FOUR MODELS OF SCIENCE JOURNALISM
A synthesis and practical assessment

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Much of the science communication and journalism studies literature continues to reiterate the same critiques about science journalism. This literature accuses science journalists of inaccuracy, sensationalism, oversimplification and failing to engage audiences in meaningful debate about scientific issues. However, research has yet to offer concrete solutions to journalists that connect theory to practice in an effort to counter these criticisms. In this paper, we approach this gap through the development of clearly articulated models of science journalism that are supported by theoretical considerations of the varying purposes of science communication, and then, importantly, tied to practical story development criteria. Four models are presented: science literacy, contextual, lay-expertise and public participation. These models are clear representations of how science journalism can be produced from within different theoretical frameworks and thereby provide a theoretically-informed but practical guide for nuanced evaluations of the quality of science journalism.

KEYWORDS models; research synthesis; science journalism; writing criteria

Introduction

In her classic book, Dorothy Nelkin argued science journalism should provide three things to non-specialists: it should help people (1) keep apprised of scientific advancements, (2) assess the appropriateness of scientific research and (3) make choices related to perceived personal risks (Nelkin, 1995). Scholars have since made heavy reference to Nelkin's work (e.g. Google Scholar currently tracks 1045 citations) to basically argue a public informed by science journalism should be better able to make decisions when faced with competing scientific arguments related to their safety, health and environment.

Despite Nelkin's vision of what science journalism should do, and some studies suggesting science journalism is of good quality (Bubela and Caulfield, 2004; Caulfield, 2004; Peters et al., 2008), scholarly criticism has more consistently pointed to shortcomings of science journalism (see, for example, Amend and Secko, 2012; Bubela et al., 2009; Cassels et al., 2003; Dentzer, 2009; Holland et al., 2011; Holtzman et al., 2005; Logan, 2001; Nelkin, 1995; Nisbet and Lewenstein, 2002; Racine et al., 2006; Russell, 2006; Weigold, 2001). Science journalists have been critiqued for uncritical reporting (Racine et al., 2006), for emphasizing frames of scientific progress and economic prospect (Nisbet and Lewenstein, 2002), for not presenting a range of expert opinion (Holtzman et al., 2005), for having preferences toward positive messages (Cassels et al., 2003), and for reporting unrealistic time lines and engaging in the production of a "cycle of hype" (Bubela et al., 2009). Added to these criticisms are a number of routine professional and institutional obstacles science journalists face, such as: deadline pressures, finding reliable sources, lack of space for science stories, budget and staff cuts, and increased commercialization (Amend and Secko, 2012). Furthermore, as journalism increasingly moves toward the

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Internet, science journalists are expected to be multi-skilled with numerous digital platforms (Allan, 2011) and are asked to do more in less time and with fewer resources. Worries abound over apparent communication and cultural gaps between journalists and scientists (Boyce, 2007; Reed, 2001), ambiguity over science journalists' proper roles (Hansen, 1994; Saari et al., 1998), uncertainty over how audiences use science news to gain knowledge (Treise and Weigold, 2002), and concerns over science and media becoming ever more intertwined as research funding grows more dependent on public legitimation (Schäfer, 2011).

While the extent and impact of these criticisms of science journalism are contested, such fault-finding themes remain recalcitrant and repetitive in the literature. So what has such critique achieved? To date, such criticism has produced no clear consensus on what "better" science journalism would be. This is in part due to: (1) the lack of clear articulation on the role of science journalists in democracy; (2) a lack of agreement on what constitutes improved public understanding of science; (3) the divide between idealistic visions of what science journalism can offer and the practical limitations faced by professional journalists; and (4) insufficiently defined and theoretically informed guidelines, news standards and fundamental norms for creating science journalism. It is apparent science journalism has yet to receive a clear, highly supported theoretical articulation in the literature that links theory to practice.

In this paper, we present one approach to bridging this gap through the development of models of science journalism supported by theoretical considerations of the varying purposes of science communication (Logan, 2001), and then tied to practical story development guidelines. We see such model-based guidelines as able to inform a line of scholarly inquiry that aims to produce robust frameworks for science journalism production. After presenting our methods, we first review and theoretically discuss various models of science communication before broaching how four specific models can be adapted to the profession of print science journalism. This adaptation is solidified into model-based guidelines involving six criteria—purpose, focus, style, sourcing, audience and science—for use by print journalists. We end with considerations of the limits and strengths of this approach and suggestions for future research.

Methods

Theoretical Approach and Research Questions

While scholarship on models of science communication largely stems from the field some term "public understanding of science" (Russell, 2006), we are particularly interested in science journalism and helping science journalists meet the multitude of critiques they face (Amend and Secko, 2012). Some recent work points to the potential of communication models to clarify the theoretical base of how science is communicated (Brossard and Lewenstein, 2010; Leach et al., 2009; Secko, 2007). From this scattered literature, this paper seeks a clearer conceptualization of models of science communication so they can be re-formulated and operationalized as *models of science journalism*. The desire is for a central point of reference that clarifies terms and linkages so the defined models can be built upon to provide a more comprehensive view of frameworks in the communication of science.

In this paper, we use the term ''model'' to refer to *a representation*, and its associated heuristic description, of the reality of how science is communicated or how it could and/or should be communicated. Models help us describe and examine phenomena that are not otherwise directly testable (Leach et al., 2009). Such models are only rough ''portraits'' of the communication of science (Logan, 2001). They are, however, useful tools to conceptualize how journalists produce science journalism. Much research to date has considered models of scientific communication solely under a theoretical lens. Thus, the use science journalism models here is aimed at providing theoretically-informed, yet practical representations of how science journalism can be produced.

To our knowledge, no robust summaries of current models exist from which to develop new hypotheses and thereby midrange theory. Drawing inspiration from the research synthesis literature (Paterson et al., 2001), we set out to discover what literature is available, to synthesize this material, and then to connect this summary to science journalism practice. This effort was constructivist in its philosophical approach (Paterson et al., 2001), seeing no piece of available literature as holding the absolute truth, but instead generated by the context of its production. We further followed Thorne's (2008) method of interpretive description to explicitly document ''what is (or seems to be) known and the nature of the inquiries of which we have come to that knowledge'' (Thorne, 2008, p. 61) with regard to models of science journalism. The following research questions guided our efforts:

RQ1: What literature is currently available on different models that can inform approaches to science journalism production?

RQ2: From this literature, can a limited number of models be chosen for further study that encompasses the diversity of approaches seen in RQ1?

RQ3: Can the information in RQ2 be connected to specific guidelines on how a science journalist would make use of a model to produce print journalism?

Systematic Literature Collection and Review

To inform this paper we conducted two types of literature review: (1) for communication models; and (2) for journalistic criteria.

First, detailed literature searches limited to peer-reviewed papers on communication models were performed on multiple databases (Academic Search Complete, Communication and Mass Media Complete, Communication Abstracts and PubMed). The searches used a combination of three concepts: (1) journalism and/or communication; (2) science, health and environment; and (3) models, theories or frameworks. For example, the search strategy used for Communication and Mass Media Complete used keywords and subject terms and comprised: (1) journalis* or mass media or ''reporting&reporters'' or ''news'' or newspaper* or press or broadcast* or blog* or investigative reporting or media spillover or digital media or photojournalis*; (2) the environment or SU (scien* or health or medic*) not SU (political science or social science*); and (3) model or framework or theor* or frame* or ''best practices'' or ''best practice'' or guideline. Other searches used adapted variations of this approach for each database. Additional searches were performed in Google Scholar, in the online databases of key journals (e.g., *Journalism*, *Journalism Studies*, *Science Communication*, *Public Understanding of Science*, *Health Communication*) and via citation, footnote, and author searches (Barroso et al., 2003). The searches retrieved 17 relevant articles (Bubela, 2006; Brossard and Lewenstein, 2010; Clarke, 2003; d'Andrea and

Declich, 2005; Davies, 2008; Gerhards and Schäfer, 2009; Kahlor and Rosentahl, 2009; Kerr et al., 2007; Kouper, 2010; Leach et al., 2009; Logan, 2001; Piolli and Conceição da Costa, 2008; Schweizer et al., 2009; Secko, 2007; Sturgis and Allum, 2004; Tlili and Dawson, 2010).

Second, to develop story-writing criteria that could be tied back to selected models, a review of the literature relating to journalistic guidelines and story-writing criteria was completed. Peer-reviewed literature on science journalism writing guidelines was investigated by performing database searches on Academic Search Complete, Communication and Mass Media Complete and Communication Abstracts. These searches utilized three main concepts, namely (1) journalism; (2) story production; and (3) guidelines. Search terms used for the journalism concept included: (''journalis*'' or ''science journalis*'' or ''mass media'' or ''news'' or ''newspaper''). Search terms for the story production guidelines concept included: (''stor*'' or ''article*'') and (''writing'' or ''production''), while the guidelines concept included (''guidelines'' or ''best practices'' or strateg*'' or ''criteria''). Six relevant articles were retrieved (Bostian, 1983; Clarke, 2003; Foote, 2008; Rovira, 2008; Weigold, 2001; Zia and Todd, 2010). To broaden the scope of these searches, classic journalism education writing and reporting guidelines were also consulted (Mencher, 2003), as well as guidelines from journalistic fields, such as peace journalism (Lynch, 2002), public/civic journalism (e.g. Glasser and Craft, 1997; Haas, 2007; Rosen, 1996), health and medical journalism (e.g. Levi, 2003; Vercellesi et al., 2010) and environmental journalism (e.g. Schweizer et al., 2009). Lastly, the development of story-writing criteria used an adaptation of Secko's (2007) method for developing 13 guiding principles for science journalism production. This method helped guide the analysis of the literature for overlapping features to suggest more refined guidelines that were ultimately conceptualized into six story-writing criteria.

Synthesis Methods

We used a reading grid assessment tool to extract content from our literature searches (Paterson et al., 2001, p. 135). The goal was to extract information on (1) the various models presented for communicating science, and contrast this against extracted information on (2) how these theories can be put into journalistic practice through various criteria. This information was used to generate summaries of articles and approaches that enabled the synthesis of material into thematic categories. In the interest of considering how new models can be created while respecting past models, we synthesized the literature to identify principal characteristics, goals, strengths and criticisms of the models under investigation to be able to tie these features and objectives to journalistic storywriting criteria. This synthesis was inspired by the methods of Sandelowski and Barroso (2003) and was used to focus our efforts on four dominant models of communication.

Findings

Science Communication Models

Overall review of identified models of science communication. Various existing models of science communication can broadly be grouped into two main categories: ''traditional'' models that view science as the legitimizing form of knowledge and aim at transmitting scientific knowledge to audiences, and more contemporary ''non-traditional'' models that value knowledge outside of science and aim at presenting science information tied to particular contexts (Brossard and Lewenstein, 2010; Gerhards and Schäfer, 2009; Logan, 2001; Sturgis and Allum, 2004; Tlili and Dawson, 2010; Weigold, 2001).

Dominant among ''traditional'' models of science communication have been ''deficit'' models concentrated on filling perceived audience knowledge gaps on a given subject (Brossard and Lewenstein, 2010), or those focused on increasing scientific literacy and public understanding of science (Davies, 2008; Gerhards and Schäfer, 2009; Logan, 2001; Schäfer, 2011). In his analysis of the evolution of what he terms the classical model of science communication, Logan (2001) suggests classical models exhibit pedagogical attributes and focus on increasing scientific literacy. Bucci (1996) has noted such canonical models view scientists as ''active'' in communicating science, publics as ''passive'', and journalists as those that ''rearrange'' science to communicate it. These traditional models often rely on classical values in science communication, such as reliability, fairness, balance, independence and relevance (Vasterman et al., 2008). Stocklmayer and Gilbert (2002, p. 855) have taken this further to suggest personal awareness of science, and hence increased science literacy, lies in three elements: (1) a communication experience is intrinsically and contextually engaging; (2) the experience evokes ''powerful remindings''; and (3) the experience has an evident relationship to the target.

''Non-traditional'' models have moved away from solely transmitting scientific knowledge, and instead seek to present information by tying science to particular communities and realities, as well as attempting to increase the value of knowledge forms outside of science (Brossard and Lewenstein, 2010; Clarke, 2003; Donghong et al., 2008; Gerhards and Schäfer, 2009). Recently, the literature has also addressed non-traditional models seeking to encourage public participation, engagement, interactivity, and ''two-way'' communication and dialogue with science (Clarke, 2003; D'Andrea and Declich, 2005; Davies, 2008), as well as reinforce meaningful debate in support of democracy (Brossard and Lewenstein, 2010; Logan, 2001; Secko, 2007). This move toward non-traditional models of science communication has come about as traditional models have been identified as too narrow (among other critiques) to fully cover the complexities of modern scientific debates (Logan, 2001; Secko, 2009).

Leach et al. conclude that to improve communication and ''clarify issues, change the tenor of the debate, and focus on more communication issues in order to make everyone's interests in the situation clear'' (2009, p. 136), new models of science communication must better address the varied agents, motivations, constraints and context of communicative acts (2009, p. 144). Logan (2001) has pointed out ''interactive models'' focus less on teaching people and more on actively engaging non-scientist groups or communities in the science communication process to improve communication among these groups. Others have suggested non-traditional models pose a possibility—even if not yet fully actualized—of creating common ground or equalizing existing inequalities between scientific and non-scientific knowledge (Bubela, 2006; Kerr et al., 2007; Piolli and Conceição da Costa, 2008). In contrast, Hurd (2000) has even suggested in the age of digital data mining a new model of science communication can be proposed where all information is regulated, reviewed and stored electronically, thereby minimizing the need for communicators.

A deeper examination of four models. Based on the above overview, we selected four models to focus on (Figure 1): the *science literacy* and *contextual* models in the traditional category, and the *lay-expertise* and *public participation* models in the non-traditional, contemporary category (Brossard and Lewenstein, 2010; Leach et al., 2009; Logan, 2001; Secko, 2007). These models were chosen as they exhibit the distinct primary goals of the traditional and non-traditional models, namely information transmission and public engagement, respectively. Additionally, these models represent the divergent treatment of scientific knowledge among traditional and non-traditional models, where a distinct difference can be found between science being the legitimizing form of knowledge among traditional models, and science being seen as equal to other forms of knowledge in the case of non-traditional models. Descriptions of these models based on our findings are given below.

Model A: the science literacy model. The science literacy model's goal is to "translate" scientific information for publics to give citizens the information needed to make decisions in their daily lives, and gain popular support for science (Figure 1A). It is a pedagogically-oriented model that focuses on raising science literacy, or the level of understanding publics have about science (Brossard and Lewenstein, 2010; Davies, 2008; Gerhards and Schäfer, 2009; Tlili and Dawson, 2010). The model treats science as fixed and certain (Brossard and Lewenstein, 2010), in that the scientific method and process justify the knowledge presented (Leach et al., 2009; Nelkin, 1995). From a journalistic perspective, use of the science literacy model involves employing traditional journalistic norms, such as objectivity (Secko, 2007), and viewing audiences as lacking knowledge. The model therefore assumes a "top-down" linear transmission structure to deliver knowledge provided by scientists to the journalists, who "translate" research and scientific

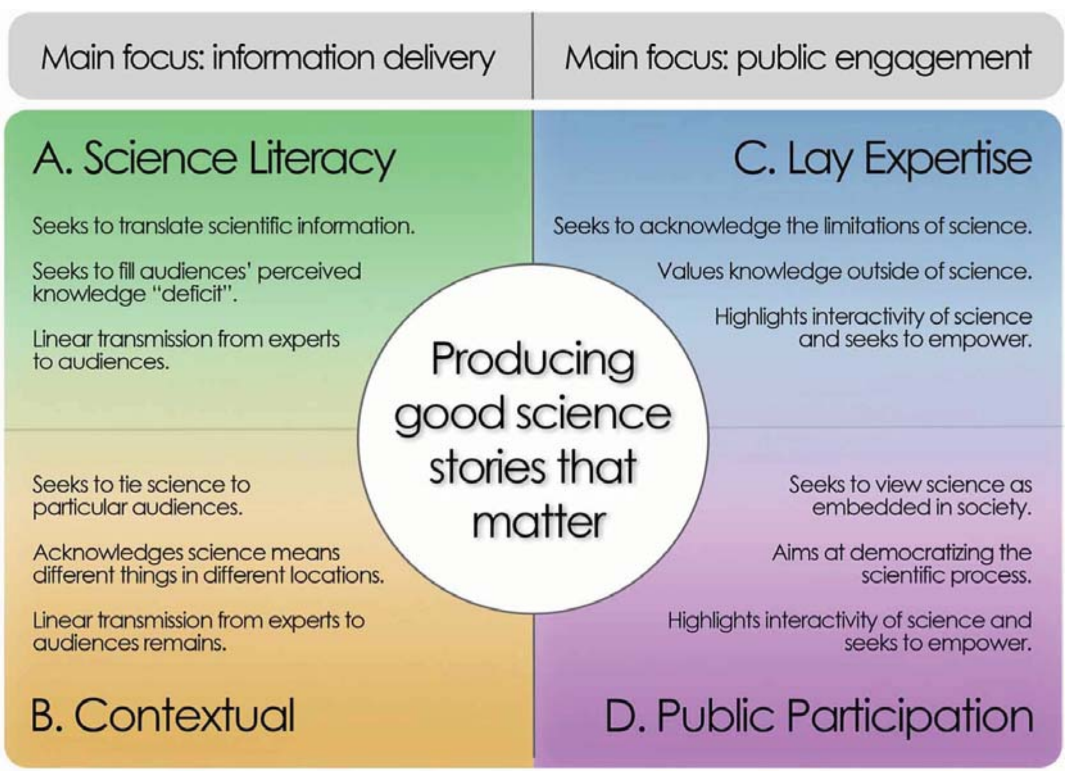

FIGURE 1
Four models of science journalism (adapted from Brossard and Lewenstein, 2010)

information into accessible news stories (Brossard and Lewenstein, 2010). The science literacy model has been criticized on a number of levels, including lack of context and failure to connect scientific information to personal relevance, uneven power relations between those viewed as having knowledge (science) and those that do not (audiences), and ignorance of other forms of (non-scientific) knowledge (Brossard and Lewenstein, 2010).

Model B: the contextual model. While the contextual model employs a ''top-down'' information delivery style similar to the deficit model, it goes a step further by addressing scientific information in specific, audience-linked contexts (Figure 1B). The contextual model acknowledges science means different things in different geographic and social locations (Donghong et al., 2008), and that individuals receive information in particular contexts that shape how people process and respond to that information (Brossard and Lewenstein, 2010; Gerhards and Schäfer, 2010; Kahlor and Rosentahl, 2009). From a journalistic perspective, the contextual model constructs messages relevant to particular audiences while paying attention to the needs and situations of these audiences.

Research has suggested the contextual model theoretically maintains more cooperative relationships between science and the public (Clarke, 2003; Davies, 2008; Irwin, 2009) while perceiving ''the audience'' as being able to quickly gain knowledge about relevant topics (Brossard and Lewenstein, 2010). However, while the contextual model theoretically aims at increasing knowledge and changing attitudes, some have critiqued it as being another version of the deficit model that maintains ''top-down'' information delivery and places scientific knowledge above other forms (Kerr et al., 2007). As Donghong et al. stated:

> [T]he contextual model, while more nuanced than the deficit model, shares the same premises: first, science and society are conceived as two autonomous spheres, distinct from one another, and with one prevailing over the other; second, only a mastery of techniques and communication enable a rapprochement and the regaining of equilibrium. (2008, p. 2)

Model C: the lay-expertise model. While much of the literature views the lay-expertise model as a version of the contextual model, Brossard and Lewenstein (2010) make a compelling argument to define it as distinct. The main separating factor is that the lay-expertise model places local knowledge equal to scientific knowledge (Figure 1C). The lay-expertise model breaks with the top-down conception of science–society relationships, and incorporates the knowledge and concerns—or ''lay-expertise''—of specific populations (Donghong et al., 2008). Under the lay-expertise model, knowledge is valued in its own right, and is validated through other social systems (Brossard and Lewenstein, 2010). Science is promoted as limited and uncertain, thereby requiring ''expertise'' from sources outside of science to examine issues (Brossard and Lewenstein, 2010; Gerhards and Schäfer, 2009). The lay-expertise model is theoretically ''based in lives and histories of real communities'' (Brossard and Lewenstein, 2010, p. 15). For example, Irwin (2009) pointed out lay-expertise may be especially useful when covering issues related to farming, as the model takes into consideration that ''scientific issues are not solely scientific'' and that ''laypeople might have 'as much to learn as to communicate''' (2009, pp. 7–8).

Audience participation and engagement is encouraged under the lay-expertise model. In terms of policy, for example, the model theoretically suggests laypeople should supply questions they want answered, and provide direct input into what they would like to see done (Nisbet, 2009). The overall goal of the lay-expertise model, as Brossard and Lewenstein (2010) suggest, is to empower local communities by fostering confidence that individuals have valuable knowledge to share and can participate in the scientific process. However, critics of the lay-expertise model suggest balancing and equalizing expert, lay-expert, and non-expert knowledge is impossible, with inequality of information from different groups as a constant obstacle (Kerr et al., 2007; Piolli and Conceição da Costa, 2008).

Model D: the public participation model. The public participation model attempts to make the scientific process more interactive and encourages public debate surrounding scientific issues (Figure 1D). Thus, it focuses less on teaching people or filling knowledge gaps, and more on actively engaging stakeholder groups in the science communication process to improve communication and trust among these groups (Logan, 2001). As with the lay-expertise model, the public participation model is "non-traditional" in that it breaks with the linear transmission structure present in mainstream journalism. The model emphasizes the democratization of and public participation in the scientific process, especially regarding policy issues (Brossard and Lewenstein, 2010). Tlili and Dawson suggest successful models of public engagement are "creative and experimental, with both educational and democratic functions" (2010, p. 429), while bridging the scientific and cultural. In journalistic terms, the public participation model focuses more on the processes behind the science and the inclusion of a multitude of stakeholder viewpoints, and aims at engaging audiences in pluralistic debate. The public participation model has been subject to criticisms as well, such as addressing politics and policy issues over public understanding of science, and emphasizing the process of science while discounting the actual content, as well as only being able to address smaller, particular audiences at a time (Brossard and Lewenstein, 2010).

Summary of the characteristics of the chosen models. The four models of science communication investigated all desire to produce "good" science stories that matter (Figure 1), but diverge on how to accomplish this goal. The traditional science literacy and contextual models share the goal of informing audiences with a "top-down" information delivery style to fill perceived knowledge gaps, and treat science as the main legitimizing form of knowledge so as to value expert scientific sources above others. However, while the science literacy model focuses solely on presenting scientific knowledge itself, the contextual model presents scientific knowledge as tied to particular contexts and communities, thereby treating audience members as concerned spectators, rather than entirely passive. The lay-expertise and public participation models share the overlapping goal of engaging publics with science. Both models value knowledge outside of science, and do not treat scientific knowledge as "better" than other forms. However, while the lay-expertise model aims at using sources and information outside of science, the public participation model takes this one step further by seeking to promote active engagement with the scientific process. When compared against identified journalistic story-writing criteria (addressed next), these similarities and differences help us move closer to connecting story production guidelines to each specific model, which will help investigate how to appropriately operationalize their use.

Criteria for the Use of Communication Models as Science Journalism Models

The need for model-based story criteria. While identifying models of science communication in the literature, it was clear current articulations of such models are not robust enough to be of direct use to science journalism production despite arguments for the need to supplement traditional practice with new approaches (Logan, 2001, pp. 157–8). Current science communication activities also tend to mix approaches from a number of models (Brossard and Lewenstein, 2010), leading to confusion over the primary goals of various communicative acts. Furthermore, research has so far only considered models of scientific communication under a theoretical lens. We seek to fill these gaps in this section through the development of story-writing criteria. To facilitate this development, we used identified literature (see Methods) to extract aspects journalists consider when producing their stories. In synthesizing such material, several trends emerged that led to the formulation of the six story-writing criteria outlined below (Figure 2). These criteria are specifically linked to our four models in the subsequent section.

Criteria 1: purpose. This criterion emerged firstly out of traditional journalistic writing and reporting guidelines commonly used in journalism education (e.g. Mencher, 2003), which referenced traditional values (e.g. informing, accuracy, fairness, balance, and objectivity) as driving principles behind journalistic story-writing. Guidelines tied to particular journalistic fields, such as peace journalism, also referenced the journalist's perceived/implied roles—such as educator, knowledge transmitter, storyteller, and informer—as driving a story's purpose (Lynch, 2002). Secko (2007) also identified "purpose" as a guiding principle in science journalism production, with a science literacy model's purpose being the transmission of information, and a public engagement model's purpose suggested as promoting "active engagement and education in support of democracy" (p. 33). Thus, this criterion asks journalists to think about *why* the story is being written.

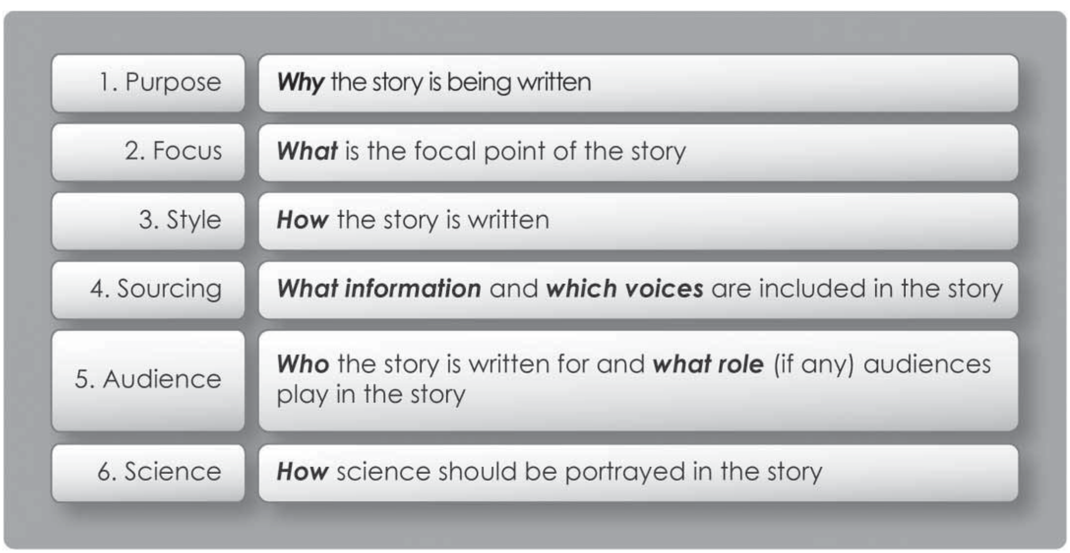

FIGURE 2
Story-writing criteria

Criteria 2: focus. Traditional journalistic writing and reporting guidelines (e.g. Mencher, 2003) offered recommendations on how to focus news stories, mainly by using traditional news values (e.g. timeliness, impact, currency and conflict) to identify a news story's focal point. Other guidelines in health reporting (e.g. Vercellesi et al., 2010) and environmental journalism (e.g. Schweizer et al., 2009) suggested the focus of a given news story should be tied to particular contexts, such as scientific, cultural, social, and political issues, or what situation or place the story is situated in (Schweizer et al., 2009). In his guidelines for peace journalism, Lynch (2002) suggested journalists focus stories by asking whether the story is event-based, or whether it seeks simplicity or to explore complexity. Secko (2007) also referenced "focus" as a guiding principle, for example with science literacy model stories focusing on events and publication, and public engagement model stories focusing on the consequences of choices made (p. 33). Thus, this criterion asks journalists to consider *what* the focal point of the story is.

Criteria 3: style. Style was also a principle for journalistic story-writing consistently referenced in the literature. Basic journalistic guidelines, as well as those focused more on science, health and environmental reporting (e.g. Levi, 2003; Schweizer et al., 2009; Vercellesi et al., 2010) referenced traditional information delivery styles that seek to inform audiences about science by translating scientific research into simple language that avoids jargon and explains complex scientific concepts by using analogies and metaphors. This style is reflective of the "transmission" view of communication (Carey, 1989, pp. 14–15), which is a linear model with three main components: the sender, the message that is being sent, and the receiver of the message. For example, under this model, journalists are considered the senders of the message, the newspaper articles they write are considered the message, and the readers are considered the receivers of the message (Leach et al., 2009, p. 138). The transmission model that characterizes journalistic story-writing style assumes that if the sender and message components can be improved, the reception of the message will also be improved (Carey, 1989; Leach et al., 2009). However, stories written according to non-traditional models may need to reconsider such traditional journalistic styles. These models require going beyond solely transmitting information and innovating more "holistic" techniques that address a range of stakeholder interests and seek to promote active public engagement. Thus, this criterion asks journalists to consider *how* the story is written.

Criteria 4: sourcing. Sourcing was commonly referenced in the literature in terms of what information and which voices to include in a news story. While basic guidelines covered the number of sources to include in a given story and leaned towards using expert sources, other guidelines for such fields of journalism as public/civic journalism (e.g. Glasser and Craft, 1997; Haas, 2007; Rosen, 1996) argued for the inclusion of additional sources beyond experts to aid in improving issues of representation and civic participation, and shift from a "journalism of information" to a "journalism of conversation" (Glasser and Craft, 1997, p. 124). Although not termed "sourcing," Secko's (2007) guiding principles also looked at how knowledge was legitimized in science stories, such as through scientific information itself in the case of a science literacy model, and through personal knowledge in the case of a public engagement model (p. 33). Thus, the sourcing criterion asks journalists to consider *what information and which voices* are included in the story.

Criteria 5: audience. Literature on fields of journalism such as the civic/public journalism movement (e.g. Glasser and Craft, 1997; Haas, 2007; Rosen, 1996) and peace journalism (Lynch, 2002) pay particular attention to audiences as they ask journalists to consider who exactly they are writing for, and whether the audience plays a passive or active role in stories. Similarly, Schweizer et al. (2009) suggested journalists include audiences' interests, values, cultural beliefs and actions in climate change coverage, as this can help readers connect to the story, make meaning of the story's message, and give audiences a sense of empowerment (pp. 271–2). Thus, this criterion asks journalists to consider *who* the story is written for and *what role* audiences play in the story.

Criteria 6: science. Although the science criterion was not an issue specifically represented across journalistic story-writing guidelines, it was deemed a necessary consideration to fully capture the essence of each model. For example, while the "traditional" models (science literacy and contextual) view science as fixed and certain (Leach et al., 2009; Nelkin, 1995), the "non-traditional" models (lay-expertise and public participation) view science as uncertain and socially bound (Brossard and Lewenstein, 2010; Secko, 2007). The "science" story-writing guideline seeks to clearly define such differences between models. This criterion thus asks journalists to consider *how* science should be portrayed in the story.

Linking Models to Criteria to Produce Practical Models of Science Journalism

Practical guidelines for journalists. As the story-writing criteria (Figure 2) are intended to be used by working journalists to produce science journalism, the six criteria and four models were linked together to produce guidelines for the practical use of each model (Table 1).

Use of Model A: the science literacy model. In keeping with the literature's definition of the science literacy model's purpose as informing and promoting science literacy (Brossard and Lewenstein, 2010; Logan, 2001), a story written according to this model should have its main purpose as informing audiences about the scientific aspects of a research project or story. Thus, the model implies journalism created within its framework should attempt to focus on specific events and publications, while making use of conflict or novelty (i.e. the science's "wow" factor) to tell a story (Table 1). As the purpose of a story based on the science literacy model is to inform audiences and promote science literacy, such a story should be written in a traditional information-delivery style that seeks to "translate" scientific research and information into understandable and accessible stories, using scientific experts as the main sources and treating readers as a passive audience. Science is viewed as fixed and certain (Leach et al., 2009; Nelkin, 1995) and expert knowledge is valued over other forms of knowledge as the main legitimizing factor (Secko, 2007). We will explore the application of this model to story examples in future work, but briefly, if we took the example of scientific research on biofuels, the science literacy model would be appropriate for a story on a new conversion technology for turning biomass into biofuel.

Use of Model B: the contextual model. The contextual model seeks to inform communities and individuals about science as it relates to their particular contexts (Brossard and Lewenstein, 2010; Donghong et al., 2008; Kahlor and Rosentahl, 2009). The purpose of a contextual model-based story is therefore to inform audiences about the science as it relates to them (Table 1). While not abandoning scientific description, this

TABLE 1
Story-writing criteria linked to four communication models

Criteria	Models			
	Science literacy	**Contextual**	**Lay expertise**	**Public participation**
Purpose	Informs audiences about science	Informs audiences about science as it relates to them	Empower communities; promote engagement	Promote active engagement and education in support of democracy
Focus	Events and publications; driven by conflict and "wow factor"	Events, issues, concerns, cultural, beliefs, realities tied to specific populations	Community attitudes; local knowledge	Processes behind science; consequences of choices
Style	Traditional information delivery (Objectivity/ Implicit Subjectivity)	Traditional information delivery (Objectivity/Implicit Subjectivity)	Active engagement (Holistic/Subjective)	Mapping viewpoints; communal (Holistic/ Subjective)
Sourcing	Official experts and/or documents	Experts as main sources; community members provide background and context	Lay people, community members, leaders and organizations as main sources; experts provide background and context	All stakeholders (scientists not presented as someone special)
Audience	Passive spectators	Concerned and questioning spectators	Those affected by the science; input sought after	Considered stakeholders; input sought after
Science	Fixed and certain; legitimizing form of knowledge	Fixed and certain; legitimizing form of knowledge	Uncertain; local and personal knowledge is the legitimizing factor	Uncertain and embedded in society

necessitates a stronger focus on issues and aspects of a science event that relate directly to the audience by tying the messages and information in the story to the personal and social contexts they will be received and interpreted within (Hall, 1993). As the purpose of a contextual model story is, like the science literacy model, mainly to transmit information and knowledge about science to audiences, a contextual model story should be written according to a traditional information delivery style. Scientific experts are again used as the main sources, as science itself is the legitimizing factor behind the information presented. As the main purpose of a contextual model story is to inform audiences about the science as it relates to them, community members or other "non-experts" may also be used as sources, but only to provide background information and context to help journalists in constructing messages. However, as contextual model stories adhere to a traditional information-delivery style, audiences do not have any direct participation within the story itself.

As with the science literacy model, science should be viewed as fixed and certain, with the experts treated as able to provide answers to the community's questions and concerns. For example, for a story on biofuels, the contextual model would still examine a new conversion technology for turning biomass into biofuel, but seek to link it to the types of biomass in a particular community.

Use of Model C: the lay-expertise model. The lay-expertise model values local knowledge as much as scientific knowledge and seeks to empower local communities in the scientific process (Brossard and Lewenstein, 2010; Irwin, 2009). Thus, a story written according to the lay-expertise model should aim at empowering local communities and promoting engagement in democratizing the scientific process, and focus on the community's attitudes toward the science and issues related to/stemming from the science (Table 1). Such an article may be driven by a community dilemma with the community seen as able to provide solutions.

As the lay-expertise-based story seeks to validate knowledge outside of science and empower communities in the scientific process, traditional linear information delivery styles may not be appropriate in representing this. Thus, such a story should step away from styles that seek to solely transmit scientific information to audiences and adopt a style that reflects ''active engagement'' of lay-people and community members in the scientific process by including voices and sources of information outside of science (Donghong et al., 2009). Thus, the story's main sources should be community members and lay people, with the story seeking and valuing input from the particular audiences it is aimed at. Additionally, in order to reflect this emphasis on lay-expertise and local knowledge, scientists and experts should act as secondary sources, with their roles limited to providing background and context (Brossard and Lewenstein, 2010). Unlike the science literacy and contextual models that legitimize knowledge and information with the scientific method and process (Leach et al., 2009; Nelkin, 1995), a lay-expertise model-based story does not value science over any other form of knowledge and correspondingly treats personal knowledge as its legitimizing factor. For example, the lay-expertise model would use information on a conversion technology for turning biomass into biofuel as background and principally explore how community members are affected by the prospect of a biorefinery in the community.

Use of Model D: the public participation model. As the public participation model aims to promote active engagement from all stakeholders and democratize the scientific process (Brossard and Lewenstein, 2010), as well as improve communication and trust among these groups, the purpose of a story based on this model should go beyond reporting the news and promote active engagement. Stories may focus on the processes behind the science, as well as the consequences of choices made (Table 1). As traditional journalistic styles may not effectively reflect such a purpose, the public participation model-based story should take on a style that maps viewpoints and opinions of the stakeholders involved, promoting channels for more active, non-linear discussion. Consequently, sourcing should include as many implicated groups as possible, including audience members, whose opinions and viewpoints are sought after. Finally, as with the lay-expertise model that accepts knowledge away from science, science in a public participation-based story should be treated as uncertain and embedded in society (Secko, 2007). As a final example again related to biofuels, the public participation model would be appropriate for a story on the social and scientific assessment of the impacts of a biorefinery that will use a new conversion technology in a rural town.

Discussion and Conclusion

It is intriguing to think the development of the *science literacy model*, which drew support from the simple shifting of standard news practices (Rensberger, 1997) from other types of journalism to science, may be at the heart of some recurring critiques leveled at science journalism. These critiques have included accusations of inaccuracy, sensationalism, oversimplification and failing to engage audiences in meaningful debate about scientific issues. Such critiques, however, have remained in stark contrast to a lack of consensus on what would be "better" science journalism. It has therefore become increasingly apparent that we have yet to find clarity on how to proceed forward with meeting these difficulties.

Consequently, beneath the many reasons ascribed to these problems, and a lack of solutions, a more fundamental problem may exist in the conceptual foundation used to develop strategies to communicate science. In North America, this conceptual foundation is partly built on a pedagogical base that turns to the transmission of understandable information, through agents such as science journalists, as a means to realize the philosophies outlined by American scientists in the early twentieth century (Logan, 2001). Implicit in this foundation are four assumptions: (1) science is grounded in absolute fact, which is separate from our conceived reality and merely tapped into by scientific inquiry, (2) such a process is too specialized to be comprehended by the general public, (3) therefore an intermediate form of scientific knowledge which requires a "third person" (i.e. science journalists) is needed, and (4) this "third person" can communicate effectively by simply calling on linguistic translations (Bucci, 1996).

For some time, scholars have recognized this traditional approach has flaws (Schäfer, 2011) and have identified a variety of other ways science could be communicated. But scholarly arguments do not always filter to those that most need them. Science journalists have largely been left adrift with no "clear" guidelines that connect these alternatives to journalistic practice. In this paper, we sought to reconnect journalistic practice to these alternatives to support a line of inquiry that aims to address such gaps. There is literature available on communication models that can be used to enrich approaches to science journalism production. The literature points to two main categories of models: "traditional" and "non-traditional" (Figure 1). More traditional models view science as the legitimizing form of knowledge and aim at transmitting scientific knowledge to audiences (Brossard and Lewenstein, 2010; Davies, 2008; Gerhards and Schäfer, 2009; Logan, 2001; Schäfer, 2011). Non-traditional models seek to value knowledge from outside science and aim at presenting science information tied to particular contexts and audience realities (Brossard and Lewenstein, 2010; Gerhards and Schäfer, 2009; Logan, 2001; Sturgis and Allum, 2004; Tlili and Dawson, 2010; Weigold, 2001). We developed six story-writing criteria—purpose, focus, style, sourcing, audience and science—(Figure 2) for the use of four models of science journalism that were drawn from this literature. This resulted in the conceptualization of model-based story-writing guidelines that could be utilized by journalists in science news story production to reflect the characteristics and goals of the individual science journalism models investigated (Table 1).

We view Table 1 as foundational work that helps advance research on how to produce theoretically-informed but practical frameworks that can give more nuanced evaluations of the quality of science journalism. We, however, are more focused on the specifics of science journalism production than past work (cf. Brossard and Lewenstein, 2010; Gerhards and Schäfer, 2009). Hence, we envision the presented model-based story-writing guidelines as serving two important functions currently missing from the literature: (1) by providing a probe aimed at more clearly defining the theory–practice unpinnings of new models of science journalism as compared to old approaches, and (2) by providing an eventual educational tool for science journalists to better understand the frameworks they utilize during story production and, in contrast to this, the possibilities of other approaches they have not considered. These functions are spurred on by an expectation scholars and journalists will see similarities and differences when comparing the presented guidelines to their personal approaches. Future work thereby needs to document this diversity and begin to test the functionality of the presented guidelines with science journalists. The richness of the presented guidelines will grow with use.

Before concluding, it is worth noting some limits of the methodology used. First, this study was limited to four models due to space considerations; however the models chosen represented both the dominant classical and contemporary models of science communication and provided a focused analysis. Second, the completed literature searches attempted to be comprehensive but with the realization it is difficult to ensure collection of every single study, with databases and literatures not being static but continuing to evolve. Third, although retrieved literature informed the development of story-writing criteria, it should be noted the researchers' backgrounds in journalism influenced assumptions on how the criteria were developed and then tied back to the models to produce the presented guidelines. Fourth, as the produced model-based guidelines are intended to be used by journalists with already-established personal routines and practices, they were limited to only making use of recognizable journalistic concepts that would appeal to working journalists. There are, of course, capacity issues embedded in this choice in terms of (for example) whether a journalist has the requisite science and social science training to make effective use of Models C and D. Fifth, the produced criteria and story-writing guidelines offer only a representation of the complex processes of science journalism and thus require further examinations in terms of usage in science journalism practice and expansion to other formats, specifically digital and online journalism.

To conclude, our methods were drawn from the research synthesis literature (Paterson et al., 2001) and Thorne's (2008) method of interpretive description, and as such this paper did not extensively address the normative implications of each model. But it is, no doubt, obvious to the reader that each model carries with it certain responsibilities and fundamental norms that ascribe to a different vision for the proper mission of science journalism. These are important complexities to be untangled in future work, and for the sake of space, we will only note here that journalists need not use only one model. Journalists can (and do) wear many hats. Similarly, the presented models are not mutually exclusive and can co-exist. Instead, their separation serves to allow a discussion of when a science literacy model is most appropriate to a story (e.g. a new conversion technology for turning biomass into biofuel) over when a story may require other approaches, such as more public participation (e.g. the social and scientific assessment of the impacts of a biorefinery that will use this conversation technology in a rural town). The models thereby move this type of conversation out of a theoretical cloud and into a practical sphere, enabling the goals of different approaches to be more precisely constructed, identified and critiqued. The ultimate goal of this approach is to point to new models of science journalism that can meet recalcitrant critiques while respecting science journalists' past accomplishments.

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