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Dialogue and Curiosity: A Science Communicator's Toolkit for Engaging Science Communication

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Abstract

Facts are not enough! The more recent wave of science communication practices have been advocating for the death of the deficit model of science communication. This model notes that by possessing sufficient information, individuals will change their attitude and behavior to align with scientific facts. However, recent research has shown that not only facts are not enough, in certain conditions, they might backfire.

To move beyond this model, the science communication community advocated for more engaging practices based on dialogue with the public and encouraging participation of all citizens in the scientific process. While there is much talk about the importance of these practices, there is limited research on how to (cognitively) engage the public, what does that engagement look like, and what are the empirical outcomes of such engagements.

In this dissertation I particularly focus on curiosity as a strategy to elicit cognitive engagement. Science curiosity has been shown to have a positive relationship with climate change risk perception and individuals' tendency to seek counter-attitudinal information.

I designed three studies to address the mentioned limitations. The first study is an ethnography, describing the ways scientists and the public use pop culture references to build mutual grounds and maintain a dialogue in the context of Adler Planetarium's Astronomy Conversation sessions. The second study is a qualitative analysis of curiosity at Astronomy Conversation sessions. I have described factors that elicit the attendees' questions and also the content of the attendees' questions. The final study is an experiment, examining the relationship between a scientist's self-disclosure, the participants' perception of the scientist's warmth and trust, their curiosity, climate change risk perception, and risk mitigation.

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"همدلی از همزبانی بهتر است"

"It's better to share a heart than a language"

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Chapter 1: Introduction

"The cure for boredom is curiosity. There is no cure for curiosity."

-Dorothy Parker

For decades the scientific community has been trying to educate the public, believing that an informed society will have a positive attitude towards science and make decisions in line with the scientific claims (Simis, Madden, Cacciatore, Yeo, 2016). We can see this perspective in the ways museums were curated, public lectures were executed, and campaigns were managed: a one-way communication from the scientist to the audience with an emphasis on presenting facts.

Years of research and experience, however, still show a gap between what the scientific community believes to be accurate and what percentages of the public consider to be true (PEW 2015). In addition, growing evidence demonstrates that the provision of facts is insufficient to change attitude and behavior towards science (Brossard et al., 2005). This realization might have contributed to the scientific community's attitude change towards science communication strategies and assuming responsibility for existing attitude gaps.

Within the past decades, science communication has taken a path towards the active role of different publics in science and fostering strategies that open a conversation about science rather than preaching facts. For example, the growing citizen science projects such as Zooniverse engage the public in scientific research by asking them to help collect data and analyze large databases that limited individuals and computers are not able to do. These projects are accompanied with spaces for discussion, interaction with experts, and even grants authorship to specific citizens that contribute directly to important discoveries.

A promising area of study in the science communication field is that of curiosity. A study by Kahan, Landrum, Carpenter, Helft, and Jamieson (2017) shows that curiosity plays a significant role in determining attitude towards climate change. They show that individuals with higher science curiosity, independent of their political views, are more likely to perceive the risks of climate change as high. The learning science researchers also study curiosity as a phenomenon that can increase exploration and encourage individuals to dedicate more resources to seeking information (Arnone et al., 2011, Kang et al., 2009). Relying on previous work, curiosity seems to play an important part in science communication as it is positively related to seeking counter-attitudinal information and is associated with risk perception.

The goal of this research is to explore how scientists and their audience engage through a conversation and understand the role of curiosity in eliciting conversations. In addition, this study examines the role of curiosity on climate change risk perception and mitigation.

Although discussing the importance of science communication methods that engage the audience cognitively is an initial and essential step to advocate for such strategies, practitioners need more concrete, evidence-based information on what those strategies are and more importantly, if those strategies have the positive effects they expect. The fields of learning sciences and psychology are two fields that have spent significant resources to examine such two-way communication strategies. Although the field of science communication advocates for these strategies, there is not much research showing how to elicit dialogue and measure the effects of this strategy. I will be using the findings from other fields to integrate those ideas into the science communication research areas.

While in the learning sciences, the primary desired outcome is learning and absorption of information, the science communication field has a greater emphasis on public engagement, defined as "seeking and facilitating the sharing and exchange of knowledge, perspectives, and preferences between or among groups who often have differences in expertise, power, and values" (NAS, 2016, p.133). This emphasis can possibly elicit more cognitive engagement with scientific topics and allow citizens to think more critically about those topics. However, there is much that researchers can learn from previous work in the learning sciences field based on inquiry-based learning and classroom involvement. Similarly, there is much science communication community can learn from psychology studies highlighting curiosity. These two lines of research provide a strong background for translating theoretical research into informal learning practices such as communication in museums and science centers. In the current work, I build on the previous work on curiosity and engagement through dialogues through a 3-study design.

This dissertation encompasses three separate studies that I have conducted for over three years. Each of the studies' outcomes and processes has informed the next study and determined the research questions and methods that can answer those questions. Having curiosity and science dialogue in mind, I have chosen the Adler Planetarium as my main field of research for my first two studies. The Space Visualization Lab at the planetarium hosts Astronomy Conversation sessions in which scientists have daily face-to-face conversations with the public.

This space not only provides a close view of how conversations develop, due to its casual nature, but it also allows for the development of an education-entertainment conversation.

One of the areas within the world of science communication where the expert's power might be more similar to the audience's, could be that of edutainment with the use of movies and science fiction to discuss science. In such a context, the audience is familiar with the movie. They have some level of expertise, providing an opportunity for a movie reference to possibly build a mutual ground between the expert and their audience (Zeh, 2014). Being able to see the formation of such conversations can be a beneficial initial step to explore the mechanisms behind engaging conversations. There is also research showing that pop culture can elicit interest and facilitate understanding of educational material (e.g., Barnett & Kafka, 2007; Efthimiou & Llewellyn, 2004). Thus in the first study, I have focused on the role of pop culture references in shaping a conversation around science.

The next step after learning about pop culture references as a proxy in science communication has been a focus on curiosity in the conversations between scientists and their audience. Due to curiosity's potential for eliciting inquiry (Jirout, 2011), this phenomenon can be a strategy to encourage more cognitive engagement with science, a process with which individuals can make decisions based on more logical reasoning rather than heuristics. As mentioned in the definition of public engagement, "exchange of knowledge, perspectives, and preferences" is a central part of this strategy. Through inquiry, both parties have an opportunity to become familiar with one another's perspectives and needs and exchange information, hence, building an equal distribution of the conversation rather than a session dominated by the experts.

A large number of studies focus on attributes of the messages or objects that elicit curiosity, such as the information gap, importance, relatedness (e.g., Silvia, 2008; Golman & Loewenstein, 2015). However, as the science communication advocates for more engagement with the public, in particular, face-to-face interactions, the community needs to gain a better understanding of the role of the messenger, encouraging inquiry. In this work, I contribute to theoretical and practical knowledge by conducting three studies using different methodologies.

Dissertation overview: The goal of this dissertation is to understand how scientists can use engaging science communication strategies specifically through curiosity and initiating conversations. This dissertation is a progression of research methods initially from an ethnography using grounded theory, a qualitative analysis of conversation transcripts, and finally, an experimental design to examine the specific hypotheses. I have developed these studies and analyzed the data with the involvement of the community of scientists who have been studied in this research project.

Study 1 - Science-Fiction as a Mutual Ground Between Science and Society: How Astronomers Use Pop Culture References for Science Communication. The first study is a descriptive overview of how scientists at the Adler Planetarium use pop culture references to have a conversation with their audience and build a mutual ground to talk about different scientific concepts. This study develops a framework depicting the formation, development, and content of these conversations. The development of this framework is based on field observations using grounded theory. It is informed by studies in the field of learning sciences, including those on scaffolding (Lajoie, 2005) and building mutual ground and the use of pop culture references in the classroom and for education (e.g., Cavanaugh, 2002; Derjani-Bayeh &

Olivera-Fuentes, 2004). The results help science communication practitioners to be aware of the formation of conversations, the potential of pop culture references, and how to build mutual grounds between oneself and their audience. In addition, it creates a theoretical framework describing the formation of conversations through the scaffolding process. Such a framework integrates various theories, where each theory addresses a slice of the dialogue. This study's observations, including the role of inquiry in the formation of conversations, have inspired the second study, emphasizing curiosity and inquiry.

Study 2 - Attributes of Science Outreach Activities that Foster Dialogue and Curiosity: A Case Study at the Adler Planetarium. This qualitative study examined curiosity and inquiry in an informal learning space (The Adler Planetarium), specifically describing the prompts used by scientists aimed at eliciting elicit curiosity and encourage inquiry. In addition, this study explores the content of questions asked by the planetarium attendees. As studies in the field of learnings science, museum studies and psychology have looked at curiosity in different ways, this study synthesizes their findings to develop coding schemes and focus on elements studied less frequently in the previous research. The central gap addressed in this qualitative study is the role of human presenters to encourage inquiry and dialogue, in addition to comparing the theoretical findings of psychology studies with the manifestation of curiosity as questions in an informal learning space.

The findings describe the content used by scientists that elicit reactions from the audience and also describe the frequency of successful interactions. The qualitative analysis of the content also elaborates on what the audience seems to be curious about and what percentage of questions are dedicated to different topics. These findings not only provide a resource for practitioners to encourage dialogue in their sessions but also helps them understand their audience better. Also, it provides an agenda for other researchers to examine the effect of different prompts to encourage inquiry and design messages and material that elicits curiosity.

Study 3 -Understanding the Relationship Between Sharing Personal Anecdotes, Warmth, Curiosity, and Risk Perception in Communicating the Threat of Climate Change. The final study takes a deeper dive into the effects of curiosity and factors that elicit curiosity. In this experiment, I relied on the effect of a scientist's self-disclosure of personal anecdotes to talk about the impact of climate change. Based on previous research, this manipulation was expected to elicit curiosity (e.g., Goldstein & Benassi, 1994), and in turn improve the participants' perception of risk of climate change and their climate change mitigating behavior (Kahan et al., 2017) compared to those who received a script with a low self-disclosure.

Other important variables included specific scientist's traits, including how the participants perceived the scientist in terms of warmth and trustworthiness. Although the manipulation did not produce the intended effect, the results show significant interactions between curiosity, measured as the number of questions listed, and risk perception behavior. The relationships between scientist's traits and curiosity and risk perception were also significant. These results affirm findings of previous work, including Kahan and colleagues' work (2017). However, using a behavioral measure of risk mitigation in addition to the more consequential measure of trust in experts, the findings show that while curiosity is associated with risk perception, it is not necessarily linked to risk mitigation behavior. Also, the measure of trust in scientists as relying on them to make decisions is a good predictor of an individual's climate change risk perception. Researchers using other measures of trust in previous studies have shown different results.

The next chapters describe the mentioned three studies: **chapter 2** presents the first study on the use of pop culture references for science communication, **chapter 3** described the second qualitative study of curiosity in an informal learning space, **chapter 4** presents the final study, an experiment dedicated to examining the relationship between scientists' traits, participants' curiosity, and climate change risk perception and mitigation. **Chapter 5** discusses the contributions of these studies for practitioners in the field of science communication and researchers in this field, in addition to the learning sciences, environmental studies, and museum studies. Lastly, chapter 6 explores future studies and draws a final conclusion.

Chapter 2: Science-Fiction as a Mutual Ground Between Science and Society: How Astronomers Use Pop Culture References for Science Communication

Introduction

Some of the most trending topics in science communication research are related to the persuasion of human made climate change deniers, anti-vaccination movements, and anti-genetically modified food groups. The National Academies of Sciences, Engineering, and Medicine (2017) recommends that scientists should work on strategies to build connections with the public and engage them in a science conversation. Such dialogue has the potential to empower the public and enables a better understanding of the public's needs, worries, and opinions. Thus, as practitioners and researchers, we need to find strategies that can connect science and society as a means for dialogue. One such approach can be the sue of pop culture references.

Research has shown that pop culture is a useful tool to elicit interest in science and improve the understanding of the educational material in K-12 and college settings (e.g., Barnett & Kafka, 2007; Efthimiou & Llewellyn, 2004; Laprise & Winrich, 2010; & Vrasidas, et al., 2015). In addition, pop culture is a tool that can potentially build a mutual ground between scientists and the audience facilitating communication (Zehr, 2014). Building mutual grounds (i.e., finding concepts, terms, or events that both parties are familiar with) is particularly crucial in informal learning spaces such as museums where scientists have opportunities for face-to-face interaction with the public.

The purpose of this study is to shed light on how experts use pop culture references in science communication. In this research, I examine why scientists use pop culture references in science communication, how scientists and the public interact with these references in conversations, and how scientists use these references. I use the grounded theory approach in this observational study to propose a model, theorizing about motivators and triggers that give rise to the use of pop culture references, how experts and the public use references, and how scientists use the references to build a mutual ground. Results from this study make two contributions to science communication research.

First, the study examines the nature of pop culture references in dialogues between scientists and the public. Understanding how pop culture develops in a conversation as a tool for science communication, and why the experts use this tool is crucial for researchers. This knowledge helps researchers develop models that describe how the conversation around pop culture references evolves and what triggers lead the expert or the public to use this tool. These findings enable communicators to become familiar with pop culture references as a tool and prepare them for future conversations using pop culture. The findings can shape a model, describing how pop culture enters a conversation, shapes it, and eventually disappears.

Second, previous studies of pop culture have been mostly limited to formal learning spaces such as schools and colleges and have failed to examine the function references have in informal learning spaces such as museums. Museums and science centers are essential sites for the dissemination of science. These centers are becoming more engaged with informal education (Zimmerman & Bell, 2008) while exposing the public to science, with around 58% of Americans in 2016 having encountered science in a science center, zoo, or a park (National Science Board, 2018). These sites provide an environment where scientists can engage with the public directly and try to understand them (Bandelli & Konjin, 2013). These features make science centers highly desirable sites for citizen-centered science communication and can highlight the importance of studying science communication in their context. In the following sections, I discuss the use of pop culture references through the learning sciences field framework, in addition to exploring the literature on the use of pop culture references in education and science communication.

Literature Review

Pop culture as a mutual ground. Through the lens of learning sciences, pop culture references are tools that facilitate science education. Educators use tools such as analogies, examples, and metaphors to draw from mental models with which the learner is familiar. In a sense, the educator uses these tools to base the unfamiliar knowledge on and facilitate learning. Lajoie (2005), based on Bruner's theory of scaffolding (Wood, Bruner, & Ross, 1976), describes the process in the following way. Scaffolding is a temporary framework that supports material and workers when constructing buildings and is eventually removed when the construction is completed. She then extends this definition to education, where a temporary framework helps learners until it is no longer needed. For example, when describing the atom, the educator can use the case of the solar system as a familiar base and describe the relationships between the nucleus of the atom and the electrons orbiting around it as planets orbit around the sun (Gentner & Markman, 1997). However, after the educator establishes the information, they can remove the analogy of the solar system. The educator can then elaborate on the information about the atom.

The two main factors that determine what type of tools individuals use (e.g., an analogy, a similar example, or a metaphor) are the relationship between the base and target and the attributes of each (Gentner, 1989). First, in *literal similarity*, relations and attributes are the same (e.g., milk is like water). Second, when talking about *analogy*, there are similar relations and fewer attribute similarity (e.g., the example of the atom and the solar system). Third, *abstraction* contains similar relations and fewer attribute similarities with an emphasis on abstract concepts (e.g., atom nucleus is the center of gravity). Fourth, unlike previous tools, in *anomaly* there is no similarity in relation and attributes (e.g., an atom is like a salamander). Fifth, *mere appearance*, exhibits more attribute similarity and fewer relations (e.g., the doorknob looks like an egg).

Scientists, similarly, establish a base, a familiar example, for the information they intend to provide. They build new information using the base as scaffolding. Such an approach is particularly important when it gets to disciplines such as astronomy and physics, where many concepts are too abstract and hard to visualize (Franknoi, 2002). I use the term mutual ground in this paper to describe the use of familiar references as the base of the scaffold. For example, an educator references *Star Wars*, where planet *Tatooine* has two "suns." They mention that there are similar planets outside our solar system that also revolve around two stars. The educator uses this similarity as a mutual ground as a scaffold. This term is particularly important, as the National Academies of Sciences, Engineering, and Medicine (2017) notes that in a formal public engagement setting, the main goal of the communicator is to find mutual grounds with their audience.

A concept very close to building mutual ground is that of building shared framing. Framing "is based on the assumption that how an issue is characterized in news reports can influence how it is understood by audiences." (Scheufele & Tewksbury, 2007, p.11) These frames can act as guides for the audience to understand the content in a certain direction. Price and Tewksbury (1997) note that framing does not determine what topic or issue is talked about but rather how is that topic being presented. Communicators choose frames that are familiar to the audience and help them reduce the complexity of information. Pop culture references act as a form of framing for scientific knowledge. By placing complex information in the frame of pop culture reference, such as a sci-fi movie, the audience can make sense of information through familiar imagery, concepts, and settings. Through framing a message can be more impactful for the audience as it is more familiar to the audience and resonates with them (applicability effect, Price & Tewksbury, 1997).

Along the same line, Frey et al. (2012) suggest that one way to facilitate education is to anchor an individual's new knowledge to something with which they are familiar (e.g., a movie). For example, if a scientist attempts to talk about the concept of "event horizon" in black holes, they can use the depiction of a black hole in a movie such as *Interstellar* as a visual reference with which the audience may be familiar. Then, they can explain based on that visual, what the event horizon is. In this example, the concept of the event horizon anchors to the audience's knowledge of a black hole from the movie *Interstellar*.

Pop culture references, mainly sci-fi movies, have been praised in multiple articles for their role in education. Sci-fi and films provide a mutual reference points (Zehr, 2014). Cavanaugh (2002), for example, notes that he uses these references in his class to create a shared experience and reference point. Arroio (2010) suggests that such examples can go as far as having the capacity to help the audience connect with the characters and their emotions.

Although these articles suggest the role of pop culture references as a mutual ground, they do not provide much information about the process by which pop culture plays the role of the mutual ground. Cavanaugh's sample is limited to his experience as one individual. To identify how pop culture becomes a mutual ground in a conversation, research that observes the phenomena in multiple situations and determines the unifying pattern across instances is needed. This need leads me to the first research question:

> ***RQ1:*** *How do scientists and the audience generate a mutual ground through interactions about pop culture?*

As mentioned, the function of pop culture as a mutual ground is to build a scaffold to improve educational outcomes, such as facilitating the understanding of scientific material. In the next section, I will explore different educational outcomes of using pop culture references and discuss the gaps in that body of research.

Pop Culture's Educational Outcomes. Educators and communicators have been suing Sci-fi to explain theories, scientific concepts, and possible ideas in extensive settings. Researchers such as Derjani-Bayeh and Olivera-Fuentes (2004), Efthimiou and Llewellyn (2003), Brake and Thornton (2003), Segall (2002) describe the use of science fiction in their classrooms to teach concepts of engineering, chemistry, and physics. Researchers mostly direct these studies at a specific audience in their respected fields, for, example chemistry educators. In particular, these examples are limited to classroom interactions, and thus, hard to generalize. Authors such as Dubeck, Moshier, and Boss (2004), Gresh and Weinberg (2003, 2004) have dedicated books to describe how sci-fi movie dynamics, characters, or events fit within the scientific world and explaining if they adhere to scientific concepts or not. This is also a trend in other media such as the *StarTalk radio* podcast, producing episodes that talk about the science of a movie or superheroes, and YouTube channels such as Kyle Hill's *Because Science*, explaining the science of pop culture.

Research suggests that the use of movies in science education improves several learning outcomes, including increased retention of information (Marzano, Pickering, & Pollock, 2001), better understanding of concepts (Barnett & Kafka, 2007; Laprise & Winrich, 2010; Sherwood et al., 1987), better performance in exams (Efthimiou & Llewellyn, 2004), higher interest as reported by students (Efthimiou & Llewellyn, 2004; Hollis, 1996; Laprise & Winrich, 2010; Vrasidas, et al., 2015), and better use of information and improved long-term memory of the information (Sherwood et al., 1987). However, misinformation in pop culture can also produce adverse outcomes. For example, Barnett et al. (2006) in their study found that students who have watched the movie *The Core* in which the Earth's core inaccurately stops moving, have more inaccurate perceptions about Earth science compared to students who have not watched the movie. However, misinformation does not always produce adverse effects. One example is Muller, Bewes, Sharma, and Reimann's (2008) study; they presented the participants with videos that talk about Newton's laws of motion, while in some conditions researchers presented the common misconceptions before the facts. Their results show that students who were presented with the misconceptions and had them refuted had the highest learning outcomes.

Although there is no specific work explaining why pop culture references might have these positive effects, one possible explanation could be their ability to elicit curiosity and interest. Kashdan et al. (2018) definitions curiosity as "the recognition, pursuit, and desire to explore novel, uncertain, complex, and ambiguous events. There is a feeling of interest in a situation where a potential exists for learning. There is a desire to seek out novel experiences -- to see what happens, to find out how one will react, or discover how others react" (p. 130).

The level of curiosity an individual shows about different topics varies extensively. We might love to hear juicy gossip about our best friend's boyfriend while we might not care about what food they had for lunch. Golman and Lowenstein introduce three main determinants of the amount of attention that goes into being curious about a topic. They present these as three factors contributing to how much one might be thinking about a certain question or topic –we will describe this feature as attention weight based on Golman and Lowenstein's work –: salience, importance, and surprise. These factors might explain the interest in pop culture references.

Salience. "Salience reflects the degree to which a particular context highlights the question" (Golman & Loewenstein, 2015, p.6). For example, during the opening week of the movie *The Martian*, our environment (e.g., billboards, online advertising, merchandise) has been covered with reminders of the movie. Thus, one might be primed about the movie and might be more likely to ask a question about *The Martian* if there is an opportunity to do so. In this scenario, the question about *The Martian* is salient. More salience increases the attention weight and makes it more likely for individuals to be curious about the primed topic.

Importance. The attention one dedicates to a question is also associated with importance, which is determined by the usefulness of the answer to the person that asks the question (Golman & Loewenstein, 2015). For example, knowing the answer to how to survive an earthquake can save one's life and, thus, has a high attention weight. In sci-fi movies, a frequent theme is surviving. These themes range from surviving the attack of aliens or an asteroid impact to living on a different planet or in space.

Surprise. Surprise is a product of any unexpected new information, leading to increased attention weight (Golman & Loewenstein, 2015). Vidler (1974) also states that presenting a contradiction can arouse curiosity. This concept can function similar to how surprise contradicts our previous understanding of the world. For example, if one believes that one side of the moon is always dark and a scientist tells them that actually, this concept is a myth, one might be willing to know more about the correct answer since this is new and unexpected information. The element of surprise seems to draw from unexpected information.

The studies in this section argue for the benefits of using pop culture references but do not provide much variety in contexts or details on underlying mechanisms. I describe three main gaps in the study of this topic as it relates to the methodology, context, and objectives. In the next paragraphs, I address each of these limitations.

Methodology. The majority of papers on the importance of pop culture references in science either express an opinion (Zehr, 2014) or draw upon their personal experiences. For example, Cavanaugh (2002) discusses why sci-fi is beneficial to science education and how he uses sci-fi in the classroom. Derjani-Bayeh and Olivera-Fuentes' (2009), describe their experience when using sci-fi to teach chemical engineering material. Some others have analyzed specific movie material, including Goll and Wood's (1999) analysis of the movie *Apollo 13*, Dubeck et al. (1988) description of the science of multiple sci-fi movies, and Arroio's (2010) explanation of how the movie *Erin Brockovich* can teach science. This type of research limits the results to the authors' opinion on the effects of the use of sci-fi. Implications of such research mainly revolve around the design of the material. Some studies use self-reports (e.g., Laprise & Winrich, 2010; Vrasidas, et al., 2015) and exam grades (e.g., Efthimiou & Llewellyn, 2004) to evaluate the effect of pop culture references. Although these evaluations and case reports are of great value, they are limited in their generalizability.

Objectives. The majority of studies of pop-culture references revolve around reporting learning outcomes and the description of the reference (e.g., Barnett et al., 2006; Barnett; Dark, 2005). However, there is little information about why and how scientists use pop culture references. Zehr (2014) and Cavanaugh (2002) point at the use of pop culture references to build a mutual ground. Others, such as Segall (2002) and Dark (2005), use them in classroom settings for physics education. Researchers also provide personal examples of how they use these references, particularly for an audience of physics educators. For instance, Segall (2002) uses the example of *Independence Day*, where an alien spaceship attacks Earth and destroys New York. In his engineering classroom, he uses this example to work on the concepts of equilibrium and pressure, calculating the force needed for the alien spaceship to be stationary. In other words, he reverse-engineers the scene, assumes for the scene to be accurate, and calculates values that a scenario needs to be valid. Dark (2003) assigns his students to explore the "good" and "bad" science in *Contact*, *Deep Impact*, and *The Matrix*. These examples demonstrate single instances of the modes were scientists use pop culture for education. Besides, there is not much work describing why the audience (e.g., the students, museum attendees, public) might be interested in these references and if such interest arises from the reference's curiosity-inducing tendency.

Context. Most of the research addresses sci-fi as a tool for classroom education and studies the effects of pop culture in a classroom setting (e.g., Barnett et al., 2006; Barnett & Kafka, 2007; Efthimiou & Llewellyn, 2003; Dennis, 2002; Vrasidas et al., 2015). Many of these studies use qualitative methods to describe the use of references and their effects, mainly focusing on how to transform a reference into an educational tool (Barnett et al., 2006; Bennett & Kafka, 2007; Vrasidas et al., 2015). Quantitative surveys also provide information on the effectiveness of the use of sci-fi in the classroom (Efthimiou & Llewellyn, 2003). Dennis's (2002) paper, however, is mainly a toolkit for educators in physics, offering exercises and tips for using pop culture references and choosing educational material.

One of the few examples of a study on pop culture conducted outside a classroom is Burks and colleagues' study (2017). They surveyed attendees after the *SciPop Talks* event, a faculty/librarian partnership to bring the science of pop culture out of the classrooms. Their results emphasize demographic differences and identify what the audience was interested in after the talk. The analysis of open-ended questions shows that the audience was most interested in a specific concept they have learned during the talk; for example, "I did not know convection was so deadly!" (p. 1923). However, the study's population is limited to a college audience (i.e., students, faculty, and the college community), and the data provide a limited understanding of motivations and outcomes based on a short survey.

Science centers can be a study site that allow researchers to examine their topic from different aspects. They attract a high number of visitors, with more than 850 million yearly visits to American museums (American Association of Museums, 2008) and a wide range of age groups (Department for Digital, Culture, Media, and Sport (UK), 2017). The study of pop culture in these sites can help researchers understand the phenomena as it forms organically on site.

Also, science centers can be hosts to "dialogue events" in which experts and the public can converse with one another. These events can empower the involvement of experts and participants and can help science and society move slowly towards more public engagement in science (Lehr et al., 2007). Besides, Gammon and Burch (2006) believe such events can build trust and empathy between experts and the public.

Considering most studies are in the form of the case studies evaluated through self-report methodologies, in addition to the limited work on understanding the motives, modes and ways scientists use pop culture in formal learning settings, I ask the following questions:

RQ2*: Why do scientists use pop culture references in informal education?*

RQ3*: What are the modes in which scientists use pop culture references in informal education?*

In this study, I examine multiple instances of pop culture use by scientists in an informal learning space of a planetarium. The study of these pop culture references as they develop and create knowledge provides an opportunity for researchers to see how one particular mutual ground (i.e., pop culture references) can build a scaffolding for co-creation of knowledge, and how the educator and the learner interact with this material.

Methodology and Data Collection

The Adler Planetarium, located in Chicago, is also the house of the Space Visualization Lab (SVL). The planetarium is distinctive in that it is one of the few planetariums that has a research staff, working as researchers, and presenting their work to the public. Every day for two hours, two scientists from the planetarium or volunteer scientists from other science centers attend the lab and talk to the attendees about their research, new topics of astronomy, or the attendees' topics of interest. The number of attendees in each session usually range between 30-100 individuals.

The lab is around 20 x 20 feet in dimension, providing a space for close contact with the scientist. The talks are labeled Astronomy Conversations (Figure 1) to foster a two-way casual conversation. This is a unique opportunity for the public to have a conversation with a scientist. This site is not representative of all sites in which science communication happens. However, I will observe the practice of science outreach in this location to provide an example for the use of pop culture in science communication in a planetarium.

Figure 1. *An astronomy conversation session at the Space Visualization Lab.*

I have spent one year observing my data collection field, attending talks at least once a week. I have spent an estimation of 8 hours for each attendance, 384 overall hours in the field for this study. Through this extended observation period, I could see the use of pop culture as happening on-site and observe how it develops organically and becomes a part of the dialogue between the expert and the attendees.

To analyze my data, I have used a grounded theory approach. In this method (Glaser & Strauss, 1967), the researcher enters the site with a general idea of what they intend to study and will eventually narrow their data collection. Through this method, the researcher can observe the field and eventually develop theories and models that can explain the existing patterns in the data. At the initial stages, after spending some time in the field, the researcher chooses a slice of data to study. This dataset would be related to the theoretical topic they intend to expand on. Next, the researcher develops a variety of codes to categorize the data (open coding) and write memos of their thoughts on the field. The researcher can also categorize the codes through axial coding, in which they can evaluate the relationships between the codes. Eventually, depending on the developing ideas, the researcher can modify their location, and content of data collection to answer the specific questions related to their emerging theory. They can engage in selective coding at this stage, which entails more focused coding of data associated with the emerging theory. This process can continue until the saturation of the different categories.

The grounded theory approach encourages no use of literature to inform one's research and to withhold the use of literature until after data analysis. However, in the informed grounded theory "both the process and the product have been thoroughly grounded in data by GT [grounded theory] methods while being informed by existing research literature and theoretical frameworks" (Thornberg, 2012, p. 8). Thornberg also notes that by ignoring the previous literature, there is the danger of missing valuable information, repeating old mistakes, or assuming that they have reached a breakthrough even though other researchers have already reached the same results.

Previous studies have proposed that researchers can use models and theories as a "lens" to examine different phenomena (Kelle, 1995). In other words, they assist researchers and provide a guideline for ways to explore the data. However, the previous literature and theories should not limit the researcher's willingness to come up with new ideas and prevent them from exploring new ways of examining the data and finding patterns that other researchers have not yet explored. Thus, in this study, although I rely on grounded theory strategies, I use the help of previous research to inform my data collection and coding scheme.

I started my data collection by taking general ethnographic field notes of the conversations between the scientist and the audience during the 1-hour SVL session. After focusing my topic on the use of pop culture references, I started to focus my field notes on the conversations related to a pop culture reference. Usually, I would type my notes and elaborate on my observations within 24 hours after the session, including comments and possible interpretations. As in grounded theory, after acquiring some data, I started doing open coding to find patterns. I then went back to the field to collect more data around initial patterns until I was confident that I had reached a saturation point. At this point, I conducted a more selective coding to come up with theories based on observations. However, I would still take note of the uses of analogies and examples and also questions asked by the scientist and the attendees for comparison goals.

I also conducted 11 interviews with the experts at Adler Planetarium, who spend at least one day a month talking to the public at SVL (five females, six males). The interviewees varied in seniority and position (student, post-doc, professor, practitioners) and included astronomers, physicists, and engineers. Except for one volunteer, the rest of the interviewees were employees of Adler's research department.

Halfway through my data collection, I interviewed the first seven experts about science communication topics, including the use of pop culture references. Within the last two months of data collection, I conducted six more interviews (2 experts were interviewed again for follow-up questions).

Analysis

In the first round of coding, I encountered different uses of pop culture references by the scientist, mainly for education and engagement of the audience. I have coded any reference that attempted to educate the attendees on a scientific topic as education. I have coded any reference that seemed intended as a joke or to produce excitement and laughter as engagement. I have made this decision due to the subjectivity of identifying jokes and excitement. Many of the identifiers of jokes and excitement are less in the content and more in the nonverbal cues such as tone, laughter, facial expressions. Since my data is audio and transcribed into text, identifying the cues is not applicable.

One of the main differences between the references was in the use of ones that were similar to scientific concepts, such as the realistic black hole in *Interstellar* versus references that were counter to scientific facts such as concepts in the movie *The Core*, where Earth's core stops rotating. Body language reactions have also been coded, including smiling, nodding, and surprise indicators such as *wow*. After conducting the first round of interviews, the central theme seemed to be the intention to build a mutual ground between the scientist and the attendees. In this phase, three main patterns emerge:

1) Scientists use pop culture references to build mutual ground (i.e., shared framing)

2) Scientists use pop culture references for education and engagement

3) Scientists use pop culture references with similarities and discrepancies to science differently for education

While I continued coding, I became more interested in how pop culture references elicit curiosity in the attendees. Hence, I also added codes for the questions asked by the scientist and the attendees. I also recorded more details in some of these interactions, such as follow-up questions, facial expressions, and occasionally the conversations before the pop culture talk started.

With more observations and analysis of my data, I have added "emulation" to my codes of pop culture use, including instances when a scientist emulates a character from the pop culture world. Emulation could include quoting a movie or act similar to a character in a movie. In the second round of interviews, I have specified my questions to pop culture use. I emphasized how and why scientists used those references and asked about their relationship with sci-fi. The last questions were about the limitations of pop culture references as perceived by the scientist. I coded these interviews based on the benefits of pop culture, mainly building common grounds, through words like *help the audience relate and connect*. Another code was the sensory descriptions of pop culture references as a mutual ground, for example, *it helps people visualize information*.

In the last round of analysis, I also looked at analogies and questions unrelated to pop culture references to use as a comparison group. Analogies work as a common ground but have specific differences with pop culture references, for example, they might not follow a narrative like a movie, or be entertaining. In addition, by observing the development of questions (ones not related to pop culture references) I examined how pop culture-related questions develop. I have also further coded references for the importance and salience of information and surprising information as they contribute to the weight of curiosity about these references, according to Golman and Lowenstein (2015). The last group of codes was a breakdown of questions to general questions of accuracy and opinion "*Did you like The Martian?*" or "*Was Gravity scientifically a good movie?*" and specific questions such as "*So what is inside a black hole* [referring to *Interstellar*]."

While coding the last round of analysis, the main categories' of codes developed into:

1) The curiosity of the audience regarding pop culture references: this category includes the content of the audience's questions. In particular, are the topics surprising, important, or relevant to the audience?

2) Development of questions asked by the audience: This category describes the process of inquiry from triggers that elicit a question to the back and forth questions and answers.

3) Modes of use of pop culture reference by scientists: Scientists use different pop culture references in different ways. Some references are based on the accuracy of the portrayal

of science, while others are based on wrong representations and “bad science.”

4) Pop culture references as mutual grounds: Pop culture references are mostly based on stories from movies and shows. These stories have different features that scientists use as a mutual ground, including characters, concepts, and objects. For example, a reference can be about a concept portrayed in a movie to explain real science.

5) Sensory mutual ground: This category is mostly based on the content of interviews with scientists and how the references can build a multisensory mutual ground.

I have coded 248 pages of field notes. Eventually, through axial coding of the code categories, I developed a model to describe the relationships between the findings.

I have presented the results of this study to the speakers and staff at SVL to confirm the accuracy of the findings. I asked the speakers to identify if the results match their perceptions of their talks and if I have interpreted the content correctly. Respondents to the request did confirm the accuracy of the findings.

Results

The results from this study form a general model, describing the interactions between the observed units and their features (Figure 2). Each unit is a behavior performed by the audience or the scientist. I will go through the findings based on three research questions. First, understanding **why** scientists and the audience use pop culture references, second, **how** do the scientists use the references, and finally, **what** are the underlying interactions that establish pop culture references as a mutual ground for knowledge-building.

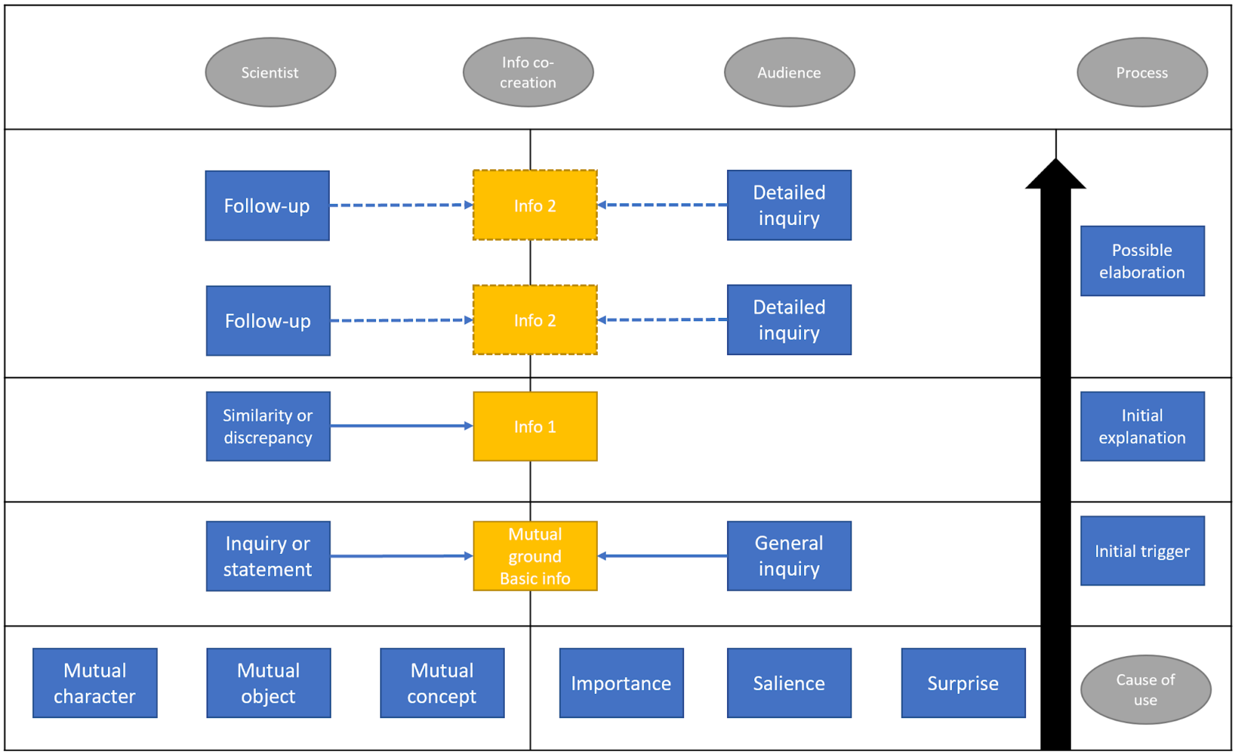


Figure 2. *Model of Science communication through pop culture references. Dashed lines show possible relations and outcomes but not necessary.*

Why Do Scientists and the Audience Use Pop Culture References? Movies and TV shows, in nature popular, seem to provide mutual ground for scientists and the audience to build a conversation. The mutual ground works as a basic piece of information, a foundation for the conversation. For example, to talk about travel to Mars, the movie *The Martian,* based on the story of an astronaut strangled on Mars, provides a mutual ground in which the audience can imagine Mars, space travel, and life on Mars. Having this mutual knowledge, the scientist can elaborate on any of these topics, knowing that the audience has a reference point for the topic of discussion. For scientists, the benefits of using the references in this context are evident from quotes such as the following statement by Dan:

"I mean, think of how many people saw the Martian, or how many people saw Gravity or Interstellar or whatever, you know compared to how many people you know heard an astronomer talk or watched an astronomy lecture or you know, it's …natural that you have so many people familiar with what they've seen in movies and it's a great opportunity."

Scientists use references to build mutual ground and to connect with their audience. The references will be able to function as a mutual ground if the audience is familiar with a specific visual and "*remembers what things look like"* Dan or when they have become familiarized with a concept. As Mike notes, pop culture references have already established a common visual "*Sometimes analogies are hard to picture, but the science fiction movies actually did it."* In other words, the references provide an analogy or example *"You've got the subject matter right there that is accessible to the public. Really, it's kind of by nature aimed at a general public level. Half of your job is done for you. It's just a matter of taking what's there and comparing that to your research."* Since these mutual grounds are usually based on elements of a science fiction story, they borrow different elements of a story including **characters** (e.g., a protagonist), **objects** (e.g., a weapon), and **concepts** (e.g., laws of physics).

Characters. Characters from movies and shows can play different roles. For instance, when Eric attempts to explain the communication delay between Earth and Mars, he uses the example of Mark Watney, the botanist/astronaut in the movie *The Martian*. He describes how Mark's messages would take a few minutes to go back and forth due to the distance between the two planets and the speed of radio waves. In this example, the character is ingrained in the story to describe how a scientific phenomenon works.

Bill uses characters in a different way to point out landmarks. Similar to how we look at clouds in the sky and imagine what they resemble, Bill engages in showing images of various nebulae, dust clouds that are the birthplace and graveyard of stars, and comparing them to pop culture characters. *Bill shows dust clouds in Eta Carinae Nebula to the kids. He then imitates the voice of the caterpillar in Alice in Wonderland "Whoooo Areeee youuuuu?" and tells the audience that the cloud looks like the caterpillar from Alice in Wonderland. A young girl sitting in front, smiles, and says, "oh yessss!"* (Figure 3). Knowing how Alice's caterpillar looks, not only the audience gets to compare the dust cloud to a character they know, its associative power might help them remember those landmarks later as well and the next time they see the cloud, they might remember the image of the caterpillar.

Figure 3. *Dust cloud in the Eat Carinae nebula, resembling the caterpillar from Alice in Wonderland.*

A third way scientists use characters is a more indirect way: by quoting or emulating a character. One such example is from the movie *Contact* in which Dr. Ellie Arroway, the protagonist, is an astronomer who is looking for extraterrestrial signals. In a scene in the movie, a young boy asks her, *"are there other people out there in the universe?"* Ellie squats down to be at eye level with the kid and tells him about how big the universe is and follows *"So if it's just us... seems like an awful waste of space. Right?"* (Figure 4). In one of the sessions at SVL, also a young child asks the speaker about aliens. The speaker goes close, squats down to eye level, and tells the kid, *"If we're alone in the universe, that would be an awful waste of space."* In this instance, although the scientist does not reference the character explicitly, they use their dialogue and manner in the conversation.

Figure 4. *Dr. Ellie Arroway from Contact has been emulated by multiple staff at the planetarium in response to questions about aliens.*

Objects. Objects and their functions are another type of reference used, and they can act as analogies or examples. For example, when talking about the sizes of different telescopes, Bill asks the audience to imagine the eyes of the T-Rex in *Jurassic Park,* which allows it to look further. In other words, bigger telescopes are like bigger eyes, an analogy for how telescopes function. When a scientist talks about the asteroid in the movie *Armageddon,* this object functions as an example for an asteroid (i.e., a rock floating in space). These objects provide the visual for the content of the scientists' talk *"If we're talking about black holes and you want people to get a picture of the environment of a black hole then, gosh, going way back there was a Disney film called the Black Hole."*

***Concepts*.** Concepts used in pop culture references are usually a straightforward way to connect the conversation with a reference. Concepts can contain different characters and objects and describe a scientific phenomenon or scenario. For example, in the movie *Armageddon*, an asteroid is on a collision course with Earth. Through the movie, we learn that an asteroid (object) is a rock moving through space (different from a comet or a meteor), and a collision course (concept) means there's a high chance that it will hit Earth. "*You know it lays a foundation of like, 'Oh, I see we're speaking the same language.' Like there's this thing hurtling through the solar system, it's coming to hit the Earth, and they send a rocket ship to it, and we're 'Ok good, at least we have [...] the terms, some of the concepts down."* In this example, the movie establishes the meaning for the concept of asteroid collision by providing a narrative and visuals.

However, in some specific more "geeky" scenarios, those common characters, objects, or concepts, might work for particular fandoms where the audience has an in-depth knowledge of the reference. For example, the *Star Trek* universe has specific rules and terminologies that scientists can use for educational purposes, but they might be applicable in situations where most of the audience is aware of the reference. *Star Trek* is a sci-fi TV series, following the adventures of a space exploration vessel crew. In this universe, one frequently used concept is that of a "Warp Speed," which can vary between different values, including the speed of light or even 2000 times the speed of light. To let the audience understand how vast our galaxy is, Eric, one of the speakers, elaborates that the show mostly happens in a very small section of our galaxy. Even if the vessel moves with Warp Speed, it might still take the crew 25 years to cross the galaxy.

In such cases, the speaker sometimes explains the terminology before using them or asks the audience if they know about the reference. On different occasions, before using the reference, the scientist starts with questions such as "*Has anyone watched Doctor Who?*" possibly to make sure the reference will work as a mutual ground. However, most examples used are blockbusters and popular shows or movies that more individuals recognize.

As mentioned earlier, scientists have also reported that they use references to build connections with their audience and to lower communication barriers. Some do so by using new blockbuster movies. Jake makes sure to be up to date with new blockbusters to use them in his talks and be prepared for questions from the audience. "*I'm not really into pop culture. I pick up on enough things that I can make references to the talk. Popular things are things that are [...] common[...] You know make a little joke, or some people feel like they can relate to me a little bit.*"

In general, it seems that to scientists, pop culture references function as a good example or analogy. One that is familiar and interesting to their audience and contains different elements for different purposes. For example, scientists can use characters for emulation, they can use objects to provide an analogy for how scientific objects or phenomena function, and use concepts to provide examples of how scientific concepts might look like and apply in real life. In addition, by using references that the audience is interested in, the scientist believes they move towards building connections and bridging gaps.

Do Pop Culture References Elicit Curiosity? An interesting observation during this study is the possible explanation for why the audience brings up questions about pop culture references. To describe the factors behind such behavior, I draw upon Golman and Loewenstein's (2015) work on attention weight as it relates to curiosity. Defined as how much one might think about a question, in this study when I discuss attention weight, I also refer to how often a topic or question might come up. I then explain how my observations fit into Golman and Loewenstein's elements of attention weight (i.e., salience, importance, surprise).

Salience. The pop culture references used at SVL, mostly of sci-fi movies are blockbusters that more people are familiar with and see references to them in regular daily lives. Thus, in the sessions, many questions about pop culture references are about the latest blockbuster movies. As it relates to movies, the audience most frequently asked questions about *The Martian*, *Interstellar*, and *Gravity* as mentioned by Jane. These are some of the latest sci-fi movie releases.

A pop culture reference that is not salient, on the other hand, might not receive much attention. This is also present when reviewing the questions asked by the audience, where almost no question is about a movie produced more than two years ago, or if the movie was not a blockbuster. Occasionally scientists use movies that might be not contemporary and well known by the public but, when they do so, they usually elaborate on the plot of the movie. For example, when one of the scientists intended to use an example from *The Theory of Everything*, he asked if the audience has watched the movie. When he realized that the audience is not familiar with the plot, he only mentioned that an essential point in this movie is coming up with a theory that integrates all theories.

Importance. Some movies used in SVL sessions, such as *Interstellar* revolve around the survival of humanity, depicting realistic concerns as it relates to the future of our planet struggling with climate change, and even natural disasters that have been experienced on earth before (Kluger, 2014). Thus, the audience's curiosity might stem from the importance of such topics. Potentially, scientists can explicitly talk about why specific topics matter to increase the audience's curiosity. Another example is *Armageddon*, as the plot entails our efforts to avoid a life-threatening collision with an asteroid. These examples do not have to be realistic to elicit curiosity, but relate more to possible scenarios that in some way, threaten humans' existence.

Surprise. In the SVL there seem to be two ways in which information is surprising concerning sci-fi movies and shows: when fiction becomes reality, and when what appears real is fiction. In some instances, science can seem fictional and limited to books and movies. One example is that of Tatooine, a planet in the movie *Star Wars* with two suns. The audience knows that *Star Wars* is a fictional movie and thus, might count many of the plots as fiction, including Tatooine's two-star system. However, the recent discovery of planets beyond our solar system has shown proof for the existence of planets that orbit around more than two stars.

The opposite of this condition is when a movie's plot seems scientific but is not, in reality, accurate. A good example is the movie, *Armageddon,* in which a crew is tasked to blow up an asteroid on its collision course with Earth. Considering the asteroid's close distance to Earth, blowing up that asteroid would only result in more scattered destruction of planet Earth. So, even though the movie does not feel like fantasy and the depictions might make the audience believe the processes and events are scientifically possible, science would reject them. In the following example, Eric exposes the audience's misconceptions.

Eric starts talking about the asteroid belt between Mars and Jupiter and its density. He references the scene in the movie Star Wars where Han Solo is in his spaceship and doges asteroids that are moving very close to each other. He tells the audience that there is a big problem in that scene: the asteroids in our asteroid belt are not that close to each other. He asks the audience, "so how long do you think it would take for two asteroids to collide accidentally ?" A few people start guessing, and when Eric tells them that the average time for two asteroids to collide is around 10 years the audience seems surprised, and a man says, "WOW!"

Eric primes the audience by talking about asteroids. He then exposes the nonfactual claims in film and elicits surprise by showing that the facts are different from the expectations. Eric then provides the audience with the information that shows the long distance between asteroids, after which an audience member shows their surprise with a "wow."

In a nutshell, the pop culture references possibly can elicit more attention weight compared to some other references, such as everyday examples. However, not all pop culture references might have high attention weight such as a reference that is not salient and well known, is not discussing an important issue, or is not surprising. The attention weight is an accumulation of different factors and the lack of one will not necessarily determine a low attention weight.

What are the modes in which scientists use pop culture references? Pop culture references seem to be mainly used at SVL to facilitate the understanding of a scientific concept. However, scientists don't use all references in the same way. Sci-fi movies are full of appealing visuals related to physics, space, and in particular, things that we do not have a visual representation for in everyday life, such as time travel. Some of the examples from movies are representative of science as we know it, while some are fiction and do not obey the laws of physics. The two main categories of references used are material with similarity to scientific knowledge and material with discrepancies to scientific knowledge.

Similarities. When scientists talk about black holes and how they curve space-time, they usually use the analogy of a blanket representing space and a heavy ball in the middle as the black hole. They explain how the curvature in the blanket forces objects on the blanket to fall in the black hole. Similar to how everyday phenomena are used as examples, the science in movies can also be used as examples to represent scientific phenomena with the advantage of having a visual reference.

Eric references a scene in *The Martian* where the astronaut on Mars had to wait for a few minutes to receive a message from Earth. He could have just said that a delay in conversation happens due to the distance, but through referencing the movie he established some common story elements. The audience knows that Mars is far, and they remember that every time the astronaut would send a message, it would take each side a few minutes to receive the next message. Besides, there is a general common visual they have in mind (i.e., the astronaut typing the message), waiting to get information back and forth while others on Earth were waiting to receive the message. So, scientists use the pop culture example and elaborate on how the pop culture example contains science.

Discrepancies. However, examples in movies do not always represent how real science works. On many occasions, scientists use “bad science” examples where there is a discrepancy between the laws of physics and the pop culture reference. Similar to using movies as an example, bad science is used as a counterexample. It needs to be followed by the scientists debunking them and explaining why they do not match our scientific understanding of the topic.

“In the movie [Armageddon], one way [to deflect the asteroid]is to blow the asteroid [that is heading towards Earth], but it will be smaller things hitting us! So the other way is a Gravity tractor, anything with mass has gravitational force, fly something massive near the asteroid and influence its direction a little, or paint one side white, the sun exerts a tiny amount of pressure.”

The example of Armageddon, not only contains the element of surprise (i.e., the solution in the movie is still going to harm the Earth) but also leaves room to discuss alternatives and potential scientific explanations. As one of the interviewees points out, this is a good educational moment to tell the audience not to believe everything that they watch on TV! Correcting misconceptions is however, a double-edged sword, as I will further discuss in the limitation of the use of pop culture references; scientists cannot just ruin a movie for the audience without providing something to substitute the exciting premise of the movie.

In any of these two types of references, similarity and discrepancy, scientists have to make the connection between the movie and the scientific knowledge, otherwise, the audience is not receiving any closure, and the communication is not complete. An example of this is when Anna showed a real picture of Eta Carinae nebula, looking like an explosion *"This is called the Death Star [from Star Wars]!"* she establishes the pop culture reference and goes on to talk about stars and how they produce energy. After a few short minutes, a young girl in the audience raises her hand and asks Anna, *"Why is it called the Death Star?"* So, even though Anna missed describing why the pop culture reference and science connect, the audience brings back the conversation to this point.

The only instance in my observations in which there was no need for introducing the reference and elaborating on the similarity or difference, is when a scientist uses a reference as a direct quote or to emulate a character in a reference. As mentioned before, one such example is that of Dr. Ellie Arroway from the movie *Contact.* As one of the attendees asks about aliens, the speaker answers in the words of Dr. Arroway *"If we're alone in the universe, that would be an awful waste of space"* without mentioning that this was a movie reference. In this instance, the quote from the movie is not an example or analogy, but is the answer to the question itself.

Although scientists use the references mainly to explain a scientific concept and as a strategy to facilitate learning, there seem to be other underlying objectives, including entertainment and engagement of the audience. Although I will not be discussing these effects in this study, they are important elements to be aware of as additional effects of the use of pop culture references. In the next section, I will be examining the dynamics involved in developing a conversation with pop culture references as a mutual ground.

How do scientists and the audience generate a mutual ground through interactions about pop culture? This section describes the processes in which the scientist or audience establishes the mutual ground of pop culture and develops it to create knowledge. This process could start with the scientists bringing up a pop culture reference or with the audience having an inquiry about a reference.

Initial Trigger. If pop cultures are used as a mutual ground, the most important thing is that the reference used is known by the audience. To do so, it seems that scientists usually evaluate their audience by finding out if they know about the specific movie or show. Questions such as *"Have you guys watched Wall-E"* or *"Do you remember Tatooine in Star Wars?"* help scientists evaluate the audience's knowledge and decide on how to proceed with the conversation. However, sometimes when the reference is very popular (e.g., *Interstellar* or *The Martian)* scientists assume that the shared knowledge exists, thus, they would proceed without much of an evaluation.

If the audience initiates the conversation about the pop culture reference, it's possible to say that either the audience has some initial knowledge of the topic (even if limited) or interest in it. This initial common knowledge can possibly establish a mutual ground. *"When people bring up science fiction examples, it sometimes means that's kind of what they're interested in, so you're meeting the person where they are."*

The audience usually starts with general questions and moves to more detailed questions. For example, an audience member asks *"So, the movie Martian was unrealistic?" Philip explains that it was realistic but that the sandstorm, in reality, is not as hard since Mars does not* *have an atmosphere "the strongest wind there can't even move that coat rack!" The woman follows up, asking "would you say that the storm is worse than the ones in Arizona?" Philip tells her that the wind on Mars won't blow you over but that the small dust particles on Mars could endanger you causing breathing problems.*

The woman's question in this example started with a general evaluative nature, and it has progressed through a more detailed nature with specific pieces of information requested. The majority of questions about pop culture references, in the beginning, have a general nature including evaluation of opinion and accuracy, "*Did you like Martian?", "Is Interstellar accurate?", "What do you think of Gravity?"*

When provided with more information on the topic, with time, questions become more specific. For instance, after a long talk about black holes and *Interstellar*, an audience member asks, *"So, what could be behind a massive black hole?"* thus, moving from a general question about the topic to a more specific question about details.

The same pattern seems to apply to other topics and not just pop culture references. The following example is a conversation regarding the Cosmic Background Radiation (CBR) temperature difference when the scientists shows a visualization of CBR in different colors.

Audience: "What does the difference in the colors represent?"

Alex: "Really small fluctuations in temperature...makes higher density in some areas...that's why we have galaxies."

Man: "Fahrenheit, Celsius, or Kelvin?[the temperature difference]"

Alex: "Kelvin"

Man: "Could it become zero in a few years?"

The conversation started with a more general question and moved to smaller details about scale models and examples of it. There are non-pop culture examples of questions that do not seem as general such as *"When we say the universe expands, what does it expand into?"* This might show that the general nature of the initial question is relative to the follow up question. Although the first question might not seem as general, the following question, if relevant, might demand more detailed information.

Initial Explanation. After the mutual ground is established via the audience's inquiry or the scientist mentioning pop culture references, scientists proceed by explaining the similarities of a pop culture example with science or debunk the discrepancies of the example with science. Through this stage, the scientist either makes sense of why they used a particular pop culture reference or answer the audience's questions. After this stage, the scientist can decide to continue the conversation about the topic and elaborate or move on to a different topic and the audience might follow up on the topic with more questions.

Possible Elaboration. If the scientist decides to stay on a topic after explaining the example or debunking the counterexample, they can elaborate on the topic. In a session with Philip, one of the attendees asks him, "*How true was the movie Martian?"* He answers, *"It was fun, but let me tell you something about the movie. You know when there was the wind, it would move heavy stuff? [...]That doesn't happen on Marscause the atmosphere is too thin, it doesn't have the energy to move stuff."* He then follows up the conversation with ***"****The thing with movies* *like this is that we still don't know how to keep humans alive on Mars for three reasons, one is the radiation that could kill people and causes cancer. The second is lack of strong gravity, and third is the dust is very thin, so even the astronauts on moon, even after taking their space suits off, they were still breathing it and had moon coughs."*

In this example, after answering the direct question, the scientist moves to a conversation about the barriers to living on Mars. Elaboration can go on for as long as the scientist decides or as long as there are follow-up questions from the audience. As mentioned previously, the questions become more detailed as they proceed.

As evident in the data, the conversation starts with the construction of a scaffold around a mutual ground. To ensure the mutual ground is functional, the scientist has to either evaluate the audience's knowledge or rely on a guess based on the fame of a reference. Alternatively, if the audience asks the question, the scientist will know that the mutual ground is familiar to them. After explaining how the mutual ground relates to science, the conversation can go on if the audience follows up the question or if the scientist adds to the content. However, at this point, the scientist can remove the scaffold and continue the conversation without referencing a specific movie. The mutual ground has reached its goal by connecting the movie to a scientific concept or by addressing the audience's interest and can now dissolve into a conversation about the scientific topic alone.

Beware…pop Culture References. Pop culture could as well have specific weaknesses, thus limiting their use by scientists. Even though pop culture references' main strength is to provide a mutual ground, it sometimes fails to be mutual when the audience is not familiar with the reference. Dominating a session with pop culture references could be overwhelming, particularly for the uninterested audience. Pop-culture-themed conversation, in particular, if they are about a reference with devoted fans that know too much about the reference, could be very exclusive and might alienate the rest of the audience if it goes on for too long. Thus, even though the purpose of this study is to encourage the communicators to take advantage of pop culture references, communicators should be aware of the extent to which one reference dominates the session and how "nerdy" it becomes. Possibly, the more in-depth and more detailed reference-related information one provides, fewer members of the audience could connect to the conversation.

Scientists mainly prevent this situation by evaluating their audience's interest and knowledge of the reference and by providing a context for those who are not familiar with the reference. Jane, in one of the sessions, talks about the new planet discovered outside of the solar system that orbits two suns. She then references the 1941 Isaac Asimov book *Nightfall*, but before going on, she pauses and asks the audience if there are any sci-fi fans. Some of the audience raise their hands. She then asks if anyone knows of the book. No one seemed to have heard about the book. So, she goes on to give them a summary of the story and then connected the story to the recent discovery. She later points out in an interview how she handles the limitation of unfamiliarity with the story.

"I often throw the question out first, "Are there any science fiction fans here?" If I see a number of hands go up, then I can make a tie-in, "Oh," that there's this curious thing about the world that you're looking at here, or about this particular discovery that was made this week. I can lead the conversation that way, depending on people's interest. If I ask, "Are there any

science fiction fans here?" and no hands go up, then I'm not going to take them down a rabbit hole and talk to them about something they're not [interested in].”

If needed, the scientist gives a summary of the story for people who do not know the plot and continues with making the connection to the reference. Evaluation of the audience by asking them questions is an important action to understand the audience’s interest and familiarity with the topic. When using the references, scientists should try to keep them limited and short and not occupying all the sessions.

Some of the audience might be very invested in a reference, so scientists likely need to discuss these references cautiously. *“Nobody wants to bring up a favorite movie or book to you and have you tell them that it's stupid, obviously”* says Jane, making an important point about how dissecting a sci-fi movie could take the fun away. *“It's no fun to just say no, that's not how it works. You have to say no, that's not how it works, here's this really cool example from real life. There is a reality in our own universe that's actually much cooler than that for different reasons”* says another scientist. The idea presented is to avoid *“Science-ruining”* and *“taking away the magic”* by appreciating the art and being able to acknowledge that the reference is fiction, and finally, appreciating the wonders of the real world.

Pop culture references, like any other teaching tool, should be treated with caution as to not overwhelm the audience with sci-fi references and making the conversation exclusive to a limited audience. It is also essential for scientists to appreciate the reference as art while acknowledging scientific flaws and following the conversation with facts of science that could elicit a sense of awe and surprise.

Discussion

The purpose of this study was to develop a model explaining how scientists and the visitors of an informal science center use pop culture references. I have used the grounded theory method to try to understand why scientists and the public use these references, how are these references used, and what are the dynamics that shape a conversation around pop culture references, with pop culture as a mutual ground.

I have described the multiple elements of a conversation from start to finish. Conversations start with an initial trigger from the scientist deciding to bring up a reference or a visitor asking a question about the reference. This initial step includes establishing that both parties are aware of the example to use it as a mutual ground. This step is followed by the scientist explaining the connection between the reference and the scientific concept. The conversation can terminate here or it can be followed up with the audience's other related questions from the audience or through the elaborations of the scientists themselves.

This model is in line with the description of scaffolding in learning sciences. As mentioned earlier in the literature review, through scaffolding in education, an educational tool is initially used to establish a new piece of knowledge and will gradually be removed after information is established (Lajoie, 2005). As observed in the developed model, after the scientist establishes the connection between the reference and the scientific concept, they can follow the conversation independent of the initial question or specific reference.

This model, however, adds to the previous knowledge by explaining the social exchange that initiates the establishment of mutual ground, including how the scientist acts to make sure the reference is an actual mutual ground and both parties are aware of the reference. The model also describes how the scaffold can be slowly changing its purpose based on the follow-up questions and eventually dissolve, for example, the scientist might use the pop culture reference to explain a concept, continue using that example to expand on the different aspects of a scientific concept, and eventually stop using the reference and only focus on the science.

I also aimed to understand the value of pop culture references as scientists perceive it and as a part of my observations. Scientists reported that the use of pop culture references helps them feel like they are lowering barriers of communication, connect to their audience, and have a mutual ground. As the public has more exposure to movies and shows and less to science lectures, scientists can use movies, especially their visuals, characters, objects, and concepts to discuss various scientific topics. These findings are also in line with Scheufele and Tewksbury's (2007) notion that information can be communicated in a familiar frame. In other words, the scientist in this study chose pop culture references as a frame understandable to their audience. Similarly, Frey and colleagues' (2012) idea of anchoring information to something familiar is reflected in the use of pop culture references as a common ground. This finding can show that the scientists do care about building connections between themselves and their audience as one of their main science communication goals.

Finally, the main two modes that scientists use pop culture references are through examining the references' similarities or discrepancies with science. The results were in line with Gentner's (1989) description of how different tools are used to describe a complicated concept. In this study, references can fall into these categories with a "base" functioning as the familiar mutual ground. Based on Gentner's work the scientific phenomena are used for literal similarity (the black hole in *Interstellar* is similar to how a real black hole is expected to be), an analogy (a big telescope is like a T-Rex's big eye), abstraction (an object that is both a spoon and a fork in the movie *Wall-E* is categorized as an object in-between, this taxonomy is used when categorizing Pluto as a dwarf planet, an object not just an asteroid and not a full planet), anomaly (unlike the sandstorm in *The Martian,* sandstorms on Mars are very mild), mere appearance (a gas cloud in space looking like Borg, a character from *Star Trek*). The frequent use of "bad science" examples shows the value of these references to highlight anomalies rather than discarding such references for their inaccuracies.

The results from this study can be used by scientists and science communicators to provide examples on how experts use pop culture references in their outreach efforts, in particular in an informal learning space where the relationship is not based on a teacher-student dynamic and is more geared to develop a conversation (Astronomy Conversations). By providing a model, communicators get a general idea of what to expect in a conversation around pop culture references, decide how they would like to establish a mutual ground and how to navigate the progress. Embedded examples throughout this study provide practical examples of how such conversations can look and proceed.

The model I suggested in this study provides a theoretical framework for how a scientist or an attendee initiates a conversation around a mutual ground, how scientists use the mutual grounds as a scaffold for education, and eventually how this scaffold dissolves while the conversation continues. This model is a comprehensive overview of this phenomenon rather than a small section of the conversation. Thus, it integrates concepts studied separately, including the use of scaffolding, analogies and examples, pop culture references, curiosity and dialogue, into one model. The model describes on-site observations that have not been discussed before in literature such as the use of similarities and discrepancies of references for science communication, the curiosity-inducing capacity of pop culture references, and the development of a conversation as stages of a process.

In this research, I use qualitative methodology to describe the use of pop culture references by scientists in a planetarium as the conversation developed organically. While such methods allow researchers to explain different phenomena, dynamics, and processes, it cannot prove existing relationships and effects. To understand if pop culture references can result in improved learning outcomes or participant engagement through dialogue, researchers should design experiments to show causal relationships. Besides, this study is limited to scientists at a planetarium who have science communication experience. To apply the results to a more general setting, researchers should find opportunities to study this phenomenon in other informal learning spaces including museums, science centers, and festivals, and with scientists who have less science communication experience.

Conclusion

This study provides a model for the use of pop culture references in an informal learning space by scientists. I describe the dynamics between the scientist and the audience and how they use references in a conversation. In addition, I examine the modes in which scientists use the references and why scientists use the references in the first place. The findings in this study can be used both by researchers to examine different steps in the science communication process in addition to the effect of different science communication tools. Results can also be used by science communication practitioners as a guideline on how the references can be used and what they can expect from the use of these references.

The public interest in science-fiction is visible through the various blockbuster movies and their sales. These movies expose a great number of the population to references that scientists can use to connect to their audience. By using these references in moderation and through strategies that assure the audience is on the same page with the scientist, this tool can potentially improve the status of science communication as a strategy to connect with the audience and involve them in a conversation.

Chapter 3: Attributes of Science Outreach Activities that Foster Dialogue and Curiosity: A Case Study at the Adler Planetarium

Introduction

Although the public has a fairly high trust in scientists compared to other sources such as the press, media, and politicians (PEW, 2017), there is still a knowledge gap between what the public believes to be true and scientists opinion (PEW, 2015). This is particularly important as it relates to controversial topics such as the dangers of genetically modified food and the threat of climate change. The older strategies of one-way science communication, such as lectures, appear to be insufficient to change the public's attitude positively towards science (Brossard, Lewenstein, Bonney, 2005). Thus, there is an increasing emphasis on moving towards citizen-centered science communication to engage the public in a conversation about science, as also noted in the National Academies of Sciences, Engineering, and Medicine's (NAS) 2017 research agenda. This strategy is not only an opportunity for more dialogue between experts and the public but also provides a platform for experts to learn about the public's concerns and questions and thus enable the scientists to potentially make science more relevant to individuals' daily lives (AAAS, 2013).

In the following study, based on site observations in a planetarium, I examine how scientists can foster a dialogue by eliciting curiosity. Also, by analyzing the content of attendees' questions, I attempt to infer what the content of attendees' curiosity. These findings are coupled with examples to show how curiosity-inducing strategies might look in an informal learning space.

Citizen-centered science communication and public engagement with science can be an opportunity to understand what the public opinion is and to build trust (Stilgoe, Lock, & Wilsdon, 2014). Strategies to engage with the public and foster a dialogue have also been advocated in STEM fields by different voices (e.g., Leshner, 2003; Rowland, 1993) and are reflected in STEM events that facilitate a direct conversation between experts and the public (e.g., Soapbox Science and Astronomy Conversations). However, most work in public engagement is limited to science policy (Stilgoe, Lock, & Wilsdon, 2014) and has limited practical advice on fostering engagement.

As defined by the NAS (2016), “Public engagement” is “seeking and facilitating the sharing and exchange of knowledge, perspectives, and preferences between or among groups who often have differences in expertise, power, and values” (p. 133). One factor that might facilitate engagement is curiosity, which can elicit inquiry (Jirout, 2011) and work as a facilitator for an interaction between scientists and the public.

However, research on engagement and curiosity has not yet fully explored the following two areas: (1) The study of curiosity in an informal learning space and a real-world context; (2) The scientists’ role as a facilitator that elicit public curiosity. Although there is extensive research on the psychological aspects of curiosity, scientists and practitioners have done little work to translate these studies into insight that’s useable within museum settings (McGee et al., 2017). From a science communication perspective, Bandelli and Konijn (2013) suggest that museums could be a place where scientists and researchers can try to understand the public based on their face-to-face interactions with them. Studying curiosity as it takes place naturally can help researchers understand this phenomenon as it relates to the environment and the context.

Although curiosity researchers have identified factors that elicit curiosity (e.g., Berlyn, 1960; Loewenstein, 1994; Silvia, 2008), they have not yet dedicated adequate attention to the role of human agents in inducing curiosity. As the STEM community encourages more engagement of scientists with the public (NAS, 2017), the study of scientists' roles in eliciting curiosity is not only a significant theoretical contribution but also has practical implications. To address these gaps, in this study, I documented the conversations between scientists and the planetarium attendees to identify how scientists encourage a conversation by eliciting curiosity and examining the content of the attendees' questions.

The findings from this study provide practical descriptions of strategies that might foster and maintain a curiosity-driven dialogue between scientists and their audience. In addition, they provide a real-world context for the findings of curiosity research in experimental settings. The qualitative descriptions of curiosity in an informal space reveal functions that other researchers in the field have not discussed, including how human agents can encourage curiosity and how they use data visualization to elicit curiosity.

In the following sections, I explore the literature to define curiosity, understand the importance of this phenomenon and its study in the museum settings. Eventually, I discuss the research on fostering curiosity and offer a summary of different factors that seem to elicit curiosity and existing gaps in that literature. Next, I describe the study design, followed by the result section. In the result section, I provide multiple examples from the field to explain how different interactions and curiosities manifest and what the frequency that various curiosity-inducing topics arose in the dialogues observed. I eventually discuss the results and conclude the study by providing an overview of the findings, the limitations, contributions, and future research.

Literature Review

What is Curiosity? Researchers have defined curiosity in a variety of ways. While these definitions have some aspects in common, such as filling a knowledge gap, other elements can be specific to one definition and not others. Most research identifies cognitive gaps to be a determining part of curiosity. Hunt (1965) and Loewenstein (1994) define curiosity in the context of cognitive shortcomings where the individual has been deprived of information needed to fill a perceptual and intellectual gap. Lowenstein suggests that curiosity is a response to becoming aware of a knowledge gap (1994), which might occur as a result of a question and uncertainty about the answer (Golman & Loewenstein, 2015). Kashdan et al. (2018) define curiosity in terms of fulfilling knowledge gaps in broader terms as “the recognition, pursuit, and desire to explore novel, uncertain, complex, and ambiguous events” (p. 130).

However, earlier researchers define curiosity as a drive (Pavlov, 2010) or an impulse (James, 1983), with the acquisition of information serving as an instrument to fulfill that drive, similar to how eating meets the need for food. Some more recent researchers define this desire for information in more behavioral terms such as exploration. Kashdan et al. (2018) define this desire in more concrete terms as “a desire to seek out novel experiences -- to see what happens, to find out how one will react, or discover how others react” (p. 130).

Some researchers discuss emotions when defining curiosity. Litman and Jimerson (2004), alongside the cognitive gap, introduce interest as one of the factors that elicits curiosity. They claim that "curiosity as a feeling-of-interest" is a result of wanting to acquire more information related to topics that are more entertaining, artistic, or casual. This could include a fun story or an entertaining movie. Kashdan et al. (2018) also bring up curiosity as a feeling of interest when there is a learning opportunity. This definition is in line with Kang's and colleagues' (2009) findings of an fMRI study in which receiving trivia questions elicits anticipation for a reward. This feeling contrasts with curiosity as a "feeling of deprivation" containing negative emotions such as frustration. In discussing the topic, researchers address a range of phenomena that could represent curiosity, such as exploring, playing, and information seeking.

Other terms might resemble curiosity, such as information-seeking, need for cognition, or interest. However, the need for cognition is personal in individuals, representing their tendency to engage in more cognitive effort (Cacioppo & Petty, 1982). In contrast, the literature describes curiosity both as a trait and a state. Tieben et al. (2011), for example, refer to personal traits related to curiosity, and Kahan et al. (2017) discuss science curiosity as a trait. Others, such as Loewenstein (1994) or Berlyn (1970), present characteristics that can elicit curiosity as a state. Across the literature, scientists treat curiosity as both a state and a trait.

Kidd and Hayder (2015), acknowledging the lack of a universal definition of curiosity, suggest that information seeking is more externally motivated and has a strategic purpose, for example, needing to know the answer to a question right before an exam, to gain good grades. But curiosity includes internally motivated behavior (e.g., desiring certain information merely for the joy of knowing it). Finally, interest expands to many situations, such as interest in food. Thus, interest in information may overlap with curiosity, but does not adequately describe the phenomena.

The literature identifies four main traits distinguishing curiosity. First, curiosity is a result of a cognitive gap and not having information on a specific topic we are thinking about. Second, it can manifest itself as a desire for more information or a behavior such as exploration. Third, both negative and positive emotions can be associated with curiosity, including the frustration of not knowing something or the positive excitement elicited by wanting to learn about a piece of gossip. And finally, distinguished by information-seeking, curiosity is mainly internally motivated and does not necessarily seek to fulfill an external goal. The definition used by Kashdan et al. (2018), includes all four of these traits and has the potential to cover different phenomena studied by researchers ranging from “openness to experience, novelty-seeking, need for cognition, intrinsic motivation, tolerance of ambiguity, tolerance for uncertainty, frustration tolerance, and sensation seeking” (p. 130). It is this definition that I will use in the current study. In the following sections, I will discuss the importance of the study of curiosity, in particular in informal learning spaces, and will elaborate on factors that elicit curiosity.

Why Curiosity? Engaging the public in a conversation about science can help experts understand the public’s questions, concerns, and needs (NAS, 2017). This objective, *being able to elicit the public’s curiosity and getting them to engage and ask questions*, is a valuable science communication objective. The less popular model of science communication, the knowledge deficit model, advocates for information provision to change attitude and behavior. The assumption is that having access to the facts and evidence guarantees an individual’s change in attitude toward accepting science. However, years of research has proved otherwise, finding that facts on their own are not be enough or even necessary (NAS, 2017) to change attitude and behavior. Views are shaped based on values and beliefs and merely being aware of the data does not guarantee behavior change towards topics such as science and environment, stem cell research, or nanotechnology (Brossard et al., 2005; Ho, Brossard, Scheufele, 2008; Scheufele & Lewenstein, 2005). Some research goes as far as showing that having greater science literacy could polarize individuals more powerfully based on their political identity for some issues (Drummond & Fischhoff, 2017). Later models of science communication advocate for two-way communication, which involves the public and encourages them to discuss their opinions (Trench & Junker, 2001). In this model, the communicator engages the audience in a dialogue. They provide opportunities to listen to the views, needs, and questions of the public. One way to engage the audience in a conversation is to elicit curiosity.

Curiosity motivates learning (Kidd & Hayder, 2015). Researchers such as Kang et al. (2009) and Jepma et al. (2012) have studied curiosity's effects through fMRI analysis. They elicit curiosity by asking participants trivia questions (Kang et al., 2009) and presenting them with blurred images (Jepma et al., 2012). Their studies show that curiosity can improve learning and memory outcomes. In addition, Kang et al. show that incorrect answers in trivia trigger the subject to have a better memory of the correct answer. Berlyn (1954) also demonstrates that new questions elicit more processing and will lead to a better memory of information. Also, a curious audience dedicates more time and resources to find answers (Kang et al., 2009). Kashdan et al. (2018) add that by acting on one's curiosity long-term, one can gather more information and increase their intellectual and creative capacities, and this can lead to better decision-making (Golam & Loewenstein, 2015). Curiosity, as a strong motivator of exploratory behavior (Arnone et al., 2011), might be a way for scientists to elicit cognitive engagement in order for individuals to think critically and make decisions based less on heuristics.

In summary, the public’s curiosity can lead to them asking more questions from scientists and share their doubts, criticism, worries, and opinion. This curiosity can benefit scientists by helping them become more aware of the public’s needs and questions and tailor information based on their audience's interests so that the audience is more invested and cognitively engaged in the conversation. Curiosity can facilitate science communication by improving learning outcomes, long-term memory, the dedication of resources, and time. However, the science communication community needs to learn more about curiosity as it manifests in the context of science communication in informal learning spaces and as used by experts to engage the public. Communicators should be able to know if the curiosity-related outcome from the learning science studies applies in science communication. Researchers can achieve this goal by focusing on informal learning spaces and expert-public communication.

Curiosity in Museums. While earlier museums had an emphasis on the display of the objects and labeling them, during the 1960s, museums started to consider more interactive exhibits and displays that would get the visitors to participate in the interpretation of information. This change was a response to policymakers and educators worrying about the lack of exhibits that could elicit critical thinking and the joy of discovery (Cain & Rader, 2017). In recent years more museums value the engagement of the audience and design of environments that could foster the audience’s curiosity.

Different studies have focused on curiosity in museums (Baniyamin & Rashid, 2016; Ciolfi & Bannon, 2002; Rounds, 2004) as it seems to be an essential objective of museum designs and engaging attendees with exhibits (Baniyamin & Rashid, 2016). As McGee et al. (2017) note, although there is research addressing the psychological elements of curiosity, little of this research is translated into the museum design field or exploring prompts that can elicit more curiosity.

In the recent National Science Board's Science and Engineering Indicators report (2018), 48% of Americans in 2016 reported encountering science in a zoo or an aquarium within the last year, 30% visited a natural history museum, and 26% a science and technology museum. Besides, a Pew report (Gottfried & Funk, 2017) shows that the public believes that science centers get the facts right more than other outlets such as science documentaries, science magazines, and news outlets. Bandelli and Konijn (2013) suggest that museums are a place where scientists and researchers can understand the public based on their face-to-face interactions with them. This high level of attendance, trust, and the opportunity for a face-to-face interaction make science centers of high value for science communication and an essential context for the study of curiosity.

Arnone et al. (2003) bring up the importance of studying curiosity in informal learning spaces and the context of new technologies. They note that limiting studies to formal contexts of learning will restrain our ability to understand curiosity, engagement, and interest in different settings. This emphasis on science centers is particularly important as they argue that curiosity is reducing in formal learning spaces and might be more ignited in informal learning spaces. By learning more about curiosity in informal learning spaces, practitioners can develop more efficient designs that produce high engagement. Such efficient designs are of particular importance, considering the high costs of exhibit designs in museums with new technologies involved. For example, the average price of 77 non-art exhibitions at the Smithsonian Museum exhibit designs (excluding staff cost and advertising), is $450,000 (OP&A survey by the Smithsonian Institution, 2002).

To summarize, science centers and museums are important venues to explore how to foster engagement and elicit curiosity. As discussed earlier, eliciting curiosity has positive outcomes for fostering engagement, which leads to better learning outcomes. These outcomes are essential factors in citizen-centered science communication practice. These centers are also sites where scientists and the public can have face-to-face conversations and foster engaging dialogues. The active role of experts in communication calls for a more comprehensive understanding of how experts can engage individuals in a science-related dialogue, and informal learning spaces can provide a site to study such interactions.

Thus, in this study, I use the Space Visualization Lab of Adler Planetarium, where experts have direct interaction with the public. The first observational study examines the factors that contribute to curiosity in an informal learning environment, such as a planetarium.

Fostering Curiosity. Although studies of curiosity have examined different triggers of curiosity in experimental settings, they have not focused on how these factors work in an informal learning setting or on the role of the source of information when the source is a human agent. In this section, I discuss the literature examining the triggers of curiosity.

Research on triggers for curiosity seems to fall into four categories: (1) exposing knowledge gaps, (2) adding weight to information, (3) environmental factors, and (4) the receiver's attributes.

Exposing Knowledge Gap. Curiosity, in part, is a response to one's knowledge gap (Loewenstein, 1994). Thus, researchers such as Berlyn (1970, as mentioned in Loewenstein, 1994) and Silvia (2008) suggest complexity and novelty as attributes that elicit curiosity as they represent knowledge gaps. In other words, when an individual is encountered with new information, they might identify certain gap in their knowledge of the information and feel a need to address those gaps. Hullman, Adar, and Shah (2011) explain that information can be novel, such as when someone talks about an unfamiliar topic. But novelty is not limited to information. The information medium can also be novel, such as an object that looks new and unfamiliar. The use of new technologies such as 3D displays or virtual reality headsets are examples of such novel media.

Novelty can be represented in a new display, visualization, or piece of information. Baruch, Spektor-Levy, and Mashal (2016) show the effect of novelty and complexity by presenting a surprising scientific phenomenon in which a cup of yeast, sugar, and water produces foam. Exposing students to their knowledge gap by offering them a novel phenomenon fosters the students' interest in the topic. The same effect happens when Hullman et al. (2011) provide participants with novel visualizations or by exposing them to blurred images (Jepma et al., 2012). Berlyn (1960) and Loewenstein (1994) also suggest surprise as a curiosity-inducing factor, represented by unexpected information.

One of the main ways to elicit curiosity in different studies is to make information gaps salient to individuals. One way to do so is by exposing the receiver of information to questions that vocalize the knowledge gap. For example, Arnone (2003) suggests the posing of thought-provoking questions to elicit curiosity. Roberts et al. (2018) demonstrate that by highlighting questions on digital displays in museums, visitors have a higher rate of interaction with the display. In this research, the interaction represents the visitors' curiosity. Spektor-Levy, Baruch, and Mevarech (2013), in a survey of teachers, identify strategies to elicit student curiosity. Teachers in the survey suggest that they can invite the students to ask more questions to foster their curiosity. However, researchers have not studied this simple strategy adequately. Another way to directly expose an individual's knowledge gap is to encourage the audience to guess the answer. Consequently, the receiver experiences an urge to know if their prediction was accurate or not (Schank & Abelson, 1977). This triggers the intention to complete the task of guessing (Zeigarnik, 1927, as mentioned in Loewenstein, 1994).

Adding Weight to Information. In the second set of studies, researchers highlight the knowledge gap by emphasizing a subject's importance, its salience in the environment, and the pleasure one achieves by exploring answers. Golman and Loewenstein (2015) identify importance as a factor that can add to one's intensity of curiosity. As a subject becomes more important to one's life and the consequences are more impactful, one pays more attention to them. Molek-Kozakowska (2013) refers to the idea of sensationalism, in which reporters present the news items as more "important, interesting, and relevant" than they truly are to draw more attention and work as click-bait.

Similarly, making information more relevant can have the same effect. Hullman et al. (2011) suggest the tailoring visualizations to an individual's attributes or prior knowledge to engage their attention. Golam and Loewenstein (2015) also identify the salience of information as another contributor to curiosity, (i.e., information that we are reminded of in our surroundings can draw more attention).

Researchers such as Hullman et al. (2011) and Amory et al. (1999) study factors that associated with pleasure—including aesthetic and game-play—as contributors to curiosity. Another example of the effect of pleasure on curiosity is through pleasure-inducing information such as gossip and scandals. Researchers discuss these factors as a form of news-for-entertainment (Schaffer, 1995). Similarly, although pleasure on its own does not produce curiosity, it functions as an attribute that can add to the intensity of curiosity.

Environmental Factors. The environment's characteristics and affordances and how individuals facilitate curiosity in an environment can play a role in eliciting curiosity. Tieben et al. (2011) identify two factors that can influence curiosity based on the context: physical characteristics of a location and the social environment and conditions. For example, individuals would behave differently in their home versus while walking in the street. People would also behave differently if a group of people gathers around an object versus if no one is surrounding that object. However, such actions might be a function of social proof (Cialdini, 1987). Based on this term, when individuals do not know how to react to a social situation, they might follow what other people in that setting undertake. Individuals assume others have more information about the correct reaction to the situation, thus following their footsteps. The response to the gathering of people around an object might arise from an individual's reliance on others' knowledge. Studies on boredom also represent the effect of the environment on curiosity. In these studies, researchers induce boredom by reducing the stimuli in the environment for a duration, and eventually, researchers present stimuli to elicit curiosity (Butler, 1957; Aart et al., 2010).

Receiver's Attributes. Finally, some studies have emphasized on the importance of the receiver's attributes that facilitate curiosity. Kashdan et al. (2018), for example, highlights individual differences that lead to higher curiosity by identifying personality types such as the fascinated, problem solvers, empathizers, and avoiders. Arnone et al. (2009) identify self-efficacy as an important factor for individuals to feel capable of seeking information. Schank and Abelson (1977) identify openness to curiosity as such a factor.

The previous four sections discuss studies that have identified different aspects of curiosity-inducing factors. However, not much research has examined the role of facilitators in eliciting curiosity. For example, what behaviors by scientists can induce more curiosity in public? What features and characteristics encourage the public to ask more questions and explore topics? As the STEM field advocates for more scientist engagement in outreach (NAS, 2017), researchers should dedicate more resources to study how scientists can foster an engaging conversation with the public through eliciting curiosity.

As mentioned earlier, Spektor-Levy et al. (2013) state that teachers identify, inviting students to ask questions, to be a helpful strategy to foster more questions and curiosity. In addition, other research, including Arnone (2003) and McGee et al. (2017), use questions to elicit curiosity and participation. Posing certain questions can expose individuals' knowledge gaps and hence, lead to more curiosity. In other words, a facilitator can use prompts to let the audience know what they don't know, to add weight to information, or to use environmental factors to elicit curiosity.

Thus, to gain a better understanding of the role of facilitators in eliciting curiosity, I examined the relationship between scientists' prompts in a conversation with the public and visitors' questions.

RQ1*: What expert prompts are associated with the public's behavior to ask questions of a scientist (interact) in an informal learning space?*

Additionally, most research that looks at curiosity takes the researcher's perspective, examining curiosity triggers that they identified previously. There is not much information available about what individuals are curious about, independent of the researcher's assumptions. Especially, in a scientific context, with the help of a facilitator, what does the audience would want to know more about? Thus, I examined the content of the audience's curiosity reflected in their questions and comments.

RQ2*: What is the content of the audience's questions and comments?*

Study Design

Setting. This study is based on a qualitative design, using naturalistic observation. There are two main objectives for this study: first, to examine what scientists' prompts can elicit curiosity and encourage inquiry, and second, to identify what the attendees are curious about by analyzing the content of their questions. I have collected my data at the Space Visualization Lab at the Adler Planetarium.The Adler Planetarium is located in Chicago. Around 636,008 people attended this center in 2017. I spent two years at the Space Visualization Lab (SVL) in the Adler Planetarium, where scientists have daily "Astronomy Conversations" with the public (Figure 1). This lab is designed based on dynamic visualizations, and it contains multiple visualization modes including two Kinect Control displays, two 3D displays, two 2D displays, one scale model of the Ice Cube telescope, three interactive digital surfaces, one Mars Rover controller screen, and more than 10 3D-printed models of astronomical objects and devices. Some of the displays are connected to a database that can be changed instantly. Every day, two different scientists speak for one hour each to the general public about scientific concepts and events with an emphasis on their field of study. The visuals change based on what each expert feels comfortable talking about and based on the audience's questions.

Scientists in the lab include graduate students and postdocs, professors from academia, and experts from science centers. They volunteer or are planetarium employees. There are around 22 individual scientists each month. The lab expects an average of 100 participants for each session. However, at any moment, usually, only 20 people are in the lab. Visitors who enter the SVL do not need a ticket and come to the lab upon invitation by a volunteer at the door or with their own will. Most individuals who refuse the invitation either have a language barrier or commitment to a show screening at the planetarium (Price, Lee, Subbarao, Kasal, & Aguilera, 2015).

Figure 1. *A scientist at the Astronomy Conversation session in SVL.*

Procedure. I observed and audio recorded 22 sessions of "Astronomy Conversations" over the course of five months containing the dialogues between scientists and the audience. Participants under 18 are not eligible due to their different developmental stage, so I have not used their recorded information. One recorder was attached to the scientist and the other to a column near the audience to capture both the scientist and the attendees voice. Several signs visible in the lab let the audience know that they are being recorded. I used the Temi transcription service to transcribe the data.

The final database contained 13 experts, specialized in astrophysics, engineering, and museum curation. The sessions accumulated to 21.5 hours of data, equivalent to 501 pages of transcription. Each session averaged to be 58 minutes and 22 pages.

Analysis. Given the goals of this research, I used a naturalistic observation method. In these types of studies, the researcher does little to control the setting while taking notes and transcribing what happens in the environment (Gorvine, Rosenger, Stein, & Biolsi, 2018). For reliability, four sessions have been coded both by an undergraduate researcher and me. During this process, I have discussed and resolved discrepancies.

I analyzed the collected data through qualitative coding of the audience's questions and scientists' prompts in the Atlas.ti software. For the first round of coding, I have used the provisional coding method (Dey, 1993; Miles & Huberman, 1994 in Saldaña, 2015). In this method, the researcher uses an initial list of codes based on expected outcomes of the field interactions. In this analysis, I have used the higher-level codes including scientists' questions, cues for interaction (e.g., sentences that show the audience questions are welcomed), statements before an audience reaction, and scientist's silence before an audience reaction, in addition to audiences' questions, comments, and answers (table 1), and finally unit of interaction between scientists and the audience, major interactions, and interactions involving individuals under 18 years of age (table 2). Although the sentences that seem to elicit curiosity but are not in the form of questions or cues are interesting, for the purposes of this analysis, I only analyzed questions and the utterances that encourage a response and exclude sentences that do not contain any encouraging content or questions.

In the second round of coding, I have used thematic coding (Saldaña, 2015). This coding allows for the unit of code to be described beyond a word. It describes the content based on its likely meaning and what it seems to be trying to accomplish. The literature also informed these themes on what triggers curiosity. I have coded some interactions, prompts, or questions through simultaneous coding. In this method of coding units will be assigned to more than one code (Saldaña, 2015). For example, a question coded as a "what" question, can also be personal (e.g., What made you interested in astronomy). Table 3 shows the list of these themes. Finally, using Atlas.ti, I have calculated the frequency of occurrence of each code.

I have eventually asked the SVL staff and other planetarium staff to examine my findings and let me know if the results reflect their perception of the sessions. After a number of clarification questions, respondents to the request confirmed that the findings seem like an appropriate representation of the sessions.

Table 1. *Thematic code scheme definition and examples*

Provisional Codes	*Definition*
Audience answer	Audience answers to questions or comments
Audience comment	Audience makes a comment
Audience question	Audience asks a question
Scientist cue	Scientist invites participation or inquiry
Scientist elicits reaction	Any statement by scientist before the audience's reaction
Scientist feedback	Any statement by scientist after audience's reaction

Scientist question	Scientist asks a question
Silence	Duration of silence by scientist before the audience's reaction

Table 2. *Units of interaction.*

Unit	*Definition*
Interact	Unit defined as the scientist's prompt, the audience's reaction, and the scientist's reaction to the audience
Major interaction	Unit defined more arbitrarily as conversations that go on for more than 5 interactions
Kids	Content by audience who are visibly under 18

Table 3. *Provisional codes scheme definition and examples.*

Thematic Codes	*Theme*	*Example*	*Agent*
What	Questions related to the nature of a phenomena, mostly starting with what	What is this object?	Audience

Where	Questions related to locations	Is the solar system inside the Milky Way?	Audience
Who	Questions related to people	Are you also an astronomer?	Audience
Why	Questions related to reasons and motivations	Why can't we see blakc holes?	Audience
How	Questions surrounding processes	How does a shuttle work?	Audience
Yes/no answer	Questions with yes/no answers, where the answer is integrated in the bulk of the questions	So Pluto is not a planet, right?	Audience
Check knowledge	Questions checking to the audience's past knowledge	I read somewhere that aliens have visited us, is that true?	Audience
Hypothetical	Questions that explore a hypothetical situation	What will happen if the sun disappears?	Audience
Unprompted	Questions that are not relevant to the ongoing conversations	[conversation about black holes] so is there life on Mars?	Audience
Repeat Q/A	Asking for the repetition of a question or an answer	Excuse me, can you repeat that?	Audience
Clarification	Content where the audience tries to see if the knowledge they acquired in the space are accurate and if they understand them correctly	So, you said Mars is red because of the iron, right?	Audience

Measure	Content related to numbers and measurements, including sizes, durations, times, etc.	How far is this galaxy?	Audience	
Relevant	Content relevant to daily life and society	How does relativity help me personally?	Audience	
Awe	Content showing a sense of awe and wonder	wow, cool!	Audience	
Knowledge check	For scientists' to evaluate or ask about the audience's knowledge	Do you know what this picture is?		Scientist
Intro	Introductory sentences that explain who the speaker is, what the lab is, and what the format of the session is	Hi My name is Amy, this is SVL and you can ask any question you want.		Scientist
Affirm	Content affirming and encouraging the continuation of a conversation	yeah, yeah, go on.	Audience	Scientist
Norms	Content related to social norms and cues of politeness	Do you mind if I sit here?	Audience	Scientist
Personal	Content that relates to the person and is not only scientific	What got you interested in this field?	Audience	Scientist
Comparison	Content comparing a scientific concept with a familiar concept	So a blakc hole is like a vacuum?	Audience	Scientist

Viz	Content related to the audio/visual/tactile content of the room	What is that shiny thing?	Audience	Scientist

Results

Expert Prompts Associated with Interaction. I categorized scientists' prompts in three different categories: Scientists' questions from the audience, scientists' cues for interaction, scientist's silence of more than a second before the audience reacts with a question or comment.

Questions. Scientists' questions elicit the second largest number of reactions from the audience (18.4% of all reactions compared to 79% of reactions after neutral sentences), e.g., *Does anyone have a question?* or *Does anyone know what a black hole is?* Scientists' questions mainly fall into the following five categories: visualizations, checking the audience's knowledge, personal questions, asking to repeat the question, inviting the audience to ask questions.

Visualizations. Since the environment for this study is the Space Visualization Lab, scientists rely heavily on visualizations to explain concepts and engage the audience. Around half of all questions are around the visualizations and the audience's understanding of them. These visualizations include content on the monitors and projectors in addition to the 3D printed objects. The questions are not just limited to the content of the visualizations but also the devices and technologies they use to produce and present the information, such as 3D projectors, 3D printers, and Kinect controls. Frequently, scientists expose the audience's knowledge gap by asking the audience to guess the visualization or if they know what the visualizations are, e.g., *So* *let me forward this. I'm going to ask you a little quiz question. What, what planet do you think that is?* In this example the questions were regarding a 3D visualization of Mars.

There have been multiple scientific discoveries that have not been possible without visualizing data and images taken from objects in space. Some scientists use the visualizations to lead the audience to scientific conclusions by asking the audience questions that scientists have asked themselves. The following conversation relates to the orbit of Pluto and asteroids that are beyond Neptune. These objects have slightly inclined orbits compared to other planets. This led scientists to guess that there might be a larger ninth planet beyond Pluto that is affecting the orbits.

Scientist: what's, what's different about like Neptune and all those other planets there compared to what's a little further out maybe? Do you notice anything?

Audience: Is it in line?

Scientist: yeah, they're in line. So [...] if you had a big enough plate, [...] you could put all of those on one plate, right? What's this one? [point at Pluto] That one doesn't fit on the plate, right? That's kind of going its own direction.

The scientist eventually explains how this observation by scientists led to the demotion of Pluto and hypothesizing a new planet. Other questions about 3D objects, such as objects from the museum's collection, can encourage a more thorough inspection of the objects from different views. The scientist in the following example uses encouraging questions to ask the audience about their observations. He then takes each answer and explains it further, thus, building the conversation on the audience's interests in an observation rather than his own. For example, a Mariner's astrolabe is a metallic, round object with holes in it.

Scientist: this is actually also an astrolabe. There's some pretty big differences, right?

Audience: Yeah you don't have any words [the previous astrolabe had different writings on it]

Scientist: What's that?

Audience: Yeah it doesn't have the numbers or words.

Scientist: Yeah, exactly. That's good observation. Part of that is because this one[...] was found in a shipwreck at the bottom of the Caribbean sea. So the water has kind of eaten away at it a little bit over the years. But even if it hadn't, even if that hadn't happened, there would be far less numbers that are on this one. What else? What else do you notice? There's no wrong answer. It's okay.

Audience: It's much thicker.

Scientist: It's much thicker Yes. So the materials are different. This one, these astrolabes are typically made out of brass, a much softer type of metal, much more decorative and more beautiful metal. This is called a Mariner's astrolabe. So these were used at sea, right? These are almost exclusively used by sailors on a ship. Um, and they're made out of iron, partially because it's a little rougher on the ship.

Visualizations also let scientists ask questions to compare different visuals. These visuals can show the passing of time, different conditions, scales, and aspects of a phenomenon. For example, two monitors show different angles of a galaxy-in-making in the following conversation:

Okay. So this is the same kind of thing, but we're seeing it at a different angle. [...] and do you notice anything about this picture compared to the other one in terms of...how about color? Is this one different than the other one? [...] what are the other one like? When we lift up the ring, is it dark? Was it red like this one? I see people nod. Yeah, I see shaking heads. Yes.

These questions not only help the audience learn about what the visualizations are but also what they are not. Scientists address misinterpretations by bringing up possible assumptions. The following example is regarding the visualization of the Milky Way: *How did we get this photograph? So It's kind of a trick question because it's not, it's not a photograph per se, but it's also not just drawing. It's a combination of what we can see from here.* Scientists can add to the weight of this information by bringing up surprising and novel information when addressing misconceptions and visualization elements that the audience might misinterpret.

Finally, the questions about visualizations can help scientists learn what the audience is interested in visually. They can follow up conversations based on the audience's curiosity, e.g.,, *What other questions do you have or what other screens are showing things that we should say that you're particularly interested in?*

Checking knowledge. The majority of questions by the scientists in someway can evaluate if the audience is knowledgeable about a specific topic or remind the audience of their knowledge gap. Questions such as, *So who here is familiar with the term dark matter?* can not only engage the audience but also can help the scientists know their audience better and tailor their talk to the audience's level of knowledge of the subject. These questions range from checking the audience's understanding of concepts, including light-years and dark matter, to the latest news such as finding a new asteroid to the audience's knowledge of the visualizations and objects surrounding them in the room.

These questions can be open or closed. Open questions allow for more flexibility in answers such as the what/why/how questions, but might be intimidating for attendees if they are not sure about the answer. Closed questions provide options for the audience and might encourage more interaction. In the following example. the scientist starts with an open question and immediately follows that with a more restrained close question to provide options: *So do you know where Mars is compared to Earth?* [open] *Is Mars closer or farther away from the Sun than earth?*[closed]

Scientists also pose knowledge check questions in the form of guessing questions, e.g., *Anyone wants to guess or heard how far we are from the center of our galaxy? Remember it takes us 250 Million years to go around. So we're talking some big spaces here. Guesses?* The audience usually offers different answers until they are reasonably close to the final answer. This kind of guessing questions can increase the weight of information by making the audience curious to see if their answers are correct.

Personal questions. In addition to knowledge check, fifteen percent of the questions were in some way related to the audience personally. While some questions are more general and seem to build rapport with the audience, such as *Are you guys all from Chicago?* others might serve to help the scientist know their audience better: *[...] what is your background? You guys* *have been asking great questions. You clearly have some knowledge already.* In addition to building rapport, scientists' personal questions can add to the scientist's knowledge of the audience as well. In one conversation, the audience talks about their interest in the game *Elite Danger*. *Elite Danger* is an adventure computer game based on real astronomical objects and phenomena that can teach the player about space. After the audience talks about the game the scientist asks about the name of the game and says *I can't wait to play it, I'm gonna look it up*. Another example is when a visiting family from Puerto Rico tells the scientist that in their culture, they refer to the three stars in Orion's Belt, a famous part of the constellation Orion, as the three kings. The scientist responds with the question, *the three stars, you guys call them the three kings?*

Personal questions can also help scientists make information relevant to their audience. One of the visualizations in the room is a screen connected to Google maps. In one of the sessions, the scientist asks a group of school students and their teacher which school they are from and helped them use their hand gestures to control the screen via a Kinect control device to find their school on the map.

Repeating. Occasionally (8%), the scientist either does not hear the questions or needs to check that they understand the audience's questions correctly. For example, an audience member asks, *What's the longest solar cycle you guys have found?* and to clarify, the scientist asks, *On our sun or other stars?* The scientist's question is a helpful evaluation and feedback tool to know where the audience is standing and if they have understood their audience correctly.

Inviting. Finally, scientists encourage participation by asking the audience if they have any questions as follow-ups to the content of the conversation. , e.g., *Um, any questions so far about astrolabes?* Less related to the content of the conversations, scientists also pose more general questions such as *any questions?*

Overall, out of 455 questions asked by the scientists, 368 almost 80% elicited some reaction in the form of questions, answers, or comments. However, not all questions to encourage more questions are as explicit; occasionally, scientists use other cues to do so.

Cues. These cues, usually used as a part of the introduction of the conversation (2.3% of all prompts) show the audience that they can ask questions if they want, e.g., *So if you guys have any questions, feel free to shout them out* or *I feel like there are questions, but they're not coming out*. In a way, they set up the rules that help the audience engage in a conversation with a note, such as *If you have any questions about anything in astronomy, I'd be happy to try to answer that.* In 62% of instances of using a cue, an interaction follows. While not as effective as a direct question, this can help the audience understand the norms of the space.

Silence. Another contributor to eliciting reaction was silence, e.g., *Yeah you're the only person in my audience, so... [3 second silence],* followed by audience's question: *So where did the big bang come from?* When a scientist asks their audience if they have any questions and immediately follows that by continuing to talk, the audience might not have time to ask a question. In addition, silence and long pauses can make the situation awkward and encourage attendees to ask questions. The analysis shows that around 8% of instances of audience reactions were following the scientist's silence of 1 second or more.

Content of Curiosity. Even though questions seem to reflect the audience member's curiosity, many comments and answers to a scientist's questions can also reflect curiosity. For example, if a scientist asks "how close do you think the closest star to us is" the audience provides an answer and might be curious to know if their guess is correct or not. In addition, some comments could be questions depending on an upward tone at the end. So in this section, I examine the audience's questions, and look at their comments and answers. Out of all reactions from the audience (1816), 12% were answers to scientists' questions, 52% were comments, and 36% were questions for the scientist. These reactions mainly fall into these categories: Unprompted questions, follow-ups, clarification, science questions, personal questions, norms, affirming, expressing a sense of awe.

Unprompted questions. Each scientist at SVL has a main field of study and usually uploads images and visualizations that are related to the topic. Most of the time, the questions and comments from the audience are related to what the expert is presenting. However, occasionally (2.4%) some questions are not related to the topic and seem not to be prompted by the conversation. For example, while the scientist might be talking about planet Mars, the following question might be about the cosmic web. In the following example the conversation moves from dinosaurs to dark matter:

Scientist: [...] maybe we'll live for millions of years, [this] remains to be seen. It could be a universe filled with dinosaurs though.

Attendee: I just have another question.

Scientist: Please. Yeah.

Attendee: Could you put dark matter in physical terms?

Scientist: Yeah, I can try.

The case of unprompted questions often happened when the audience asks about one of the visualizations in the room. In other words, even if the content of the expert's talk doesn't primed the audience, they may still be primed by their environment.

Follow-ups. The majority of questions and comments, however (97.6%), in some way build up on the expert's presentation and are a follow up of the previous statements. They seem to be interactions that expand the audience's knowledge of the topic. Consider the following conversation:

Scientist: Um, but yeah, the energy that goes into the black hole is not destroyed. It's just converted into like individual atoms

Attendee: But then is light not considered energy?

Scientist: Light is energy. The light going into the black hole is also not destroyed.

Attendee: What happens?

Scientist: It just never escapes.

In this example with their question, the audience member learns that light is also energy, and with the next question they learn that the energy going into a black hole never escapes the black hole.

Clarifications. A specific kind of follow up question is in the form of clarifications. Clarifications either rephrase something that the expert has already said, or is a repetition of the information. In other words, they are a way for the audience to check if they have understood the information. The clarifications could be to make sure they heard something right and to double-check information. The clarification questions can also remedy misunderstandings, such as in the following example when the scientist clarifies where asteroid Itokawa is currently located:

Scientist: Yeah, I think that is in the asteroid belt. Some of the stuff that we have up on display is from the Kuiper belt, which is way far outside of Pluto, but I think this is—

Attendee: Outside the solar system?

Scientist: Um, oh, it's still in the solar system, but it's outside of Pluto.

Scientific questions. The audience questions and comments are primarily scientific questions ranging from *What is a supernova?* to more complicated questions such as *So how do they detect black holes? Like light, we can't see light...is there an emission…?* These questions cover the 5 why/what/where/when/who types with a great emphasis on measures such as size, distance, duration, and weight, e.g., *How many galaxies are there? How long will it take to go to Mars? When did Kepler go up?* A great number of the "what" questions were related to the visualizations simply being *What is this?* in which *this* refers to the content of different monitors, projections, 3D models. Other science-related questions include checking their previous knowledge of a topic, e.g., *I have a question about Mars, travel to Mars. I've heard people want to be on a one-way trip, is it true that the trip is one-way?* or even playing with sophisticated hypothetical situations, e.g., *Is it possible, I know you're going to say this is ridiculous[...] but* *isn't it possible that all this is just an optical illusion based on the fact that we see things through a gravitational lens?*

Personal questions. The who question (11% of all audience questions) however, was related, scientifically and unscientifically to the expert. The audience sometimes comments on their personal lives and the way it connects to the topic of the conversation: *We're from Michigan and there was a [inaudible] from [inaudible] Michigan University who went out and took pictures of the night sky, Sequential pictures of the Milky Way.* Other times they are curious about the expert and their questions range from those on the scientist's education and personal research, e.g., *Yeah So what is your like wheelhouse?* to their motivation e.g., *Totally random, what made you choose astronomy?*

Social Norms. A portion of the answers, questions, and comments (6%) are related to social norms, signs of politeness, and courtesy. These reactions include asking for permission to sit, to leave, or to thank the speaker. The audience also sometimes asks the scientist if they can ask questions.

Affirming. The audience also frequently uses affirming words such as *aha*, *yes*, and *yeah.* Affirming can signal that the audience is actively listening or agreeing with the speaker. They can also do so to continue a conversation (Drummond & Hopper, 1993).

Sense of awe. Finally is reactions to show a sense of awe and wonder, such as *wow* and *cool.* Such reactions happen dominantly in response to visualizations (86%), which can show the importance of visualization to elicit a sense of wonder.

Discussion

In this study, I aimed to take a more in-depth look at curiosity, and the engagement between scientists and the public. To do that, I have examined the content of conversations between scientists and planetarium attendees during the one-hour "Astronomy Conversation" sessions. I have looked explicitly at prompts used by scientists that elicit a reaction from the audience, including questions. I have also examined the content of the audience members' reactions, mainly their questions and comments.

The analysis of the prompts shows that most reactions happen organically as a part of the conversation, and not followed by questions and invitations by the scientist. The results of this study can tell communicators and researchers a lot about their audience. The audience enters the rooms with questions, develop questions, and asks questions. Scientists do not need to force interactions as their audience are curious individuals who have found a way to explore their curiosity. As the findings show, a high number of interactions are based on the audience's comments and not questions. This can point that the audience is not necessarily experiencing the sessions with experts as a place to only receive information, but rather an environment to build warmth and personal connections and exchange ideas, opinions, and experiences. Communicators need to keep this in mind and allow for a truly conversational climate in which both parties can contribute with their expertise and experiences. However, this large difference between the number of comments and questions could also arise from questions in the form of comments. For example, when an attendee makes a statement about a planet, if that statement is incorrect, the scientist will correct them. In other words, while they did not pose a question, the comment was a means to check their knowledge.

However, a possible way to elicit participation and encourage questions is to explicitly ask the audience for participation and questions (Spektor-Levy, Baruch, & Mevarech, 2013). Scientists can let the audience know that their participation is welcomed, that they can ask questions, and that this is a conversation rather than a one-way lecture. Considering that most public outreach events are one-way lectures, audiences might be used to experiencing outreach efforts as mainly one where the scientist is the sole speaker and the Q&A is at the end of the session. Thus, establishing that the conversational format is an accepted style should be the scientist's priority. Establishing this format can happen both through frequent invitations for participation, and introductions of the form of the session for the audience.

The experts' questions can also be a way to evaluate the audience's knowledge and interest. They can help the expert tailor the conversation in a way that responds to the audience's needs. Through questions, scientists can expose audience's knowledge gap, present dilemmas, and topics that the audience has not thought about previously. Besides, through guessing games, the audience will offer answers and might be curious to know if their guesses were correct or not. Kang et al. (2009), in their study, show that for a trivia game, individuals were most curious about answers when they had moderate confidence in their response. When they knew nothing about the information or thought they know it with high certainty, curiosity was lowest. Thus, the role of a facilitator in the context of inducing curiosity is to challenge their existing knowledge or provide enough information to elicit curiosity. Posing questions that demand an answer and interaction might need more encouraging since the audience might worry about wrong answers. In these situations, scientists can facilitate the process by offering options.

One small adjustment that might also contribute to interactions is silence. With the experts allowing for a few seconds of silence, the attendees might find more space to ask questions and participate in some way— or just to avoid an awkward silence! Inviting the audience to ask questions followed by no space to pose questions might not have the same effect as having enough silence to allow for the audience's questions.

Visualizations play a crucial role as prompts for scientists. As most visualizations are not explanatory on their own, scientists use them to ask questions and invite guessing. These visualizations' colorful and mesmerizing content (such as star formation visuals) might also add to their curiosity weight. Through visualizations, scientists can discuss dynamic concepts such as time, distances, and sizes. Scientists also address visual misinformation by asking the audience about their interpretations. For example, a line drawn to show the orbit of a planet is not an actual object in space, but rather the representation of an abstract concept. A scientist can not know what misinformations to answer before knowing what the audience assumes about visualizations. Thus, similar to the audience learning new information through inquiry, scientists should also learn more about the audience through inquiry. Such conversations can also lead to the scientists learning about topics and events they are not aware of in addition to learning about their audience's expertise.

The content of the audience's questions and comments are heavily related to the content of the expert's statements. In other words, the expert primes the audience's questions (Golman & Loewenstein, 2015). When a scientist introduces a topic, allowing for interactions and questions can help the audience to expand their knowledge by asking questions that go deeper into a topic and address the different aspects of a phenomenon. This back-and-forth nature is a strength of these live face-to-face interactions. Through them, not only the audience can learn more, they can instantly clarify information, make sure they understand the topic right, and even reveal any information they have misinterpreted.

More importantly, these relevant questions and follow-ups show that the audience is not a superficial, passive learner. The audience is curious and willing to go deep into science, to examine different aspects of the phenomena, to think critically, and even challenge conventional science by offering alternative explanations and asking thought-provoking questions. By knowing their audience, scientists can feed the audience's curiosity in different levels.

The questions that are irrelevant to the topic of conversation are mostly about visualizations in the room. So, the environment, in some way, determined what the content of the attendees' curiosity would be (Tieben et al., 2011). This could be an important asset in two specific ways: 1) if the expert does not want to bring up a specific topic explicitly, they can design the environment and visualizations to elicit curiosity and allow for the public to ask questions about them, 2) when researchers talk about data visualization, one of the important elements is that the data should be labeled clearly and in a way the audience will be able to understand it (Hullman, 2011). This goal is strongly related to learning outcomes. Hullman (2011), however, emphasizes the concept of visualization difficulty for engagement, leading to better learning outcomes. An example of the visual difficulty could be the lab visualizations, where the display shows bright, colorful dots going around the screen to shape a web-shaped structure. At the same time, no label or information is showing what they represent. As Hullman notes in her paper, "Often visual difficulties induce engagement with a graph design by manipulating novelty, tailoring and personalization, challenge and game-play, and aesthetic appeal. Engagement, in turn, increases the likelihood of active processing and thus may benefit learning." (p. 3)

In this example, the audience encounters novel, colorful information and to understand the meaning of the representation, they engage in a conversation with an expert. In other words, specific visualizations can contribute to audience engagement with the expert even if they do not immediately understand the data. This finding is helpful in contexts where the audience can interact with someone to talk about visualizations, and when engagement is a priority.

Most audience questions have been around science topics, understanding the what, why, how, where, and when questions. However, ten percent of all audience questions were "who" questions. These questions were related to the scientist, their motivations, interest, and personal research. This finding might be an indicator that the planetarium attendees are interested in the scientist as a person and that scientists can talk about themselves in addition to scientific concepts. The audience would also talk about their personal astronomy-related stories and their interests or the latest sci-fi movie. These fields can be of great value since this theme can distribute power between the attendees and the expert and provide an opportunity for attendees to have more of a say in the conversation as it relates to their personal lives. Other reactions associated with social norms of politeness, apologies, and permissions, and also to show one's wonder about science and sense of awe.

In line with the core research on curiosity (e.g., Berlyn, 1970; Loewenstein, 1994), the questions seem to address a knowledge gap for the attendees, whether the gap is on a scientific topic or information about an individual. As discussed in the literature review, the weight of information can affect curiosity (e.g., Golman & Loewenstein, 2015). Different questions in the session might reflect the importance of the information weight, such as relevant information: *I'm planning to Switch to solar power in house. If we were to get something like that will that make that worse or would make it better?* or information that is very important and is a matter of life and death, such as *Is there an asteroid that is going to come near the earth?* However, not all questions will be containing all elements of curiosity weight. For example, a question about the rings of Saturn is not relevant and might be curiosity inducing for the sake of curiosity!

Previous studies on curiosity usually pick a single or few attributes of curiosity and examine it in an experimental setting. The current study places the theoretical contribution of these studies in a real-world context and instead of limiting the audience's curiosity, allows for the expression of curiosity about a variety of different topics and in different ways. The findings reveal much about the audience, their interests, and their level of engagement. They contribute to aspects of audience's curiosity that are directly related to the audience's “wants” rather than the study’s demands.

This study also explores the role of a facilitator (scientist) in inducing curiosity. This helps researchers examine aspects of curiosity that might not be visible when only studying a single trait, e.g., how the presence of an expert and their encouragement for inquiry can help attendees express their curiosity about surprising information.

These findings provide a view of the landscape of curiosity and dialogue with the expert in an informal learning space. However, they do not provide any causal relationships or correlations between expert prompts and reactions. They also do not show any causal relationship between the attributes of the environment or the expert and the content of the audience's questions. With these possible relationships as a starting point, future studies can determine if such relations exist. As this study takes place in a natural environment, there is no control on the number of individuals in the room, their entrance and exit, or the visuals scientists use in the room. Besides, each scientist has specific characteristics that can affect the outcome of the interactions. Such inconsistencies between sessions, makes comparison between sessions very limited.

The data is based on audio cues and limited visual context (i.e., notes taken during the session). Thus, specific interactions such as a hand raising and nodding, are missed in the recordings. This sample is also limited to planetarium attendees who may be more interested in science than the average person, and the content of their questions could be different from a sample that does not attend museums and science centers.

This study provides many different pathways to study curiosity in different contexts and sites as various curiosity-inducing factors interact with one another. Possible other sites to study curiosity include semi-experimental settings where the speakers, the material used, and the format of the sessions are controlled but executed in a natural environment. In addition, future studies can examine how facilitators' features and audience perceptions of them can affect the audience's level of dialogue and curiosity.

Table 4. *Practical engagement tips for practitioners.*

"Do"s	*"Don't"s*
Ask open questions (what do you want to	Don't talk non-stop, have breathers

know?)	
Ask close questions (is this a picture of Jupiter or Saturn?)	Don't have a full lecture style (a one-way talk), make sure to fit in conversations
Encourage questions (let me know if you have any questions.)	Don't immediately give up when there are questions, sometimes the audience needs extra time and encouragement
Pause and allow for audience to think and form questions	Don't shut down wrong answers, lead the audience towards the right answer
Use visualizations and prompts to encourage questions	Don't explain everything immediately, allow for some guessing
Provide examples of questions the audience can ask (you can point at anything and ask what this is.)	Don't assume the audience have understood your presentation, always ask and check with them

Conclusion

There is an increasing emphasis on moving towards citizen-centered science communication (e.g., NAS, 2017). In this study, I examine the interactions between scientists and planetarium attendees to explore the role of facilitators in encouraging attendees to engage with scientists and ask questions and to understand what the content of the questions is. By understanding what elicits questions, scientists can practice skills that help them interact with the audience. In addition, knowing what the audience is curious about helps museums and media, design content that elicits curiosity and responds to the audience's interest.

This study suggests that the public mostly asks questions organically as a part of a science conversation, but is also responsive to being invited to ask questions. Silence and allowing for space for the public to talk, play a role in allowing for engagement with the scientist as well. Planetarium attendees mostly ask questions related to the scientists' talk but also sway away from the conversation by asking questions about the visualizations in the environment. On top of scientific questions, the audience is also interested in the scientists themselves.

I am hoping that this study allows for science communication trainers and practitioners to get a better picture of how an engaging science conversation looks and how they can foster one. Face-to-face interactions have great power to allow the experts to know their audience and understand what they are interested in and curious about and this could be a useful strategy for more engaging science communication practices. I hope this work also inspires controlled experiments and studies to specifically examine curiosity-inducing prompts and their effects on eliciting curiosity and encouraging interaction.

Chapter 4: Understanding the Relationship Between Sharing Personal Anecdotes, Warmth, Curiosity, and Risk Perception in Communicating the Threat of Climate Change

Introduction

The 2020 Yale Climate Opinion map of the US shows that 64% of Americans rarely or never discuss global warming. Seventy-four percent of Americans hear about global warming once a week or less, and only 43% perceive that global warming will at least moderately affect them. This report highlights the lack of public curiosity and dialogue in the scientific discussion, hindering the public's participation in the scientific discourse. This data also shows the fairly low perception of risk of climate (Marlon, 2020).

Scientific communities such as the National Academies of Sciences (2017) advocate a move towards citizen-centered strategies to improve the status of science outreach. Other examples include the Mechelen-declaration for museums to focus on engagement and the emergence of outreach events that emphasize scientists' dialogue with the public, such as SciPop Talks!, the Space Visualization Lab's Astronomy Conversations, and science festivals. However, little research has examined how the public's curiosity in science might encourage dialogue.

In this study, I examine how scientists can elicit curiosity and if curiosity can increase climate change perception and risk mitigation. Throughout this experimental design, I also investigate the role of political partisanship and education on risk perception and mitigation. In addition, I examine the effect of how individuals perceive scientists on their curiosity, risk perception, and mitigation.

I suggest the study of curiosity in science communication for three reasons. First, eliciting public curiosity assumes a more active role for the public and changes the expert-centered narrative to one that focuses on the public's questions, needs, and opinions. This narrative is in line with the engagement model of communication (Trench, 2008) and the advocacy for public engagement in science (Lehr et al., 2007). Second, studies, including Kahan et al. (2017) and Sjoberg (2007), show the effect of curiosity on risk perception and risk mitigation. Risk perception is associated with an individual's views on risk rather than objective risk (Renn and Rohrmann, 2000). Risk mitigation includes activities one engages in to mitigate that risk. As researchers seek to develop models explaining the factors contributing to risk perception, curiosity seems to have a significant role in risk perception and mitigation. Finally, the results of this research may provide a stronger argument for the use of curiosity in science communication as a tool for expert's outreach activities. The results can also provide a base for the design of science communication material to elicit dialogue through curiosity, rather than educating the public and engaging in a one-way communication.

To elicit a dialogue by eliciting curiosity, I have reviewed different studies that suggest strategies to elicit curiosity in interactions. One such approach to elicit curiosity is the use of personal anecdotes in communication. Some studies (e.g., Goldstein & Benassi, 1994; Mazer, Murphy, & Simond, 2007) suggest that using personal anecdotes in the classroom improves classroom participation and students asking questions. However, these results are based on surveys and not other measurement strategies (Wambach & Brothen, 1997). In this study, I examined the relationship between the use of personal anecdotes and curiosity through an experiment to establish causality. Moreover, I examine curiosity behavior, not just intent.

I discuss factors that mediate the effect of personal anecdotes on curiosity. Some studies in the learning sciences show that personal anecdotes can elicit the perception of speaker warmth. Others show that a speaker's perceived warmth evokes higher curiosity. Based on these studies and those on the use of personal anecdotes, I suggest that a speaker's perceived warmth mediates the effect of personal anecdotes on curiosity.

In the following section, I introduce curiosity and review the literature that shows the connection between disclosing personal anecdotes and curiosity. I examine the research that suggests relationships between self-disclosure and perception of speaker warmth, warmth perception and curiosity, and eventually self-disclosure and curiosity. This section is followed by the introduction of risk perception and risk mitigation and their relationship with curiosity. Finally, I elaborate on studies examining the relationships between risk perception, warmth, and trust. The methodology section describes the experiment design and analysis. Finally, I discuss the results, limitations, and future directions of this work followed by the conclusion.

Literature Review

Curiosity. Curiosity is a tool with different potentials ranging from a motivation to find answers to a way to engage the public in a conversation around science through inquiry. Kashdan et al. (2018) define curiosity "as the recognition, pursuit, and desire to explore novel, uncertain, complex, and ambiguous events" (p. 130). Thus, curiosity is a result of a cognitive gap and manifested as a desire or behavior. These desires and actions include "openness to experience, novelty seeking, need for cognition, intrinsic motivation, tolerance of ambiguity, tolerance for uncertainty, frustration tolerance, and sensation seeking" (p. 130).

Curiosity has shown to improve learning outcomes and long-term memory (Jepma et al., 2012; Kang et al., 2009) encourage individuals to dedicate resources and time to find answers (Kang et al., 2009) and motivate them to engage in exploratory behavior (Arnone et al., 2011). These outcomes are particularly important in the field of science communication that seeks to promote public engagement through dialogues about science (NAS, 2017).

The engagement model of science communication advocates public engagement with science. One way that this model advocates for fostering engagement is through encouraging individuals to talk to experts, ask questions, and voice their opinions; in other words, scientists should have dialogues with the public. Practitioners and researchers have been arguing for the importance of dialogue for learning purposes (e.g., Allan, 2002; Lehr et al. 2007) and empowering the public's involvement in science in society (Lehr, 2007). For example, citizen science projects, in which the public engages in analyzing data collected by scientists, can improve the participants' field-specific knowledge (Brossard, Lewenstein, and Bonny, 2005; Jordan et al., 2011). Others (Jensen & Buckley, 2012) show that individuals who attended a science festival, report higher interest and curiosity in science when participating in engagement events. Although the outcomes show positive effects of the engagement model, in the citizen science realm, for example, no change in attitude (Brossard et al., 2005) or behavior (Jordan et al. 2011) was reported. These results suggest a need to evaluate the effect of science engagement, including public curiosity, on more practical outcomes, including risk perception and mitigation.

Thus, in this study, I focus on curiosity as a tool for dialogue. Expressed curiosity in the form of inquiry (Getahun, Aulls, & Saroyan, 2014) can lead to a conversation between a curious public and a responsive expert. Due to the nature of curiosity as a latent variable (Kahan, 2016), different phenomena can reflect curiosity, such as the time one spends exploring an object or asking questions. Thus, in this study, I have chosen Kashdan et al., (2018) definition of curiosity, encompassing various exploratory behaviors and desires. Also, when examining the literature, I include topics that fall into the definition of curiosity, but are not referred to explicitly as curiosity in the original studies. The main topics I will be examining include engagement, dialogues, questions, participation, and conversations.

The National Academies of Sciences, Engineering, and Medicine (2016) defines public engagement as “seeking and facilitating the sharing and exchange of knowledge, perspectives, and preferences between or among groups who often have differences in expertise, power, and values”(p. 131). This definition sheds light on the expansive behaviors that reflect engagement. Kidd and Hayden (2016) state that some researchers suggest that curiosity is a type of information-seeking. As noted in the definition of engagement, the overlap between public engagement with science and curiosity is in the behavior of information-seeking.

As for other terms, I refer to conversations, as engagement between the expert and the audience. In addition, when studies examine participants asking questions, I referred to the action as “dialogue” even if the studies refer to them otherwise. I will still refer to the goal of the study as eliciting curiosity.

Curiosity, Personal Anecdotes, and Warmth Perception. Scholars have suggested multiple ways to elicit curiosity. Examples include offering novel and complex information, expressing the importance of a piece of information, or announcing a surprising piece of information (Golman & Loewenstein, 2015; Loewenstein, 1994; Silvia, 2008). For example, “Did you know that comets can hit the Earth and have devastating impacts?” can be new information if someone was not aware that comets can hit Earth, is important since it is a matter of life and death, and by adding “Did you know that comets can be deflected by being painted all white” the information can become surprising. However, one strategy that I argue has the potential to elicit curiosity is disclosing personal anecdotes. Researchers have been arguing about the effect of using personal anecdotes and self-disclosure on student dialogues and curiosity. As discussed further, depending on the methodology used, results show the existence and the lack of such a relationship.

In this section, I particularly examine how self-disclosure affects students’ willingness to ask more questions. Some studies refer to the term interpersonal self-disclosure to describe the sharing of personal stories and anecdotes. Wheeless and Grotz (1976) define this term as ‘‘any message about the self that a person communicates to another’’ (p. 47). Although most studies show the positive effect of self-disclosure on students’ expression of curiosity, I suggest the methods used in these studies leave room for a causal investigation of this relationship.

Most studies that show a positive effect have one important point in common; they use self-reports for evaluation. Goldstein and Benassi (1994) show that students report being more willing to participate in class when teachers engage in more self-disclosure. Goldstein and Benassi use a survey that examine both the student and teacher’s perception of the teacher’s self-disclosure and the student’s participation, including willingness to ask more questions. These results are in line with Cayanus, Martin, and Goodboy’s findings (2009) that with the teacher’s relevant self-disclosure, the students were more motivated to participate in class dialogues and are more likely to ask questions.

Similarly, using self-reports in an experimental context, Mazer, Murphy, and Simonds (2007) examine the effect of online self-disclosure through surveys. Their study shows that more self-disclosure leads to more positive classroom climate perception. In this study, researchers manipulated self-disclosure through the number of pictures and the amount of information posted by a female teaching assistant. High self-disclosure conditions contained multiple images with family and friends and posts about attending gatherings and favorite activities, medium self-disclosure provided family images and fewer posts, and low self-disclosure, only a headshot and no posts. The variable of classroom climate, evaluated by undergraduate students, includes items such as the perception of teachers empathy, more discussion rather than lecturing style, and more open-minded discussion. These items can also reflect possible student participation in classroom and dialogues. Researchers asked the students to review the teacher assistant's Facebook page and evaluate what they think the climate of the classroom would be.

These studies, however, have limitations that can result in outcomes that counter one another. Wambach and Brothen (1997) claim that the previously mentioned study may contain biases related to participation in surveys. Besides, the self-report measure might not be an accurate representation of participation in a dialogue in the classroom. Also, in Mazer and colleagues' study (2007), the participants have never actually been in the evaluated classroom. The students' evaluation is their perception of the class climate.

In Wambach and Brothen's study, eight students observed 22 randomly chosen college classroom sessions. Each session was monitored by two students who would record if participation existed or not in 5-minute intervals. They found that the teacher's self-disclosure did not significantly affect students' participation in the classroom, including how often they ask questions. An essential difference between the studies showing the positive effect of self-disclosure on participation in classroom dialogue, and Wambach and Brothen's study (1997), showing no such relationship, is their methods. The first group of studies evaluated students' interest in participation via a survey, but Wambach and Brothen (1997) analyze the participation behavior. Thus, Wambach and Brothen's research may suggest that disclosure only affects perception of classroom participation rather than participation behavior. However, one possible explanation for such a difference might be the methods they used to record information. When a teacher discloses information, possibly most interactions happen within a period of time after the disclosure. Thus, when documenting if within 5 minutes participation did or did not happen, researchers might miss substantial participation (e.g., asking ten questions) 5 minutes after the disclosure, and low participation (e.g., asking 1 question) another 5 minutes during the class. While there is a difference between the two scenarios, students evaluate both 5 minutes equally.

From these studies, there are three points to consider. First, due to their design as measuring observations or surveys of classroom participants, the findings demonstrate a correlation between self-disclosure and participation in the classroom (including inquiries) but no causation. An experimental design can contribute to the understanding of self-disclosure and the use of personal anecdotes as a factor that causes curiosity. Second, studies that show the positive relationship between self-disclosure and dialogue rely on student self-reports. This mode of evaluation can not only reduce the validity of information but could also be a representation of perception of participation and not behavior. Third, these studies refer to engagement and participation as a group of behaviors. To have a more detailed understanding of the matter, researchers should refine the topic of participation to smaller components, including more concrete actions such as asking questions as an indicator of curiosity.

In sum, studies suggest that self-disclosure is related to curiosity. However, they are unable to establish causation. In this study, I use an experimental design. Thus, to establish causality while focusing on curiosity. When referring to greater curiosity here, it refers to higher number of questions asked by the audience. I suggest the following hypothesis (figure 1):

H1: *Scientists who engage in higher levels of self-disclosure will induce greater curiosity than scientists who engage in lower levels of self-disclosure.*

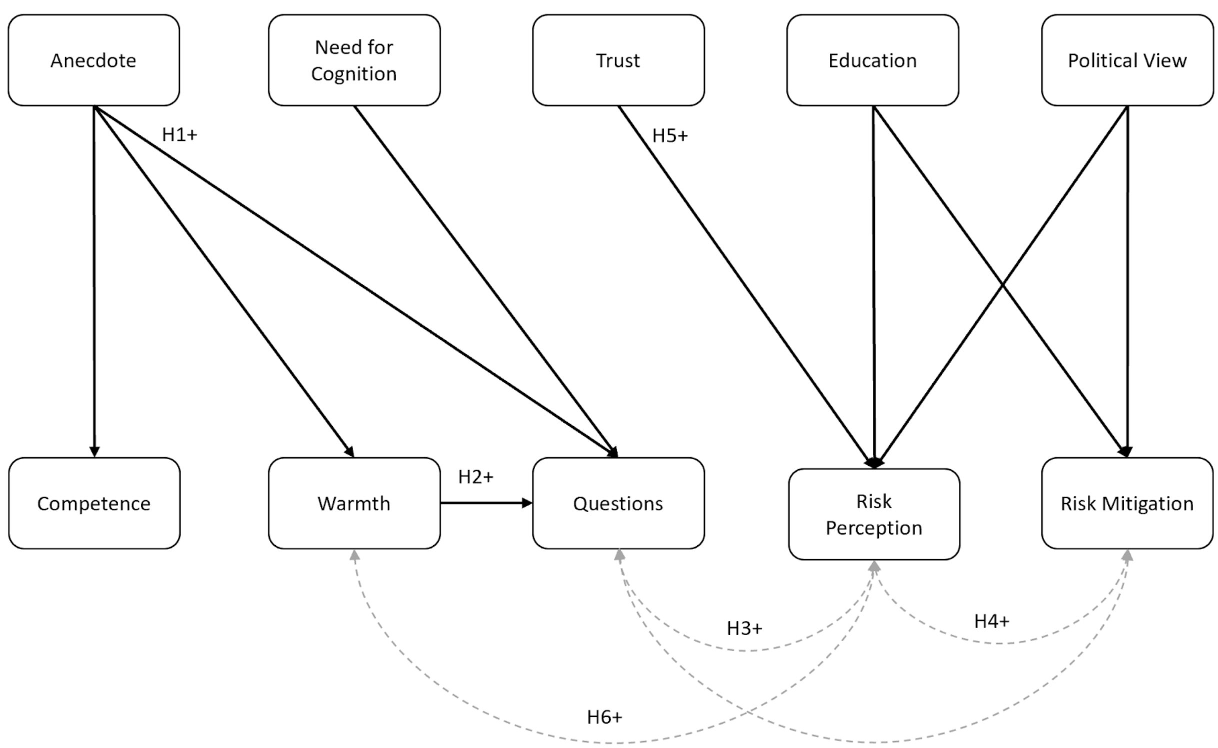


Figure 1. *Suggested model for a Structural Equation Modeling analysis (trust: trust in*

scientist's reliability).

NOTE: dashed lines represent correlational relationships.

For science communicators to elicit the audience's curiosity and engage them in a dialogue, it would be of great help to know if self-disclosure can elicit curiosity. Understanding what mediates the effect of self-disclosure can improve researchers and communicators' understanding of the mechanisms behind eliciting curiosity. This can provide an opportunity to use other strategies to elicit curiosity. In this section, I discuss that one possible mediating factor: warmth.

Warmth has been defined in different ways by scholars, mostly emphasizing on a range of characteristics such as commonality and collectivism (Judd, James-Hawkins, Yzerbyt, & Kashima, 2005), trustworthiness and kindness (Aaker, Vohs & Mogilner, 2010; Cuddy, Glick, & Beninger, 2011), other-profitable (Peeters, 1995 as cited in Xu, Glick, Cuddy, & Fiske, 2018), friendliness and empathy (Cuddy, Glick, & Beninger, 2011), generosity, honesty, sincerity, helpfulness, and thoughtfulness (Aaker, et al. 2010). Some learning sciences studies in classroom education refer to warmth as teacher warmth, supportiveness and caring (Voelkl, 1995) or the teacher's attempt to know their students better and integrate their opinion into their decision-making (Epstein, 1981). Fiske, Xu, Cuddy, and Glick (1999) use warmth and likability interchangeably. In this review, I treat studies that evaluate likability as studies that assess an element of warmth.

Different studies have suggested various strategies to improve the perception of the source's warmth, friendliness, and benevolence. For example, studies suggest helpfulness and caring to build warmth (e.g., Aaker, et al. 2010; Peloza & Hassay, 2006; Voelkl, 1995). Others, including Moreland and Zajonc (1982), use familiarity to elicit likability and warmth. Also, the use of family and friends can help with the perception of warmth. For example, Aaker et al. (1986) use an ad in which a couple we reunited to elicit the perception of warmth. A multitude of studies produce the perception of benevolence and warmth through facial expressions such as smiling (Landrum, Mills, & Johnston, 2013; Gheorghiu, Callan, & Skylark, 2017). Lakoff (1977), mentions the rule of equality, for the speaker to avoid being perceived as superior and pulling ranks. Thus, the use of first names or nicknames can be a strategy to elicit warmth and not attempting to assert superiority.

However, in this study the primary strategy I focus on is the use of a personal anecdote. Several studies describe how self-disclosure and the use of personal stories affect speaker's perception of warmth. A study by Sorensen (1989) shows that teachers' self-disclosure leads to more affective learning in students, including more liking of class and the teacher. This result is in line with a meta-analysis by Collins and Miller (1994), concluding that self-disclosure leads to more liking of the speaker. However, this strategy can have different effects depending on the intensity of its use. Cozby (1972) shows a curvilinear relationship between self-disclosure and liking. Although medium amount of self-disclosure can help with the speaker's likability, the disclosure of highly intimate information or very low level of disclosure can reduce their likability. There is also a positive relationship between self-disclosure and connection with the speaker (Abrahamson, 2005; Altman & Taylor, 1973) and more empathy with them

(Abrahamson, 2005). These indicators of warmth show that self-disclosure can improve one's perception of warmth and likability.

The second part of this section is regarding the effect of speaker's warmth on the expression of curiosity and engagement. Studies of classroom participation and engagement have found a positive correlation between warmth and student engagement (Hamre & Piata, 20031; Hughes, Luo, Kwok, & Loyd, 2008; Skinner & Belmont, 1993; Skinner, et al., 1990; Voelkl, 1995). Engagement in the context of these classroom studies is based on emotional and behavioral factors. For example, when students concentrate on the material and make intense efforts to implement learning material, they are considered engaged. Other activities showing engagement include showing enthusiasm, interest, and curiosity (Fredricks, Blumenfeld, & Paris, 2004; Hughes et al., 2008; Skinner et al.,1990). Researchers mainly assessed these variables based on the teacher's report of student's listening, study habits, compliance, cooperation, and participation (e.g., Hamre & Piata, 2001). Epstein (1981) shows that warmth motivates students to pay more attention in class and be more interested in the material, thus improving participation and leading to student success. Bergin and Bergin (2009) also review the studies that show a closer student-teacher relationship contributes to student engagement in class; in the same line, when teachers build a trusting relationship with students, they have increased engagement in class (Gregory & Ripski, 2008).

Based on the evidence I presented in this section, I suggest examining if warmth mediates the effect of personal anecdotes on curiosity (Figure 1). As personal anecdotes correlate with warmth perception and engagement, including inquiring from speaker, and warmth correlates with participation in classroom and inquiring from the speaker, warmth may be the path between personal anecdotes and curiosity. In addition to examining the mediating effect of warmth, investigating the effect of warmth contributes to the understanding of this variable in deeper ways as well: the studies in the classroom context vaguely conceptualize and measure warmth, focusing on friendliness and caring. Although the definitions can provide practitioners and researchers with general instructions to build warmth, there is no one particular method named in the mentioned studies to do so. For example, a general suggestion encompasses "be friendlier," while a concrete skill would be "tell your audience, they can call you by your first name." The general representation of warmth in studies, makes replication subjective for practitioners and does not offers skill-based information. Similarly, the measurement of warmth is not explicit and is either encoded in a measurement of teacher involvement (Skinner & Belmont, 1993) or is limited to general student perceptions of limited items such as caring for students (Robinson, Wilson, & Robinson, 1981) or interest in student opinion and willingness to hear more about the student (Skinner, Wellborn, & Connell, 1990).

Considering the evidence suggesting a relationship between self-disclosure and warmth, warmth and curiosity, and self-disclosure and curiosity, I suggest examining if warmth mediates the effect of disclosing personal anecdotes on curiosity (figure 1), leading to the following hypothesis:

> ***H2****: Scientists who are perceived as warmer, will elicit more expression questions than scientists who are perceived as less warm.*

Curiosity and Risk Perception/Mitigation. Eliciting curiosity contributes to science communication in various ways, such as fostering dialogue and interest in science. In this study, I examine how scientists can elicit curiosity through disclosure of personal stories and eliciting warmth-perception, but I will also investigate the potential impacts of curiosity. One such impact is risk perception, referring to people's views on risk and is usually as a counterpart to "real" or "actual" risk (Renn and Rohrmann, 2000). For example, while shark attacks in "reality" have a low probability, perhaps due to the depiction of sharks in movies, people have higher "risk perception" of a shark attack. The understanding of what determines risk perception is a complex matter and many researchers have contributed to the literature by focusing on a range of factors from individual-level factors (e.g., Sjoberg, 2000) to cultural ones (e.g., Dough & Wildavsky, 1982).

Renn and Rohrmann (2000) describe an integrative model of risk perception with four main levels: heuristics of information processing, cognitive-affective factors, cultural backgrounds, and social-political institutions. An earlier model by Fischhoff et al. (1978), the psychometric model, focuses on the two elements, dread and novelty of the threat. The higher an individual perceives the dread as the severity of outcomes, the higher they perceive the risk. Renn and Rohrmann's model encompasses these factors but does not focus on curiosity as an important variable affecting risk perception.

Curiosity is a specific factor that may have a strong effect on risk perception, but there have been few studies examining it. A study by Kahan et al. (2017) shows how individuals with higher science curiosity, measured as a desire to consume more science-related content, were more likely to look for counter-attitudinal information, in this case, information about global warming. They were also more likely to perceive higher risk regarding global-warming regardless of their political partisanship. This finding hints at the possible effects of curiosity on societal risk perception and calls for a more in-depth examination of this relationship.

Sjoberg's study (2007) also addresses the topic of "interest" measured through the question "How interesting do you think the following risks are – how much do you, for example, want to read about them, discuss them or think about them? " Followed by a question regarding risk mitigation " How important do you think it is that the Swedish state or municipalities (local and regional) acts to diminish the following risks? " (p. 226). His results show a positive correlation between interest and risk perception in the case of terrorism but not regarding genetically modified food and mobile telephone use. The study shows a correlation between interest and expressed desire for risk mitigation. The author explains that perhaps, when individuals encounter a threatening situation, instead of suppressing the topic, they are willing to take action to mitigate the effects. He then calls for more research on "interest as a spontaneous reaction vs. interest as allocation of time and commitment (p. 233)."

The study of curiosity and its relationship to risk perception can be of great value to the science communication community due to not only its substantial effect on risk perception but also on risk mitigation. However, there is still scarce evidence supporting such relationships. As shown in the study of Sjoberg (2007) only one out of three threat's risk perceptions were significantly correlated with interest. Researchers need to conduct more studies to examine the effect of interest and curiosity on the perception of risk. In addition, when the measurements focus on the participants' self-report of interest and curiosity, the outcomes are intentions and not behaviors. Thus, I will evaluate the relationship between curiosity and risk perception and risk mitigation (figure 1), while measuring curiosity as a behavior. The same problem arises in

Sjoberg (2007) when measuring risk mitigation as an intention rather than a behavior. Thus, I will examine risk mitigation through a behavioral measure of risk mitigation. The shortcomings in the study of risk perception lead me to test the following hypothesis:

H3*: There is a positive relationship between curiosity in societal risk topics and risk perception.*

H4*: There is a positive relationship between curiosity in societal risk topics and risk mitigation behavior.*

Risk Perception, Warmth, and Trust. One important factor influencing risk perception is trust in institutions and the competence of the source. Trust in authorities has been widely studies. Studies on trust in authorities who manage hazards (Flynn et al., 1992; Siegrist, 2000), government and businesses (Siegrist, 1999 & Flynn et al., 1994), industry and the consumer's associations (Stephanie et al., 2008), experts (Biel & Dahlstrand, 1995) and other institutes seem to show that when one trusts the source, they perceive less threat from that institutions' product. Similarly, Grewal, Gotlieb, and Marmorstein (1994) show that the source's higher credibility, (e.g., a product's spokesperson), is correlated with lower risk perception of the product.

Researchers more frequently study the source attributes of trust and competence and not their warmth and friendliness. Fiske and Dupree (2014) suggest that trust in an individual is associated with how warm they are perceived. Researchers frequently use these terms (warmth and trust) interchangeably (e.g., Cuddy, Glick, Beninger, 2011). Communication scholars suggest that scientists should foster warmth to be trusted by the public. They see this as a potential remedy to public's refusal of facts and scientists' warnings. However, the proposed relationship might not be fully reflective of the public's thought-process. Studies of Viklund (2003) and Sjoberg (2001) provide a possible explanation for the disconnect between trust and risk perception.

Sjoberg (2001) finds low correlation ($r = 0.3$) between trust (defined as an individual's competence and care)and risk perception. He notes that the small effect of trust might be due to the public believing that there are limits to what experts and science knows. Sjoberg also shows that one's knowledge of the topic moderates the effect of trust (i.e., higher knowledge reduces the effect of trust). Similarly, Viklund (2003), through his analysis of multiple cross-cultural studies of trust has shown that trust's power to predict perception of risk differs amongst countries and depending on the risk itself. A possible explanation for this controversy could be related to the measurement tools. Measures such as that of Colquitt (2001) examines trust in a practical sense (i.e., relying on experts for decision-making). This measure of trust reflects reliance and willingness to be vulnerable. This could possibly eliminate the significant effect of trust on risk perception when the previous study results were an outcome of trusting the expert's intentions, rather than trust in their competence and the willingness to reply on them. In other words, measuring an individual's trust in the intention of a scientist could result in different outcomes compared to measuring an individual's trust in the scientist's behavior as it might affect an individual. Thus, in this study, instead of examining trust as an intention, I examine trust in scientist's reliability, as the participants' willingness to be vulnerable.

In addition, the majority of the previous studies examine the effect of trust on the reduction of risk perception. For example, Flynn et al. (1992) show that higher trust in risk management reduces the public's perception of the risk of radioactive waste (also, Siegert 2000, 2006). In this study, I examine if trust can also **increase** risk perception (figure 1). Thus, I hypothesize the following:

> ***H5:*** *There is a positive relationship between trust in scientists' reliability and perception of risk about the harms of the topic they introduce.*

The previous arguments highlight interesting gaps in the study of risk perception as it relates to trust in reliability and warmth. Although researchers occasionally use trust and warmth interchangeably, researchers have done a fair number of studies to investigate the effect of trust (perceiving positive intentions) in institutes on risk perception but have not studied warmth independently. Even though to my knowledge, there are no mentions of warmth in risk perception literature, some of these studies include elements of warmth in their evaluation of trust. For example, Kasperson, Golding, and Tuler (1992) and Sjoberg's measure (2001) include caring, which is also present in the evaluation of warmth. Expanding on this measurement, I suggest that warmth could also produce effects similar to those of trust (figure 1). Thus, I hypothesize:

> ***H6****: There is a positive relationship between the scientist's perceived warmth and perception of risk about the harms of the topic they introduce.*

In addition, to examine if the results of studies extend from institutions to individual actors, studies should examine the relationships in the context of one individual, such as a scientist. As science communication calls for more face-to-face interaction of experts and the public there's more need for science communication scholars to understand the effect of the source as a particular individual on risk perception.

Study Design

The purpose of this experiment is to examine the effect of disclosing personal anecdotes on the individual's curiosity, risk perception and risk mitigation, in addition to their perception of scientist's warmth. This study also examines if there is a positive correlation between curiosity and risk perception, curiosity and risk mitigation, and perception of warmth and trust, and trust and risk perception. To address these objectives, I have conducted an online experiment on the Qualtrics platform. The intervention was in the form of an online post, read by the participants.

Participants. After a pilot run of 30 participants to determine the sample size, I have decided to recruit 385 participants for a power of 0.95 and an effect size of 0.26. In this study 385 adults (18+) from the US were recruited through the Qualtrics online survey platform. They compensated each participant based on their company criteria. Qualtrics recruited participants based on a quota for an equal representation of political views (extremely conservative, conservative, moderate, liberal, extremely liberal, 20% each), education (high school degree, bachelors, advanced degree, 33% each), and gender (female, male, 50% each).

Measures. In this section I will be describing different dependent and independent variables and how I measure them.

Warmth and competence perception. The Judd et al. (2005) measure of warmth evaluated based on a 0 (not at all) to 4 (extremely) scale is a simple tool to measure the perception of an individual's warmth (Appendix B). This measure examines an individual's perception of the subject's "sociability, warmth, friendliness, and caring" as their measure of warmth (Chronbach's $\alpha = 0.89$). The final score was an accumulation of the four items ($M =$

14.11, *SD* = 3.44). The Judd et al. measure also contains an evaluation of competence "motivated, intelligence, energy, and organization." I measured the perception of competence (*M* = 15.64, *SD* = 3.23) caused by any of the four elements to make sure the effect is limited to increased warmth and no change in competence perception (Chronbach's α = 0.87).

Curiosity. As mentioned earlier, to acquire a measure of curiosity that reflects one's behavior rather than intention, I avoided using measures based on the participants' self-report. I instead used the participants' questions, and their willingness to be given more information as a behavioral measure of curiosity. However, even these measures of curiosity cannot directly evaluate "curiosity", as this trait can be measured indirectly, as a latent variable (Kahan, 2016). Kahan also notes that the measures of interest and curiosity based on self-report are not necessarily predictive of behaviors. Thus, by measuring the attributes of the participants' inquiries, researchers can acquire an indirect evaluation of curiosity as a behavior.

Researchers such as DuVall (2001) or Kowalski and Kowalski (2013), treat inquiry as a representation of curiosity. For example, Getahun and colleagues (2014) using a questionnaire filled by undergraduate students, ask participants to define inquiry, leading to 13 final categories. One of this conceptualization is "gaining information/knowledge". In this category "inquiry corresponds with the curiosity for acquisition of facts or details about something or an event as part of everyday life experience" (p. 7). In addition to this conceptual suggestion, the study of Jirout (2011) shows a significant correlation between the level of curiosity and questions asked by participants.

Thus, in this study I used a behavioral measure of curiosity. This measure examines the intensity of participants' curiosity by asking the participants to list their questions. This method is in some ways similar to the thought-listing technique (Cacioppo, Von Hipple, & Ernst, 1997) used to reach an individual's mental content (e.g., thoughts, images, ideas). In the thought-listing technique, individuals are asked to write down everything that comes to their mind at a specific time or regarding a specific topic. There are certain limitations to this technique, for example, not being willing to express one's thoughts. Such reactions might occur in this study as individuals might think that their questions are naive. However, anonymity might alleviate the participants' concern about being judged. This method is also used to examine the intensity of one's elaboration about a topic (e.g., Frewer, Howard, Hedderley, & Shepherd, 1997). Similarly, using the prompt "please list any question you might have regarding the article" I am assessing the participants intensity of curiosity depending on the number of questions they ask. Listing one's questions is different from the thought-listing technique as instead of asking individuals to list terms that come to mind, they are asked about questions related to the topic. This measure as the number of questions asked, (M = 1.4, SD = 1.17) represents curiosity as a behavior.

Risk perception. To measure risk perception, I have used the Industrial Strength Risk Perception Measure (ISRPM) developed by Kahan (2011) in which individuals are asked to evaluate the seriousness of a risk on 0-7 Likert scale (Appendix C). This measure used in different research has shown to be highly reliable. This measure will evaluate the participants' perception of the general risks of reduction in snowfall and river volumes, deforestation, ground sinking, and in general, climate change (Chronbach's α = 0.89). The final measure is an accumulation of the 4 items (M = 22.67, SD = 7.31).

Risk mitigation. Although there are self-report measures of risk mitigation (e.g., Sjoberg, 2007) to obtain a behavioral measure of the action, participants were asked to consider donating all or part of their compensation to a nonprofit active in climate change efforts. This measure is similar to that of Liu and Aakers (2008) asking individuals “In today’s session, five participants will be randomly selected to win a bonus payment of $20. If you are chosen as a winner, you can donate all or part of the $20 to HopeLab. If you are a winner, how much of the $20 would you like to donate to HopeLab?” (p. 550). Using this measure, the authors examine “actual donation” as opposed to intention. Thus, I have examined the behavior to mitigate risk, I also examined the percentage of actual donation alongside risk perception (*M* = 12.24%, *SD* = 25.02%).

Trust in scientist’s reliability. To measure trust in reliability, I used the Colquitt (2001) questionnaire (Appendix D). This measure particularly evaluates if the individual is willing to trust the scientists with practical tasks that influence them. This is done through questions such as trusting them with an important task without monitoring them, letting them take over an important issue and having control over one’s future (rated 0-5). To calculate the final score I accumulated five items related to trust in reliability (*M* = 13.44, *SD* = 2.56) with a high Chronbach’s α of 0.89.

Covariates. Two measures were used as covariates: education and partisanship. Education, as shown before, seem to have significant effects on risk perception (Kahan et al, 2017; Newport & Dugan, 2015). In addition, political partisanship seems to also determine an individual's risk perception (Renn & Rohrmann, 2000; Leiserowitz, 2006). This effect is also visible in the PEW (2016) national report; in that report, political partisanship is an important determinant of one’s risk perception towards societal issues perception of danger for social risks such as being anti-vaccination, GMOs, global warming, and fracking. I measured both variables based on a categorical scale, from “less than high school graduate" to "graduate or professional degree" rated from one to seven ($M = 4.46$, $SD = 1.56$) and from "extremely conservative" to "extremely liberal democrat" rated from one to five ($M = 3.01$, $SD = 1.41$). I have also included the measure for need for cognition (Cacioppo, Petty, & Kao, 1984). This measure evaluates curiosity as an attribute rather than a state that can be elicited externally ($M = 59.8$, $SD = 11.31$). It explores the individuals' willingness to think critically and appreciate complexity and is comprised of 18 items (Chronbach's $\alpha = 0.83$).

Procedure. After completing the demographic information (i.e., age, sex, education, race, residency, income) in addition to a need-for-cognition questionnaire, participants reported their identification with one of the political parties. Qualtrics then randomized participants into either the low personal anecdote disclosure or high personal anecdote disclosure ($n = 204$ in low self-disclosure and $n = 181$ in the high self-disclosure condition). The disproportionate number of participants in the two conditions is due to the data cleaning process. There were instances where the same participants responded twice. I have eliminated these cases if they provided the same question in the "question-listing" section and were answered in the same time-frame. I have also eliminated participants who were not paying attention to the questions. In addition to an attention-check questions, I have excluded participants that provided irrelevant answers and typed meaningless words.

As mentioned in Collins et al. (1994), self-disclosure is operationalized through the manipulation of depth and breadth of self-disclosure. More intimate topics are considered to have more depth (e.g., disclosing information on one's personal life events versus one's education level). The breadth of disclosure is associated with the time spent talking about personal information and the number of "self-relevant statements" shared with others.

In this study, to operationalize self-disclosure through personal anecdotes, in the high disclosure condition, I have designed the manipulation based on a scientist disclosing more intimate and extensive personal information compared to the low-disclosure condition. This manipulation was similar to the manipulation used by Mazer and colleague's study design (2007). They manipulate self-disclosure by using high, medium, and low self-disclosure. In the high self-disclosure scenario, the subject revealed more information about themselves, such as their interests and memberships. In the medium scenario, they only disclosed their interests, and in the low disclosure scenario, they only reveal their educational information.

Participants in the high disclosure of personal anecdote condition read news exert consisting of a small bio on a scientist's education (Dr. Mary Smith), followed by a section including a personal anecdote about the scientist's experience living near the mountains and being a climber. In the last section, the scientist talks about the effects of climate change on the amount of snowfall, melting of glaciers, reduction of river volumes, and deforestation, and how these changes affect the population. The low-disclosure condition included the same bio regarding the scientist's education. An intro follows this to the status quo regarding mountains and the amount of snow and glaciers in the mountains (parallel to the high-disclosure condition's personal story). This section was eventually followed with the same content on the effects of climate change (Appendix A). I have written these scenarios based on the World Wildlife Fund's Climate Witness Project (2008), interviewing individuals around the world who have witnessed the effects of climate change.

However, I have made major modifications to the original script to build a more anecdotal approach and to introduce the speaker as a scientist. I use a female scientist in the biography. As the STEM community encourages more involvement of female scientists in public engagement, researchers need to facilitate the process by tailoring study designs with female scientists as their focus. With the existing differences in how the public views female and male scientists, the results of studies with male scientists in their center cannot be necessarily applied to female scientists (Knobloch-Westerwick, Glynn, & Huge, 2013). Thus, by having the biography of a female scientist, I will be able to make inferences that apply to female scientists.

After reading the biography, participants were then asked to fill the warmth and competence questionnaire to determine their perception of the speaker's warmth and competence. Participants were then asked to list questions about the content of the material and write the number of questions they asked. Next, the audience was given a short questionnaire to measure their climate change risk perception followed by a behavioral measure of risk mitigation. This measure offers the participant to donate a portion of their compensation to a fictional nonprofit "Act Against Climate Change." They were free to determine how much of their compensation they were willing to donate. Finally, the participants were provided with a questionnaire to evaluate their trust in scientist's reliability. This measure was the last question to avoid any priming biases (Figure 2).

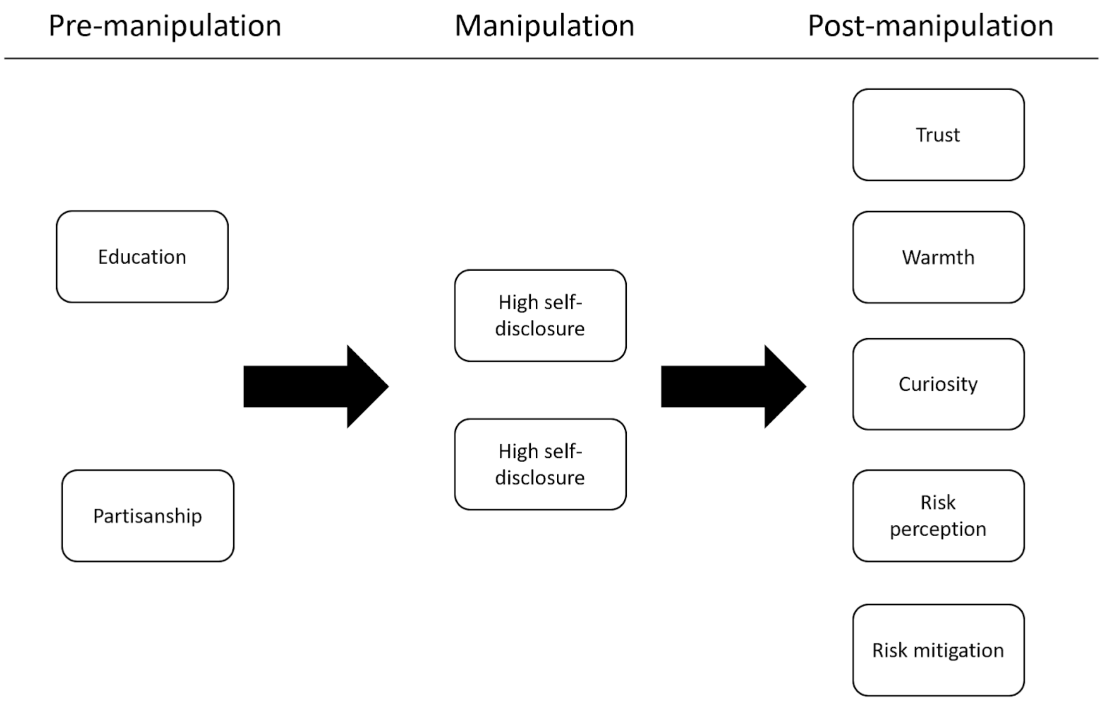


Figure 2. *The design of the main study.*

Analysis. I analyzed the results through structural equation modeling (SEM), treating disclosure of personal anecdotes, trust in the reliability, need for cognition, education, and partisanship as exogenous factors and warmth, competence, curiosity, risk perception and risk mitigation as endogenous factors. I will examine the effect of disclosure on curiosity (H1) and examine if this effect is mediated through warmth (H2). I will also examine the relationship between curiosity and risk perception (H3) and risk mitigation (H4). I will eventually test the effect of trust in scientist's reliability on risk perception (H5) and the relationship between warmth and risk perception(H6). Education and partisanship are the covariates influencing risk perception and risk mitigation (Figure 3). I used R software's Lavaan package for this analysis.

When reporting this data, I will not use the Chi square to judge the fitness of the model. According to Kyriazos (2018), based on the work of Gatignon (2010) and Singh et al., (2016) Chi square is extremely sensitive to the sample size. Thus, the test might fail to reject an unfit model in small sample sizes while it might falsely reject a model with good fit in a large sample size. The same paper suggests that based on a study by Curran et al. (2002) with sample sizes of more than 200, and in a model with moderate misspecification, RMSEA was an accurate indicator of fit. Although the X^2/df ratio is similar to Chi square in sensitivity to sample size, it is still reported in SEM analysis. Thus, in this study, to examine the fit of the model instead of reporting Chi square, I mainly rely on the RMSEA indicator, followed by GFI, AGFI, and CFI. Based on the Schreiber et al. (2006) in this model, a good fit is indicated by the RMSEA < .06 to .08, AGFI, GFI and CFI above 0.95 and finally a lower X^2/df ratio also indicates a better fit, recommended below 2 or 3.

Results

Manipulation Check. The t-test analysis for the effect of self-disclosure on curiosity shows no significant difference between low self-disclosure (M = 1.39, SD = 1.13) and high self-disclosure group (M = 41, SD = 1.21) conditions; $t(370.17) = -\ 0.23024$, $p = 0.81$. The main purpose of the manipulation was to produce two conditions with separate levels of induced-curiosity to examine if curiosity can cause increased risk perception and mitigation. However, since the manipulation did not cause such an effect, I will interpret all following outcomes as correlations.

Tests of Baseline Conceptual Model. The SEM analysis of the baseline model shows the X^2/df ratio of 25.09, highly above the suggested ratio of 3 shows the weak fit of the model, along the GFI, AGFI, and CFI below the 0.9 conventional criterion. However, the RMSA of < 0.00 is below the 0.06 conventional criterion, indicating a good fit. Collectively, these indicators show a low fit of the baseline model (Table 1).

Model Revision and Tests. To address the low fit of the baseline model, I have used a modification test, examining what suggested changes can improve the model to the point of good fit to observed data.

First modification. The first software suggestion to improve the model is warmth being explained by competence, and second, that competence and warmth are correlated. Rather than warmth being explained by competence, there is more research supporting a negative relationship between the two variables including Jaudd and colleague's (2005) analysis of three studies. Thus, I have started the modification by addition this correlation into the model. The results of the analysis of the modified model shows a GFI, AGFI, and CFI below their conventional criterion indicating a bad fit. The $X^2/df = 9.34$ show improvement with a RMSEA < 0.000, below the conventional 0.6, showing a good fit.

Second modification. The next modification suggests trust in scientist's reliability being explained by the perception of competence and next by warmth. While these two are separate suggestions, to be in line with the research suggesting trust is a construct of warmth and competence (Sirdeshmukh, Singh, & Sabol, 2002) I add both variables to explain trust. Results still show a GFI, AGFI, and CFI below their conventional criterion indicating a bad fit. The

X^2/df = 5.44 show improvement with a RMSEA < 0.000, below the conventional 0.6, showing a good fit with.

Third modification. This model's first four suggestions are that political partisanship are determined by the perception of scientist's competence, warmth and trustworthiness, and perception of scientist's competence is determined by the participant's risk perception. Since these suggestions are not widely supported by established research, I take the fifth modification suggestion the participant's perception of risk of climate change is explained by their perception of the scientist's competence. Grewal et al. (1994) in their study show that the source's higher competence is correlated with lower risk perception of the product. This study shows that the higher credibility relates to believing that the product is harmless, (i.e., agreeing with the statement of the subject, in this case, that a product is harmless). However, in this study, I assume that the same relationship exists when the agent advocates for the risks of a product. As suggested by the model, I include this relationship as a causal one.

Results show an improvement in the model's fit, but still a general bad fit of the model. While GFI and AGFI still are below their conventional criterion, CFI has moved above the 0.9 conventional criterion, and along with the X^2/df = 4.55 and RMSEA < 0.000 show an improved model.

Fourth modification. The first four modification suggestions include that political partisanship is affected by the participant's perception of the scientist's competence, warmth, and trust in reliability, and by their perception of climate change risk. As also suggested in the previous model modification, these suggestions are not widely supported by research. The next suggestion is that the number of participants' questions is affected by their level of education, and finally that education is affected by the number of questions. However, none of these modifications are supported widely by research. Thus, I include the next modification in the model suggesting that the participants' perception of the scientist's competence is dependent on participants' political partisanship. I will also add that the participants' perception of the scientist's warmth is affected by political partisanship. This decision is based on studies and surveys such as PEW's 2019 report (Funk, Hefferon, Kennedy & Johnson), showing that democrats have more trust in environmental researchers compared to Republicans. This shows the role of political partisanship in how individuals perceive scientists.

The results from this analysis show a GFI and CFI above the conventional criterion, as the AGFI of 0.89 is marginally below the 0.9 conventional criterion. As the RMSEA is below the conventional criterion and the X^2/df ratio of 2.60 has been improved, I will consider the model as one with a generally good fit. The changes in chi square between models also shows an improvement in the model's ability to explain the variance in each of the dependent variables (Table 2).

Table 1. *Summary of fit indices.*

Models	X^2	*df*	*p*	X^2/df	*RMSEA*	*GFI*	*AGFI*	*CFI*
User model	451.66	18	0.000	25.09	0.000	0.71	0.11	0.41
Revised model 1	168.27	17	0.000	9.34	0.000	0.87	0.59	0.79

Revised model 2	119.78	22	0.000	5.44	0.000	0.91	0.79	0.87
Revised model 3	95.59	21	0.000	4.55	0.000	0.93	0.81	0.90
Revised model 4	49.56	19	0.000	2.60	0.000	0.96	0.89	0.96

Table 2. *Summary of R squared for dependent variables in each model.*

DV	*Base model*	*Model 1*	*Model 2*	*Model 3*	*Model 4*
Warmth	0.006	0.008	0.006	0.006	0.08
Competence	0.000	0.000	0.001	0.001	0.11
Questions	0.04	0.04	0.04	0.04	0.05
Risk perception	0.36	0.37	0.39	0.41	0.47
Risk mitigation	0.05	0.06	0.06	0.06	0.06
Trust	-	-	0.25	0.25	0.25

New Suggested Model. Table 3 shows the summary of results from the final model (figure 4). In this section, I will go through the results based on the study's hypotheses (table 4):

H1: Scientists who engage in higher levels of self-disclosure will induce greater curiosity than scientists who engage in lower levels of self-disclosure. Results show that the manipulation to elicit curiosity through self-disclosure does not have any significant effect ($\beta = 0.03$, $p = 0.77$) and there was no difference between the low and high self-disclosure groups. Self disclosure also had no significant effect on the perception of the scientist's warmth or competence.

H2: Scientists who are perceived as warmer, will elicit more expression of curiosity than scientists who are perceived as less warm. As the results show the significant effect of perception of warmth on the number of questions ($\beta = 0.04$, $p = 004$), The data is consistent with the second hypothesis. However, since I have rejected the first hypothesis, showing the manipulation did not have an effect, I cannot establish a causal relationship between warmth and curiosity, but would rather state that there is a significantly positive relationship between scientist's warmth perception and the participants' number of questions. Additionally, there is a significant correlation between number of questions and need for cognition ($\beta = 0.017$, $p = 0.001$).

H3: There is a positive relationship between curiosity in societal risk topics and risk perception. Risk perception is significantly correlated with the number of questions ($\beta = 0.90$, $p = 0.003$). So, I will accept the second hypothesis.

H4: There is a positive relationship between curiosity in societal risk topics and risk mitigation behavior. Unlike risk perception, risk mitigation is not significantly correlated with curiosity (β = -0.04, p = 0.61), thus, rejecting the fourth hypothesis. Risk mitigation is only significantly correlated with political partisanship (β = 0.272, $p < 0.001$).

H5: There is a positive relationship between trust in scientists' reliability and perception of risk about the harms of the topic they introduce. In line with this hypothesis, risk perception is significantly and positively correlated with trust in scientist's reliability (β = 0.52, $p < 0.001$). In addition, risk perception is positively correlated with political partisanship (β = 2.56, $p < 0.001$), and perception of scientist's competence (β = 0.47, $p < 0.001$). These findings show that higher trust in scientist's reliability, perceiving them as more competence, and being more liberal positively correlates with perceiving the dangers of climate change.

H6: There is a positive relationship between the scientist's perceived warmth and perception of risk about the harms of the topic they introduce. The results show no significant relationship between warmth perception and climate change risk perception (β = 0.23, $p = 0.7$), so I reject the final hypothesis.

In addition to these results related to the study's hypotheses, the analysis showed that perception of trust is significantly affected by perception of warmth (β = 0.172, $p < 0.001$), and competence (β = 02.244, $p < 0.001$) and warmth and competence are significantly correlated with one another (β = 6.975, $p < 0.001$). Both perceptions of warmth and competence are significantly correlated by individual's political partisanship (β = 0.681, $p < 0.001$ and β= 0.754, $p < 0.001$, respectively). These relationships are also depicted in figure 4.

Table 3. *Summary of regressions, covariances and variances from the final model.*

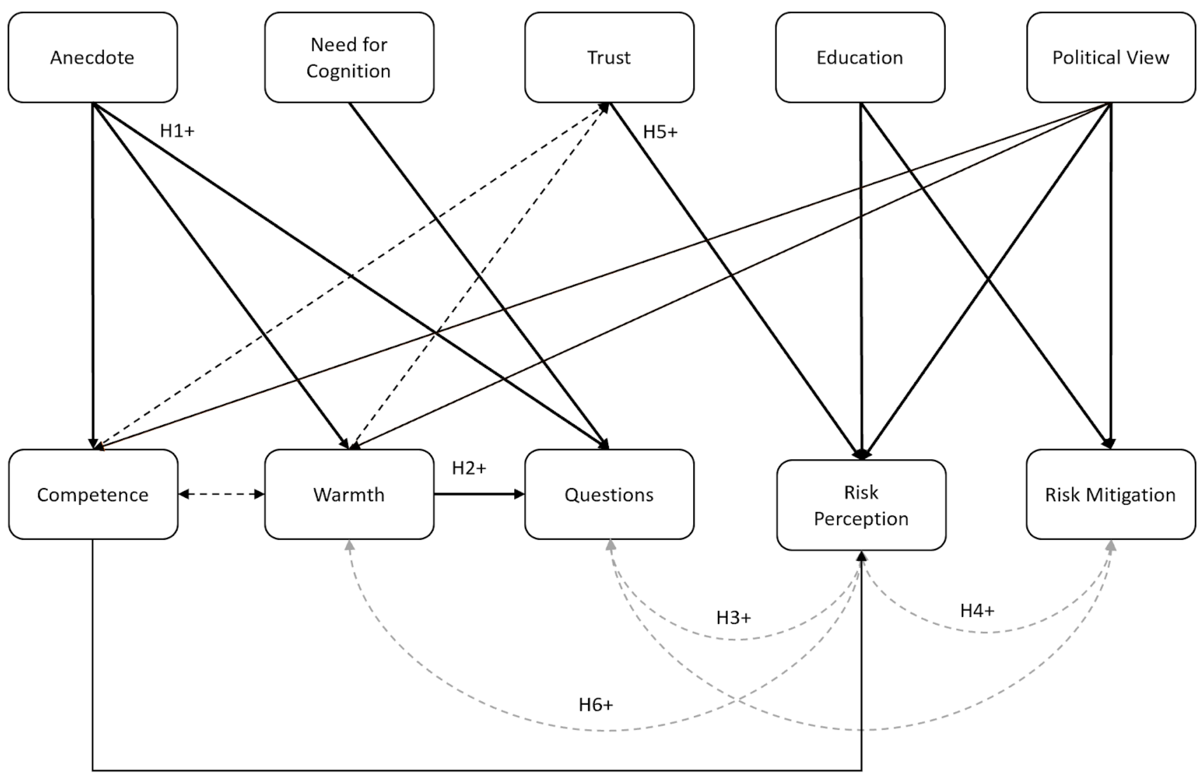
Regressions	*Estimate*	*Std. Err*	*z-value*	*P(>|z|)*
Warmth ~ self-disclosure	0.47	0.33	1.42	0.15
Competence ~ self-disclosure	-0.28	0.31	-0.92	0.35
Questions ~ self-disclosure	0.03	0.11	0.28	0.77
Questions ~ Warmth	0.04	0.01	2.84	0.004 *
Questions ~ Need For Cognition	0.01	0.005	3.42	0.001 *
Risk Perception ~Political view	2.56	0.2	12.84	0.000 *
Risk Perception ~Education	-0.08	0.17	-0.47	0.63
Risk Perception ~Trust	0.52	0.11	4.42	0.000 *
Risk Perception ~Competence	0.47	0.09	4.92	0.000 *
Risk Mitigation ~ Political view	0.27	0.05	4.94	0.000 *
Risk Mitigation ~ Education	0.01	0.05	0.25	0.8
Trust ~ Competence	0.24	0.05	4.85	0.000 *
Trust ~ Warmth	0.17	0.04	3.64	0.000 *
Warmth ~ Political view	0.68	0.11	5.73	0.000 *
Competence ~ Political view	0.75	0.11	6.86	0.000 *
Covariance				
Warmth ~~ Risk Perception	0.23	0.63	0.37	0.7
Questions ~~ Risk Perception	0.9	0.3	2.93	0.003 *
Questions ~~ Risk Mitigation	-0.04	0.08	-0.49	0.61
Risk Perception ~~ Risk Mitigation	0.78	0.4	1.94	0.05

Warmth ~~ Competence	6.97	0.62	11.2	0.000 *
Variances				
Warmth	10.83	0.78	13.87	0.000
Competence	9.27	0.66	13.87	0.000
Questions	1.29	0.09	13.87	0.000
Risk perception	27.51	1.98	13.87	0.000
Risk mitigation	2.28	0.16	13.87	0.000
Trust	4.9	0.35	13.87	0.000

Table 4. *Hypothesis summary.*

Hypothesis	*Conclusion*
H1: Scientists who engage in higher levels of self-disclosure will induce greater curiosity than scientists who engage in lower levels of self-disclosure.	Not supported
H2: Scientists who are perceived as warmer, will elicit more questions than scientists who are perceived as less warm.	Supported
H3: There is a positive relationship between curiosity in societal risk topics and risk perception.	Supported
H4: There is a positive relationship between curiosity in societal risk topics and risk mitigation behavior.	Not supported

H5: There is a positive relationship between trust in scientists' reliability and perception of risk about the harms of the topic they introduce.	Supported
H6: There is a positive relationship between the scientist's perceived warmth and perception of risk about the harms of the topic they introduce.	Not supported



NOTE: dashed lines represent correlational relationships.

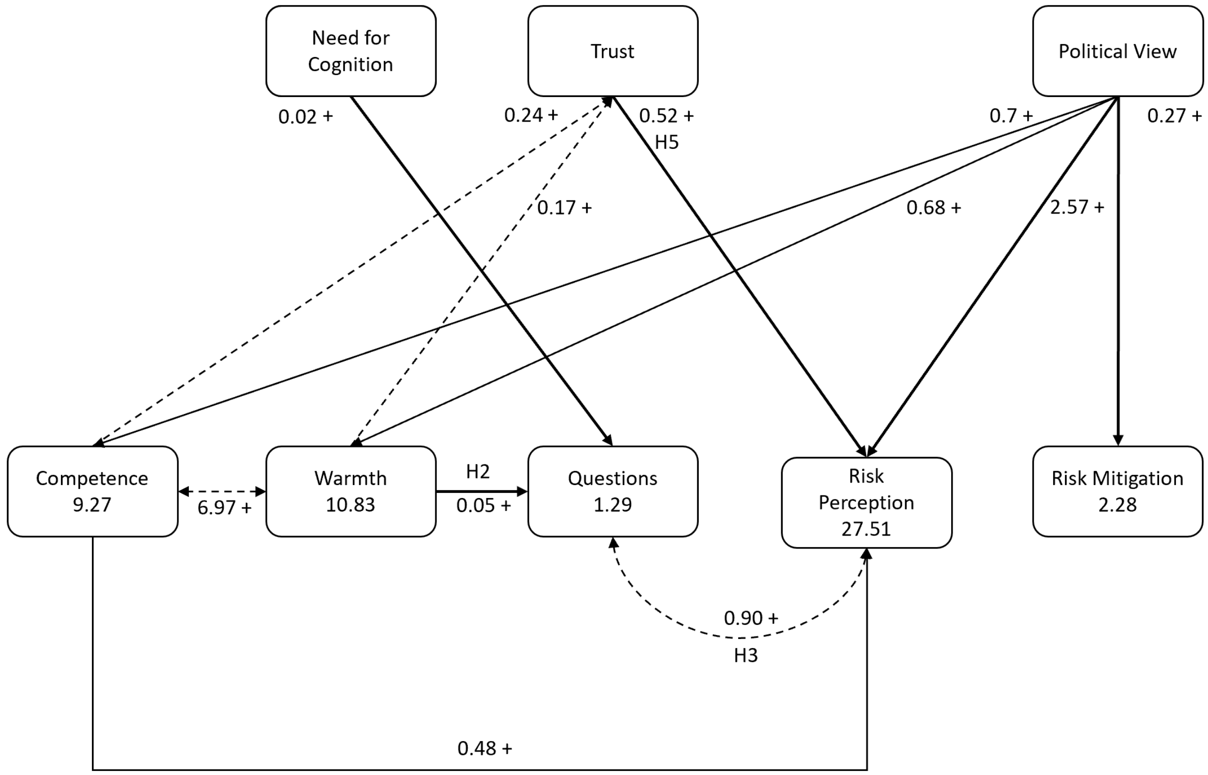


Figure 4. *Final modified model for a Structural Equation Modeling analysis, only showing significant results.*

NOTE: dashed lines represent correlational relationships.

Discussion

The purpose of this study was to examine the relationship between scientist's features of warmth, competence, and trustworthiness with the number of questions asked by individuals as it relates to climate change, and how these factors affect the perception of risk of climate change and individual's actions to mitigate the risk. To elicit changes in the scientist's perception of warmth and competence and the number of questions asked by the participants, I have used scientist's self-disclosure manipulation. The results of this study show that scientist's self-disclosure as manipulated in the current study, does not significantly induce a higher number of questions. This could be due to a number of reasons, for one, the self-disclosure might have not been emotionally strong enough or revealing enough to elicit a reaction. The effect of self-disclosure on other studies might have also been a function of it being a narrative. Some narratives and stories have the ability to transport their audience and lower their defensive barriers (Green & Brock, 2000). It is possible that the narrative used in this study did not have a strong element of transportation or an impactful story. Since the manipulation (self-disclosure) failed to invoke the desired effects, there is no distinction between the conditions, so I will not be able to make any causal inferences, and I will be describing all results as correlations rather than causations.

The studies on the effect of self-disclosure, mainly show the students' perception of participation in dialogue as, i.e., self-reports of being motivated to ask more questions or engage in more dialogues (Cayanus, Martin, & Goodboy, 2009; Goldstein & Benassi, 1994). However, Wambach and Brothen (1997) have studied the behavior of student participation (i.e., if they ask more questions when the teacher engages in more self-disclosure). Their results, similar to the current study, show no significant change. As listing questions is a behavior, self-disclosure may affect perception of one's interest in asking more questions and being more cognitively engaged, rather than asking more questions. Another possible explanation could be that of the manipulation design and the weakness of the self-disclosure material to elicit effects shown in previous research. These findings point at the importance of measuring both intention and behavior when evaluating the effect of such manipulations. Besides, it highlights the need for more research on developing effective manipulations.

In line with the second hypothesis, the positive relationship between scientists' perceived warmth and higher number of questions affirms previous work on teacher warmth and student engagement (Hamre & Piata, 20031; Hughes, Luo, Kwok, & Loyd, 2008; Skinner & Belmont, 1993; Skinner, et al., 1990; Voelkl, 1995). Most previous works have been evaluating engagement based on participants' self-reports. However, this study shows that warmth is positively correlated with engagement as curiosity behavior and not just intention and interests. In addition, the results expand the relationship beyond the teacher-student relationship to one between scientists and their audience.

The third hypothesis was aimed to examine if inducing curiosity, operationalized as asking more questions, will elicit higher risk perception to follow up on Kahan et al.'s (2017) study showing higher science curiosity is correlated with higher risk perception. Although due to the failed manipulation, the results cannot show the effect of induced curiosity, they do show a positive correlation. Kahan et al. in their study, evaluate science curiosity based on participants' desire to consume more science information when provided with different options. This study provides an additional means of assessing curiosity to confirm the existing relationship between curiosity and risk perception.

However, the same relationship between curiosity and risk mitigation, as per hypothesis four, does not exist. This finding is counter to that of Sjoberg (2007). Sjoberg examines if an individual's interest in a topic improves their report of risk mitigation activities. The differences between the results of this study and Sjoberg's can arise from: 1) how the concept of interest works, in other words, interests in a topic does not equal higher cognitive engagement and curiosity, manifested as asking more questions, and 2) the measurements used, (i.e., Sjoberg measures individual's reporting their intention to mitigate risks). The current study demands real action on the spot (donating money) as a mitigation strategy. An important takeaway from the relationship between curiosity and risk perception and risk mitigation might be to emphasize on the practical effects of manipulations. Risk mitigation demands personal sacrifices such as money, time, and other resources, and this extra step might dramatically reduce the impact of a manipulation.

Results also confirm the fifth hypothesis, that the participants' trust in the scientist's reliability is positively correlated with perceiving the risk of climate change. This result builds upon previous studies that have been frequently examining how trust in a scientist can reduce the public's perception of risk of a threat (Flynn et al., 1992; Siegert 2000, 2006). For example, if one trusts a company, they are more likely to perceive their products to be safe. This study shows that trust in a scientist's reliability is connected to accepting the scientist's views pro and against an issue, in this case, threats of climate change.

These results can also explain/complement Sjoberg's (2001) findings. Sjoberg shows a low correlation between trust and risk perception, attributing this to the way the public perceives scientist's limits, (i.e., scientist's might have good intentions but might not have all the knowledge needed to be trusted and be competent). To understand this relationship better, I have used a measure that examines trust in a more practical sense representing the competence of the scientist to make decisions for the public. The findings shed light on this relationship by showing that if trust is defined as trust in scientist's reliability, then higher trust leads to higher risk perception, but the same is not necessarily true when trust represents believing a scientist has good intentions but not necessarily the competence to execute the right decision. This distinction can help future research to define trust as good intentions or as reliability, knowing that each might result in different outcomes.

Counter to trust, warmth did not significantly correlate to perception of the risk of climate change, as suggested in hypothesis six but competence was significantly correlated to risk perception. The significant effect of trust can be possibly connected scientist's competence rather than warmth. In other words, the participants might care more about the scientist's ability to make the right decisions rather than their positive intention (warmth). It seems like competence might play a more important role, with higher weight in determining trust in the scientist and perception of risk of climate change.

One of the most impactful variables in this model is the participants' political partisanship as a covariate. This variable significantly affects an individual's risk perception and risk mitigation, perception of scientist's warmth, competence, and trust in scientist's reliability. Individuals with conservative views show lower perception of risk of climate change, and risk mitigation behavior, lower perception of scientists' warmth, trust, and competence. These results are expected as also shown in different studies on the impact of political partisanship including Pew's latest report (2019). However, the second covariance, education, seems to have no significant effect on perception of risk. This outcome is also in line with Allum and colleagues' (2008) literature review showing that the relationship between general knowledge and attitude towards specific topics in science such a GMOs is not significant.

The findings from this study contribute to various fields, including science communication, learning sciences, risk perception, and persuasion. However, the main contribution of this research originates from the behavioral and practical measurements of the variables. As mentioned above, by evaluating risk mitigation and curiosity through behavioral measures, I provide additional evidence for how these variables act differently as self-reports versus behaviors. Similarly, I measure trust as a more practical variable that signals reliability rather than good intentions and provides results that are contrary to some previous work.

These results can contribute to how we value training scientists to manage their perception by the public and develop strategies to engage the public in dialogue. The outcomes also show the strength of pre-existing political views and how they are a powerful determinant of an individual's perceptions and actions. The power of this variable also suggests that many researchers and practitioners' communication strategies, including storytelling and self-disclosure might be limited by the audience's values, beliefs, and attitudes. This does not mean that communicators should not use these strategies, but that their effects might not be as expected and there is a possibility that some of the strategies might backfire. Additionally, the positive relationship between curiosity and risk perception can be encouraging to communicators.

Although this study and previous studies have not examined a causal relationship, there is a possibility for the effectiveness of this strategy in science communication practice, especially as it relates to controversial science topics.

Limitations and Future Directions. I have designed this study to examine different causal relationships between variables, however, due to the ineffectiveness of the manipulation, the outcomes show correlations rather than causations. Future researchers can design experiments with different manipulations to elicit specific effects, examining causal relationships between scientist's traits, public curiosity and risk perception and mitigation. In addition, the scientist in this study is a female climate scientist, not only a gender that faces more prejudice, but also an expertise that draws more controversy. While this agent can show certain aspects of science communication, it leaves out the comparison between different genders as the source and the effect of communicating less controversial science topics.

Future researchers should attempt to develop self-disclosure manipulations with stronger narratives that could elicit curiosity. The self-disclosure manipulation can also be stronger if placed in a more cohesive and transporting narrative (Green & Brock, 2000) where the reader feels the teller's emotions, is immersed in the story and is less aware of their surroundings. Narrative transportation is an effective tool to change attitude and can be explored further by researchers in the context of curiosity and risk perception. Also, manipulating different source attributes can provide valuable information about how different source attributes such as demographics, gender, and profession affect the message outcomes. The findings from this study are based on print messages in the form of interviews. Future research can also experiment with different message formats, including audio and video material.

Conclusion

The results of this study show that the manipulation to elicit warmth and curiosity by sharing different levels of disclosing personal anecdotes in the manner executed in this study does not make a significant impact. However, scientists' perceived warmth has a positive relationship with the number of questions participants asked about the topic, and this number is positively correlated with perceiving the risks of climate change. In addition, although warmth perception does not significantly affect risk perception, perception of scientist's competence and trust in their reliability have a positive relationship with risk perception. The results also show that affecting risk mitigation, as an act of donating money to climate change combating nonprofits might take more work compared to increasing risk perception.

I am hoping that the results of this study contribute to advocating for more dialogue and discussion about climate change and other controversial science topics to increase the public's perception of risk of climate change in addition to their mitigative behavior. Additionally, as a community of science communication researchers and communicators, we should explore ways to elicit curiosity about climate change and strategies to facilitate dialogue about this topic. This attempt can not only benefit the perception of science topics in society but is also a democratic way to build a participatory science environment.

Chapter 5: Discussion

This dissertation project examines different tools used by scientists to elicit and maintain an engaging conversation with their audience, particularly the use of curiosity and pop culture references as a mutual ground for conversations and looks at potential effects of eliciting curiosity and in particular the effects of curiosity on climate change risk perception and mitigation. This project is heavily influenced by my interactions with science communication practitioners. Hence, I have designed the research questions and hypotheses to correspond to the needs of practitioners and provide them with concrete advice on how to elicit engaging conversations and to let them know what effects they can expect using these strategies.

The findings from this study describe a framework in which scientists and the public use pop culture references. The observations and interviews describe these references as a scaffold (Lajoie, 2005) to build new information on in addition to connecting with the audience and lower communication barriers. This scaffold is a familiar concept, a mutual ground between the scientist and the public, one that the audience can visualize or conceptualize. In this sense, pop culture references work the same way metaphors and examples function (Gentner & Markman, 1997). These references can not only work as examples of scientific concepts but also provide examples of when the depiction of scientific concepts is not accurate. These examples can contain elements of surprise, be important to the audience, and be salient in the environment of the audience. These characteristics are described by Golman and Lowenstein (2015) as featured that add to the weight of curiosity about information.

Findings also take a more in-depth look at curiosity and features of audience questions for scientists, describing different activities that scientists can engage in to elicit curiosity, such as asking questions from the audience. This finding is particularly important since it complements the previous work on curiosity. While multiple studies have focused on the characteristics of messages and designs that elicit curiosity, this study emphasizes the human medium of information and their role to elicit curiosity and encourage inquiry. The findings also reflect the findings from psychology studies describing features that can elicit curiosity. For example, the observations from this study provide examples of questions that reflect curiosity about important information, aesthetically pleasing visualizations, and topics relevant to daily life. However, this study goes beyond the general categories of curiosity-inducing features. It provides more information that can relate specifically to the field of science communication, for example, the audience's curiosity about the scientists themselves, or the importance of vague visualizations paired with an expert to elicit an engaging conversation.

The findings from the experiment design confirm findings from Kahan et al. (2017) study showing a relationship between individuals' curiosity and their perception of risk. But this study also points to the importance of one's political views to determine our beliefs, attitude, and behavior. Most variables, including the perception of the scientist's warmth, competence, and trustworthiness, and climate change risk perception and mitigation, are heavily influenced by political partisanship. However, higher perception of scientist's credibility and trustworthiness elicits higher climate change risk perception for any political partisanship. Besides, as also shown in the learnings science literature, and to add on the possible factors that elicit curiosity, the results show a relationship between perceiving the scientist as warm and asking more questions. The collection of these findings not only allows for facilitated use of curiosity to elicit engaging conversations but also provides evidence for the positive relationship between curiosity and risk perception.

Practitioners can use this information in different ways. First, these studies advocate for the use of mutual grounds that both the audience and the scientist are familiar with, such as movies, and tv shows. They can start conversations with such references and build upon the connection made through the reference to elaborate on complex and unfamiliar pieces of information.

Second, to elicit a conversation by eliciting curiosity, the scientist doesn't have to only rely on the content of information but can play an active role by inviting their audience, asking questions, and allowing time for the participation of the audience. In addition, they can design spaces and messages to elicit curiosity by relying on curiosity-inducing principles such as adding to the weight of information, exposing the audience's knowledge gap or developing visualizations that are flashy and vague.

Third, the audience's perception of the scientist matters. Although the results show only correlations and not necessarily causal relationships, there is a possibility that a scientist perceived as warmer can make the audience feel more comfortable to ask questions. Thus, the scientist can work on strategies to be warmer and friendlier with the audience. In addition, the scientist's trustworthiness and credibility can play an important role as it relates to risk perception. This finding highlights that scientists need to dedicate more resources establish their competence.

Finally, changing attitude and behavior is not easy. Scientists should be aware of their goals and possibly invest more in steps such as gaining trust and fostering conversations rather than immediately inducing risk mitigating behavior, especially considering the strong effect of one's political views. These studies collectively advocate for an audience with an interest in conversations, and show the important role of curiosity in science communication.

Chapter 6: Conclusion

With the growing importance of civic engagement in science, in this study I examine the processes that lead to a dialogue between scientists and their audience through the lens of curiosity. I also evaluate the outcomes of these strategies as they relate to climate change risk perception and mitigation. To do that, I have conducted three separate studies using qualitative and quantitative methods for a comprehensive understanding of these phenomena.

The first study's observations lead me to develop a framework that summarizes how scientists and their audience develop conversations centering pop culture references. This framework shows that scientists seem to use pop culture references as a mutual ground to have a science conversation, talking about similarities and discrepancies between science fiction examples and real science. These pop culture references can function similar to metaphors and examples used in education as a scaffold for knowledge development; however, they are more faceted than a non-pop-culture example. The references are usually embedded in stories, so the scientist can use different parts of a reference such as a characters, an object, or a concept, depending on the scientific fact, to make a statement. The audience and scientists use pop culture references in various ways to connect and build a two-way conversation with one another.

The second study describes different strategies and prompts scientists use to encourage inquiry form their audience in a planetarium. Strategies include asking direct questions, being silent, and inviting participation. I also describe the content of the audience's questions and their frequency, showing that while the majority of questions are related to the topic introduced by the scientist, vague visualizations in the environment can elicit questions without the scientist bringing them up. In addition, the audience is curious about the scientists themselves and are open to sharing information about their personal experiences. The analysis of the audience's questions reflects what previous studies on curiosity suggest to be eliciting curiosity. Based on a literature review, I have categorized these factors into those that show the knowledge gap, information with high weight, and environmental factors. The content of questions reflect that questions come from a knowledge gap, can be elicited because of the weight of the information, e.g., important piece of news or relevant information, and are affected by the environment as shown through questions about visualizations in the room. However, the content also shows that scientists play an important role in encouraging questions and facilitating participation. Besides, the depth of the audience's questions and follow-up questions shows their willingness to engage and learn more about science in an in-depth manner.

The final study shows the positive relationship between curiosity and climate change risk perception, even considering one’s political partisanship. Findings also show the critical relationship between perception of scientist’s warmth and being able to ask more questions from the scientists, in addition to perception of scientist’s credibility and trust in scientist’s reliability on climate change risk perception.

This dissertation contributes to several fields that overlap in various ways. These fields include the learning sciences, psychology, museum studies, and science communication. In this project, I have limited the study of engagement to dialogue through curiosity. This constraint allows researchers to understand and recreate a specific and particular aspect of engagement rather than engagement in a vague, general sense. Although the scientific community advocates for the importance of engagement (e.g., NAS, 2017), the research related to engagement do little work to show the effect of engagement on attitude and behavior change or the ways scientists and the public interact.

This project describes how dialogues form and how curiosity shape conversations, in addition to their potential effect on climate change risk perception. In all stages of this project, I have measured different variables, including risk mitigation and curiosity as behaviors rather than self-reports of interest in risk mitigation activities or in more information. This approach allows me to interpret findings as concrete outcomes rather than intentions, especially since both these variables are frequently measured as intentions (e.g., Sjoberg, 2007).

I also believe that science communication is a processed-based endeavor, as in, while communicators set goals based on final outcomes such as attitude change and behavior change, they should also identify goals that lead to engaging and empathetic processes in science communication such as building rapport and continuous conversations. I have dedicated more resources and time in this project describing underlying processes leading to an engaging dialogue based on curiosity, rather than an emphasis on final outcomes.

While conducting this project, I have kept evidence-based practice in mind and have investigated the answer to questions that can be directly used by practitioners. Science communication practitioners, in particular, those who engage in more face-to-face interaction, can use these findings to design environments and sessions around curiosity and dialogue. The multiple examples I provide in the first two studies can facilitate the use of dialogue-centric communication strategies.

The results also focus on specific outcomes, including the relationship between different scientists' perceived traits and risk perception and inquiry, in addition to the relationship between the number of questions asked and risk perception. This can justify dedicating resources to eliciting curiosity and building a trusting relationship by showing warmth and credibility. However, practitioners would have to keep in mind that political partisanship has a powerful role in one's attitude and behavior and to now expect the same outcomes for different audiences.

After gaining a better understanding of the nature of conversations elicited possibly by curiosity and examining the effects of curiosity, there are different questions to be investigated in future work. Primarily, future research should examine how to elicit curiosity externally and if such externally induced curiosity can have the same effects on risk perception as internal curiosity or one's inherent need for more information. As shown in the final study, a simple manipulation such as self-disclosure did not have any effect on any of the outcome variables, specifically on curiosity. One possibility for the lack of such an effect is the inability of the manipulation to transport the reader. Green and Brock (2000) describe transportation as one's absorption into a story "a distinct mental process, an integrative melding of attention, imagery, and feelings" (p. 701). Green and Brock suggest that the effectiveness of narratives and stories relies on their transportation ability. I recommend for the future researchers to work on narratives with the power to transport the audience for a possibly stronger effect. Additionally, considering the differences between how female and male subjects in different professional positions can be perceived by individuals (Fiske et al., 1999), researchers can examine the differences not only between the perception of female and male scientists but also how the perceptions affect risk perception and risk mitigation. For example, it might be possible that while in the current study competence plays a significant role in risk perception, for a male scientist, warmth is the more determining factor. Due to limited resources in this study, findings have been limited to the demographics of the expert (a female scientist with a western name). To be able to apply the findings to a diverse community of scientists, studies should consider examining how scientists of color are perceived as well.

I suggest that future research examines the development and role of curiosity in different platforms, including on digital and mass media. Since these platforms can engage a larger number of audiences and are more accessible to different individuals as opposed to face-to-face interactions, researchers need to gain a better understanding of how these platforms can be used by communicators to elicit and engaging dialogue via curiosity. These studies should also look at the differences between various voices as the communicator and in particular examine how different identities might communicate differently and be perceived differently by their audience.

This dissertation emphasizes on turning the idea of engaging science communication in concrete terms, by examining a smaller section of engagement, conversations elicited by curiosity. The progression from qualitative methods to a quantitative experiment allows for a comprehensive understanding of this phenomenon, from shaping to its effects. By evaluating the impact of curiosity through not just the measure of engagement but actual behavioral measures, these findings can show the implications of eliciting curiosity while highlighting the limitations of curiosity in eliciting mitigating behavior.

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Appendix A

Warmth – Scenario 3

An interview with Dr. Mary Smith

How did you get involved in climate science?

My name is Mary and I am 31 years old and was born in Alaska, where I have lived my whole life. From an early age, my parents taught me about nature's value. When we would go camping, my mom always reminded me that the trees around us are Earth's lungs. That they provide us with clean air and we should make sure to take care of them. So, it was easy for me to grow up aware of the environment and how we impact it.

From an early age, I became involved in outdoor activities, from camping to climbing and hiking. This all increased my love for all kinds of natural life. I pursued a bachelor in ecology and the study of different natural environments. Now, after doing a doctorate in climate sciences, I am working as a climate scientist.

When did you first become concerned about climate change?

I have been practicing mountaineering since I was very young. I went into this because I needed to be closer to the mountains I always watched from my house. At first, it was very difficult because of the physical demands. But, it was worth it because I love watching a sunset from the top of a mountain, very far away from the city's noise, with my dog, Mr. Snuggles.

Whenever I could, I observed two mountains from the rooftop of my parents' house. I have very vivid images of both of them fully covered with snow about three or four months a year, beginning from early autumn to early spring.

But now I am worried that climate change will affect the time during which the mountains are covered by snow. This time will get shorter and shorter and can be reduced to almost only one month per year. The changes in the climate will also affect the glaciers in the mountains and make them disappear and reduce the ice and snow in the mountains.

What are the consequences of climate change?

One of the noticeable impacts from the loss of snow is that the surrounding rivers can get almost dry, affecting individuals living around these rivers. As an alternative, groundwater reserves would be drained with no natural process refilling them, at least not fast enough. As a result, large areas in the city can literally sink. In addition, the lack of water can lead to major deforestation.

I am sure the water cycle is being deeply altered because of the changes I have described. Between increasing temperatures and deforestation, one can expect something will have to give eventually.

Control

An interview with Dr. Mary Smith

How did you get involved in climate science?

I am 31 years old and was born in Alaska, where I have lived my whole life. Knowing about nature's value, from how trees provide us with clear air, to how the oceans keep the temperature low, I have always been aware of the environment and how we impact it.

Due to my interest in understanding how humans impact the environment, I pursued a bachelor in ecology and the study of different natural environments. A degree in ecology requires spending a significant amount of time in nature, hiking, climbing mountains, and camping. Wanting to learn more about this field, I did a doctorate in climate sciences and I am currently working as a climate scientist.

When did you first become concerned about climate change?

At the beginning of my studies I have been reading a lot about the changes in the environment, what causes them and what is considered "normal". I think something that really concerned me was a National Climate Assessment report, describing the possible changes due to climate change and how they affect us. This report mentioned that one place to see the environmental effects of climate change could be in mountains and surrounding areas. The mountains could be fully covered with snow about three or four months a year, beginning from early autumn to early spring.

These changes could affect the time during which the mountains are covered by snow. This time will get shorter and shorter and can be reduced to almost only one month per year. The changes in the climate will also affect the glaciers in the mountains and make them disappear and reduce the ice and snow in the mountains.

What are the consequences of climate change?

One of the noticeable impacts from the loss of snow is that the surrounding rivers can get almost dry, affecting individuals living around these rivers. As an alternative, groundwater reserves would be drained with no natural process refilling them, at least not fast enough. As a result, large areas in the city can literally sink. In addition, the lack of water can lead to major deforestation.

I am sure the water cycle is being deeply altered because of the changes I have described. Between increasing temperatures and deforestation, one can expect something will have to give eventually.

Appendix B

Measure of warmth and competence (Judd et al., 2005):

[Extremely, very, moderately, slightly, not at all]

Competence:

How motivated do you think this scientist is?

How intelligent do you think this scientist is?

How energetic do you think this scientist is?

How organized do you think this scientist is?

Warmth:

How sociable do you think this scientist is?

How warm do you think this scientist is?

How friendly do you think this scientist is?

How caring do you think this scientist is?

Appendix C

Industrial Strength Risk Perception Measure (ISRPM), Kahan (2011):

How much risk do you believe each of the following poses to human health, safety, or prosperity? [0 “no risk at all”; 1 “Very low risk”; 2 “Low risk”; 3 “Between low and moderate risk”; 4 “Moderate risk”; 5 “Between moderate and high risk”; 6 “High risk”; 7 “Very high risk”]

1. Decreased snowfall and reduction in river volumes
2. Deforestation
3. Sinking of the ground
4. Climate change

Appendix D

Measure of Trustworthiness, Colquitt (2001):

1. How comfortable would you be giving scientists a task or problem that is critical to you, even if you could not monitor his/her actions?

    - Very uncomfortable
    - Somewhat uncomfortable
    - Neither comfortable nor uncomfortable
    - Somewhat comfortable
    - Very comfortable

2. How likely would you be to give this scientist the benefit of the doubt if their motives were questioned?

    - Very unlikely
    - Somewhat unlikely
    - Neither likely nor unlikely
    - Somewhat likely
    - Very likely

3. How much control would you be willing to let this scientist have over your future?

- No control at all
- Low control
- Moderate control
- High control
- Complete control

4. How necessary is it to keep an eye on this scientist?
    - Very unnecessary
    - Somewhat unnecessary
    - Neither necessary nor unnecessary
    - Somewhat necessary
    - Very necessary

5. How much influence are you willing to let this scientist have over issues that are important to you?
    - No influence at all
    - Very little influence
    - Moderate influence
    - Very high influence

- Complete influence