination of hashtags and URLs ($n = 313$); hashtags only ($n = 167$); no element at all ($n = 131$); and URLs only ($n = 116$). The least-used message elements were mentions only ($n = 6$) and messages with a combination of hashtags and mentions ($n = 2$). On Twitter, the pattern differed slightly, with a combination of hashtags, mentions, and URLs ($n = 143$), and hashtags and URLs ($n = 133$) as the most commonly used messaging elements and messages with URLs only ($n = 42$), mentions only ($n = 27$), and messages with no element ($n = 3$) as the least commonly used.

Following an overall description of most-used and least-used elements, we used a statistical comparison to examine engagement rates for messaging elements, focusing on engagement rates when messages employed singular elements and combinations of elements. First, we removed categories of design elements that had less than 10 total messages (e.g., messages on Facebook that used only mentions). Then, we sampled a specific percentage of messages, dependent on niche.

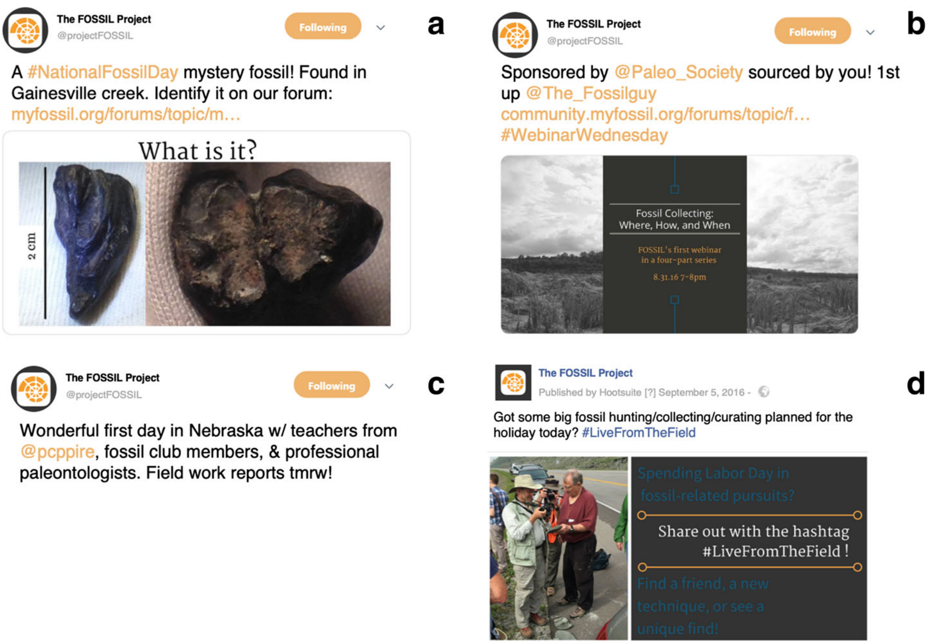

Fig. 2 Examples of Facebook and Twitter messages which used message design elements. Parts **a**–**c** highlight posts from Twitter, while part **d** shows a Facebook post. Part **a** features a message with a hashtag and a URL; Part **b**, a message with mentions and a hashtag; Part **c**, a message with a mention. Part **d** features a message with a hashtag

Table 1 Number of posts with design elements and mean engagement rate across niches

	Facebook			Twitter		
	N	Mean (SD)	95% CI	*N*	Mean (SD)	95% CI
Hashtags only	167	4.9 (2.6)	[4.5, 5.3]	75	1.3 (1.2)	[1.0, 1.6]
Mention only	6*	2.6 (2.4)	[0, 5.1]	27	2.1 (1.5)	[1.5, 2.7]
URL only	116	3.6 (2.3)	[3.2, 4.1]	42	2.1 (1.0)	[1.7, 2.4]
Hashtag and mention	2*	3.5 (1.1)	[.81, 25]	66	1.8 (1.2)	[1.5, 2.1]
Hashtag and URL	313	4.5 (2.4)	[4.2, 4.4]	133	2.4 (1.5)	[2.1, 2.7]
Mention and URL	13	3.7 (1.1)	[3.1, 4.4]	65	2.0 (1.0)	[1.7, 2.2]
Hashtag, mention, and URL	11	3.0 (1.8)	[1.7, 4.2]	143	2.3 (1.2)	[2.1, 2.5]
No element	131	4.2 (2.5)	[3.8, 4.6]	3*	1.4 (1.4)	[− 2.1, 5.0]
Total	759	4.4 (2.5)	[4.2, 4.5]	554	2.1 (1.3)	[1.9, 2.2]

*Indicates category was excluded from analysis

Each percentage per niche was based on the category with the fewest number of associated posts, although each category was only included if it exceeded 10 associated posts. Therefore, for Facebook, we randomly sampled 1% of messages within each category ($n = 13$ per category) to compare against one another. For Twitter, we randomly sampled 5% of messages within each category ($n = 42$ per category) to make comparisons.

Some design elements mattered and others did not on Facebook. There were significant differences in engagement rates when messaging elements were analyzed, $F(7, 751) = 3.918$, $p < .05$, $r = .035$. Post hoc comparisons indicated that the mean score for messages with hashtags only (M = 4.9, SD = 2.6) was significantly different that messages with URLs only (M = 3.6, SD = 2.4). This is to say that messages with hashtags only were interacted with at a significantly higher rate than messages with URLs only (Fig. 3). No other significant differences in messaging elements within the niche of Facebook were found.

Significant differences in engagement rates for messaging elements were also found on Twitter, $F(7, 546) = 5.748$, $p < .05$, $r = .070$. Post hoc comparisons indicated that the mean rate for messages with hashtags only (M = 1.3, SD = 1.2) differed significantly from both messages with hashtags and URLs (M = 2.4, SD = 1.5) and messages with all three design elements (M = 2.3, SD = 1.2). This is to say that messages with hashtags and URLs, as well as all three design elements, generated higher interaction on Twitter than messages with only hashtags (Fig. 4). When hashtags were included with other elements, the interaction was higher, but when used alone, there was minimal engagement. These results indicate that a mixture of design elements can influence engagement with science-based social media content. For practitioners who develop and deliver scientific social media content, these results emphasize the need for varied and multiple design elements in messages. For educational researchers, these results can showcase pathways towards developing interventions that focus on meaning-making in digital, social environments.

Paleontological Practice and Interactions

While messaging elements afford either enhancement of the message, as in the use an image or interaction, such as with URLs or hashtags, the essence of the message was a paleontological practice, which was coded as the practice-based type of post (Table 2). With this distinction, we sought to determine which post types as depictions of scientific practice elicited more interaction. Both niches included posts that were coded as information, news, opportunity, and research (Table 3).

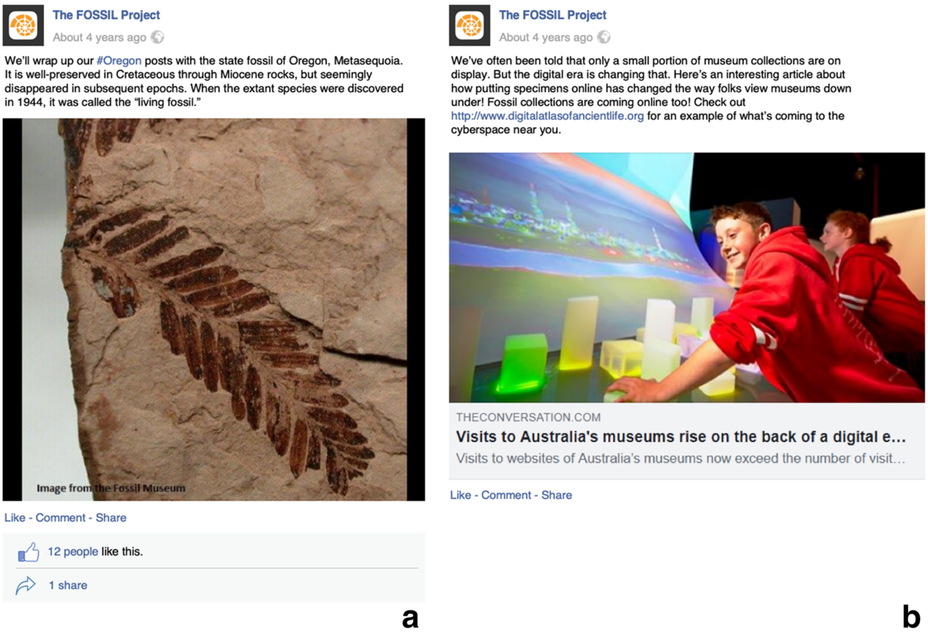

Fig. 3 Examples of Facebook messages with high and low engagement rates. Part **a** features a message that had a high engagement rate (9.8%), and used only the hashtag design element. Part **b** features a message that had a low engagement rate (0.0%), and used only the URL design element

On average, within the niche of Twitter, posts that were coded as information, news, or research all met or surpassed Twitter's benchmark engagement rate of 2.0%. Specifically, research posts had the highest engagement rate (2.4%, SD = 1.3%) information posts had an overall engagement rate of 2.2% (SD = 1.3%), and opportunity posts had an engagement rate of 2.0% (SD = 1.4%). Even news posts approached the benchmark engagement rate (1.9%, SD = 1.1%). However, on Facebook, no post type surpassed the benchmark engagement rate of 5.0%. The only post type that approached the benchmark rate was information posts (4.6%, SD = 2.6%). The most-used post type on Facebook was that of information posts ($n = 377$) followed by opportunity posts ($n = 200$). News posts ($n = 169$) and research posts ($n = 71$) were used with less frequency. On Twitter, the pattern was somewhat similar with a larger number of information posts ($n = 234$), although news posts ($n = 144$) superseded opportunity posts ($n = 138$). As with Facebook, research posts were used less frequently ($n = 37$).

For a statistical comparison, we followed a similar procedure to that used for message elements, in that we sampled a specific percentage of messages, dependent on niche. For Facebook, we

Fig. 4 Examples of Twitter messages with design elements that had high versus low engagement. Part **a** shows a message that included all three design elements and had an engagement rate of 4.7%. Part **b** shows a message that included a hashtag and a URL and had an engagement rate of 2.8%. Part **c** shows a message with only hashtags and featured a low engagement rate of 2.6%

Table 2 Examples of messages coded using the paleontological practice-based post type framework

Niche	Message text	P3T code
Twitter	Casual collection on all fed. lands does NOT equal commercial collection. #GSA2016 #PubPaleo	Information
Facebook	The Natural History Museum, London is digitizing their collection of British Mesozoic vertebrates. We love the Iguanodon thumb-spike featured below—what's your favorite photo? Check out the blog post and let us know! #MesozoicMonday http://ow.ly/4n0ZT4	Information
Twitter	New mammoth excavation in @CHISNPS uncovers one w/ weird tusks. This one's for you, @MostlyMammoths! #MammothMonday https://t.co/VsnTarW4A9	News
Facebook	Digging through a mass extinction (and keeping the fossils you find!) http://www.nytimes.com/2016/01/05/science/behind-a-shopping-center-in-new-jersey-signs-of-a-mass-extinction.html?emc=eta1&_r=0	News
Twitter	PSA: MAPS fossil expo April 1-3. Keynote speaker: Philip J. Currie! #MidwestIsBest #Fossils https://t.co/jYBcWxHAEw https://t.co/97RbKuE8SL	Opportunity
Facebook	Identify your specimens, network with other paleontologists, and see their collections! Head to the Greensboro Science Center for the North Carolina Fossil Fair hosted by The North Carolina Fossil Club. Read more about them and get info about the Fossil Fair in our newsletter: [url]	Opportunity
Twitter	#OpenAccessSunday @MontanaState paleo researchers study unusual growth structures in Maiasaura tibiae. #paleontology http://t.co/LPuMRMVcxn	Research
Facebook	Since the discovery and naming of Maiasaura (good mother lizard), dinosaur parental care has interested scientists. In this paper, Jason Moore and David Varricchio explore the trends of parental care in diapsids (of which dinosaurs are members). Check it out! #OpenAccessSunday http://ow.ly/yRS4303p9dp	Research

Table 3 Number of posts divided by post types and mean engagement rate across niches

	Facebook			Twitter		
	N	Mean (SD)	95% CI	*N*	Mean (SD)	95% CI
Information	377	4.6 (2.6)	[4.4, 4.9]	234	2.2 (1.3)	[2.0, 2.4]
News	169	4.0 (2.2)	[3.6, 4.3]	144	1.9 (1.1)	[1.7, 2.1]
Opportunity	200	3.8 (2.5)	[3.5, 4.2]	138	2.0 (1.4)	[1.7, 2.2]
Research	71	3.5 (1.1)	[3.8, 5.0]	37	2.4 (1.4)	[1.9, 2.8]
Total	817	4.3 (2.5)	[4.1, 4.4]	553	2.1 (1.3)	[1.9, 2.2]

randomly sampled 8% of messages within each category ($n = 71$ per category) to compare against one another. Eight percent was chosen as the threshold as we wanted to make equal group comparisons based on the post type with the fewest number of codes (i.e., research posts). For Twitter, we randomly sampled 6% of messages within each category ($n = 37$ per category) to make equal group comparisons, as this was the number of research posts coded on Twitter.

On Facebook, certain types of posts generated more engagement whereas on Twitter all post types generated equivalent engagement. For Facebook, there were significant differences in engagement rates when post types were analyzed $F(3,813) = 5.357$, $p = .001$, $r = .019$. Post hoc comparison indicated that the mean score for information posts (M = 4.6, SD = 2.6) was significantly higher than opportunity posts (M = 3.8, SD = 2.5). Thus, information posts generated a greater degree of interaction than opportunity posts within the niche of Facebook (Fig. 5). For Twitter, there were no significant differences $F(3,549) = 2.908$, $p = .034$, $r = .020$; post types on Twitter were interacted with equally. These results indicate that on Facebook, people engaged with posts that presented paleontology as person-centered or provided general information, whereas on Twitter, people frequently engaged with content regardless of the way in which it was presented to them. Interaction, as measured by engagement, thus represents a step towards scientific meaning-making within these niches.

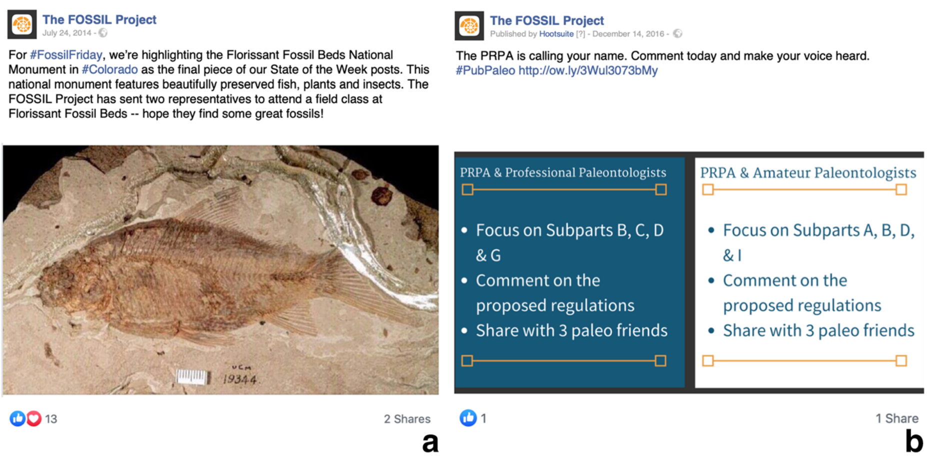

Fig. 5 Examples of Facebook messages coded using the P3T framework, showing the differences in engagement rate. Part **a** shows a message coded as information and had a high engagement rate (12.2%), while part **b** shows a message coded as opportunity and had a low engagement rate (0.3%)

Limitations

Engagement rates are limited, providing narrow explanations for the ways in which learners can participate in, contribute to, and further develop their scientific expertise in online environments. In its current form, this metric only serves to quantify a user's interactions. However, these currently are the only metrics that are available, and as such, we seek to utilize them to their full potential. Furthermore, the lack of equal and consistent distribution of message element and practice-based post types with the categories is a limitation which could account for the numerical disparity within the niches. For future studies, this disparity could be accounted for using an a priori quasi-experimental design.

Discussion

Social media exemplify social worlds in which shared meanings, knowledge, and understandings are built upon conventions and the ways people interact with such conventions (Crossley 2011). Within this study, we sought to elucidate the ways that social media messaging elements and post types seeded interaction and enhance the potential for the construction of shared meaning. Analysis of messages within the niches of Facebook and Twitter led to three key findings: the usage frequency of some messaging elements varied depending on niche; interaction within each niche differed, varying by messaging element; and differential interactions were found to be associated with different post types within Facebook only. We discuss these findings in depth as follows.

Benchmarks

Both messaging elements and post types for Facebook and Twitter had some effect on members' interactions; this is especially apparent when examining the benchmark engagement rates established by Bugeaud et al. (2016). Within the realm of informal science education, this study is the first of its kind to examine how the messaging elements in a post and the type of post affect engagement rate. As such, we suggest that the benchmark rates for posts might differ slightly than what has been established for the field of education. Informal science education is effectively different than formal education and the ways with which people interact with content is likely to differ. We propose that the average engagement rates from this study, 4.4% for Facebook and 2.1% for Twitter, can serve as a starting point or initial benchmark rates for others researching the ways in which learners interact with science content in informal digital spaces.

Messaging Elements and Interactions

As Crossley (2011) indicates, interactions represent negotiation of norms, values, roles, rules, and shared understanding; thus, a community's response to messaging elements is indicative of the implied meaning of messages. Previous research has shown that on Twitter, regardless of topic, the addition of message elements can positively affect interaction (Suh et al. 2010; Naveed et al. 2011). However, previous research did not attempt to parse out the ways in which individual message elements (i.e., hashtags, mentions, URLs) impact interaction, instead, design elements were examined in aggregate. For example, Naveed et al. (2011) indicate that either URLs or hashtags correlate with retweetability; they did not parse out the content of the message further. With the current study, we found that when used singularly or in combination, these design elements impact specific niches in different ways. With Twitter, the use of hashtags alone did not support interactions; instead, the use of design elements in conjunction encouraged this. This finding is supported by previous work on Twitter, in which tweets with design elements such as URLs are retweeted (i.e., disseminated) at high rates (Bruns and Stieglitz 2012). This finding highlights the shared meaning-making that can occur through interaction within digital social worlds. The development of people and their relationship with the social world can be augmented by the inclusion of design elements.

We have also shown that on Facebook, the social world was built through open communication with the curatorial capacity of hashtags. Community members could use hashtags to manage their newsfeeds or strategically connect their messages to wider themes for further interaction. Perhaps, the increased interaction with hashtags on Facebook could be interpreted as a user strategy for infusing their personalized newsfeeds with additional content that is currently hidden by Facebook's algorithm (Use #Hashtags on Facebook, http://bit.ly/2OMUb7V). In contrast, the use of mentions on Facebook did not provide any significant interaction. This is at odds with traditional best practice suggestions for social media, in which mentioning (i.e., calling out certain people) is hypothesized to generate interaction (Vaynerchuk 2013). For this study, this was not the case. Interaction and building open communication are the goals of educative social media; mentions were not a useful strategy, as they seemingly allowed for the message to be spread, not interacted with. For messages with URLs, the interactions were significantly lower than those messages that included hashtags only. This is to say that for Facebook users, the addition of external content in the form of URLs does not result in additional interaction with messages.

Recognizing and evaluating the effectiveness of messages and their design elements is a first step in capturing their science learning potential in digital informal learning spaces. Niches in a digital habitat each provide different affordances for people to use in their communication, and in turn, these affordances are what lead to interaction (Bucher and Helmond 2017). For example, the proprietary algorithm used by Facebook dictates the content seen by individuals (Bringing People Together, https://bit.ly/2CSwaWC); for Twitter, the single, time-based newsfeed that displays all posts does not. Research into public engagement with science via social media is occurring in multiple contexts, including YouTube (Welbourne and Grant 2016), Twitter (Daume and Galaz 2016), and Facebook (Fauville et al. 2015), yet these empirical studies do not necessarily capture the ways in which social media can be used for educative purposes.

Recent research on social media use related to the topic of space science found that hashtags, along with communication styles, capture attention more so than other messages; however, this focused on predictive forecasting and the data were not separated by social media niche (Hwong et al. 2017). This study furthers the research fields that are focused on social media and informal science education, describing the creation of evidence-based, educative, science-specific social media messaging that focus on gateway science (i.e., paleontology), acknowledging the differences in niches, and adding to our understanding of how messaging elements contribute to interaction among community members. Further work involving people's interactions with social media messages needs to involve a more nuanced method for determining the identity of those people, as the research to date has relied on broad, overly-generalized characteristics, such as content creators versus lurkers (Sun et al. 2014; van Mierlo 2014). Moving beyond the examination of members in aggregate requires the use of agile tools to help parse out these members. Such tools could aid researchers who seek to build and study online communities.

Paleontological Practice and Interactions

To further explicate the interplay of individuals and community, as well as the potential for learning in digital informal learning spaces, we also examined the types of posts that encourage interaction. Previous work regarding post types is confined to the niche of Facebook, in which researchers examined posts created within the field of conservation biology (Cardoso et al. 2016). In that study, post types were examined based on intent to participate in citizen science. Cardoso and colleagues defined four post types: motivational, invitational, informational, and investigational, and found that motivational posts, defined as posts having incentives, rewards, or appreciative expressions, were engaged with at higher rates than the three other post types they studied. Within the current study, information post types provided the Facebook community with generalizable, relatable content concerning paleontology or with links to blogs or photos from scientists, amateur paleontologists, and organizations. Increased interaction with information posts on Facebook indicates that within this niche, members were interested in posts that highlight paleontological constructs with which they have familiarity, which is an important finding for improving the accessibility of the domain. The interactions that occurred on Twitter, especially with information, opportunity, and research posts that were meeting or exceeding benchmark rates, indicate that members were highly interested in paleontology, if it was presented in a practice-based format.

We postulate that the difference in interaction for the two niches is likely related to segmented populations. While there is evidence that there are differences in populations dependent on niche (Zhao et al. 2016), there is still a need for understanding the demographics of such users, which could entail the creation of an analytical tool that allows for such classification. In addition to segmented social media users, as supported by this study, the differences in interactions on each niche are likely related to the affordances of each niche.

Conclusion

In this study, we sought to understand how digital niches can act as social realities for those within an informal science community. We explored three research questions concerning messaging elements, interaction with messages based upon post type, and the relationship between the social media environment and engagement with messages, their elements, and post types. We addressed how such messaging elements and post types can seed and support interactions as shared conventions in informal digital science learning spaces. We found that within the niche of Facebook, the design element of hashtags led to significantly higher interaction than messages with URLs. The use of message elements on Facebook, in particular, hashtags, should be considered a best practice for informal science learning as they play a key role in increasing interactions within this niche. In contrast, on Twitter, hashtags tended to reduce interaction when used alone, but when utilized with the additional elements of URLs or URLs and mentions, engagement rates were higher. Therefore, for Twitter, best practice should involve the use of hashtags in combination with other elements that provide further information. For Facebook, we found that information posts had higher engagement rates than opportunity posts, which indicates that Facebook interacted with posts that were of general usage to them. These findings can be explained by current research in the field of informal science learning, which recognizes the process as an interest-based activity (Falk and Dierking 2013).

Social media messaging can support science learning in informal spaces, offering the possibility for new or sustained science-related discourse. Message elements and posts that visually illustrate scientific practice are tools for achieving this outcome, but their effectiveness varies based upon the kinds of interactions they afford and the niche they are used in. Social media managers, teachers, or anyone hoping to create content should be mindful of these issues as well as the marketing trap of only using social media to inform. Purposefully designed messages that connect with people's science interests, but also provide a need for interaction can produce rich interactions and sustained conversations. For educational researchers, this study provides initial evidence for benchmarking messages for this genre and indicates a pathway for developing and examining social media as an educational component of informal science learning.

Future Research Directions

All content, regardless of social media niche, competes for attention and interaction in this age of constant digital marketing. By providing evidence for which messaging elements and post types within which niches produce higher behavioral engagement, researchers and practitioners can integrate such practices into their own research. By determining engaging messaging elements and post types, scientists and informal educators can work to build messages that highlight key science issues while reaching diverse networks. Robust explorations of this could involve qualitative studies of practice-based post types, in which participants from across the continuum of paleontological expertise are interviewed to understand how different types of social media messages can allow for the construction of shared meaning-making around scientific topics. Future work in designing, developing, and analyzing scientific social media could examine this topic more fully.

Acknowledgments This material is based upon work supported by the National Science Foundation under Grant No. (1322725). Any opinions, findings, and conclusions or recommendations expressed in this material are those of the authors and do not necessarily reflect the views of the NSF. We thank the undergraduate intern who initially helped with coding of posts in 2017 as well as the three undergraduate interns who assisted with coding posts as part of their undergraduate research project in spring 2018.

Compliance with Ethical Standards

The research was approved and found to be exempt under University of Florida institutional review board, protocol number IRB201601751.

Conflict of Interest The authors declare that they have no conflicts of interest.

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