Outreach as a Unifying Concept in Science Education and Science Communication

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Abstract

Recently there have been many calls for enhanced communication between scientists and the public in order to increase scientific literacy and improve attitudes toward science. However, these educational outreach (E/O) efforts often encounter structural barriers and the processes that support attainment of the goals of E/O are not well documented. This paper provides a look at the current state of the literature on E/O done by scientists. The goal is to understand what research has been done on E/O, where and how this research has been done, the outcomes of the research on E/O and how to coordinate future research. In order to examine these topics, I used a systematic literature search and performed a thematic analysis of the literature I found. The results show that E/O endeavors are diverse and not well-studied. Research efforts have concentrated on evaluation of specific programs, rather than the underlying principles and processes that influence how scientists interact and communicate with the public. The outcomes that have been examined focus on participants rather than facilitators. The research findings are also varied and exist in different disciplines with little overlap, making it difficult to synthesize our understanding of E/O. In this review, I contend that increasing dialogue between the fields of science education and science communication as well as building and utilizing theoretical foundations will help to scaffold the research on E/O. I argue that the field of informal science education research can be a useful model for how to accomplish these goals.

Keywords: educational outreach, science education, science communication, public engagement with science, community engagement

Introduction

Over the last few decades there are have been significant developments in both the science education and science communication literature. With the rise of informal science education (ISE), the boundaries between science communication and science education have become more blurred. Funding agencies, higher education institutions such as colleges and universities, scientists, and science communication scholars have advocated for improved communication of scientific information and engagement with the public (e.g. Byrne, 1998; Chan, Higgins, & Porder, 2005; Gelmon, Jordan, & Seifer, 2013; Groffman et al., 2010; Hobbs, 2006; Holbrook, 2005; Mooney & Kirshenbaum, 2009; Pace et al., 2010; Stern, 2015; Willems, 2003). Subsequently, there has been increased attention on outreach activities in both the education and communication fields and a developing awareness of commonalities between these fields. However, despite the parallels, there still exists different origins, goals, terminology, and methods found in education and communication research.

Despite calls from several fields to increase science communication and outreach efforts, there remains a shortage of literature on how scientists communicate and what makes education outreach (E/O) efforts successful. Natural scientists have made appeals for more E/O (Chan et al., 2005; D. P. Friedman, 2008). Science communication and education scholars argue that we need to increase scientific literacy to allow the public to make informed decisions regarding socio-scientific issues (Sadler, 2004). Funding agencies and higher education institutions have requested greater community engagement and broader impacts for the research that they support (Byrne, 1998; Gelmon et al., 2013; Holbrook, 2005; Simpson, 2000). E/O can heed many of these calls by showcasing active scientific research and providing access to or engagement in authentic and rare science (Braund & Reiss, 2006). Although these demands have become more common in recent decades, there is little research on how scientists communicate through E/O, what makes E/O successful, or on the outcomes of E/O (Dyer, 1999; S. Laursen, Liston, Thiry, & Graf, 2007; Miranda & Hermann, 2010; Rennie, 2007). Existing research is often burdened by the absence of correspondence between the fields in which it is contained.

This review will attempt to bridge the divide that exists in the literature fields that undertake research on how scientists communicate with the public. The research on E/O spans the fields of education and communication, providing an ideal subject for a literature review. E/O is not well researched and the goal of this review is to establish a baseline to understand what is known and what needs further understanding. This paper will determine where E/O exists in the scientific literature, the current state of the research on E/O, and directions for future work. It will also attempt to establish a dialogue between distinct fields that work on similar topics.

Theoretical Perspective

Educational Outreach

Educational outreach (E/O) provides an illustrative example of the divide between the education and communication research fields. E/O has many forms and functions and is defined in a variety of ways in the numerous education and communication publications. For example, science communication research often defines E/O as science dissemination, public engagement (PE) of science, or public participation in science. However, the education and higher education literature uses terms like educational outreach, community engagement, or service. Within the education discipline, E/O is typically considered a form of ISE and includes learning that occurs outside of formal or school settings, such as summer camps, museum visits, TV shows, IMAX movies, public talks, and science festivals. ISE encompasses one-time events or longer programs and targets audiences that range from Pre-K to senior citizens. Falk and Dierking (2010) note that an average American will spend less than five percent of his or her life in classrooms; hence, most science learning occurs outside of a school context. However, the classroom visits, teacher professional development workshops, curriculum development, and higher education institutional partnerships with K-12 school districts that are often forms of E/O expose how it lives on the edges of formal and informal education.

Not only is E/O unformulated within the education discipline, it also overlaps heavily with the field of communication. In the communication literature, E/O falls into PE activities. PE activities are becoming increasingly diverse in response to the growing demand for scientists to participate in discussions about science. This may include scientists talking to the media, giving public lectures, acting as docents in museums, and participating in science fairs, festivals, cafes, and citizen forums. More recently, there are expanding opportunities for online engagement (e.g., blogging, creating videos, and participation in social media and sites like Story Collider and Climate Voices). One can see that the pursuits of ISE and PE are similar and warrant alignment. Yet defining a diverse endeavor such as E/O is a challenge, particularly one found within two fields with different theoretical foundations and intellectual traditions.

Definition of E/O

E/O is not well defined in either the science communication or science education literature. This is likely due to its many different forms, outcomes, and goals, therefore making it difficult to rigorously define. In this review, I will be defining E/O broadly by using elements from both communication and education. Pearson (2001) defined public communication of science as the "communication of science by scientists to people not involved with research in their field" (p. 122). ISE is generally considered as science learning that occurs outside of school in an informal setting (National Research Council [NRC], 2009). Jarman (2005) has argued that more structured learning opportunities with specified outcomes are defined as informal education, while those that offer more openness and choice are considered free-choice learning. The American Association for the Advancement of Science (AAAS) defines PE as an interaction between scientists and the public (American Association for the Advancement of Science, 2013). AAAS argues that PE can take many forms, and it is therefore hard to define. Considering these diverse definitions of engagement, communication, and outreach, it is necessary to operationalize the definition of E/O used in this review. Therefore, I will classify E/O broadly as the "direct communication or instruction of science by scientists to those not involved with scientific research." Scientists in this sense means those involved with scientific research and include scientists at non-governmental organizations, research facilities, or universities.

Theoretical Framework

Science education and science communication often have similar objectives. One specific goal on the forefront of these fields is engaging audiences in science (McKinnon

& Vos, 2015). Another goal is to increase scientific literacy (Feinstein, 2011). As a result, the diverse developments of these fields have produced a variety of terminology and methods. Foundationally they differ due to their origin in separate applied disciplines (Feinstein, 2015; Haywood, 2014; Lewenstein, 2015). Despite the differences, there are parallels between many of the recent developments regarding theoretical foundations of these fields.

The field of science communication has evolved over time and research directions have been diverse throughout this evolution. Science communication can be considered an umbrella term for many different fields of research, including public awareness of science, public engagement (PE) with science and public understanding of science. Due to the focus of this review on E/O, science communication here will generally refer to PE or participation in science as well as science dissemination activities. Science literacy and public understanding of science, major focuses in the communication field, will not be discussed, as they do not pertain to interactions of scientists and the public.

The theoretical foundations of science communication have evolved with its research. Traditional views in this field focused on the 'deficit model', where one-way transmission of knowledge from scientists to the public would lead to increased scientific knowledge, often termed science dissemination (Gilbert & Stocklmayer, 2013; Sturgis & Allum, 2004). This idea arose from an emphasis on science literacy and a desire to educate the public about scientific advances (Bauer, Allum, & Miller, 2007). The primary method of dissemination was transmission through science journalism, which does not require direct communication by scientists (Bucchi & Trench, 2014; Weigold, 2001). Over the past three decades the focus shifted to public mindsets and how increased science literacy would translate into improved attitudes toward science, with scientists involved in this effort (Bauer et al., 2007; Besley, Dudo, & Storksdieck, 2015). More recently, research has shown the deficit model to be unsuccessful, prompting communication scholars to develop a more effective view of science and its interactions with society (Nisbet & Scheufele, 2009; Sturgis & Allum, 2004). Resultant participatory models promote the democratization of science and advocate engagement and dialogues with scientists over dissemination of science. These reciprocal models of mutual communication tap into societal attitudes, values, and beliefs, which theory predicts will influence behavior (Bandura, 1977; Fishbein & Ajzen, 1975). The ultimate objective for science literacy is informed decision-making and these engagement models are more effective at achieving that fundamental goal (AAAS, 1990).

Science education has experienced its own evolution. Traditional models of education were rooted in positivism, or the epistemological view that there is an attainable, absolute ‘truth’ where knowledge is derived through sensory experiences and interpreted through logic and reason (Alvesson & Sköldberg, 2009; Lindlof & Taylor, 2002). Pedagogically, positivism led to the notion that knowledge was transferred directly from teacher to student (Lemke, 1990). This produced teaching methods that focused on the passive transmission of information from an authority figure to the learner, or a ‘teacher-centered’ approach (Lemke, 1990). Over the last century however, researchers began to develop a new psychology of how people learn (NRC, 1999). As a result, teaching principles moved to a more constructivist framework (NRC, 2007; NRC, 2000). Constructivism is essentially the theory that people ‘construct’ their own understanding and knowledge of the world through their experiences and reflection on those experiences (Baviskar, Hartle, & Whitney, 2009). In constructivist education, knowledge is seen as something the learner builds rather than something received from an authority, making teaching practices more student-centered (Feucht & Bendixen, 2010). Along with constructivism there has been an increase in social-learning theories, which are often based in socio-cultural theory. Research from a socio-cultural perspective views learning as a collaborative activity in which interactions with others and the world influence how we interpret information (Vygotsky, Rieber, & Carton, 1987; Zady, Portes, & Ochs, 2003). In this way, the social and cultural context shapes learning.

The theoretical perspectives of education are reminiscent of models that have been used in communication. Teacher-centered pedagogy is comparable to the deficit model of dissemination. The socio-cultural perspective is similar to the emphasis on interaction between science and society that science communication scholars have advocated, because learning occurs through these interactions (Bauer et al., 2007). The focus in science communication on how public values, attitudes, and beliefs predict public understanding of science and engagement with science is analogous to the social-cognitive theory used in education, which describes how knowledge, attitudes, and skills influence self-efficacy and therefore behavior (Bandura, 1977). Within science communication, the few studies focused on predicting the motivations of scientists to engage with the public is often based on the theory of planned behavior (Ajzen, 1991), which links beliefs to behavior. Therefore, despite the varied and diverse foundations of these fields, there are many parallels that can be drawn from their theoretical underpinnings.

Motivation

The parallels between the fields of science communication and science education, along with the lack of interdisciplinary work within them, foster a prime opportunity to critically analyze the literature of these subjects. I assert that a focus on E/O is a sound approach for determining where the disciplines overlap and where more research is needed. E/O provides this capacity because of its unique juxtaposition between education and communication. The goals of science education and science communication are similar but the audiences are different. Education tends to concentrate on schools and learners, whereas communication focuses on the general public. Contrary to ISE with its focus on the environment in which learning occurs, E/O spans the boundaries of environment and audience in order to provide a unique glimpse at the intersection between fields.

Based on these ideas, the following research questions guided this literature review:

RQ1: In which literature fields (education or communication) are E/O efforts grounded?

RQ2: What theoretical frameworks shape the literature on E/O?

RQ3: Which formats of E/O are documented in the literature?

RQ4: What variables/aspects of E/O are analyzed in the literature?

Methodology

This review combines the methods and outcomes of both the systematic literature review and the critical literature review that are described in Grant and Booth (2009). It uses the methodical approach to the literature search and the analysis techniques of the systematic review, but the appraisal and synthesis techniques of the critical review. These methodologies were combined because the exploratory and novel nature of this analysis called for a systematic literature review (rather than solely seeking to identify the most significant literature) as well as a critical examination of the state of the literature.

Data Collection

In order to identify the congruencies and divergences within these two fields in regards to E/O, a systematic literature search was conducted in six electronic databases: Web of Science, Academic Search Premier, Communication & Mass Media Complete, ERIC, PsycINFO, and the Psychology and Behavioral Sciences Collection. Derivations and combinations of keywords including “science education”, “outreach”, “education outreach”, “community engagement”, “service”, “higher education”, “public engagement”, “science communication”, and “public participation” were all used to find relevant literature (see Table 1). Most keywords were established as relevant prior to the searches, but some were determined through reading literature obtained during the search process. Other resources were found by searching the reference lists of articles. Some publications were found by means of previous searches that had been performed in Web of Science, ERIC, Academic Search Premier, and Google Scholar for earlier work, which focused on the “education outreach” keywords. Articles were determined to be relevant through the reading of abstracts. These methods were used until saturation was reached (i.e., articles became repetitive and no new articles from searches or reference lists were found that were relevant to this review; Onwuegbuzie, Leech, & Collins, 2012).

Sample Determination

Out of the 465 articles and books found, 320 were considered relevant to this review (Table 1). Many of these were not specific to E/O but remained pertinent to grounding the findings in the larger context, since they included other factors around science communication, science education, or faculty engagement that were applicable to the ideas presented in this paper. These articles included commentaries and opinion pieces as well as higher education research, which often described the necessity of E/O and contextualized it in the larger education or communication fields. Reading of abstracts determined that 229 articles were specifically relevant to E/O and used in the thematic analysis (see Figure 1 & Table 2). After initial marginal analysis, conclusions regarding theories, methods, and findings became saturated (Onwuegbuzie et al., 2012) because many articles merely documented E/O programs or provided evaluation of their success. Therefore, a final sample of 111 papers and books were more thoroughly analyzed and used in the coding processes (although the larger set of 229 resources were still employed to illustrate findings and include E/O efforts that have been documented and the overall set of 320 were skimmed or read to help contextualize the findings).

In order to determine the final set of 111 articles used for analysis, the larger set of 229 were first organized by search keywords or discipline by reading the abstracts for each paper (see Figure 1). A read-through of the introductions and/or conclusions found that many of the articles were documentation of existing E/O programs without further analysis of outcomes, conference proceedings without detail on the study, or duplicate descriptions of E/O programs in multiple sources. There were also E/O programs that appeared to be recruitment programs or service learning, rather than E/O programs targeted to audiences outside of the university, so these were left out. Some involved only undergraduate students (not research scientists) or otherwise did not involve natural science/scientists (e.g., university-wide programs, community-based programs, industry) and were omitted. Finally, articles that focused on the media, communication training, how to evaluate programs, or those otherwise deemed irrelevant after reading past the abstract were removed.

Data Analysis

Following Onwuegbuzie et al. (2012) and Braun and Clarke (2006), a thematic analysis was performed on the literature. A thematic analysis involves a search for relationships among various domains as well as the underlying trends that link these domains to the larger context in which they are grounded (Onwuegbuzie et al., 2012). This process was used to answer RQs 1-4 by categorizing the types and methods of E/O, as well as determining the theoretical underpinnings and the findings in the research on E/O. These were then related to the overall context of the education and communication literature to determine how E/O has been incorporated into the literature. Finally, the findings were synthesized to determine where and how the holes in the research might potentially be filled, which will be presented in the discussion section.

For the 111 sources analyzed in the thematic analysis, a read-through of the articles was performed and marginal notes were taken on the theories, formats, and findings (Saldaña, 2016). Next, codes were created based on the marginal notes to categorize the domains of the research. Finally, these categories were collected into over-arching themes from each of the two fields in which articles were found (education and communication) and the various sections of the article (theory, approaches to E/O, and findings) (Birks & Mills, 2011; Saldaña, 2016; see Figure 2). Categories within these themes were used to classify articles within the taxonomy (see Figure 3; Spradley, 1980). Themes and categories were tracked using the Zotero citation database and a Microsoft Excel spreadsheet.

Findings

The findings below concentrate on the positioning of E/O in the research literature as well as the conclusions chronicled in this work. It also documents the approaches to E/O and helps to define this unclear topic. Figure 3 organizes the categories and themes found during this review and the sections below are arranged based on this taxonomy. The taxonomy showcases the theories, approaches to E/O, and findings that were found in the articles analyzed for this project. It separates these categories by research field, but also includes the intersections where the fields overlap based on similar theories, approaches, and/or findings. This figure is included to help contextualize the findings discussed below.

RQ1: Location in the Literature

Natural sciences. 84 articles were published in various science journals (e.g., Science, Nature, Frontiers in Ecology and the Environment, Conservation Biology). These were then categorized into the education (30) and communication (22) categories because they often focused on how scientists could engage with the public (communication), or how they could interact specifically with K-12 education or some other form of educational outreach (education). The remaining 32 of the articles in natural science journals were more general opinions and commentary about science communication, engagement, and outreach.

Education. The E/O literature is diverse and is published in many different domains, including higher education, formal education, and ISE journals. Out of 229 total papers, 127 were considered to fit into the Education field. 97 articles were categorized as appearing in education-focused journals. 68 entries to the literature database were included in various education journals (e.g., Journal of Research in Science Teaching, Journal of Geoscience Education, International Journal of Science Education, etc.). 26 articles were published within the Higher Education literature (e.g. Higher Education Research & Development, Higher Education Outreach & Engagement, etc.), where the emphasis was on faculty engagement in E/O and the institutional contexts for E/O. Three articles were published in ISE journals (e.g. Curator, Informal Learning Review, etc.). 30 were placed in this category because of their focus on education, even though they were published in natural science journals. These often focused on science collaborations with teachers, museums, or some other form of classroom interaction.

Communication. The E/O literature is also prevalent in communication research. 70 entries to the literature database were categorized in the Communication field. 48 were included in various science communication journals (e.g., Science Communication, Public Understanding of Science, Journal of Communication, Environmental Communication, Science & Public Policy, etc.). 22 were included in this category because of their concentration on communication, even though they were published in natural science journals. The majority of science communication research has historically focused on and continues to spotlight science communication as mediated through science journalists in TV, radio, and newspaper interviews. Although research around scientists engaging with the media comprises a large portion of the science communication literature and is an important avenue for engaging with the public, it was not included in this review due to the previously established definition of E/O. Instead, the communication literature highlighted in this review is focused on PE with scientists or direct communication of scientists to the general public.

RQ2: Theoretical foundations of E/O Research

The majority of articles that focused on E/O work did not mention a theoretical framework (only 29%, or 66 articles out of 229 utilized a theoretical or conceptual foundation, and most of these were in the communication category). The over-arching categories for theoretical frameworks were:

1) participatory models of communication (28 or 12%; e.g., deficit model vs. engagement model, theories of democratizing science, one-way communication vs. dialogues, etc.),
2) motivation theories (14 or 6%; usually discussed as either theories surrounding interest or Ajzen's (1991) theory of planned behavior),
3) socio-cultural theory (12 or 5%; or similar social learning theories),
4) constructivism (10 or 4%), and
5) no framework mentioned (163 or 71%).

Several of the communication articles on motivations for scientists to engage with the public used the theory of planned behavior. Other work based in communication used the deficit and engagement models (e.g., Besley & Tanner, 2011). E/O programs based in the education literature typically used theoretical frameworks that were categorized as socio-cultural theory because they often referred to the social nature of learning or professional socialization processes (e.g., Krasny, 2005; Laursen, Thiry, & Liston, 2012; Lehr et al., 2007). Those that discussed inquiry-based pedagogy were catalogued as constructivist (e.g. Laursen et al., 2007; Thompson, Collins, Metzgar, Joeston, & Shepherd, 2002).

RQ3: E/O Approaches

Formats documented for engaging with E/O in the education category included:

- teacher professional development (Brey et al., 2015; Fakayode, Pollard, Snipes, & Atkinson, 2014),
- collaborations with teachers (Hedley, Templin, Czajkowski, & Czerniak, 2013; Rahm, Miller, Hartley, & Moore, 2003),
- classroom visits (Woods-Townsend et al., 2016),
- field trips or educational expeditions (Diego, 2007; Miller et al., 2015),
- summer or after-school programs (Markowitz, 2004),
- curriculum and educational resource development (Allner et al., 2010),
- scientists working in or with museums (Hopwood, Berry, & Ambrose, 2013),
- mentoring (Torres et al., 1997),
- science fairs, festivals, and open houses (Bultitude, McDonald, & Custead, 2011),
- public presentations or lectures (Banner et al., 2008), and
- collaborative or participatory research (Drayton & Falk, 2006).

The higher education literature focused on community engagement and therefore many of the articles documented community partnerships or engagement within the community, such as with specific schools or school districts (e.g., Furco, 2013).

Within the communication category (which includes PE), approaches to E/O included:

- citizen science programs (Conrad & Hilchey, 2011),

- writing for popular science outlets (e.g., magazines, newspapers, etc.; Bentley & Kyvik, 2011),
- public forums (Reich, Chin, & Kunz, 2006),
- science cafes (Navid & Einsiedel, 2012), and
- online engagement through blogs, social media, or website development (Kedrowicz & Sullivan, 2012; Mahrt & Puschmann, 2014; McClain & Neeley, 2014; Powell, Jacob, & Chapman, 2012).

Many of the approaches listed above do not fit neatly into the fields of education and communication. For example, citizen science programs are often utilized in classrooms to engage students in science (e.g. Bestelmeyer et al., 2015). Science festivals, fairs, and open houses have been documented in both education and communication journals (e.g. Bultitude et al., 2011; Jensen & Buckley, 2014; Kato-Nitta, 2013; Molina-Gaudo, Baldassarri, Villarroya-Gaudo, & Cerezo, 2010). Public presentations and lectures can be given in classrooms or to the general public at locations like museums or libraries (e.g. Alexander, Waldron, & Abell, 2011; Clark et al., 2016; Hunter, 2006; Micklavzina, Almqvist, & Sörensen, 2014). Museums highlight the boundary-spanning nature of E/O activities, since they are considered part of the ISE field, but often act as locations for science communication with the general public. As will be discussed in the following section, even within the communication literature motivations for PE are often still based on a desire to educate the public, illustrating the indistinct boundary between these fields.

RQ4: Results from E/O Research

Motivations of scientists to engage in and institutional support for E/O. The communication literature has documented the motivations, supports, and barriers for scientists to engage in E/O. They generally found that threats to reputation, time constraints, lack of training or resources for E/O, lack of funding, and perceptions of science in the public can hinder scientists from engaging with the public (Andrews, Weaver, Hanley, Shamatha, & Melton, 2005; Dolan, Soots, Lemaux, Rhee, & Reiser, 2004; Ecklund, James, & Lincoln, 2012; Johnson, Ecklund, & Lincoln, 2014). One of the most prevalent impediments to E/O participation was the culture of research, which tends to devalue outreach, especially when promotion policies lack incentives or rewards for participating (Pace et al., 2010). Despite these barriers, some studies have shown that participation did not influence academic success and actually showed that scientists who were more active in research were more involved in PE (Bentley & Kyvik, 2011; Jensen, Rouquier, Kreimer, & Croissant, 2008).

The most prominent motivations for engagement included a desire to educate the public or to counteract misinformation and a commitment to the public good through an interest in contributing to society (Andrews et al., 2005; Besley, Oh, & Nisbet, 2012; Dudo, 2013; Jensen et al., 2008; Wilke & Morton, 2015). Other reasons included wishes to increase interest in science and increase appreciation of scientists, a sense of duty, or professional obligations (Besley et al., 2012; Martin-Sempere, Garzon-Garcia, & Rey-Rocha, 2008). Finally, enjoyment or intrinsic rewards were also motivating considerations for some scientists (Andrews et al., 2005; Dudo, 2013; Martin-Sempere et al., 2008). Factors that predict whether scientists will participate or that influence their participation include demographics, academic status, field of research, amount of training, normative beliefs (whether they think others are participating), and attitudes towards E/O (Dudo, 2013; Ecklund et al., 2012; Jensen et al., 2008; Johnson et al., 2014; Poliakoff & Webb, 2007; Silva & Bultitude, 2009; von Roten, 2010).

Higher education research also focused on motivations and support for E/O. Here the emphasis was on how institutional and personal contexts influenced faculty to engage with the community. Similar to the communication literature, the higher education literature reported that the most significant barrier to engagement was the promotion and tenure reward system, which created a culture focused on research and promoted stigmas around E/O (e.g., O'Meara, Sandmann, Saltmarsh, & Giles, 2011; Schuster & Finkelstein, 2006). Other impediments included a lack of departmental and institutional support, a shortage of resources and funding, time constraints and a deficit of connections in the community (e.g., McCann, Cramer, & Taylor, 2015; O'Meara & Jaeger, 2006). This 'publish or perish' attitude inherent in the tenure reward system is a significant structural inhibition that researchers face even outside of academia (Davies, 2013). Wade and Demb (2009) created a model of contextual factors that influence faculty engagement, which not only focused on these structural contexts but also included personal contexts. These personal factors included demographics, epistemological beliefs, values, motivations, previous experiences, status, research discipline, and time spent in academia. Despite the similar interests and findings in this field as compared to communication literature, it is interesting to note that there appeared to be very little overlap between these fields, with only one paper citing communication references, thereby crossing the discipline divide (Davies, 2013). Although the research from both fields paints a negative picture of support for E/O, there is hope in the higher education literature that the culture is changing. Several papers discussed how to change the reward structures in universities and support E/O through establishment of outreach offices or hiring of outreach staff (e.g., O'Meara, 2005; Wise, Retzleff, & Reilly, 2002).

Impacts on participants. Another major theme that came out of the E/O research results was impacts on participants. These impacts spanned both the education and communication fields, but they were more prevalent in education. The most prominent impact on students who participated in E/O programs was an increased interest in science or STEM careers (Amato-Henderson, Lehman, & Cattelino, 2009; Clark et al., 2016; Dommett, Westwell, & Greenfield, 2007; Felix et al., 2004; Laursen et al., 2007; Moskal et al., 2007; Nadelson & Callahan, 2011; Pierret et al., 2012; Woods-Townsend et al., 2016). A few studies documented increased conceptual knowledge or understanding of scientific concepts (Clark et al., 2016; Feldstein & Benner, 2004; Goldschmidt & Bogner, 2016; Hedley et al., 2013; Moskal et al., 2007; Pierret et al., 2012; Schollaert Uz et al., 2014). Teachers who participated in professional development or collaborations with scientists reported increased access to or improved resources and curriculum, increased science content knowledge and confidence teaching science, and improved instructional efficiency (Iskander, Kapila, & Kriftcher, 2010; Moskal et al., 2007; Pierret et al., 2012; Scharfenberg, 2014; Stamp & O'Brien, 2005). More engaged programs reported even more positive outcomes for teachers, such as research experiences (Drayton & Falk, 2006) and bringing authentic experiences into the classroom through collaborations with scientists (Rahm et al., 2003). Within the communication literature, citizen science programs measured and documented similar findings for increased interest and knowledge or improved attitudes toward science in participants; however, they also reported changes in environmental behavior (e.g. Brossard, Lewenstein, & Bonney, 2005; Crall et al., 2013; Jordan, Gray, Howe, Brooks, & Ehrenfeld, 2011; Price & Lee, 2013; Toomey & Domroese, 2013). PE endeavors such as science festivals and open houses showed that attendees enjoyed these events and reported increased interest in science and cultural capital as well (Jensen & Buckley, 2014; Kato-Nitta, 2013; Sardo & Grand, 2016). Public dialogue events can increase positive views of scientists, augment congruence between views of scientists and laypeople, and enhance self-efficacy for communication (Zorn, Roper, Weaver, & Rigby, 2012). They also act as learning sites where issues of science and society can be explored, which might increase understanding of the nature of science (NOS). Only six articles documented E/O effects on NOS knowledge and generally found that participants made gains in their understanding of the processes of science (Brossard et al., 2005; Fergusson, Oliver, & Walter, 2012; Jordan et al., 2011; Laursen & Brickley, 2011; Price & Lee, 2013; Trumbull, Bonney, Bascom, & Cabral, 2000).

Impacts on Scientists. The few studies that analyzed impacts on scientists who engage in E/O concentrated on graduate students and were more prevalent in education than communication. Conclusions from these studies reported how participation in E/O enhanced communication skills, developed or expanded teaching approaches, improved knowledge and perspectives of teaching or education, enhanced understanding of science content, influenced career decisions, and even enhanced or expanded their research (Alexander, Waldron, & Abell, 2011; Clark et al., 2016; Hinko & Finkelstein, 2012; Laursen et al., 2007; Laursen et al., 2012; Pierret et al., 2012; Stamp & O’Brien, 2005;

Thompson et al., 2002; Trumbull, 2002; Woods-Townsend et al., 2016). Intangible benefits such as increased confidence, intrinsic satisfaction, and feeling that graduate students fulfilled a sense of duty were also documented (Clark et al., 2016; Hinko & Finkelstein, 2012; Laursen et al., 2012; Stamp & O'Brien, 2005; Trumbull, 2002). There were a few articles that discussed impacts on research scientists or faculty and these found similar results as those documented for graduate students (e.g., Kaser, Dougherty, & Bourexis, 2013; McCann et al., 2015; Pace et al., 2010). However, a few studies noted that faculty experienced increased funding opportunities, expanded publication and presentation prospects, career enhancement and professional recognition, as well as improved research skills due to engagement in E/O (Buys & Bursnall, 2007; Felix et al., 2004; Moskal et al., 2007). Most of these are self-reported or evaluative conclusions, but Feldon and colleagues (2011) empirically studied the connection between teaching and research in graduate students and found that teaching experience can improve research skills. Since Kaser et al. (2013) established that E/O can impact teaching, E/O may also have impacts on the research of scientists. A review of citizen science projects claimed that community based monitoring can help scientists collect data and perform their research (Dickinson et al., 2012), although some scientists don't use this data for quality and other issues (Riesch & Potter, 2014). Additionally, although it is merely correlational, two studies have shown that that more engaged scientists are more active in research (Bentley & Kyvik, 2011; Jensen et al., 2008). This does not necessarily indicate that E/O work leads to increased productivity, but it is beneficial to know that more E/O does not inhibit scientific work.

Documentation and evaluation of successful programs. The final major theme found in the results of the E/O literature was documentation of the development of successful E/O programs (e.g., Buxner et al., 2012; Dahl & Droser, 2016; Dowie & Nicholson, 2011; Rosendhal, Sakimoto, Pertzborn, & Cooper, 2004; Salmon et al., 2011). 30% (68/229) of the E/O literature merely documented and evaluated programs. In communication, citizen science programs were sometimes written as documentation or evaluation articles (e.g. Dickerson-Lange, Eitel, Dorsey, Link, & Lundquist, 2016; Ferster & Coops, 2016; Ries & Oberhauser, 2015). In education however, documentation of programs was very diverse, including class visits or teacher workshops, collaborations with teachers, websites, lectures, science fairs, mentoring, curriculum or educational resource development, and museum education programs (e.g., Salmon et al., 2011). This may be due to the fact that many E/O programs are developed as broader impact strategies for grant funds and often require program evaluation from the funding agencies. Findings from these documentation style papers often focused on the evaluation of factors that influenced success of programs, outcomes for participants, or recommendations for future development of E/O programs (e.g., Alpert, Isaacs, Barry, Miller, & Busnaina, 2005; Buxner et al., 2012; Conrad & Hilchey, 2011; Drayton & Falk, 2006; Miranda & Hermann, 2010).

Calls for E/O and PE. About 23% of the E/O literature (53/229) were commentaries, opinions, or otherwise gave recommendations for research, resources, communication training, and frameworks for engagement. They are included here in the findings despite not detailing research outcomes because they often utilize the research around E/O to communicate its importance to natural scientists and are published in natural science journals where scientists are more likely to read them, rather than education or communication journals. Many of these articles, especially in the natural science literature, were calls for E/O (e.g., Chan et al., 2005; Friedman, 2008; Groffman et al., 2010; Varner, 2014). Other articles, especially in the higher education literature, were appeals for institutional support of E/O (e.g., Byrne, 1998; Gelmon et al., 2013; Holbrook, 2005; Simpson, 2000). One of the commonly documented barriers to E/O at universities is the promotion and tenure system with its focus on research over service and teaching. As a result, several articles requested that higher education institutions update these reward systems (e.g. Smith, Else, & Crookes, 2014). Other themes in the commentaries were discussions of how scientists can support science education (e.g., Alberts, 1991; Alper, 1994; Bestelmeyer et al., 2015). All commentaries encouraged more E/O or communication by scientists. Most of the appeals for E/O or communication discussed how science needed to reach out to the general public (Friedman, 2008; Groffman et al., 2010; Stern, 2015). Others focused on how scientists could impact education initiatives (e.g. Alper, 1994; Bestelmeyer et al., 2015). Finally, a few discussed the need for communication training or other E/O professional development for scientists (Leshner, 2007; Thiry, Laursen, & Hunter, 2008; Varner, 2014; Warren, Weiss, Wolfe, Friedlander, & Lewenstein, 2007).

Discussion

Intersections

The literature on E/O spans several disciplines, including education, higher education, ISE, communication, and the natural sciences. The similarities across these fields include the theoretical foundations in which the research is based, the approaches to E/O programming, and the outcomes of E/O. Figure 3 highlights these intersections in the '(Overlaps)' column.

Locations in the Literature. E/O literature was found in many disciplines, including education, communication, and the natural sciences. The interdisciplinary nature of the endeavor of communicating science to the public has made it relevant to these distinct disciplines. However, science education and science communication are not as distinct as they seem since they have similar goals and histories. Both fields stemmed from a growing societal interest in science that was sparked in the 20th century by scientific advancements produced during WWII and the Cold War (e.g., the launch of Sputnik; Gregory & Miller, 1998; Mooney & Kirshenbaum, 2009). They were developed during this time as their fields became more professionalized in order to understand best practices (Cuban, 1999; DeBoer, 1991; Friedman, Dunwoody, & Rogers, 1986; Krieghbaum, 1967). They even use similar theoretical frameworks, as will be discussed in the next section.

Theoretical Foundations. Despite differences in the terms used (as discussed in the 'Theoretical Foundations of E/O Research' section), the foundational theories in science education and science communication are similar. In science communication, the movement away from indirect and transmission methods of communication and towards engagement and dialogues between the public and scientists is reminiscent of recent educational reforms. However, only a small percentage of the E/O research reports using theoretical frameworks, whether they are used to develop the program or to inform any research or evaluation. A focus on theory would help frame the research, but also can inform programs that are documented in the E/O literature.

In both fields it seems that practice is lagging behind the research, where it is understood that audience-centric and value-oriented methods are more effective. These types of direct and engaging programs still comprise a small portion of the overall science communication literature. The most significant form of PE chronicled has been and continues to be scientists speaking with the media (e.g., Bucchi & Trench, 2014; Weigold, 2001). Communication training for scientists is still concentrated on methods for interacting with the media (Besley & Tanner, 2011). This is also true in education practice, where the reform movement is slow to be implemented in schools (Nuthall, 2004).

Approaches to E/O. Many of the approaches to E/O overlap. This is not surprising, given the congruencies between the foundations and goals of these fields. For example, public lectures or forums, science fairs/festivals/open houses, and citizen science projects can be categorized in both the education and communication literature. Not only are there parallels between the overall methods, but the environments, audiences, and forms of communication are also often related and transcend disciplines. E/O and communication can be accomplished online, on school and university campuses, in research facilities, in libraries, outside, and a variety of other environments. Even museums could be considered an environment for both ISE and science communication.

In the communication literature, the audience is often considered to be the ‘general public’, but this could include anyone, even K-12 students. In fact, many citizen science programs encourage schools to participate. Further, education is not relegated to K-12 or even university students, as described in the ISE literature. Many E/O programs are targeted toward the general public, rather than a specific group of students. The forms of communication used can span disciplinary boundaries as well. Lectures, stories, demonstrations, discussions, engaging in science or experimentation, videos, audio, and visual methods can all be used to communicate science effectively in multiple environments with a variety of audiences.

Outcomes. From the research that does exist on E/O, many of the findings overlap. Outcomes for participants have been noted with many programs reporting an increase in science interest or knowledge in participants. The calls for scientists to participate in E/O and communication sound similar across fields. In fact, in both arenas, there has been research exploring the steps necessary to train scientists for these endeavors (e.g., Varner, 2014). In education, Thiry et al. (2008) discuss professional development needs for scientists; in communication, Silva and Bultitude (2009) look at communication training. Both Silva and Bultitude (2009) and Dudo (2013) showed that scientists were more willing to engage with the public if they had training or previous experience. The higher education literature on motivations and barriers to E/O has documented conclusions similar to the communication literature. Granted, this remains a small portion of the work in these fields and more research is without doubt needed.

Unsubstantiated Areas and Opportunities for Future Research

Despite the overlaps and similarities across disciplines where E&O research occurs, the field is new and there are many gaps to fill. Much of the literature is focused on the documentation of programs without further evaluation or understanding of what makes them successful or not. The research that has been done does not utilize the theoretical framing that has improved other research in the fields of education and communication. This theoretical framing is often what allows successful outcomes to be understood. I argue that grounding research on E&O in education and communication and applying social science research methods would enhance our understanding of successful E&O efforts.

Locations in the Literature. Not only is E/O hard to define due to its positioning within several fields, but even in the field of education it can be difficult to locate. The literature on ISE, formal education, and higher education do not always align or communicate with each other. In the formal education literature E/O is often omitted because it falls outside the scope of a traditional classroom setting. The ISE literature is dominated by research focused on museums and science centers and E/O does not consistently fit these categories. In the higher education work, service and community engagement are broadly defined and do not necessarily focus specifically on science E/O. In communication, more direct communication efforts by scientists are often mixed in with those that are mediated by journalists. There is a large literature around the public understanding of science, but it does not necessarily include PE activities. A more complete definition and placement of the E/O research, starting with this report, will help frame what is considered E/O. Beyond this report, we will need more review articles and meta-analyses of E/O research to establish the field and define what constitutes E/O.

Theoretical foundations. Over 50% of the articles that focused on E/O of some nature were categorized as commentaries or documentation pieces. Many of these discussed the need for more outreach, engagement, and communication, or provided recommendations for doing so. However, documenting programs or presenting evaluation results does not aid our understanding of the foundational concepts that influence the processes or outcomes of E/O. Over one-third of the articles presented here merely assessed program outcomes without attempting to understand the variables or causes behind those outcomes. We need to go beyond evaluation and documentation to answer questions such as: What variables influence the formats and approaches to E/O? What facilitates learning in E/O? How do scientists foster positive attitudes towards science through E/O?

One means to move away from evaluation and toward research is to emphasize and integrate theoretical foundations or conceptual frameworks into the work. During most of the 20th century, the ISE field documented visitor behavior in museums, but much of the work was focused on programming and lacked theoretical underpinnings or definitions of learning. The Public Institutions for Private Learning (PIPL) conference in 1995 was held to define learning outcomes in museums and frame the goals for ISE research in order to investigate the impacts of museum visits on science knowledge (Phipps, 2010). This conference facilitated the guiding principles for a research agenda in the field of ISE, including theoretical parameters to examine learning in informal settings. Phipps (2010) reports that since that conference ISE has moved toward a theoretical basis for research. This has benefited ISE in being able to track outcomes like learning gains, motivation, and interest, as well as determine processes that influence these outcomes such as discourse, interactions and engagement with science. I contend that the E/O literature would benefit from a similar mandate, since so little of the research is grounded within specific disciplines and lacks this important foundation.

Theoretical foundations have been developed in both the education and communication fields, so future research should include testing these ideas in the new environments and situations that E/O presents. Perhaps E/O can follow the pathway of

ISE by documenting projects and their evaluation outcomes in a depository like the Center for the Advancement of Informal Science Education, where practitioners can access that information. That way, education and communication researchers can focus the E/O literature around more in-depth research grounded in the theoretical frameworks that have already been developed in their fields.

Approaches to E/O. The diversity of E/O not only makes it difficult to define, it causes problems for research on this topic as well. The NRC highlights the difficulty of assessing learning outcomes in informal environments (NRC, 2009) due to the diversity of programs and environments and the inability to isolate effects. Many E/O programs are limited in duration and often run by scientists who may not possess skills or knowledge to evaluate education programs or perform social science research. Participants often set their own learning agendas and have no obligation to participate in research, making outcomes difficult to study empirically.

Despite these difficulties, we need to understand whether the different approaches to E/O are successful. In order to do this, not only do we need to study the underlying foundational concepts like theory and the variables that have roles in E/O, we also need to understand the processes involved and how these influence outcomes. The education literature has documented how teachers engage in discourse in the classroom to facilitate learning (Dannels, 2000; DeHaan, 2005; Duff, 2010; Kelly, 2007; Kelly & Chen, 1999; van Zee, Iwasyk, Kurose, Simpson, & Wild, 2001; van Zee & Minstrell, 1997). The ISE literature has shown that family or peer interactions can similarly structure learning (DeWitt & Storksdieck, 2008; Falk & Dierking, 2000; Falk, Moussouri, & Coulson, 1998). In order to understand whether and how E/O is achieving its goals, we should examine how scientists communicate and engage with audiences during E/O.

Outcomes. Both the formal education and ISE communities have documented multiple goals for education in order to improve science literacy. These include increasing interest and knowledge, doing science or engaging with the processes of science, and understanding NOS (NRC, 2007; NRC, 2009). However, E/O research in education primarily focuses on science interest and not other outcomes. Those that do consider impacts on knowledge focus on conceptual understanding. However, conceptual knowledge is not the only characteristic of science literacy; it is also important to understand the processes related to science (AAAS, 1993). Only six articles in this review documented learning outcomes related to NOS (Brossard et al., 2005; Fergusson, Oliver, & Walter, 2012; Jordan et al., 2011; Laursen & Brickley, 2011; Price & Lee, 2013; Trumbull, Bonney, Bascom, & Cabral, 2000). Conceptual learning gains can be difficult to observe in E/O because they are often short duration one-time events (NRC, 2009), but interacting with scientists through discussions of science and NOS can benefit participants and aid understanding of scientific processes (e.g., Zorn et al., 2012). A focus on NOS knowledge along with conceptual understanding may help E&O research to measure different learning outcomes. Along with outcomes, an understanding of the processes of learning and what variables influence this process would help identify how participants engage with E/O and how they make meaning during E/O activities.

Similarly, there is very little research on outcomes for the scientists who engage in E/O because the majority of documented outcomes are on participants. Some work in the education field has documented positive benefits for graduate students who participate in E/O (Hinko & Finkelstein, 2012; Laursen et al., 2012). The communication literature focuses on motivations for why scientists participate in PE activities (Andrews et al., 2005; Dudo, 2013). However, insufficient work has been completed in any field on whether engagement positively or negatively impacts scientists' careers beyond graduate school. More research would help to justify the broader impacts required by funding agencies and the higher education institution service category in promotion and tenure rules. The calls for increasing E/O and communication are often hindered by lack of support for these endeavors. Documenting benefits of scientists' interactions with the public would encourage efforts to restructure these service commitments and the support received.

Bridging the fields. There has not been substantial dialogue between the education and communication disciplines. Around the turn of the 20th century, a few researchers noticed the similarities between the fields (Feinstein, 2015; Lewenstein, 2015) and have since worked to create the NRC report, *Learning Science in Informal Environments* (NRC, 2009). As recently as 2015, the Journal of Research in Science Teaching published a special issue that was the first attempt to engage these fields intellectually, even though some of these articles did not truly develop the connection between disciplines and work remains to foster collaboration and share knowledge.

I recommend that more work on E/O utilize and acknowledge both science education and science communication disciplines. There are significant overlaps between these fields but little dialogue. I contend that we need to reconcile the divides between these fields for the benefit of all researchers within them. For example, the communication literature focuses on motivations for E/O and the education literature focuses on outcomes. Uniting these results has already given us a better picture of the state of the research on E/O. The communication literature could benefit by focusing on the educational aspect of PE which may help bridge the gap between the literature on PE and that on the public understanding of science within that field. Research in education is often focused on how discourse and engagement shapes learning. Therefore, research on the discourse of scientists and their communication with audiences may unite the two domains of education and communication to create an interdisciplinary understanding of E/O efforts.

More information is mandatory and I reason that using foundations from and situating future work within both disciplines will benefit the research on E/O. Others have called for integration of these fields as well (Baram-Tsabari & Osborne, 2015; Feinstein, 2011; Feinstein, 2015; Haywood, 2014; Lewenstein, 2015; McKinnon & Vos, 2015), but it is still rare to see these types of connections being made. I have confidence that E/O is ideal for this interaction because it is situated within both fields.

Conclusion

This review found that science educational outreach (E/O) is not well defined in the literature. The research on E/O is scattered throughout several different fields, including education and communication, and within many different sub-disciplines in the natural sciences. The types and formats of E/O are incredibly diverse and can be difficult to delineate. Despite the diversity in how E/O is described, I offered a broad definition to establish basic parameters on the field. The literature review findings described the state of the E/O literature and found that it is not well developed. An absence of theoretical foundations and a focus on program evaluation has impeded research on E/O.

Furthermore, the disconnect and deficiency of communication between the various fields that deal with E/O has hampered efforts to understand influences on E/O success and its impacts on participants and scientists.

Despite these challenges, there remains ample opportunity for expanding and enhancing our understanding of E/O. I have made recommendations for future research and described how this research can be implemented. First, E/O researchers must venture beyond evaluation and attempt to understand the foundational concepts and patterns of E/O rather than focusing on programmatic outcomes. Development of theoretical foundations and conceptual frameworks will benefit E/O as it has ISE. Acknowledgment of other disciplines and interaction between the fields of science, education, and communication will assist future research regarding E/O. Because E/O lives within the margins of other fields, an ideal opportunity for collaboration between natural and social scientists awaits. The sharing of knowledge between education and communication fields will not only aid E/O research, it will benefit both disciplines in their parallel efforts and goals. Interdisciplinary research is necessary for understanding the various and diverse methods and issues surrounding E/O, which ultimately will provide benefits to other research endeavors as well.

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Appendix A – Tables and Figures

Table 1
Articles found in literature searches

Search Title	Search Terms	Number of articles	Articles deemed relevant
Outreach and Education	"outreach" with "science education" and derivations/combinations (e.g. educational outreach, informal science education)	116	62
Communication	"public engagement" with "science communication" and derivations/combinations (e.g. communication in science)	46	27
Community Service & Higher Education	Either "community engagement" or "community service" with "higher education" or "scientists" and combinations/derivations	84	33
Public Participation	"public participation in science" & derivations (e.g. scientific research)	38	19
Previous literature searches	Previous literature searches mostly used outreach, science communication, public engagement, and public participation keywords and derivations	83	83
Found from reference lists		98	98
Total		465	322

Table 2
Articles used in thematic analysis

Category Title	Articles used in analysis	Articles used for in-depth analysis
Education (including higher education & ISE)	127	52
Communication (including engagement and public participation)	70	49
Natural Science	32	10
Total	229	111

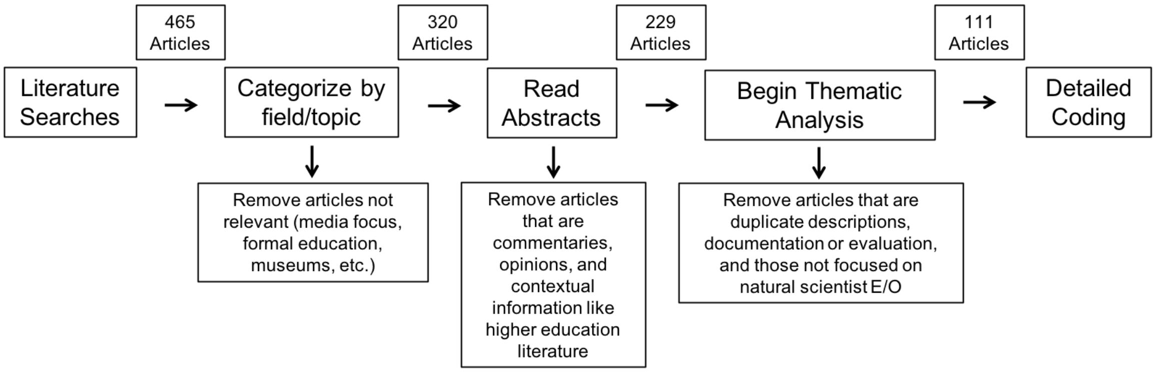

Figure 1. Sampling Process

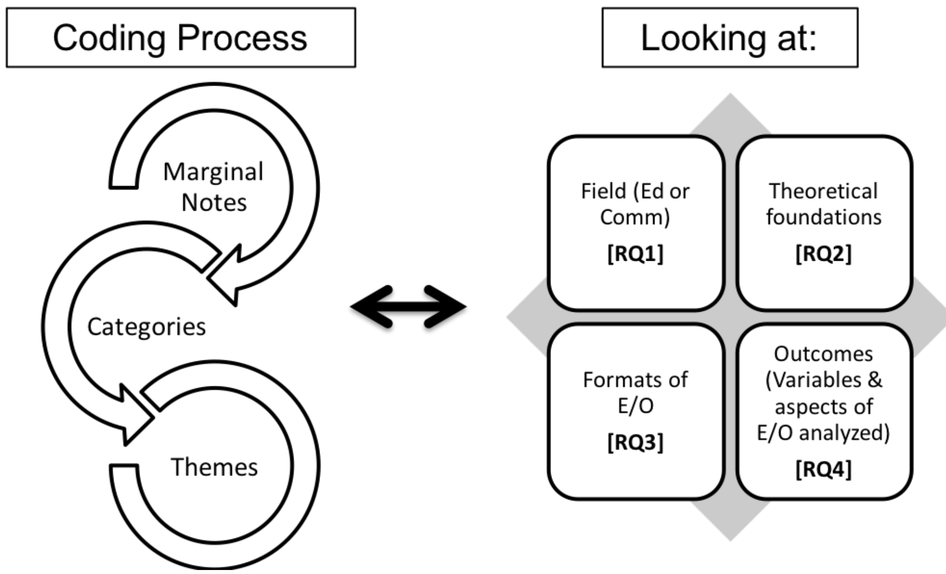

Figure 2. Thematic Analysis Coding Process

Education/ Outreach	Education (Formal/Higher/ISE)	(Overlaps)	Communication
Theory	Socio-cultural theory Constructivism	(similar theories with different names)	Theory of planned behavior Deficit vs. engagement
E/O approach: Audience, environment, communication method	Teacher PD/collaborations, resources & curriculum, class visits, field trips, summer camps, museums, mentoring, research	Lectures/public forum, science fairs/festivals/ open houses, citizen science	Popular science publishing, online engagement, science cafes
Findings	Documentation/ evaluation, impacts on scientists, impacts on participants	Supports, barriers	Motivations, attitudes towards E/O

Figure 3. Taxonomy of categories and sub-categories developed during thematic analysis