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Toward narrowing the gap between science communication and science education disciplines

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Science communication and science education aim to expose citizens to scientific knowledge, which is increasingly becoming a prerequisite for effective participation in modern society. We aim to present a review of science communication and science education literature, for highlighting the need for and importance of narrowing the gap between the two communities. Our objective was to find what themes, if any, are common to the two disciplines, based on keyword searches of the literature, that represent overlap constructs between the two communities. We searched for academic articles published from 2000 to 2017 in three science communication journals and three science education journals, which contained the keywords *science communication*, *science engagement* and *science understanding*. A three-stage literature review yielded 70 papers that provided the basis for common theme identification: (i) attitudes towards the importance of science communication, (ii) communication channel types and (iii) scientific knowledge construction. Findings reveal similarities and disparities between the two communities and the stakeholders they investigated. Both communities agree on the meaning of process and product science communication constructs. Yet, while the science education community mainly relates to the product construct, the science communication community mainly relays to the communication construct. We then discuss the value of fostering dialogue between the two communities. Our research contributes to raising the awareness of the value of maintaining ongoing dialogue between science communication and science education communities, accounting for the three common themes we have identified, implying that a common language is emerging, and the variety of stakeholders involved.

Introduction

Science communication and science education researchers' goals are to foster citizens' scientific knowledge and increase effective participation in modern society (Gilbert & Stocklmayer, 2013). Science education is a community of research aimed at increasing students' scientific literacy and their ability to make informed decisions in matters that impact their daily lives and their future as adults. Yet, from a historical perspective, science education focused on pre-college and college levels, and the research by science educators focusing on the contribution of school science learning to the long-term public understanding of science (PUS) is limited. Standards, such as those proposed by the National Research Council (NRC, 2012) Framework for

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K-12 Science Education, encourage educators to supplement their formal classroom environments with science communication resources, to enable students' future participation in and contribution to society. Feinstein (2011) suggested redefining scientific literacy to include applying science in daily life and involving laypeople in science—citizen science. Indeed, researchers (e.g. Podgornik et al., 2017) suggest that educators should emphasise various modes of communication, which have been studied by science communication scholars. As Rennie (2011) noted, science communication should enable students to find the knowledge they need when they need it. Yet, most high school and younger students do not experience direct interaction with scientists, who are the most reliable source of scientific knowledge (Baram-Tsabari & Segev, 2011; Zhai et al., 2013). This view of scientific knowledge goes beyond acquaintance with a list of science concepts, principles or scientific and technical vocabulary (e.g. Wallace, 2004; Fogg-Rogers et al., 2015). It complements the call to connect science to real-life applications of a well informed and engaged public (Wu, 2003), who is scientifically literate and able to understand and critically evaluate scientific content (Roos, 2014).

Science communication has received significant attention since the beginning of the twenty-first century in an effort to improve PUS hand-in-hand with improving the public's positive attitudes towards science (Sharon & Baram-Tsabari, 2014; Short, 2013). As PUS refers to the 'ability of individuals to read and understand information about basic scientific constructs, including some technological constructs' (Miller, 2015, p. 812), it is oriented to the *product*, or outcome, of science communication. Researchers (e.g. Stocklmayer, 2015) have indicated a tendency in science communication to transition from product to the *process* of science communication. As cited by Stocklmayer (2015), the British House of Lords presented a review (House of Lords, 2000) that called on the public to rethink the relationships between science and public at large, emphasising that scientists and the scientific community should be responsible for bridging the gap between them and citizens, rather than the other way around. Along this line, they suggested replacing the term PUS with Public Engagement with Science (PES), which involves public outreach activities and a two-way *dialogue* with public stakeholders as the cornerstone of the communication process.

Despite the common goals between the science communication and science education communities, there is scarcity of dialogue and lack of exchange of ideas between these communities. Indeed, researchers (e.g. Ogawa, 2011; Baram-Tsabari & Osborne, 2015; Gardner et al., 2017) noted that there has been little dialogue between science communication researchers and science education researchers. The working assumption underlying this review is that science communication and science education share some common themes and a few overlap constructs. We conducted a keyword-based literature review of science communication and science education journals in order to compare and contrast science education as a sister discipline of science communication. We chose to use the term 'sister disciplines' since there have been more and more science education scholars who investigate the science communication discipline, and vice versa. See, for example, the *International Journal of Science Education (IJSE)—Part B*, which serves as a platform for science educators to write about science communication.

Our selection of keywords was mainly influenced by the theoretical background of science communication, as described in the next section. We then present our search methodology and the review findings. Finally, we discuss how the findings can enhance synergy between the science communication and science education communities.

Theoretical background

Science communication researchers, such as Burns et al. (2003), emphasised the need to streamline and strengthen the communication *process* by 'the use of appropriate skills, media, activities and dialogue' (p. 191) to produce the resulting *product*—the public's level of Awareness, Enjoyment, Interest, Opinions or Understanding of science (AEIOU). Beyond the process and product of science communication, this definition refers to the need of *directionality*: namely, providing an opportunity for dialogue and interaction between science professionals and the public, listening to the *voice of the customers*—the student or the public—while accounting for their previous knowledge, interest and motivation and merging the plan of action of the learner or the public with that of the science educator or science communicator (Besley et al., 2015). In what follows, we elaborate on important science constructs for this review: *process*, *product*, *directionality* and *participants*.

Cloitre and Shinn (1985) listed several science communication vehicles, including scientific journals specific to the research domain, professional conferences, publications in interdisciplinary domains, pedagogical science textbooks and popular presentations via the mass media. The latter include magazines, television shows and social networks. While these researchers discussed the process of science communication as achievable via this set of products, Palmer and Schibeci (2014) emphasised dialogue itself as a primary trait of the science communication process. They characterised several types of science communication, including *professional science communication*, *deficit science communication*, *consultative science communication* and *deliberative science communication*. Professional science communication relates to communication among scientists only, and, as such, it is not within the scope of our research. The latter three involve communication between scientists and various other stakeholders, corresponding to points along the spectrum of knowledge exchange between scientists and citizens. Indeed, there are several types of science communication models along a continuum, spanning from being completely one-way—the *deficit* model, to being completely bidirectional—the *dialogue* model (Petts & Brooks, 2006; Brossard & Lewenstein, 2010).

The *deficit* model refers to '... a unidirectional flow of information from active knowledge producer to passive knowledge receiver' (Ryder, 2002, p. 158). It features a one-way communication process from the scientists to the public, with the assumption that the public is deficient in scientific knowledge. This unidirectional form of science communication does not pay sufficient attention to stakeholders other than scientists, such as students, teachers and science education professionals, who are interested in gaining scientific knowledge (Luers & Kroodsma, 2014). The *dialogue* model advocates two-way communication between scientists and the other science communication stakeholders. Schibeci and Williams (2014) noted that the dichotomy between the *deficit* model and the *dialogue* model is simplistic, as it overlooks communication among peers. However, the traditional *deficit* model was, and still is, prevalent among scientists while they communicate with the public (Davies, 2008; Watermeyer, 2012).

Vogt (2012) emphasised the aspect of *participants*, or in our terms *stakeholders*, in various phases of science communication. The composition of the stakeholder groups has been gradually evolving. Initially, the participants on both sides of the communication, the disseminators, from whom scientific knowledge originates and the recipients, to whom delivery of scientific knowledge is directed, were scientists. This is what Palmer and Schibeci (2014) referred to as *professional science communication*. In the next phase, the disseminators were scientists and teachers while the recipients were students. The disseminator group later expanded to include museum directors and cultural promoters of science, while the recipient stakeholder group grew to encompass the public more broadly, and not just students. Currently, the disseminators also include journalists and policy-makers—informed by scientists or by science communicators—whereas the target audience includes all members of public. The type of science communication we evaluate in this study targets the public at large, with the intention of making all members of society scientifically literate, rather than just students in schools and universities (Feinstein, 2011).

The close relationships between science communication and science education, along with their similar goals and underlying didactics, indicate that there may be more points of shared interest and mutual benefit from understanding them than what meets the eye. The intricate interplay between these disciplines and the potential benefit to both disciplines has motivated this study, in which we reference, compare and contrast science education as a sister discipline of science communication. In this review we aimed to identify similarities and disparities, in terms of themes and target stakeholders, between these two seemingly close communities. The main guiding objective in our study was to find what themes, if any, are common to the science communication and science education disciplines. To this end, we conducted a keyword-based literature review of science communication and science education journals.

Method

Approach and study methodology

Since this study aims to extract themes from current literature in the two sister disciplines, we based our research, and the analytical generalisation of our resulting themes, on looking into the data inductively (Yin, 1984; Creswell, 2014). We followed Lather (1986) and Creswell (2014) who advocated that for extracting themes, one should build empirically grounded theory from particulars to general, while interpreting the meaning of the data. We can then find bidirectional relationships between data and theory, where a possible relationship is allowed to be generated in a manner that goes hand-in-hand with the theory. Indeed, we start by theorising that since science education and science communication are closely related; it must be the case that they have common themes, which require identification and specification. This has led to our three-stage literature review, which, as we explain below, enabled us to narrow the set of retrieved articles from over 10,000 after the first round to just 70 after the third round. This is a manageable quantity of articles that can be analysed one by one and provide a solid basis for pinpointing common themes, as well as similarities and differences between the two disciplines.

Sample selection

Communication and education paradigms continue to quickly evolve and change as we approach the second decade of the twenty-first century (Shea, 2015). Reviewing all that has been published on science communication in science communication and science education journals is an impossible task for humans, and the number of articles about these topics continues to grow daily with emphasis on different audiences.

We focused on research studies published by six highly cited international peer-reviewed journals; each represents pertinence to the two disciplines, from pure to a potential joint interest between the disciplines: The first pair of journals is *Science Communication* and *Science Education*; the second pair of journals is *International Journal of Science Education (IJSE) – Part A* that focuses on traditional science education studies vs. *Part B* that targets the issues of communication and public engagement; and the third pair of journals is *Public Understanding of Science*, which pertains science education particularly through the studies of informal educational settings and *Journal of Research in Science Teaching*, which has just lately dedicated a special issue to science communication, titled *Bridging Science Education and Science Communication Research*.

Search criteria

Our search within the aforementioned journals was limited to articles published between 2000 and 2017, as these articles are the most informative in regards to the current state of science communication and education. The literature search was performed by concatenating the term science with the following three additional keywords, representing the aspects of science communication and science education we aimed to investigate:

(1) *Communication*—a term relating to models of science communication between different stakeholders;
(2) *Engagement*—a term related to Public Engagement with Science (PES) with reference to the involvement of various stakeholders in the process of science communication or science education; and
(3) *Understanding*—a term relating to the product, namely, the Public Understanding of Science (PUS), which refers to the level of scientific knowledge gained by the various stakeholders, including students (the target of science education) and the general public (the target of science communication).

Science education is a much older and established discipline, and presumably covers more ground than science communication. Yet, while keeping in mind our intent to emphasise educational aspects, it made sense to pick keywords that, while being common to both disciplines, are more prevalent in science communication. For example, including a keyword such as *teaching* or *learning* would result in numerous science education articles, but few if any in science communication articles. Therefore, we excluded these words from our review. The keywords we chose, which are common to the two disciplines under study (with the exception of *communication*, which is a term used almost exclusively in science communication), enabled us to find similarities and differences between the science communication and science education disciplines, helping to obtain the goal of narrowing the gap between the two disciplines. With respect to this gap, there is a wide spectrum of learning settings for communicating science to different stakeholders, starting with a traditional teacher–student interaction in a formal school setting within science education studies and informal settings for communicating science to the public, such as the media. Within this spectrum, there are intermediate settings, referring to formal school settings that use diverse teaching methods, such as inquiry learning and informal settings for learning, such as museums. Our premise in this study was that while these two disciplines are still distant from each other, we can focus on the intermediate spectrum within this gap (excluding the formal students–teacher interaction in the schools setting).

Paper selection procedure

Our review process involved three searches and filtering rounds (marked I, II and III). In round I, we conducted a Boolean search, including each one of the three unquoted keyword *science communication*, *science engagement* and *science understanding* with the operator AND between the two words. Unquoted Boolean searches look at the entire database for the entered keywords, regardless of their location in the article. The total number of papers retrieved this way was overwhelming (N_{I} = 10,209), and most were irrelevant to any of the science communication constructs, such as *process* or *product*. To narrow the search, in round II we added quotation marks around each word pair, e.g. '*science engagement*', searching for the entire quoted phrase. Such Boolean search looks in the database for the exact quoted term. This round filtered out about 95% of the papers retrieved in the previous round, leaving N_{II} = 609. Finally, in round III, we examined 609 abstracts and about half-full articles, and filtered them according to the following criteria.

Inclusion criteria

Since our initial sample included over 10,000 papers, we had to apply stringent criteria in order to reduce the number of studies and make the review more coherent and focused. Therefore, we applied the following criteria.

- We included only empirical papers, because they are more likely to investigate dialogues between two or more stakeholder groups than theoretical or practice-oriented papers.
- Each paper that was included in the review had to involve a dialogue between at least two different stakeholder groups. Examples include dialogues between scientists and the general public, scientists and students and students and media. We

even included a paper (Roos, 2014), which presents a hypothetical dialogue between the National Science Foundation (NSF) personnel and scientists.
- At least one science communication construct—*process*, *product*, *directionality* or *stakeholders*—must appear in the paper in the title or abstract of the publication.

Abstracts serve as 'advance indicators of the content and structure of the following text' (Swales, 1990, p. 179). Indeed, as we focused our search on studies that appeared in highly rated journals, most of the abstracts followed a structure of Problem–Method–Results–Conclusions, which enabled us to understand their main research goal, participants and conclusions. Yet, when one or more of these components were unclear, we read the entire article. This was the case with about half of the papers that we ultimately included in the review.

Exclusion criteria

Most science education papers describe dialogues that take place inside traditional classrooms between teachers and students. As our aim was to investigate informal means of science communication and their impact on science understanding, we excluded papers reporting on traditional classroom settings. Other excluded studies were those that investigated communication in only one type of stakeholders, such as those investigating how science communicators communicate with one another (e.g. Jarman et al., 2012), as well as studies that did not investigate any dialogue. After applying these inclusion and exclusion criteria, N_{III} = 70 papers remained. The primary goal of these papers was communicating science to diverse stakeholder groups, which are not only school students and teachers.

Table 1 summarises the number of papers found in the science communication and science education literature, using the two methods of Boolean keywords search.

The same search method was applied when searching each of the six journals, of which three—science communication journals and the other three—science education journals. The far left column of Table 1 indicates the research community (science education and science communication), while the adjacent column to the right includes the journal name. The three middle columns represent the three search rounds and the filtering criteria for each round. The next column to the right presents the percentage of the total number papers found in round II out of those found in round I and the percentage of papers found in round III out of those found in round II. The far right column in Table 1 presents examples of six papers, resulting from round III, indicating the focus of the study, its scientific discipline, and the stakeholders involved. The remaining 64 papers are described in Appendix A.

Validity and inter-rater reliability

Taking a holistic approach, we looked over the 70 papers that remained after the third round of screening. We used thematic analysis (Braun & Clarke, 2006; Strauss & Corbin, 1994) that is a theoretically flexible approach for the analysis of qualitative data. Using this approach, we were looking for a pattern within the data set, attempting to capture the important themes that are identified with both science communication and science education disciplines. A recursive process of thematic analysis was

Table 1. Numbers and percentages of the papers found in the science education and science communication literature

(a) Keyword searched '*science communication*'

Research community[1]	Search round & keywords	Round I—Science communication	Round II—'*Science communication*' as whole phrase	Round III—'*Science communication*' among at least two stakeholder groups[2]	% of total papers found from previous round: Round II/ Round I	% of total papers found from previous round: Round III/ Round II	Examples of studies focusing on the three themes
SCI ED	Journal *Journal of Research in Science Teaching*—JRST	432	15	**1** – Zhai and Dillon (2014)	4%	9%	**Theme** *Communication channels types* **Goal** The study investigates patterns of discourse during guided school visits (Zhai & Dillon, 2014) **Scientific discipline** Plant-based science **Stakeholders** *Scientists*—botanic garden educators (BGEs) *Students*—elementary school
	Science Education	359	25	**1** – Wallace (2004)			
	International Journal of Science Education—IJSE, *Part A*	849	30	**4** – e.g. Bultitude and Sardo (2012)			

Table 1. (Continued)

(a) Keyword searched '*science communication*'

Research community[1]	Search round & keywords	Round I—Science communication	Round II—'*Science communication*' as whole phrase	Round III—'*Science communication*' among at least two stakeholder groups[2]	% of total papers found from previous round: Round II/Round I	% of total papers found from previous round: Round III/Round II	Examples of studies focusing on the three themes
SCI COM	*International Journal of Science Education*—IJSE, *Part B: Comm. & Public Engagement*	52	26	**8** – e.g. Schibeci and Williams (2014)	12%	20%	**Theme** *Attitudes toward the importance of science communication* **Goal** The study questions whether technology policy formation should rely on experts' recommendations or on opinions of the public (Sapp et al., 2013) **Scientific discipline** Agriculture **Stakeholders** *Scientists* *Policy-makers* *Public*—adults, ages 21–65
	Public Understanding of Science	707	60	**6** – e.g. Besley et al. (2012)			
	Science Communication	553	65	**16** – e.g. Sapp et al. (2013)			
Total		2952	221	36	**8%**	**16%**	

Table 1. (Continued)

(b) Keyword searched '*science engagement*'

Research community	Search round & keywords Journal	Round I—*Science engagement*	Round II—*Science engagement* as whole phrase	Round III—*Science engagement* among at least two groups	% of total papers found from previous round Round II/Round I	 Round III/Round II	Examples of studies focusing on the three themes
SCI ED	JRST	396	13	**0**	2%	9%	**Theme** *Communication channel types* **Goal** The study examines how teachers evaluate an out-of-school science enrichment programme—a one-year partnership with a local university, which culminated in a half-day laboratory experience for their students (Luehmann & Markowitz, 2007) **Scientific discipline** Science in general **Stakeholders** *Scientists* *Teachers*—science teachers *Students*—secondary science students
	Science Education	360	5	**1** – Mestad and Kolstø (2014)			
	IJSE, Part A	1123	15	**2** – e.g. Luehmann and Markowitz (2007)			

Table 1. (Continued)

(b) Keyword searched '*science engagement*'

Research community	Search round & keywords Journal	Round I—*Science engagement*	Round II—*Science engagement* as whole phrase	Round III—*Science engagement* among at least two groups	% of total papers found from previous round		Examples of studies focusing on the three themes
					Round II/ Round I	Round III/ Round II	
SCI COM	IJSE, Part B	55	5	**1** – Wilkinson et al. (2012)	3%	45%	**Theme** *Communication channel types* **Goal** The study explores collaboration between scientists and games developers for observing how 'gamifying' science can be used to engage the wider public (Curtis, 2014) **Scientific discipline** Biomedical sciences or medical humanities **Stakeholders** *Scientists* *Undergraduate Students*—biomedical sciences or medical humanities *Public*—professional game developers
	Public Understanding of Science	425	9	**3** – e.g. Kamolpattana et al. (2015)			
	Science Communication	186	6	**5** – e.g. Curtis (2014)			
Total		2545	53	12	**2%**	**23%**	

Table 1. (Continued)

(c) Keyword searched '*science understanding*'

Research community	Search round & keywords Journal	Round I—*Science understanding*	Round II—*Science understanding* as a whole phrase	Round III—*Science understanding* among at least two groups	% of total papers found from previous round: Round II/Round I	% of total papers found from previous round: Round III/Round II	Examples of studies focusing on the three themes
SCI ED	JRST	825	104	**2** – e.g. Tal and Dierking (2014	9%	4%	**Theme** *Attitudes toward the importance of science communication* **Goal**: The study describes the potential for collaborative work between science educators and citizenship educators **Scientific discipline**: Science in general **Stakeholders:** *Scientists*—science educators *Teachers*—citizenship educators (Davies, 2004)
	Science Education	835	94	**3** – e.g. Barak and Dori (2005			
	IJSE, Part A	1554	97	**8** – e.g. Davies (2004)			

Table 1. (Continued)

(c) Keyword searched ‘*science understanding*’

Research community	Search round & keywords Journal	Round I—*Science understanding*	Round II—*Science understanding* as a whole phrase	Round III—*Science understanding* among at least two groups	% of total papers found from previous round: Round II/Round I	% of total papers found from previous round: Round III/Round II	Examples of studies focusing on the three themes
SCI COM	IJSE, Part B	56	4	0	2%	34%	**Theme** *Scientific knowledge construction* **Goal**: The study presents a method of assessing the lay public scientific knowledge or literacy, using the NSF science literacy scale, and refers to this scale as a single dimension via bi-dimensional structure **Scientific discipline**: Evolution **Stakeholders:** *Scientists* —The National Science Foundation (NSF) *Public* (Roos, 2014)
	Public Understanding of Science	1022	21	**7** – e.g. Roos (2014)			
	Science Communication	420	4	**3** – e.g. Fogg-Rogers et al. (2015)			
Total		4712	324	23	**7%**	**7%**	

Note: [1]SCI ED = Science Education, SCI COM = Science Communication.
[2]Additional citations are presented in Appendix B.

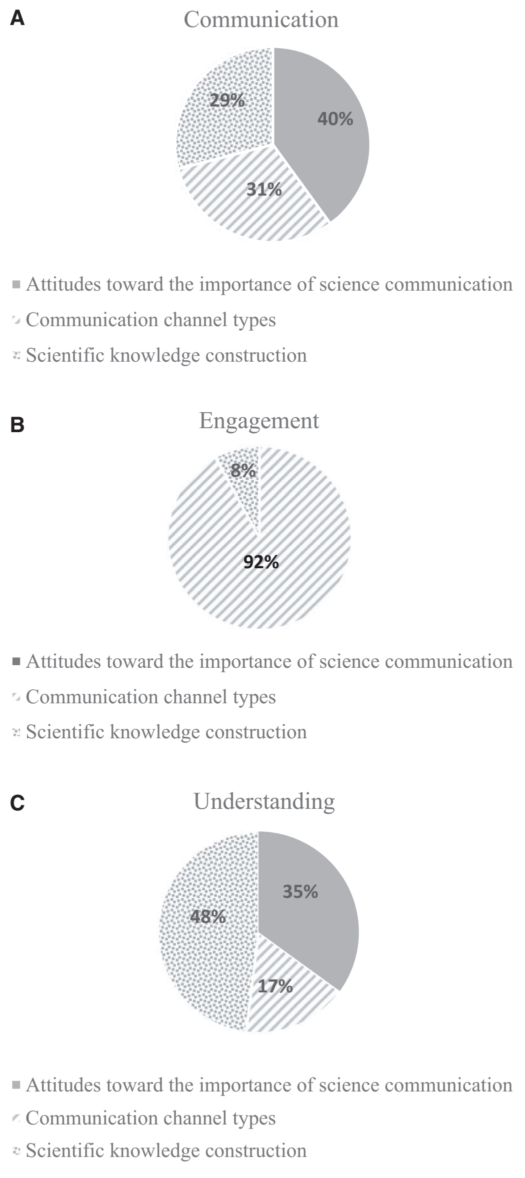

Figure 1. Frequencies of papers retrieved for each of the three keywords: Communication, Engagement, and Understanding

repeated five times, until the authors reached full agreement with respect to the following three main themes: (a) attitudes towards the importance of science communication, (b) communication channel types and (c) scientific knowledge construction. These themes are explained in detail in the findings section.

For each one of the three themes we have discovered, the far left column in Appendix A indicates the research community (science education or science communication), the adjacent column to the right describes the scientific domain of study, the next two columns to the right include the focus of the study and the stakeholders, and the far right column includes the citation of the specific paper.

Figure 2. A word cloud generated from the titles and abstracts of the 70 papers that remained after the third filtering round

An inter-rater reliability analysis using Cohen's κ statistic was performed by three science education experts to determine raters' consistency regarding (1) inclusion of each study in the review and (2) categorising each selected paper into one of the three themes. The inter-rater reliability of this process was $\kappa = 0.83$ and $\kappa = 0.86$ respectively, indicating above satisfactory level of agreement.

After the themes were determined and validated, we calculated the frequencies of studies associated to each of the literature-based keywords searched (see Figure 1), sorted by theme. We also created a word cloud (see Figure 2), also known as a text cloud or a tag cloud, which enabled us to create a visual representation for the textual data (Cui et al., 2010). According to McNaught and Lam (2010), word clouds serve as a tool for data representation/visualisation that can strengthen findings and interpretations of those findings. A word cloud is generated as follows: the more frequently a specific word appears in a source of textual data, the bigger and bolder it appears in the word cloud. The methodological terms were extracted from all titles and abstracts of the 70 studies and entered as a one long text sequence into Wordle (Feinberg, 2009), an online tool that generates a word cloud. It allowed us to quickly and meaningfully visualise the most frequent terms found within the selected literature.

Mapping the results

In order to find similarities and disparities between science communication and science education papers, we performed quantitative analysis of the number and frequencies of papers retrieved for each community of stakeholders. By examining the frequencies and the relations between the keywords and the themes, we made comparisons, based on: (a) papers retrieved by keywords; (b) papers that were categorised by themes; and finally, (c) the relationships between the keywords and the themes.

Results

Inspired by the four science communication constructs of *process*, *product*, *directionality* and *stakeholders*;" (Cloitre & Shinn, 1985; Bucchi, 1999, 2012; Vogt, 2012), after reading and re-reading the retrieved papers, we extracted three themes that are common to the two communities: (i) *attitudes toward the importance of science communication*, which involves various stakeholders beyond scientists and the public, (ii) *communication channel types*, which refers to the process of science communication and (iii) *scientific knowledge construction*, which refers to the product of science communication, i.e. stakeholders' level of scientific knowledge and science understanding.

Attitudes towards the importance of science communication

This theme refers to one's attitudes towards, and awareness or perceptions of science —simply, one's beliefs about science. For example, a study from the science education literature, conducted by Bennett and Hogarth (2009), described the development of an instrument, called the Attitudes to School Science and to Science, which aimed at providing insights into shaping students' attitudes toward science, especially outside of school. A different study from the science communication literature (Besley et al., 2012), investigated the motivations, beliefs, and conditions that promote scientists' involvement in communication with the public and the news media.

Communication channel types

The *communication channels* theme concerns the instruments or methods that enable the *process* of scientific discourse, which is aimed at knowledge construction, primarily between scientists as knowledge disseminators and the other stakeholders as knowledge recipients. Studies suggest that the most common channels scientists tend to use for communicating with the public are mass media (e.g. Tøsse, 2013). Inspecting two other examples in the *communication channels* theme include (1) a science communication study by Kurath and Gisler's (2009), which investigated the shift towards more democratic interactions in six public engagement projects in nanoscale sciences and technologies, and (2) a science education study by Fields (2009), which explored American high-school students' perceptions of the benefits of an astronomy summer camp.

Scientific knowledge construction

The *scientific knowledge construction* theme pertains to creating the *product*—scientific knowledge—expected to increase as a result of the discourse between scientists and other stakeholders. The following are two examples for assigning studies to the *scientific knowledge construction* theme. A study by Linn (2000), from the science education literature, described the partnership process between scientists and teachers, which guided the design of the Knowledge Integration Environment (KIE) activities for engaging students in debating science questions in order to make scientifically oriented design decisions to critique science claims in the popular press. Another science communication study, conducted by Baram-Tsabari and Lewenstein (2013), described the development of a tool for measuring scientists' written skills, such as knowledge organisation and conducting dialogue in public communication of science. More examples for each one of the themes are presented in Table 1 and in Appendix A.

Figure 1 presents the frequencies of papers retrieved that focus on each one of the three themes found for each of the three keywords, *Communication* (Figure 1a), *Engagement* (Figure 1b) and *Understanding* (Figure 1c).

As Figure 1 shows, in studies focusing on communication between different stakeholders, the three resulting themes are distributed almost equally. This makes sense, because communication is the focus of the entire science communication discipline, the three themes are distributed more or less evenly. However, upon examining papers retrieved with the keyword 'engagement', or Public Engagement with Science (PES), we found they almost exclusively focused on the process of science communication, i.e. the communication channel theme. Finally, searching for the keyword 'understanding', which is identified as the *product* of science communication, or Public Understanding of Science (PUS), led to us retrieving studies whose main focus is the scientific knowledge construction theme.

Our decision to define the three themes the way we did is reinforced in Figure 2, which presents a word cloud of the text contained in the titles and abstracts of the 70 papers that remained after the third filtering round.

Words that appear more frequently in the source text are larger in the word cloud. Indeed, the word cloud provides a holistic view of our review. It consists of the main keywords used for the literature search: *science*, *communication*, *engagement* and *understanding*. The largest word is *science*, followed by *communication*—the two words that are at the core of the study. The word cloud also contains words that comprise our main themes: *scientific*, *knowledge* and *attitudes*. The words *channel* or *channels* from the theme *communication channels* do not appear, but we see words that represent channels of communication, such as *media*, *technology* and *activities*. One of the important types of science communication models, *dialogue*, is also present. Finally, the word cloud contains all the major science communication stakeholders: *participants*, *scientists*, *teachers*, *students*, *experts*, *children*, *people* and *publics*. This weighted aggregation of words is unique in that it points to the commonality of terms or concepts between the two communities researched in this study.

Similarities and disparities between the communities

Table 2 presents the number of papers first retrieved by keywords and then sorted by themes for each community (Table 2a & 2b respectively).

One similar aspect of papers from both communities, is that the keyword *engagement* appeared with the least frequency, accounting for less than 20% of the papers

Table 2. Quantitative summary of the third-round results

(a) Numbers and frequencies of papers retrieved by keywords

Keyword searched	Science communication	Science engagement	Science understanding	Total
Community				
Science Education	6 (27%)	3 (14%)	13 (59%)	22 (100%)
Science Communication	29 (60%)	9 (19%)	10 (21%)	48 (100%)

(b) Numbers and frequencies of papers categorised by themes

Theme	Attitudes toward the importance of science communication	Communication channel types	Scientific knowledge construction	Total
Community				
Science Education	6 (27%)	5 (23%)	11 (50%)	22 (100%)
Science Communication	16 (33%)	21 (44%)	11 (23%)	48 (100%)

(c) Numbers and frequencies of papers for which a theme corresponded to a keyword

		Themes			
Community	Keyword	Attitudes toward the importance	Channel types	Knowledge construction	Total (N_{papers} = 70)
Science Education	*Communication*	0 (0%)	2 (33%)	4 (67%)	6
	Engagement	0 (0%)	2 (67%)	1 (33%)	3
	Understanding	6 (46%)	1 (8%)	6 (46%)	13
Science Communication	*Communication*	14 (48%)	9 (31%)	6 (21%)	29
	Engagement	0 (0%)	9 (100%)	0 (0%)	9
	Understanding	2 (20%)	3 (30%)	5 (50%)	10

Note: The grey shaded cells indicate the highest frequency in which the theme appeared, based on each keyword.

(see Table 2a). Examining Table 2b, we see that in both communities, the frequency of papers focusing on the theme *attitudes toward the importance of science communication* was about 30% among both communities. Finally, Table 2c shows similarities between the numbers of papers retrieved for two keyword–theme combinations of about 50% or more, between both communities: (i) the keyword *science engagement* and the *communication channel types* theme, and (ii) the keyword *science understanding* and the *scientific knowledge construction* theme.

Turning to differences between the science communication and science education communities, we see in Table 2a that in science education, most of the papers (59%) were yielded by searching for the keyword *science understanding*, while in science communication, the most frequent keyword (60%) was *science communication*. As for the themes, half of the science education papers were categorised under the theme *scientific knowledge construction*, while slightly less than half (44%) of the science communication papers were categorised under the theme *communication channel types*. Another difference between the two communities is presented in Table 2c with respect to the commonalities between the keyword *science communication* and *science understanding* with the two themes *attitudes toward the importance of science communication* and *scientific knowledge construction*. In the science education literature, there was a high correspondence to the *scientific knowledge construction* theme for both keywords—*science communication* (67%) and *science understanding* (46%)—while in science communication, about half of the papers that were retrieved for the keyword *science communication* common to the theme of *attitudes toward the importance of science communication* and half of the papers that were retrieved for the keyword *science understanding* were common to the theme of *scientific knowledge construction*.

Finally, there was also a difference between levels of stakeholder diversity in the two communities. We found this difference through careful examination of the various stakeholders as they are reflected in the studies selected in our review (see Appendix A). Stakeholders, also referred to as *participants* (Vogt, 2012), are the individuals and groups that take part in the science communication process. The science communication literature recognises the existence and roles of the different stakeholders that are involved in science communication, namely scientists, science communicators, journalists, media professionals, policy-makers and the public, and to a lesser extent teachers and students. Conversely, the primary stakeholders in science education are students and teachers, while the secondary stakeholders are scientists and the public. Figure 3 summarises the three themes of science communication that are common to science communication and science education literature and the different stakeholders who are commonly investigated in these communities.

Discussion and conclusion

One important area where goals of science educators and science communicators overlap is fostering the importance of science in society and engaging various stakeholders in fruitful dialogue about science (Baram-Tsabari & Osborne, 2015). The current literature review presents a theoretical contribution that lies in the identification and exploration of similarities and disparities between science communication and science education. Based on three main themes that are common to the two

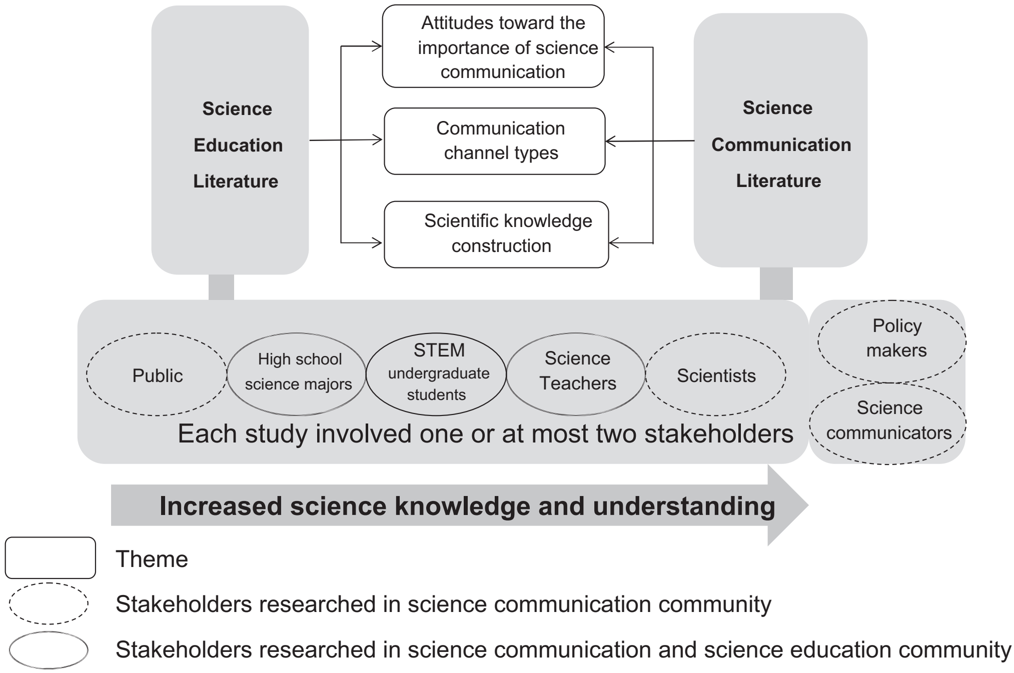

Figure 3. Stakeholders and themes in science communication and science education

disciplines: *attitudes towards the importance of science communication*, *communication channel types* and *scientific knowledge construction*, we show that both communities recognise the importance of science communication. This is reflected by the fact that about one-third of the papers focus around the theme *attitudes towards the importance of science communication*. We restricted our search to papers in which there were more than two stakeholders and no formal student–teacher interaction, as this is a clear signal of the high importance that the two communities attribute to informal, non-traditional science communication (Feinstein, 2011). Our findings reveal that about half of the papers represented informal learning settings and the other half represented formal, but with diverse learning methods (not traditional), which both represent the intermediate spectrum within the gap between the two disciplines. While it is not surprising that science communication researchers view the focus of their research as important (e.g. Winter, 2004; Baker-Doyle, 2013), it is not trivial that many science education researchers hold a similar view on the topic of citizen science and exposing the public at large to informal science learning.

We found similarities between the two communities in terms of studies focusing on the three themes (see Table 2). The corresponding keywords between the papers, and the themes these papers focused on, revealed interesting findings. The search for the keyword *science engagement* matched, for the most part, papers that focus on the *communication channel types* theme. This makes sense, because engagement in science is made possible via communication channels (Rennie, 2011). Papers found with the keyword *science understanding* matched mostly the *scientific knowledge construction* and the *attitudes toward the importance of science communication* themes. This is also logical, because science understanding is tightly coupled with knowledge construction (France & Bay, 2010). Even more importantly, this finding implies that both communities agree on the meaning of *process* and *product*, as defined in the theoretical framework of science communication (Cloitre & Shinn, 1985; Palmer & Schibeci, 2014), and value its importance. The two communities view *communication channel types* as enabling the *process* of scientific dialogue for knowledge construction, and the dialogue between the scientists and the other stakeholders as the constructor of the *product*—the scientific knowledge of the public at large and of specific portions within it. One key sector of the public is, of course, the student population; indeed, the focus of science communication in the context of science education is the discourse that involves scientists, teachers and students as the three main stakeholder groups (Hall et al., 2013; Huttunen & Hildén, 2014).

Turning to the disparities, we found that one obvious difference was that the majority of the papers in the science education community were retrieved via the keyword *understanding of science*, whereas the papers from the science communication community were found by looking for the keyword *science communication*. This finding underscores the differences between the ways the two communities conceive *process* and *product*. As Table 2c shows, articles that were found by searching for *science engagement* matched mostly the theme *communication channels types* rather than *scientific knowledge construction*, particularly with papers retrieved from science communication journals (e.g. Anderson et al., 2011; Drumm et al., 2015). This finding implies that the science education literature views communicating science not just as a means to promote scientific knowledge (e.g. Barak & Dori, 2005), but for the promotion of communication channels, almost as an end in itself (e.g. Bultitude & Sardo, 2012).

Almost half of the articles in the science education literature highlight the importance of science communication in promoting scientific knowledge construction. In the science communication literature, about half of the articles focus on *communication channel types*. This difference between the two communities demonstrates that the science communication community mostly considers the process of communicating science to the public, whereas the science education community by and large focuses on the product—the knowledge and understanding of science that students gain as a result of learning and engaging with science (Bromme & Goldman, 2014).

The most notable difference between studies conducted by the two communities relates to the type of investigated stakeholders. Science communication investigations mainly encompass scientists and citizens, while in science education, the main stakeholders are teachers and students, with the occasional involvement of scientists. Still, the focus of communicating science to various stakeholders among the science education community has become more widespread. At the same time, the science communication literature has broadened its view of how science is communicated, which currently includes the community at large as well as the need for decision-makers to promote scientific knowledge among the entire public (e.g. Korsmo, 2004).

The two disciplines contain several key overlapping constructs, but some of them are explicit in one and implicit in the other, and vice versa. For example, knowledge construction is explicit in science education but implicit in science communication. Conversely, communication channels are at the core of science communication, but are considered to a lesser extent in science education. Both communities consider knowledge acquisition as the central theme of their work, but their target audiences are different. This review makes it possible for each community to explicate the constructs that are still implicit and not well defined, using definitions and experience gathered in the sister community. The study provides a firm basis for future, large-scale research that encompasses the various stakeholders in each community.

We are aware of the limited choice of keywords for this literature review, and that they were more prevalent in the science communication discipline. We are also aware to the fact that our choice of keywords stems from our wish to narrow educational aspects of science communication on the one hand, and ignoring other perspectives of science communication that are not relevant for educational research, such as civic or historical ones, on the other hand. Yet, the benefit of this decision was ultimately reinforced in our study, as we managed to find three common themes for both disciplines, which were not unique to either community. Our practical contribution lies in raising the awareness of stakeholders from both communities to the three common themes, thus creating a common language for encouraging various stakeholders to investigate shared goals and practices. Besley et al. (2015) have strengthened the claim that each of the two communities needs the other in order to further develop and flourish. Our review supports this claim by showing that a common language is emerging. While researchers often refer to the three themes as distinct and separable, we assert that they are interwoven and often inseparable, and should be considered as part of a holistic system within the two following aspects. The first aspect is *public engagement in science*, which has typically addressed the outcomes of visiting an institution such as a museum, or engaging in a science-related hobby, where learning about science and technology occurs. The second aspect, *public understanding of science*, concerns what lay people know and understand about science. We brought to the forefront the literature of both communities and the merit of brining the two together. A future step could involve science communication as a supplement, and in some cases even as an enrichment, to classroom-based instruction, assisting in fulfilment of the goals of the Framework for K-12 Science Education (NRC, 2012).

Another practical contribution for both communities is the importance of dialogue we have discovered between scientists and the other stakeholders, which constructs the *product* of scientific knowledge. The significance of this finding is reinforced as the type of science communication we evaluated in this study targets the public at large, with the intention of making all members of society—and not just school and university students—scientifically literate. That is why we excluded papers reporting on traditional classroom settings, which involve traditional science communication between teachers and students. Yet, it would be helpful to further investigate the overlap between these two communities and we suggest expanding the review to include also the formal learning as well as the number and types of stakeholders, such as students, school teachers and principals.

Our study shows that both disciplines have very much in common in terms of research interests and stakeholders. This growing similarity is a welcome trajectory, as both communities can benefit from joint research revolving around the three common themes and the common stakeholders we have identified in this study, as well as from investigating the nuances along the science communication and science education process–product spectrum.

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Appendix A: Additional examples for Table 1: Studies focusing on the three themes

Research com-munity	Scientific discipline	The focus of the study	Stakeholders	Reference
(a) Attitudes toward the importance of science communication				
SCI ED	Health	This article uses the outbreak of severe acute respiratory syndrome—a recent health scare—as a case study to explore the roles of science and their relationship with the nature of science and societal factors	**Policy-makers** **Students** **Public**—citizens	Lee (2008)
SCI ED	Science in general	The study describes a four-year project involving the development of a new instrument, the Attitudes to School Science and to Science instrument, giving insights on attitudes toward science, in particular the view of science outside of school and shaping students' attitudes	**Scientists** **Students**—high school	Bennett and Hogarth (2009)
SCI ED	Science in general	Exploring the kinds of identities female students construct and how they perceive themselves as successful in doing science	**Teachers** **Students**—middle school African American female students **Public**—students' parents and focus groups	Brickhouse et al. (2000)
SCI ED	Science in general	The study explores teachers' views of scientists and scientific research, in order to understand how they negotiate their views of scientists and scientific research in the classroom, and how these views informed their practices of using inquiry in the classroom	**Scientists** **Teachers**—science teachers	Mansour (2015)

Appendix A. (Continued)

Research com-munity	Scientific discipline	The focus of the study	Stakeholders	Reference
SCI ED	Science in general	The study is a position paper that reinforces the need to enrich curricula that emphasise the nature of science (NOS) by exposing students to voices of practicing scientists	**Scientists** **Students**	Hodson and Wong (2014)
SCI COM	Biotechnology	The study examines views of science communication training for undergraduate science students and its possible inclusion in a biotechnology degree course at an Australian university	**Scientists**—biotechnology lecturers **Science communicators**—lecturers	Edmondston and Dawson (2014)
SCI COM	Biotechnology and Nanotechnology	The study investigates the role of scientists in public communication, and introduces three different types of presenters	**Scientists—**expert, research manager, guardian of science **Public**	Horst (2013)
SCI COM	Geology	The study explores attitudes regarding the policy debate of fracking in the United Kingdom	**Policy-makers**—UK institutional stakeholders familiar with the scientific aspects of 'fracking' **Public**	Williams et al. (2015)
SCI COM	Human Biotechnology (HBT)	The present study investigates experienced benefits of dialogue by examining attitudinal changes among laypeople and scientists in dialogue on the topic of human biotechnology (HBT)	**Scientists** **Public**	Zorn et al. (2010)
SCI COM	Geoengineering	The study explore how researchers frame geoengineering and what implications these frames have for the science–policy interface and the politicisation of science	**Scientists** **Public**	Huttunen and Hildén (2014)

Appendix A. (Continued)

Research com-munity	Scientific discipline	The focus of the study	Stakeholders	Reference
SCI COM	Nanotechnology and biofuels	The study presents a systematic comparison of two alternative measures of citizens' perceptions of risks and benefits of emerging technologies and refers to the need of scientists to revisit notions of measurement for informing other stakeholders	**Scientists** **Policy-makers** **Science communicators**—journalists **Public**	Binder et al. (2011)
SCI COM	Science in general	The study investigates motivations, beliefs, and conditions that promote scientists' involvement in communication with the public and the news media	**Scientists** **Public**	Besley et al. (2012)
SCI COM	Science in general	The study introduces the 'Cafe Scientifique' model for engaging adults in dialogue with scientists on issues at the nexus of science and society to address the specific needs and interests of high-school age youth	**Scientists** **Science communicators** **Students**—youth	Hall et al. (2013)
SCI COM	Science in general	The article introduces the special issue of Science Communication on 'nanotechnology and the public', arguing the importance of studies that deal of 'nanotechnology and the public' for science and society	**Scientists** **Public**	Lewenstein (2005)
SCI COM	Science in general	The study investigates if and how a science-rich episode of the animated sitcom—The Simpsons—influences participants' perceptions of science in an undergraduate science communication course	**Scientists**—university scholars **Undergraduate Students**	Orthia et al. (2012)

Appendix A. (Continued)

Research com-munity	Scientific discipline	The focus of the study	Stakeholders	Reference
SCI COM	Science in general	The study assesses the perceived image of scientists	**Scientists** **Students** **Public**	Ruiz-Mallén and Escalas (2012)
SCI COM	Science in general	The article presents a report of the 2004 Annual Meeting and Science Innovation Exposition of the American Association for the Advancement of Science	**Scientists**—engineers **Science communicators**—journalists **Public**—parents, children, and others interested in science	Valenti (2004)
SCI COM	Science in general	This article provides an overview of science communication, reviewing the problem of science communication, which may be partly responsible for widespread science illiteracy and ways for improving the practice of science communication	**Scientists**—scientists and science information professionals **Science communicators**—news organisations and reporters **Public**	Weigold (2001)
SCI COM	Science in general	The article describes the German initiative Science in Dialogue and its projects in the field of (1) informal science education at the interface of universities and schools, (2) science in fiction to reach a wider audience, and (3) public engagement in scientific issues	**Scientists** **Undergraduate students** **Students**—school students **Public**	Winter (2004)
SCI COM	Biotechnology	The study introduces the importance of active consultation and inclusion of 'the public' in government and commercial innovation	**Policy-makers**—Australian government **Scientists**—biotechnologists **Public**—Australians	Dietrich and Schibeci (2003)

Appendix A. (Continued)

Research com-munity	Scientific discipline	The focus of the study	Stakeholders	Reference
(b) *Communication channel types*				
SCI ED	Astronomy	This study explores American high-school students' perceptions of the benefits of a summer astronomy camp. Interviews with students and staff were used to elicit the specific benefits that campers perceived from their experiences and examine them in relation to the stated goals and strategies of camp staff	**Teachers**—summer camp staff/informal educators **Students**—high school	Fields (2009)
SCI ED	Science in general	The study compares science-related activities, which successfully engaged public audiences at three different 'generic' locations: a garden festival, a public park, and a music festival in order to identify what factors contribute to the perceived success of science communication activities occurring within leisure spaces	**Scientists** **Public**	Bultitude and Sardo (2012)
SCI ED	Science in general	The study investigates a one-year partnership with a university-based science outreach programme and its influence on students' (especially those from under-resourced schools) experiences of science as well as bridges them to school science	**Scientists** **Teachers** **Students**—secondary school	Luehmann (2009)

Appendix A. (Continued)

Research com-munity	Scientific discipline	The focus of the study	Stakeholders	Reference
SCI COM	Acoustics	This study explores a large-scale public engagement project, the 'Aeolus project' that was created to raise awareness of acoustics science	**Students**—primary and secondary school **Public**—visitors in exhibitions, participants in workshops	Drumm et al. (2015)
SCI COM	Astronomy	The study examines one project and its potential impact in public science, for enhancing and supporting society's relationship with science by embedding science content into everyday experiences	**Scientists** **Public**	Arcand and Watzke (2011)
SCI COM	Climate science	The study analyses the 'medialising of science' among German climate scientists	**Scientists** **Science communicators**—journalists	Ivanova et al. (2013)
SCI COM	Climate science	The study discusses how climate scientists weigh concerns of control, openness, and transparency when considering how to best communicate with the public through the mass media	**Scientists** **Science communicators**—journalists **Public**	Tøsse (2013)
SCI COM	Ethics and sociology	The study describes an engagement activity developed for engaging young offender with ethical and social issues surrounding the National DNA Database and the facilitation of their views to policy-makers	**Policy-makers** **Public**—general public and young offenders	Anderson et al. (2011)

Appendix A. (Continued)

Research com-munity	Scientific discipline	The focus of the study	Stakeholders	Reference
SCI COM	Nanoscale sciences and nanotechnologies (NST)	The study investigates the informing, involving and engaging of communication in stages of technology development. Also, the study investigates that the shift towards more democratic engagement in six public engagement projects in NST	**Scientists** **Public**	Kurath and Gisler (2009)
SCI COM	Nanotechnology	The current study explores interpersonal discussion following participation in a novel programme of citizen engagement about nanotechnology	**Scientists**—nanotechnology experts **Public**	Besley et al. (2008)
SCI COM	Robotics	Exploring motivations, expectations and expertise via public participants' reactions to 'engagement' events in UK	**Scientists** **Students**—junior and high school **Public**	Wilkinson et al. (2012)
SCI COM	Science and popular culture	The study focuses on the role of museum explainers for enhancing visitors' learning	**Science communicators**—museum explainers **Public**—visitors in museums	Kamolpattana et al. (2015)
SCI COM	Science in general	This article describes a study from the Linking Instructors Networks of Knowledge in Science Education project, which aims to examine the informal science curriculum support networks of teachers in a school–university curriculum reform partnership	**Scientists**—university scholars **Teachers**	Baker-Doyle (2013)

Appendix A. (Continued)

Research com-munity	Scientific discipline	The focus of the study	Stakeholders	Reference
SCI COM	Science in general	The study presents an analysis of actors that mediate science–society interactions, their roles and relationships, and the nature of learning and reflexivity in relation to public dialogue	**Scientists**—academic social **Policy-makers**—government departments and agencies **Public**—citizens	Chilvers (2013)
SCI COM	Science in general	The study presents workshops to best practice in science communication and provides insights into the diversity of the community of practice and the discords between best practice and popular ideas among practitioners	**Scientists**—science experts **Science communicators**—workshop moderators **Public**	Cormick et al. (2014)
SCI COM	Science in general	The nature of the flows of knowledge between science and non-science cultures is used to critique both traditional canonical models of science communication, and more recent constructivist accounts	**Scientists** **Public**	Goulden (2011)
SCI COM	Science in general	The study reviews the literature, mostly historical, on the relationship between science and film-making	**Scientists** **Public**—general public and film-makers	Gouyon (2015)
SCI COM	Science in general	The study presents South Africa's science communication aims, with examples of successes, highlighting the progress and gaps, and recommendations for action	**Scientists** **Science communicators**	Joubert (2001)

Appendix A. (Continued)

Research com-munity	Scientific discipline	The focus of the study	Stakeholders	Reference
SCI COM	Zoology	The study investigates laypeople's interests in science, based on questions received by the interactive web site *Scienzaonline*. The contents of the questions were categorised to reveal the function and the nature of the knowledge that people expect from 'experts'	**Scientists**—science 'experts' **Public**	Falchettiet al. (2007)
SCI COM	Robotics	The study explores conceptions of 'public engagement' and its benefits and constraints, across 11 public engagement activities focused on the robotics field within the United Kingdom	**Scientists**—scientists and practitioners in robotics **Science communicators** **Public**	Wilkinson et al. (2010)
SCI COM	Science in general	The study summarises the results of a content analysis of Web pages of German universities and non-university-based research institutions, for investigating whether the Internet provides new possibilities for global science communication	**Scientists** **Public**	Lederbogen and Trebbe (2003)
SCI COM	Science in general	The study argues for the need for a new 'architecture of interaction' in museum settings based on art installation and simulation techniques, to enhance the communication potentials of science museums and to provide conditions for a fruitful even-handed exchange of expert and lay knowledge	**Scientists** **Public**	Yaneva et al. (2009)

Appendix A. (Continued)

Research com-munity	Scientific discipline	The focus of the study	Stakeholders	Reference
SCI COM	Science in general	The study explores FameLab as a successful model for developing young scientists as science communicators, as well as for engaging general audiences with science	**Scientists**—young scientists **Public** **Science communicators**—FameLab (a philanthropic group)	Zarkadakis (2010)

Research com-munity	Scientific discipline	The focus of the study	Stakeholders	Reference
(c) *Scientific knowledge construction*				
SCI ED	Chemistry	Investigating how class members construct meanings of chemical representations by connecting them to real-life experiences and how the teachers' content knowledge shapes their ways to co-construct links with students	**A teacher** **Students**—eleventh graders **An undergraduate student-teacher**	Wu (2003)
SCI ED	Science in general	The purposes of the study were to analyse the promotion of scientific literacy through practical research activities and to identify children's conceptions about scientists and how they do science	**Scientists** **Students**—elementary school	Boaventura et al. (2013)
SCI ED	Science in general	This study investigates staff members' ideas and assumptions about visitors' learning at science and technology centres. It also aims to explore in what ways their reasoning intersect with existing theories about learning within the field of science and technology centre research	**Scientists**—in science and technology centres **Public**—visitors	Davidsson and Jakobsson (2009)
SCI ED	Chemistry	Investigating students' learning outcomes and engagement in constructing computerised molecular models through a dialogue among the students, a chemist (the instructor), and chemical educators	**Scientists**—science education experts and a chemistry expert **Students**—Undergraduate chemistry students	Barak and Dori (2005)

Appendix A. (Continued)

Research com-munity	Scientific discipline	The focus of the study	Stakeholders	Reference
SCI ED	Science in general	The research aims to explore the role of science for employees in science-based industries and for members of the public interacting with science in their everyday lives	**Students**—science students (11–16 years of age) **Public**—employees in science-based industries and general public	Duggan and Gott (2002)
SCI ED	Science in general	The study investigates public engagement with science and technology (PEST) by evaluating informal science institutions (ISI)-based 'dialogue events' as sites of learning	**Scientists**—scientific and technical experts and social scientists **Policy-makers** **Public**	Lehr et al. (2007)
SCI ED	Science in general	This study describes the partnership process that guided the design of the Knowledge Integration Environment (KIE) activities as well as the Scaffolded Knowledge Integration framework that gave the partnership a head start on creating effective materials	**Scientists**—natural scientists, science education researchers, technology experts **Teachers**	Linn (2000)
SCI ED	Science in general	The study describes how two researchers collaborated with five teachers to facilitate discourse activities aimed to enhance students' learning from practical activities. The study explores how certain teacher practices support or hinder students' learning	**Scientists** **Teachers**	Mestad and Kolstø (2014)
SCI ED	Science in general	Examining similarities and differences between learning science in the workplace and school	**Scientists**—veterinary experts **Students**	Munby et al. (2007)
SCI ED	Science in general	Presenting a theoretical framework for research in scientific literacy and opportunities to learn the meaning of scientific language via collaboration with teachers, students, and their peers	**Teachers** **Students** **Public**	Wallace (2004)

Appendix A. (Continued)

Research com-munity	Scientific discipline	The focus of the study	Stakeholders	Reference
SCI ED	Science in general	The study presents a special issue of JRST, highlighting the role of learning science in everyday life and the importance of informal science education	**Scientists** **Students** **Public**	Tal and Dierking (2014)
SCI COM	Biometrics technology	This paper analyses the discourses that pervaded the case in order to untangle how various publics are formed and exhibit differing, conflicting understandings of a novel technology	**Science communicators**—home office supporters and implementers **Public**—end-users	Martin and Donovan (2015)
SCI COM	Water desalination	The study investigates how desalination experts perceive communication with 'interested publics', regarding four aspects, among them is knowledge construction	**Scientists** **Public**—interested public (engineers)	Schibeci and Williams (2014)
SCI COM	Cultural	The study introduces an open network of professionals at the 8th International Conference on the Public Communication of Science and Technology, discussing and developing a dialogue between the different forms of local knowledge and scientific knowledge	**Scientists** **Science communicators**—journalists **Policy-makers**	De Semir and Revuelta (2004)
SCI COM	Food science and technology	The study explores science theatre as a method for teaching socio-scientific issues (SSI), and investigates students' experiences in coherence with the views from experts about the play's possibilities and limitations, in the context of a performance about food science and technology	**Scientists**—science experts **Students**	Wieringa et al. (2011)

Appendix A. (Continued)

Research com-munity	Scientific discipline	The focus of the study	Stakeholders	Reference
SCI COM	Health science	This study explores audience preferences for dissemination or dialogue formats for non-formal learning in a health science festival, and reveals that knowledge/understanding acquisition is perceived as empowering greater health literacy	**Scientists** **Public**	Fogg-Rogers et al. (2015)
SCI COM	Science in general	This article describes the development of the first tool for measuring scientists' written skills in public communication of science	**Scientists** **Graduate and undergraduate students**—science majors	Baram-Tsabari and Lewenstein (2013)
SCI COM	Science in general	The study examines the influence of narrative transportation, role of science within the movie, and gender of the viewer on evaluation of incorrect scientific information in fiction	**Science communicators**—the National Science Board **Public**	Barriga et al. (2010)
SCI COM	Science in general	The study presents the U.S. National Academy of Sciences efforts to bring the earth, atmospheric, and oceanic sciences into the classrooms and living rooms of the lay public and attract more students into scientific careers	**Scientists** **Policy-makers** **Public**	Korsmo (2004)
SCI COM	Science in general	This paper describes a pilot programme, which was designed to engage mothers in the kind of science that their children would encounter in high school, to encourage greater confidence in their science knowledge and experience	**Students**—high school **Public**	Stocklmayer et al. (2011)
SCI COM	Environmental science	The study aims to investigate the role that science and scientific uncertainty play among individual business managers and decision-makers and the assessment of environmental issues	**Scientists** **Policy-makers**—corporate 'decision-makers' and legislators **Public**	Drake et al. (2001)

Appendix B: Numbers of the papers found in the science education and science communication literature

Research community	Search round & keywords Journal	Round I—'Science <keyword>' & year range 2000–2015			Round II—'*science* <keyword>' as whole phrase			Round III—'*science* <keyword>' among at least two stakeholder groups		
		Commu-nication	Engage-ment	Underst-anding	Commu-nication	Engage-ment	Underst-anding	Communication	Engagement	Understanding
SCI ED	JRST	432	396	825	15	13	104	**1** – Zhai and Dillon (2014)	**0**	**2** – Brickhouse et al. (2000), Tal and Dierking (2014)
	Science Education	359	360	835	25	5	94	**1** – Wallace (2004)	**1** – Mestad and Kolstø (2014)	**3** – Barak and Dori (2005), Munby et al. (2007), Wu (2003)
	IJSE, Part A	849	1123	1554	30	15	97	**4** – Bultitude and Sardo (2012); Davidsson and Jakobsson (2009); Duggan and Gott (2002); Lehr et al. (2007)	**2** – Fields (2009); Luehmann and Markowitz (2007)	**8** – Bennett and Hogarth (2009), Boaventura et al. (2013), Davies (2004), Hodson and Wong (2014), Lee (2008), Linn (2000), Luehmann (2009), Mansour (2015)
SCI COM	IJSE, Part B	52	55	56	26	5	4	**7** – Baker-Doyle (2013); Edmondston and Dawson (2014); Hall et al. (2013); Orthia et al. (2012); Schibeci and Williams (2014); Stocklmayer, et al. (2011); Wieringa et al. (2011)	**1** – Wilkinson et al. (2012)	**0**

Appendix B. (Continued)

Research community	Search round & keywords Journal	Round I—'Science <keyword>' & year range 2000–2015			Round II—'*science* <keyword>' as whole phrase			Round III—'*science* <keyword>' among at least two stakeholder groups		
		Commu-nication	Engage-ment	Underst-anding	Commu-nication	Engage-ment	Underst-anding	Communication	Engagement	Understanding
	Public Understanding of Science	707	425	1022	60	9	21	**6** – Besley et al. (2012); Binder et al. (2011); Goulden (2011); Kurath and Gisler (2009); Yaneva et al. (2009); Zorn et al. (2010)	**3** – Anderson et al. (2011); Drumm et al. (2015) Kamolpattana et al. (2015)	**7** – Drake et al. (2001), Dietrich and Schibeci (2003), Falchettiet al. (2007), Gouyon (2015), Martin and Donovan (2015), Roos (2014), Williams et al. (2015)
	Science Communication	553	186	420	65	6	4	**16** – Arcand and Watzke (2011); Baram-Tsabari and Lewenstein (2013); Horst (2013); De Semir and Revuelta (2004); Huttunen and Hildén (2014); Ivanova et al. (2013); Joubert (2001); Korsmo (2004); Lederbogen and Trebbe (2003); Lewenstein (2005); Ruiz-Mallén and Escalas (2012); Sapp et al. (2013); Tøsse (2013); Valenti (2004); Weigold (2001); Winter (2004)	**5** – Besley et al. (2008); Chilvers (2013); Cormick et al. (2014); Curtis (2014); Wilkinson et al. (2010)	**3** – Barriga et al. (2010), Fogg-Rogers et al. (2015), Zarkadakis (2010)
Total		2952	2545	4712	221	53	324	35	12	23