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Science Communication Training: What are We Trying to Teach?

ABSTRACT

The rapid growth in public communication of science and technology has led to a highly diverse and large number of training programs. Using a learning-centered approach, we ask: What are the learning goals of science communication training? As the science communication field matures, a comprehensive set of learning goals for future trainings will draw fully from the range of fields that contribute to it. Learning goals provide a framework for deciding what to count as success and how to gather evidence of learning.

Based on the six strands of learning developed for "learning science in informal environments", we built a conceptually-coherent definition of science communication learning that addresses affective issues, content knowledge, methods, reflection, participation, and identity.

We then reviewed dozens of research articles describing science communication training for scientists, identifying both explicit and implicit learning goals. Classifying them with our conceptual definition, we identified gaps in the outcomes commonly used for training programs; these gaps appeared especially in the areas of affective learning and identity formation.

We do not expect any one program would attempt to achieve all learning goals. Different courses might be tailored differently for training scientists who remain in science, who wish to become journalists, who wish to work for museums, etc. But we believe that conceptual coherence can help course designers identify important goals. Creating a common language will increase the ability to compare outcomes across courses and programs, identifying approaches that best fit particular education, training, and communication contexts.

KEYWORDS

MEDIA TRAINING, SCIENCE COMMUNICATION TRAINING, SCIENCE COMMUNICATION, SCIENTISTS AS SCIENCE COMMUNICATORS

Science Communication Training: What are We Trying to Teach?

RATIONALE

The field of science communication is growing rapidly, both in practice and in scholarly attention. Within just the last three years, three special issues have appeared in journals *outside* science communication about that growth: *Proceedings of the (U.S.) National Academy of Sciences* (Fischhoff & Scheufele, 2014), *Journal of Research in Science Teaching* (Baram-Tsabari & Osborne, 2015), and *Educational Psychologist* (Bromme & Goldman, 2014). This attention to the field is gratifying, but also brings a need to integrate ideas across a wide range of disciplines. One area of particular concern is the growing number of training programs in science communication. Some of these are directed at undergraduate or graduate students, others at working scientists, and yet others at nonscientists who participate in science events or work at science museums and other sites. Some of these trainings are 'one-offs', occurring for an hour or two on a single day; others are day-long or week-long workshops repeated multiple times each year; and yet others are full degree programs. Some participants attend a single event, others participate in repeated opportunities for learning how to improve their science communication. Although some of these courses are limited to training in specific skills, others seek to educate participants in broader concepts of education, of communication, and of science and society (e.g., Burns, O'Connor, & Stocklmayer, 2003; Gold, 2001; Ham, 2008; Latimore, Dreelin, & Burroughs, 2014; Miller, Fahy, & Team, 2009; Mulder, Longnecker, & Davis, 2008; Silva & Bultitude, 2009; Trench & Miller, 2012).

Even courses with broader perspectives, however, are usually based on practical skills. They are often designed for the particular context of interest to the producers. Several articles and projects have captured the richness of these programs (e.g., Longnecker & Gondwe, 2014; Mulder et al., 2008; Trench & Miller, 2012; Turney, 1994). Whether called 'training' or 'education', each of these programs engages in teaching. And where there is teaching, there are (one hopes) learners. That shift to a focus on learning is what interests us. What are we trying to teach in science communication? Are our students learning it? What else are they learning? How can the learning be assessed? These are important questions as we further develop education and training programs in science communication.

In this article, we focus on the first question: What are we trying to teach? In reviewing previous publications (more fully described below), we found that most research and commentary emphasize either particular communication contexts (e.g., writing popular articles, being interviewed on television) or describe specific educational contexts (e.g., the design of particular training programs). Yet the differences among the different communication contexts is not always recognized. For example, 'media training' and 'communication training' are sometimes used interchangeably; but the first is focused on speaking with journalists, dealing with unpleasant questions in live broadcast TV shows, etc., while the latter is about helping scientists to communicate with the public, focusing on abilities such as creating trust and appearing involved and empathic. Similarly, some lists of training goals elide the differences between half-day workshops and semester-long courses. These conflations represent the exuberance of a rapidly developing, but as yet under-conceptualized field.

As the field matures, we believe it will be useful to identify a comprehensive set of learning goals, ones that draw fully from the range of fields that comprise public communication of science and technology, including at least communication, journalism, arts and media production, education, public relations and marketing, and science & technology studies. Learning *goals* address what one, as a teacher or trainer, is trying to achieve. For example, learning goals might specify what scientists engaged in media training will be able to do or demonstrate at the end of the training, or what types of knowledge are appropriate for public communication of science and technology[1]. A course designed to help scientists work with museums might have different learning goals than a course designed to introduce nonscientists to science journalism. The goals shape what teachers will be teaching. Teachers can choose goals that might, for example, be relevant for students across different communication contexts. Learning *objectives* describe the expected results of teaching; they are more specific and measurable[2]. Learning goals and objectives provide a framework both for assessing individual achievement and for evaluating course accomplishments. In practice, the line between learning goals and learning objectives can be ambiguous. In this project we focus on learning goals, but also sometimes provide learning objectives. We do this in part because the literature on which we draw does not always make the distinction, and because we want to make our broader set of ideas available to the community for discussion. We have deliberately not tried to restrict our review to courses for specific groups (such as scientists interested in media, or training for community presentations); the goals that we have collated bring together those for multiple sets of learners.

A word about what this project is not: It is not an attempt to put forward a curriculum (a set of learning goals articulated across the full educational experience), or a syllabus (an outline of topics to be covered in a course). These are also not standards expected to be achieved by everyone who trains in science communication. It does not offer a framework for assessment (although it does list some measurable objectives; see (Baram-Tsabari & Lewenstein, 2016)), and it is not yet complete (e.g. key issues for different science communication environments still

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[1] Stating educational standards in terms of student outcomes is a relatively new experience for many countries, especially European ones, who had previously focused on the quality of educational inputs (e.g., the curriculum, instructional materials, and pedagogical strategies). The United States, on the other hand, has focused on outcome measures in education since the early 20th century when large-scale standardized testing became popular; those goals now appear in its (voluntary) national standards (DeBoer, 2011).

[2] A brief note on the terminology of ‘goals’ and ‘objectives’: Different disciplines use different jargon. For example, many professional fields, such as dentistry, nursing and social work, use the language of ‘competencies’. A competency is a general statement detailing the desired knowledge, skills, and behaviors of a graduating student (similar to learning goals). But in science education, ‘competence’ is a broad concept that involves the application of science knowledge to real-world problems involving science and technology, including the capacity and disposition to use that knowledge. It can be a difficult concept to operationalize, and, as an outcome goal it can be difficult to measure (DeBoer, 2011), because ‘outcomes’ or ‘learning outcomes’ are specific statements that describe what a student will be able to do in some measurable way. In place of ‘outcomes’, the *Next Generation Science Standards* recently developed in the United States uses ‘performance expectations’ – performances that can be assessed in multiple ways to determine whether or not students have met the standard.

need to be developed). Our goal is to provoke conversation about the contours of the overall field of science communication training.

For any field, learning goals are strongest when they emerge from a coherent conceptual base, rather than being simply a laundry list of possible goals (Driscoll, 2004). As Ogawa (2013) notes, science communication works best when its goals are identified in advance. A similar concept applies to *learning* science communication. A coherent conceptual base relies at least to some degree on the structure of the discipline one is teaching. When teaching biology, for example, the structure of the scientific discipline and its central theories sets the framework for deciding what to teach. The curriculum developer who sets the learning goals, and a teacher who sets learning objectives based on the learning goals, would then decide which ideas and skills to teach within the world of biology, based on their own values and perspectives, what it teachable and learnable considering the age/developmental stage, students' prior knowledge and background, their own interests, etc.

In the case of science communication, the situation is more complicated since many different disciplines contribute ideas, content and skills to the field, so the structure of the discipline is not at all obvious (Kuehne et al., 2014; Mulder et al., 2008). By developing conceptual coherence, we can help designers identify the particular components they wish to include in their science communication courses, as well as understanding how different components relate to each other. Creating a common conceptual language can increase the ability to compare outcomes across courses and programs, identifying approaches that best fit particular education, training, institutional, and communication contexts. As noted above, we do not expect that any one program would attempt to achieve all possible learning goals. Public communication of science and technology takes place in many contexts: science journalism, science museums, informal science education, science outreach, public information for research-focused organizations, etc. Attempting to address all these fields in a single curriculum would be beyond the scope of most educational programs. But a clear conceptual base can help make clear the relationships, complementarities, and tensions among these subfields.

One conceptual approach might draw on communication research, which is often tied to designing communication campaigns and focuses on knowledge, attitude, skills, and behavior change. Another approach might be to align goals with particular practical dimensions, such as types of activities being trained for (e.g., museums, media), types of program goals (conceptual knowledge, specific skills), types of skills/competencies/domains of knowledge being taught (principles of learning, media production techniques), types of audiences being engaged (children, adults) , and types of science communicators being trained (scientists doing outreach, environmental writers). Since we are primarily interested in education and learning, we have chosen an approach based in the education literature. We encourage discussion of what other approaches might yield.

We based our work on a set of concepts developed for the context of ‘learning science in informal environments’: six strands of learning identified in the 2009 report on informal science learning from the U.S. National Research Council (Bell et al. 2009). According to that report, someone who has learned science:

1. Experiences excitement, interest, and motivation to learn about phenomena in the natural and physical world.
2. Comes to generate, understand, remember, and use concepts, explanations, arguments, models, and facts related to science.
3. Manipulates, tests, explores, predicts, questions, observes, and makes sense of the natural and physical world.
4. Reflects on science as a way of knowing; on processes, concepts, and institutions of science; and on their own process of learning about phenomena.
5. Participates in scientific activities and learning practices with others, using scientific language and tools.
6. Thinks about themselves as a science learners and develops an identity as someone who knows about, uses, and sometimes contributes to science.

We will use this approach of an interwoven set of strands related to science education as a conceptual base.

We will also assume that we know what constitutes a rich science communication environment. Recent research builds on the distinction between "deficit" and "dialogue" models and acknowledges the strengths of these alternative approaches [e.g., (Bauer, 2014; Davies & Selin, 2012)]. Thus a rich science communication environment provides opportunities for people to acquire, use and explore multiple layers of information. A rich environment provides opportunities for creating new meanings drawn from exposure to science (Davies & Horst, 2016). Good science communication enables its audience to make informed judgments about sources and expertise, regardless of the audience's level of technical knowledge. In this environment, an individual can adapt information to her own situation, including bringing in her own knowledge and experience to address values, politics, culture, and other social dimensions of the context that interests her. Similarly, a rich environment allows groups to engage in informed discussions about complex issues, whether for making immediate choices, for planning political action, or for mutual enrichment.

From this general understanding of learning and of effective science communication, we have developed a high-level set of science communication learning goals adapted from the 6 strands of science learning. Someone who has learned science communication:

1. Experiences excitement, interest, and motivation about science communication activities and develops attitudes supportive of effective science communication (*affective goal*)

2. Comes to generate, understand, remember, and use concepts, explanations, arguments, models, and facts related to science communication (*content goal*)

3. Uses science communication methods, including written, oral, and visual communication skills and tools for fostering fruitful dialogues with diverse audiences (*methods goal*)

4. Can reflect on science and science communication's role within society; on processes, concepts, and institutions of science communication, and on their own process of learning about and doing science communication (*reflective goal*)

5. Participates in scientific communication activities in authentic settings, creating written, oral and visual science messages suitable for various non-technical audiences and engaging in fruitful dialogues with those audiences (*participatory goal*)

6. Thinks about her- or himself as a science communicator and develops an identity as someone who is able to contribute to science communication (*identity goal*)[3]

Our objective in the remainder of this paper is to collate existing statements about goals for and outcomes of science communication training, organize them according to the conceptual frame we have suggested above, and if necessary identify additional learning goals that have not previously been listed but that are suggested by the conceptual frame.

METHODS

Given the structure of learning goals that we suggest above, we began by collating statements that have appeared in the published literature. Some of these statements were worded as goals, others as objectives, others as 'essential elements', and so on. Some of these statements were developed from practical experience, others through formal methodology such as Delphi studies or systematic surveys of teachers or potential students of training experiences. Our own method was qualitative: We were deliberately catholic in our reading, seeking as broad a conception as possible of what might be considered a learning goal for science communication training. We went through several iterations of placing the statements into the 6-strand structure, merging similar statements, and rewording them into consistent "learning goal" form (see supplementary online material). We began with articles we knew, used the references lists in those articles to track down earlier articles, and did literature searches using a variety of terms around "science communication training." Several papers were particularly important, because they themselves were summaries of some science communication training literature (Besley & Tanner, 2011; Bray, France, & Gilbert, 2011; Longnecker & Gondwe, 2014; Miller et al., 2009; Mulder et al., 2008; Silva & Bultitude, 2009; Trench & Miller, 2012). Ultimately, we based the list on more than 20 publications (see supplementary material for full list). While we do not claim that we found all relevant literature, we believe that we have reviewed most major statements published through 2015 about what should be included in science communication training.[4]

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[3] If we had chosen, for example, the "communication" approach, the same educational strands might be organized differently:

Knowledge:	Content [Strand 2]
Attitude:	Affect [Strand 1]
	Reflection [Strand 4]
	Identity [Strand 6]
Skills:	Methods [Strand 3]
Behavior:	Participation [Strand 5]

[4] We thank an anonymous reviewer of this paper for reminding us that many medical schools have created communication courses directed at future doctors. These projects are typically focused on training medical personnel on how to convey medical information clearly and with

RESULTS

The overwhelming majority of learning goals present in the literature (see our initial compilation in Supplementary Table S1) belong to the strands of content knowledge (2) and methods (3). A number of items appeared in the reflection (4) and participation (5) strands. As the goals were expressed in the literature, no items appeared in the affective (1) strand and only one item in the strand on identity (6). Many previous publications identified the same learning goals, such as understanding of audience, understanding how the media works, and thus these goals showed up multiple times in our initial compilation. Across all the strands, most of the items referred to media and to outreach events or activities; relatively few items referred to science museums (a major site of science communication). Few items referred to communication with science policymakers, suggesting that the assumed audiences were largely “public” audiences rather than specialized audiences such as policymakers or business leaders.

As we combined and reworded items, we added items where we recognized specific gaps (such as adding additional items to the strand on identity (6)). We also moved to the strand on affect (3) some items for which the initial wording put them in the strands on content (2) or methods (3), rewording them to emphasize the importance of issues like trust and caring. That is: science communicators shouldn’t just know that trust and caring matter (a content issue), and have the skill to cultivate them (a methods issue), but they should *actually* trust and care (an affect issue). Trust and caring are not instrumental, but a mental state or deeply felt approach to the challenge of science communication.

From this process, we produced a final compilation of learning goals, shown in Supplementary Material Table S1. For some of the strands, we broke the goals into separate blocks, highlighting sub-domains of the goals. We made some attempt to keep goals at about the same conceptual level; this was a challenge because some previous literature contained very general goals (know communication models and theories) while other literature included more specific learning goals (know about the deficit model, the dialogue model, risk communication theories, and health communication theories).

Here we provide some comment on each of the strands in their final form.

1. Experiences excitement, interest, and motivation about science communication activities and develops attitudes supportive of effective science communication (*affective goal*)

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emotional sensitivity, rather than on broader science information or science literacy goals (see, for example, (Skye, Wagenschutz, Steiger, & Kumagai, 2014)). Some science communication trainings specifically draw on theatrical techniques, such as improvisation (Bernstein, 2014) (Olson, 2015); goals from these training programs appeared in some of the articles we reviewed. We have not systematically reviewed articles coming specifically from the medical or theatrical traditions.

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The key idea underlying this strand is that excitement and motivation are not *prior to* learning, but are a fundamental *part of* learning. Without excitement and motivation, students may go through a course and perform well, but educational literature shows that they are much less likely to retain and use what they have learned (Bransford, Brown, & Cocking, 2000; Pintrich & Schunk, 2002).

Some motivation is *intrinsic* – doing something for its own sake[5], and most of the goals listed in the literature address this aspect of strand 1. In the context of science communication training, then, students must think that communicating science is important, value interaction with public audiences, and believe that training itself is useful. Research has found that feeling that one is contributing to others, feeling a sense of usefulness and impact, are especially motivating (McCombs, 1996; Pintrich & Schunk, 2002; Schwartz, Lin, Brophy, & Bransford, 1999). Only from that base will other strands of learning be achieved successfully.

We also included in this strand various attitudes and values that successful science communicators hold themselves, not as cynical justifications but as deep beliefs. These include developing an audience focus, being sensitive towards community views and concerns, and believing in the importance of sharing perspectives among different stakeholders about science and society issues.

Interestingly, missing from the lists of goals prepared by others – and even in our own first passes – were *extrinsic* motivations. These include the need to meet grant requirements for broader impacts, the potential for raises or institutional advancement, potentially higher citation rates, and similar items. Yet surveys of scientists asking about their public engagement activity show that such extrinsic motivations are often important (Besley, Dudo, Yuan, & Abi Ghannam, 2016; Besley, Oh, & Nisbet, 2013; Dudo & Besley, 2016; Hamlyn et al., 2015; Kiernan, 2003; Peters, 2013; Phillips, Kanter, Bednarczyk, & Tastad, 1991). Thus we added a third block, on extrinsic motivations.

2. Comes to generate[6], understand, remember, and use concepts, explanations, arguments, models, and facts related to science communication (*content goal*)

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[5] Following Deci and Ryan's (2000) taxonomy of human motivation we do not view intrinsic and extrinsic motivation as entirely separate, but rather as two ends of a continuum. A scientist may agree to be interviewed because she enjoys it (intrinsic motivation), or because her department director has told her she must be interviewed (extrinsic motivation). But many cases are more complex, for an individual might agree to be interviewed (even though she distinctly does not enjoy appearing on television) because she wants to advance a purpose she values, such as advancing public understanding of science (an extrinsic motivation, which is internally regulated). For the purposes of this paper we highlight the ends of the continuum, intrinsic and extrinsic motivation.

[6] By "generate," we mean that students use processes of inquiry to create new knowledge for themselves. The knowledge might be well known by experts, but our understanding of the value of inquiry-based learning is that learning is most effective when individuals regenerate knowledge for themselves.

This strand captures what many people instinctively think of as learning: learning specific content. Not surprisingly, then, existing literature presents rich and detailed items related to this strand. Some of the key issues identified in this segment include the importance of multiple venues for science communication, the multiple kinds of knowledge necessary for good science communication (such as science content knowledge, audience knowledge, historical understanding of issues affecting relations among science and society, etc.).

As noted earlier, to keep the lists at approximately the same level we have not included some of the more specific goals identified in the literature (such as knowledge of particular kinds of media stories – news, features, etc. – or principles of narrative, digital communication, and visual communication). But we did notice that previous publications have developed detailed lists of key issues in media and journalism (Baron, 2010; Christensen, 2007; Cribb & Hartomo, 2002; Dean, 2009; Hayes & Grossman, 2006; Meredith, 2010). To our knowledge, similar lists don't yet exist for museums or social media or public presentation and deliberation. Thus we call attention to the need to develop more specific learning objectives for these areas. Similarly, bringing together so many areas of science communication points to the need for more widespread knowledge about issues like family learning (Borun, Chambers, & Cleghorn, 1996) or citizen science (Lewenstein, 2016; McKinley et al., 2015).

A number of publications have pointed to the importance of learning about theoretical discussions of science communication (Dunwoody, 2014; Fischhoff & Scheufele, 2014, 2013; Scheufele & Jamieson, in press). The field is no longer just a compilation of best practices, but now has concepts (such as dialogue, deficit, engagement) that cross different kinds of science communication practice. But science communication trainers must be careful not to make the same mistake as scientists themselves, believing that if only people knew (for example) that the deficit model has limits, then they wouldn't rely on it. Just as providing information to citizens doesn't magically change the underlying values and cultural commitments that shape their response to that information, so providing science communication concepts and techniques to scientists won't magically change their underlying commitments to information and cultural commitment to sharing that information.

3. **Uses science communication methods, including written, oral, and visual communication skills and tools for fostering fruitful dialogues with diverse audiences** (*methods goal*)

As in the previous strand, this strand captures one of the most common sets of goals expressed in the existing literature: learning particular skills for public communication of science and technology. Thus knowledge of media skills, risk communication skills, public presentation skills, and message construction skills appeared frequently in previous lists. Less common, but also important, are skills for leading public deliberations, building community partnerships, and especially using appropriate evaluation strategies – areas of practice that are important across many science communication contexts but are not as widely present in current science communication training contexts.

One challenge for this strand is that some of the skills -- such as demonstrating trust and willingness to listen to audience concerns -- can be read cynically: communicators don't really want to listen to the audience, but they know how to appear to be willing to listen. A classic example of the challenge is the *GM Nation?* program in the UK; although program goals included listening to audiences, the actual practices were much more instrumental, more focused on information delivery and persuasion. Evaluations of the program highlighted the conflict between stated goals and perceived goals (Bauer, Allum, & Miller, 2007; Bauer & Bucchi, 2007; Horlick-Jones et al., 2006; Rowe, Horlick-Jones, Walls, & Pidgeon, 2005). The more thoughtful reading is that true communication requires open listening and honest response. We don't think any of the authors of previous literature intended the cynical reading that would endorse what happened in the *GM Nation?* case, and this is part of why we have highlighted the importance of particular values such as listening in the affect strand (1). Similarly, although it would seem to be obvious that 'showing respect' implies 'not showing disrespect', disrespect is a recurring concern in commentaries about improving science communication.

4. Can reflect on science and science communication's role within society; on processes, concepts, and institutions of science communication, and on their own process of learning about and doing science communication (*reflective goal*)

The results for this strand highlight two issues: self-reflection and broader social context. Self-reflection is a fundamental need for good learning, according to education theory (Ertmer & Newby, 1996). Although individuals can be exposed to much information and many ideas, that information is learned and maintained best when learners stop to reflect on what they've learned, how it connects to other things they've learned, how they might use the knowledge, what questions the new knowledge suggests for future learning, and so on. Part of self-reflection is thinking about the learning process itself: Did I learn by reading? By doing? By explaining to someone else? Self-reflection is part of self-regulation, the process by which learners become responsible for their own learning. Self-regulated learners set goals, select strategies to achieve those goals, implement those strategies, and monitor progress towards the goals (Schunk & Zimmerman, 1998).

One particular aspect of self-reflection for scientists who are learning science communication is the need to consider the aims and outcomes of their own research. Though scientists often describe their research motivations in terms of particular theories or particular localized research problems, they are often also motivated by broader social aims – curing cancer, addressing energy sustainability, finding alternatives to expensive or impractical approaches that may be theoretically "clean" but practically complex. The mental exercise of reflection is very important for placing one's story in the greater picture and making it relevant to societal concerns. Reflecting on the outcomes of one's research is particularly important since this is what many audiences would consider most important. Scientists tend to complain about the public's preference for "jumping ahead" to the implications of basic research, but the literature on science communication makes it clear that scientists would be wise to actually consider the implications as well.

The connection with social outcomes is also important for the second major theme of this strand: an understanding that much of science communication can be strengthened with better understanding of the social context in which the communication takes place. The literature we examined highlighted this issue particularly in the context of the shift from deficit to dialogue. In the deficit model, one can deliver simply the information one wants. But in the dialogue model, as one seeks to make connections with and understand the positions of different audiences, one needs to know more about the history, philosophy, ideology, and social context that motivate those audiences. Furthermore, recognizing these contexts can help scientists see that they, too, can learn from outreach, in ways that make their own science richer and more relevant (Brandenberg, 2016; Pennisi, 2015; Risk and Policy Analysis Consultancy, 2015). The items collected in this strand emphasize the importance for science communicators of identifying their own values and goals in science communication.

5. **Participates in scientific communication activities in authentic settings, creating written, oral and visual science messages suitable for various non-technical audiences and engaging in fruitful dialogues with those audiences** (*participatory goal*)

The components of strand 5 are relatively straightforward: once you've learned something, go out and do it to cement the learning. This, too, is a standard element of many learning theories. For us, the surprising finding was that relatively few of the previous descriptions of science communication emphasized the element of participation. Presumably the goal of most science communication training programs (and their funders) is to increase the amount of science communication that occurs. Thus participation addresses both an internal or 'process' goal, to improve the learning of science communication concepts and skills, and an external or 'outcome' goal, to increase science communication itself.

6. **Thinks about her- or himself as a science communicator and develops an identity as someone who is able to contribute to science communication** (*identity goal*)

One of the most important contributions of the science learning model developed by the 2009 report on learning science in informal settings (Bell, Lewenstein, Shouse, & Feder, 2009) is the inclusion of "identity" in learning. Someone only learns something when they realize that they *can* learn it, when they acquire an identity as a learner. For science communication, this concept can be understood as achieving an identity as a science communicator. Many scientists, for example, think of themselves as not very good communicators. But if they have successfully learned science communication, they will have learned that they have the ability to communicate. They will have included "science communicator" in their own self-image. This can play out in multiple ways: willingness to participate in science communication activities, support for their students and colleagues who communicate, reaching out to network with other science communicators.

The concept of identity was generally not addressed by the existing literature (although one or two articles did refer to it obliquely). But many people who conduct science communication training are aware of the ways that graduate students (especially) seek out such training as a way of exploring a new professional identity (Cornell University, 2014; Neeley, Goldman, Smith, Baron, & Sunu, 2014). While these students are often good at science, and have been encouraged to remain in science, they are gradually finding that they do not wish to be scientists. They are casting about for a new professional identity that lets them continue to participate in the scientific community. At the same time that they explore science communication, they may explore scientific entrepreneurship, policymaking, regulatory management, science education, and similar alternatives.

Not all science communicators are seeking to change professional identities. A science communicator identity can also be an expansion of an existing identity as a practicing scientist. Some scientists become quite visible for their science communication activities (Goodell, 1977), and in recent years some scientists such as Brian Greene, Susan Greenfield, Stephen Pinker, and Jane Goodall have explicitly chosen to embrace the celebrity that science communication affords them (Fahy, 2014). They do this both because of a commitment to broader social discussion of science, but also because they see ways that the broader discussion can help their own scientific fields.

For younger scientists, science communication identity is also part of a changing notion of what it means to ‘be’ a scientist. While the ‘Carl Sagan effect’ is said to discourage scientists from engaging with publics, the reality is somewhat different: Substantial evidence over the last 40 years has shown that three-quarters or more of scientists engage with public audiences on a regular basis (Peters et al., 2008). The frequent commitment of major scientific organizations to public engagement is also a sign of the value that the scientific community in some countries gives to science communication (Anon., 2004; Leshner, 2007; Royal Society, 2006). Of course, not every scientist, scientific organization, or national science body is equally excited by science communication and there is substantial variety. But the trend is clear. Many science communication trainers report anecdotally that students no longer fear that their advisors will find out that they are taking the training; instead, they report that advisors are the ones who suggested that they get the training (Hundey et al., 2016; Kuehne et al., 2014; Neeley et al., 2014).

NEXT STEPS: BENCHMARKING, ASSESSMENT, AND EVALUATION

Putting the learning goals for science communication into a single conceptually-driven list helps identify areas of strength in current programs and areas where more work is needed. Individual programs can compare their own focus with the broader field of science communication to which they want to contribute.

To better achieve these outcomes, however, will require identifying benchmarks for what constitutes good science communication practice, as well as tools for assessing programs and evaluating specific trainings. This is not a straightforward task.

For example, many programs teach scientists how to work more effectively with media. But what is the standard for being interviewed or for producing a good press release? Although many science communicators and science communication trainers have their own subjective judgments about what constitutes good practice, is there a standard that all trainers could agree on?

Some of the claims in the learning goals have not yet been demonstrated. For example, while a number of publications point to the development of broader conceptual themes in science communication (such as deficit, dialogue, and engagement), published research has not yet shown whether or not learners need those concepts to be better science communicators. Does knowing theory support effective science communication? Future research should try to connect these learning goals with the greater goal of effective science communication. It might also distinguish which learning goals are appropriate for which audiences: Are some of the goals more appropriate for scientists, some for people explicitly seeking careers in science communication, some for people seeking to place science communication a broader context (such as students in science-and-society programs)?

Notwithstanding these issues, the recent drive to include science communication training as a strongly-recommended or even mandatory part of graduate education in science, technology, engineering and mathematics (STEM) means that a need for assessment will arise (Cornell University, 2014; Heath et al., 2014; Neeley et al., 2014). Currently, claims for the efficacy of such training programs are often based on anecdotes and basic self-report evaluations. Training programs have remained relatively isolated, pursuing their own paths with little or no comparison (Silva & Bultitude, 2009). This lack of comparative data prevents the development of evidence-based planning or policy regarding communication training for scientists. Similarly, the participants of the GradSciCom workshop for integrating communication training into STEM graduate education (COMPASS, 2014) identified two critical roadblocks to the process: faculty support and monitoring and evaluation. They stated that “few programs do sufficient and/or appropriate evaluation to demonstrate the efficacy of their approach, making it difficult to justify large-scale return on investment” (p. 2).

By identifying the conceptually-based learning goals collated in this paper, we hope to contribute to a more robust conceptualization of science communication. From that conception, we hope that assessments for individual learning and evaluations of training programs will emerge.

Table 1. Science Communication Learning Goals

Based on the goals and objectives collated in Supplementary Table S1 from previous publications, in in this table we add learning goals that fill out the definition of learning science communication modeled on the U.S. National Research Council's definition of learning science(Bell et al., 2009).(Bell et al., 2009)

Someone who has learned science communication...

Strand	Learning goal	Learning objectives
1. Affective	Experiences excitement, interest, and motivation about science communication activities and develops attitudes supportive of effective science communication	● Thinks communicating about science is important ● Values public engagement with science ● Motivated to take part in public engagement with science activities ● Thinks science communication training is useful ● Develops audience-focused attitude ● Values trust among communicators and audiences ● Approach communication with openness, honesty, and responsibility ● Values varied perspectives among different stakeholders about science and society issues ● Being sensitive towards community views and concerns ● Feels comfortable interacting with the media ● Recognizes usefulness of science communication for career goals ● Recognizes usefulness of science communication for institutional goals
2. Content knowledge	Comes to generate, understand, remember, and use concepts, explanations, arguments, models, and facts related to science communication	● Recognizes that science communication can have multiple goals -- which are sometimes in conflict ○ Promoting excitement and interest in science, including recruiting people into science careers ○ Delivering valuable and useful information for personal or collective purposes ○ Promoting public discussion of conflicts that involve science-based issues, including identifying social values relevant to those conflicts ○ Support or critique of specific science-linked activities or technologies (such as using animals in research or using GMOs) ○ Opening new opportunities for audiences to seek out and explore science information ○ Entertainment and cultural enrichment ○ Support for science funding or for promotion of particular science institutions ● Knows the opportunities, resources, affordances, and constraints of different science communication environments

    - Knows key issues about media and journalism
        - Knows about news values/norms
        - Knows about constraints of journalism
        - Knows work patterns of science journalists and general assignment journalists who cover science
    - Knows key issues about museums
        - *To be developed in the future*
    - Knows key issues about social media
        - *To be developed in the future*
    - Knows key issues about public deliberative events
        - *To be developed in the future*
    - Knows key issues about public participation in research (citizen science)
        - *To be developed in the future*
    - Knows key issues about public science events (science fairs, etc.)
        - *To be developed in the future*
- Knows that specific communication practices (such as dialogue or message delivery) will be appropriate in different contexts depending on audience needs and communicators' objectives
- Recognizes key issues related to audiences
    - Recognizes different roles audiences can take, such as being passive receivers of information, active participants in a discussion, and generators and users of knowledge
    - Understands the importance of identifying specific audiences and reasons for communicating with them, including being sensitive to different audiences' needs and interests
- Pays attention to science communication theory, goals, and processes
    - Knows about different models of science communication (such as deficit model, dialogue model, engagement model, science literacy), including their origins, empirical support, conceptual critiques, etc.
    - Knows about the "science of science communication" and its rapid development (e.g., that how messages are framed impacts how those messages are received, how attitudes and behaviour can be changed)
    - Knows research on science, society, and culture
    - Knows principles of education, including informal science education, inquiry-based learning, and other aspects of how people learn
    - Knows that research suggests knowledge can be distributed across individuals, families, or communities
- Knows that good science communication requires multiple kinds of knowledge
    - Science content knowledge
    - Knowledge of both benefits and potential risks and limits of the science
    - Knowledge of organizations and institutions of science and their relationship with other

		parts of society (including politics, education, and media) ● Knows about institutional issues that affect science communication ○ Knows about “broader impact” criterion for judging grant proposals used by many granting agencies ○ Knows about regulatory issues affecting some science communication (such as nutrition labels and pharmaceutical advertising) ○ Understands the needs of the scientists and organisations that want to communicate
3. Methods	Uses science communication methods, including written, oral, and visual communication skills and tools for fostering fruitful dialogues with diverse audiences	● Knows how to connect with audiences ○ Defines specific audiences (e.g., policymakers, consumers, voters, children, science teachers, curious people) ○ Assesses different audiences’ needs ■ Listens to audience to understand its needs and goals ■ Uses market research to better understand target audiences ■ Uses empirical evidence to design and create appropriate and effective resources that meet audiences’ needs ○ Identifies the purpose of their interaction to themselves and their audiences ○ Develops personal connections with audiences based on shared experiences and values ○ Listens and adjust one’s interaction ○ Shows respect for an audience (and avoids showing disrespect) ● Demonstrates that scientists ○ Want to listen to audiences’ concerns ○ Are trustworthy and credible ○ Are caring and concerned about public needs ● Crafts messages suitable for specific audiences ○ Makes messages and complex ideas understandable to a range of audiences ○ Frames messages that resonate with audiences’ values or predispositions ○ Uses tools for effective storytelling ■ Engages the imagination of the audience ■ Uses common structures for narrative ● Has media skills ○ Knows how to be interviewed by media, including on-camera practice ○ Knows how to conduct an interview ○ Writes clearly for public media ○ Knows how to produce video, including specific genres, such as science documentary and video blogs ○ Knows how to produce sound, including specific genres such as podcasts ○ Knows how to produce digital media

		○ Knows how to produce and manage social media ● Has public speaking skills ○ Knows how to create and deliver presentations ● Assesses and demonstrates credibility of sources and information ● Uses principles of risk communication ● Knows tools for dealing with science controversies and social/political controversies that have scientific aspects ● Use informal science education and public participation venues (such as science museums, science festivals, science cafes, public meetings, consensus conferences) ○ Knows how to manage and facilitate public discussions ○ Engages with the public through hands-on activities ○ Develops communication strategies and artifacts that support inquiry and ○ active learning ● Has skills for managing science communication projects ○ includes “broader impact” goals and activities in funding proposals ○ Knows project management tools ○ Forms partnerships with appropriate organizations and agencies (e.g., community groups, evaluation companies, scientific societies, outreach/interface organizations) ○ Uses appropriate evaluation strategies, including front-end, formative, and summative
4. Reflection	Can reflect on science and science communication’s role within society; on processes, concepts, and institutions of science communication, and on their own process of learning about and doing science communication	● Knows something of the history, philosophy, and social context of science ● Knows about arguments about what counts as established knowledge ● Understands differences between science knowledge and other forms of knowledge ● Is aware of limitations of scientific approaches to understanding the natural world ● Recognizes both the explicit and implicit goals of research ● Recognizes the different organizational and institutional cultures in which scientists, journalists, informal science educators, and other science communicators work ● Knows that science improves when scientists have the skills for participating throughout the complex web of the science communication system ● Applies that historical, philosophical, and social context knowledge to the specific science that is being communicated ● Can critique the process and outcomes of science communication ● Is self-reflective about his or her own practice of science communication ○ Is aware of his or her own scientific values/norms (and the relationship between those values and his or her own social, political, and ethical values) ○ Is aware of the difference between providing information and acting as an advocate or persuader ○ Feels responsible for his/her own learning about the process and outcomes of science

		communication ○ Knows one’s own strengths and challenges as a science communicator ● Shares experiences with other science communicators for the purpose of learning
5. Participation	Participates in scientific communication activities in authentic settings, creating written, oral and visual science messages suitable for various non-technical audiences and engaging in fruitful dialogues with those audiences	● Increases involvement in science communication events ● Practices one’s skills in authentic science communication in a variety of environments ● Becomes a member of a network of science communicators ● Connects with local, regional, national, and international science communication networks ● Identifies and develops local community connections that enhance outreach opportunities
6. Identity	Thinks about her- or himself as a science communicator and develops an identity as someone who is able to contribute to science communication	● Feels confident and able to engage ● Identifies one’s self as a science communicator ● Includes “science communication” as a fundamental component of what it means to be a scientist ● Is perceived by others to be a science communicator

SUPPLEMENTARY ONLINE MATERIAL

Table S1: Science communication learning goals collated from published literature

(submitted as separate file)

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