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Informing public perceptions about climate change: A 'mental models' approach

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Abstract

As the specter of climate change looms on the horizon, people will face complex decisions about whether to support climate change policies and how to cope with climate change impacts on their lives. Without some grasp of the relevant science, they may find it hard to make informed decisions. Climate experts therefore face the ethical need to effectively communicate to non-expert audiences. Unfortunately, climate experts may inadvertently violate the maxims of effective communication, which require sharing communications that are truthful, brief, relevant, clear, and tested for effectiveness. Here, we discuss the 'mental models' approach towards developing communications, which aims to help experts to meet the maxims of effective communications, and to better inform the judgments and decisions of non-expert audiences.

Keywords

Climate change communication; mental models approach; decision making

1. Introduction

Climate change requires people to make complex decisions about whether or not to support climate change policies and how to cope with climate impacts on their daily lives. To make informed decisions, it is ethically imperative that people receive the relevant science in a way that they can use and understand (Fischhoff 2013; Gazmaraian et al. 2005). Climate scientists therefore are increasingly recognizing the ethical need to share their findings with non-expert audiences, through, for example reports, brochures, and websites (Fischhoff 2007). However, climate scientists may find it difficult to communicate effectively with non-expert audiences (see e.g., Beyth-Marom 1982; Budescu et al. 2009; Nisbet and Scheufele 2009) – as do experts in other domains (Bruine de Bruin & Bostrom 2013).

Communications that just present scientific information can be obscure and confusing to non-expert recipients (Brewer 2011). Experts' conceptualization of risk is often based on morbidity and mortality statistics, while non-experts also tend to want to incorporate moral and emotional considerations (Slovic 2000). To effectively help individuals make an informed decision, they may need more than just the scientific information (Fischhoff 2013). Philosophers have emphasized that effective communications follow conversational norms, and take into account the goals and needs of intended recipients (Grice 1975; 1978). Those conversational norms have been applied to designing written communications (White 2001) and as well as survey questions (Schwarz 1996). Here, we adapt these conversational norms to communications between domain experts and their non-expert audiences.

Table 1 summarizes the maxims that should be met by communications, including (1) the maxim of quality, which requires that the content presented is an accurate reflection of the scientific evidence; (2) the maxim of quantity, which requires that communications are concise;

(3) the maxim of relation, which requires that the presented topics are relevant to the recipients; (4) the maxim of manner, requires that information is presented in a way that can be understood by recipients, by avoiding obscure references and ambiguous terms. Violating these maxims leads recipients to form inferences that may not necessarily be in line with the communicator's intentions (Grice 1975, 1978).

Thus, communications from climate experts should be accurate, concise, relevant, and clear. Here, we add a fifth maxim of proven effectiveness which posits that communications should be tested for their effectiveness, before being widely disseminated to large audiences. Below, we present examples to suggest that climate scientists have sometimes struggled to meet each of the five maxims of effective communication.

1.1. Struggles to meet the maxim of quality

Climate experts' scientific understanding of climate change has accumulated over 150 years through observational data, model-based forecasting, and other methods (National Research Council 2010). The evidence on climate change has been carefully summarized in peer-reviewed reports of Intergovernmental Panel on Climate Change (IPCC) (2014a). Over the years, these IPCC reports have been expressing increasing scientific certainty that climate change is real and is largely caused by human actions (IPCC 1990; IPCC 1995; IPCC 2001; IPCC 2014). However, some of the consequences of climate change may be less certain, such as when and where the most severe heat waves or flooding will occur (IPCC 2014b). Uncertainty may stem from different sources, including the limited ability to apply historical data to predict future outcomes, and the complexity of the forecasting models.

Although the communication of scientific uncertainty is needed to avoid a false sense of confidence, some climate change deniers use it to question whether climate change is caused by

human activities, or whether climate change exists at all (Oreskes 2007). An additional challenge in communicating that uncertainty is that experts from different disciplines disagree about the methods for assessing uncertainty (Wesselink et al. 2014). Yet, omitting expressions of scientific uncertainty can make communications seem exaggerated and undermine public trust (Nisbet and Scheufele, 2009).

To communicate scientific uncertainty, IPCC reports present climate change projections with verbal descriptions of probability (e.g., 'likely' or 'virtually certain') (IPCC 2014b). Some experts like verbal probability terms because they allow imprecision (Beyth-Marom 1982). However, verbal probability terms have widely differing interpretations between individuals, introducing ambiguities that violate the maxim of manner (Beyth-Marom 1982; Budescu et al. 2009). Recipients may also interpret phrases like 'very likely' as less extreme than intended by the IPCC, which may lead them to underestimate the magnitude of the presented problems (Budescu et al. 2009). IPCC reports include a 'translation table' that shows how to interpret verbal probabilities (see e.g., IPCC 2014a). However, unless the suggested numerical translations are directly presented in the same text as the verbal probability terms, many readers tend to use their own – widely varying – numerical translations of the verbal probability terms (Budescu et al. 2009).

Another potentially backfiring strategy that experts have used is a 'myths vs. facts' strategy for debunking common myths (Morgan et al. 2002; National Education Association 2015; World Health Organization 2013). Brochures that use the 'myths vs. facts' format actually increase the likelihood that recipients will remember the myths, as compared to brochures that only focus on the facts (Schwarz et al. 2007). Drawing people's attention to the falsehood of previously presented information does little to change initial beliefs (Green and Donahue 2011), and may

actually strengthen them (Cook et al. 2015; Skurnik et al. 2005). Thus, effective climate change communication is not as straightforward as "just showing the facts" and requires an understanding of how recipients interpret and use the presented information.

1.2. Struggles to meet the maxim of quantity

Under the assumption that more information is better, experts often offer laundry lists of actions that people can take to mitigate climate change (Dietz et al. 2009). Critics have noted that these long lists fail to identify which actions are the most effective, realistic, and cost-effective (Gardner and Stern 2008; Krishnamurti et al. 2013). As a result, people may continue to focus on salient behaviors such as turning off the lights, which saves relatively little energy as compared to other actions (Attari et al. 2010). People may also fail to realize that energy efficiency actions will save more energy than energy conservation actions (Gardner and Stern 2008).

Another downside of giving people many options and extensive amounts of information is that it can lead to cognitive overload (Bawden and Robinson 2009) and decision avoidance (Scheibehenne et al. 2010). People are more likely to implement decisions when they have a smaller set of options (Iyengar and Lepper 2000). Therefore, it is best to provide people with a limited list of the most effective actions that they can take (Gardner and Stern 2008).

1.3. Struggles to meet the maxim of relation

What information is relevant to non-expert audiences depends on the specific decisions they are trying to make. Experts tend to communicate their climate forecasts in ways that may seem relevant to them, but that non-experts find difficult to use in their decision making (Taylor et al. 2015). Moreover, decisions about climate change mitigation likely require different information than decisions about climate change adaptation. The former focuses on

implementing actions that reduce CO_2 emissions, while the latter focuses on implementing actions to protect against the actual or expected impacts of climate change such as extreme weather events (IPCC 2014b). Communications about climate change adaptation may be more effective if they focus on preparedness for extreme weather, without mentioning the term 'climate change.' Especially conservative audiences may question the occurrence of climate change while they agree that local weather is becoming more extreme (Bruine de Bruin et al. 2014). Some conservative U.S. towns have opted to invest in their infrastructure without mentioning the term 'climate change' (Crain's Detroit Business 2014).

It is also important to recognize that people may have different goals, when making their decisions. Frugal consumers may be motivated by financial incentives, at least for as long as they are being provided (Fischer 2008). However, pro-environmental consumers may be turned off by financial incentives, because it undermines the "warm glow" of pro-environmental motivations (Schwartz et al. 2015; Taufik et al. 2014). Social rewards may therefore be more effective than financial rewards (Agrawal et al. 2014; Handgraaf et al. 2013).

1.4. Struggles to meet the maxim of manner

Even though a significant proportion of the general population tends to read at the elementary school level, experts tend to produce communications that are written at the university level (Daraz et al. 2011; Davis et al. 1996; Neuhauser and Paul 2011; Paashe-Orlow et al. 2003). Yet, there is a growing body of research suggesting that plain language, shorter words, and shorter sentences are easier for recipients to read (Flesch 1948; Kincaid et al. 1975; Oakland and Lane 2004).

Experts sometimes resist the use of plain language, because they don't want to appear to talk down to their audience members (Bruine de Bruin and Bostrom 2013). However,

simplifying text does not necessarily affect recipients' perceptions of the quality of the communication (Wong-Parodi et al. 2013). Even recipients with higher literacy levels may prefer communications that are easier to read (Davis et al. 2006; Smith et al. 2008).

Climate scientists may not be aware of their tendency to use difficult concepts or wording. After decades of specialized training, experts have acquired a specialist lexicon that facilitates communication with other experts in their field, but may hamper their communications with non-expert audiences (Ericsson et al. 1993; Wong-Parodi and Strauss 2014). For example, engineers may talk about a "100-year flood" rather than a flood that has a "1% chance of happening each year" without realizing that people interpret the former as occurring at more predictable regular intervals than the latter (Bell and Tobin 2007; Keller et al. 2006). Experts may use seemingly simple terms such as 'climate' without realizing that people confuse it with 'weather' (Bostrom et al. 1994; Read et al. 1994; Reynolds et al. 2010). Indeed, Americans may become more concerned about climate change when local temperatures get hotter (Weber and Stern 2011) and UK residents when it gets wetter (Spence et al. 2011; Taylor et al. 2014).

While it is important that text is written at an appropriate reading level for the intended audience, experts may fear a loss of scientific accuracy (Wong-Parodi and Strauss 2014). Thus, experts may perceive a tension between meeting the maxim of quality, which requires that communications are accurate, and the maxim of manner, which requires that communications can be understood. For many complex topics, however, it has been possible to present information in a way that is accurate, concise, relevant, and clear (Morgan et al. 2002).

1.5. Struggles to meet the maxim of proven effectiveness

Communications in many domains are often shared without being tested for effectiveness. Indeed, communicators may forego evaluating their communication materials, because they fail

to see the need, lack the expertise, or are unwilling to cover the costs (Downs et al. 2011). Without evaluation, there is no guarantee that a communication is effective, especially given the findings (summarized above) that experts often struggle to present information that is accurate, concise, relevant, and clear.

2. Mental models approach for developing communications

Because experts no longer think and talk like non-experts, they may not have good intuitions of what information their audiences need or want to inform their decisions (Ericsson et al. 1993; Wong-Parodi and Strauss 2014). Fortunately, there is a systematic social science available for developing communications, which specifically aims to meet the maxims of quantity, quality, relation, manner, and proven effectiveness. Research in psychology, education, health, and other fields (Chi 2000; Gentner and Stevens 1983; Meyer et al. 1985), suggests that people interpret new information in light of their existing beliefs, also referred to as their "mental models" (Johnson-Laird 1983; Gentner and Stevens 1983). In decision making, mental models include individuals' perceptions of a decision situation, alternative solutions, decision premises, and biases (Chermack 2003).

The four steps of the mental models approach (as described by Bruine de Bruin and Bostrom 2013; Morgan et al. 2002) are presented in Figure 1, and their mapping onto the maxims of effective communication is presented in Table 1. The first step involves normative research, which identifies what experts believe people should know to make more informed decisions, as well as to effectively implement those decisions. The second step consists of descriptive research, which characterizes what people already know and what they are missing, when they are making their decisions. Prescriptive research in the third step involves the

development of a communication that aims to address what people still need to know to make more informed decisions, on the basis of a systematic comparison between the findings from the normative and the descriptive steps. The fourth step involves evaluation research, which aims to test how well the communication improves recipients' understanding of the topic and helps them to make more informed decisions. In the next section, we discuss each step of this approach in further detail (following Bruine de Bruin and Bostrom 2013; Morgan et al. 2002).

2.1. Normative research

Normative research involves identifying what aspects of experts' knowledge people should understand in order to make informed decisions, as well as to effectively implement those decisions. Hence, involving normative research in communication design is a first step towards meeting the maxims of quality and relation (Table 1). Typically, normative research includes a review of the scientific literature followed by a consultation with experts. Elicitation of experts' scientific and technical judgments, informed by all formal and informal evidence available to them, is especially valuable when advice is needed on issues for which scientific evidence is missing, inconsistent, or incomplete (Environmental Protection Agency 2012; Knol 2010; Morgan 2014). For example, experts have been asked to assess the likely nature, extent, and impacts of climate change (Morgan and Keith 1995; Morgan, Pitelka, and Shevliakova 2001; Zickfield, Morgan, Frame, and Field 2010), the costs of mitigation options (Curtright, Morgan, and Keith 2008; Rao, Rubin, Keith, and Morgan 2006), and the definition of successful adaptation (De França Doria, Boyd, Tompkins, and Adger 2009). The most well-known expert panels on climate change have been convened through the above-mentioned Intergovernmental Panel on Climate Change, which have covered the scientific basis, mitigation, and adaptation (1990; 1995; 2001; 2007; 2014a; 2014b).

The goal of expert consultation is to represent the wide range of existing beliefs from across the different relevant disciplines (Environmental Protection Agency 2012; Morgan 2014). Especially if the topic is contested and value-laden, it is ethically imperative that the panel includes experts who represent opposing points of view (Nihlén Fahlquist and Roeser 2014; Knol 2010). Formal procedures for selecting experts have been suggested to improve panel diversity, as well as transparency and fairness (Environmental Protection Agency 2012; Knol et al. 2010). Confidentiality should be provided so as to allow experts to share their views without concern for deviating from the norms of their scientific community or institutions (Knol 2010; Morgan 2014).

The focus of the normative research should depend on the goal of the communication. If the goal is to inform recipients' decisions about climate change mitigation, the review should focus on what can be done to reduce greenhouse gas emissions. If the goal is to inform recipients' decisions about adaptation to climate change impacts such as more extreme weather, the review should focus on what people can do to protect themselves against the specific types of extreme weather that would be expected in their area. Communications will be easier to develop, and easier for recipients to process, if they target a specific behavior. For example, a mitigation communication might cover how to reduce electricity use in one's household or how to support policies to change electricity generation, and an adaptation communication might cover how to prepare one's home against increasing flood risks.

For the topic under consideration, review efforts should identify the risks, and which actions are recommended to reduce those risks. It should be identified whether or not the recommendations apply to everyone (e.g., mandatory evacuation in flood zone), or should depend on individual's preferences (e.g., purchasing flood insurance). Only the former may

warrant persuasive messages or interventions that 'nudge' people towards the recommended action, perhaps combined with an information-based approach (Brewer 2011). The latter requires an information-based approach, so as to allow recipients to decide for themselves.

Additionally, social science is needed to find out how easy it would be for recipients to understand the risks, how realistic it would be for them to effectively implement the recommended actions, and how any barriers to implementation might be overcome. Thus, a focused review of the relevant technical and social science will identify possible communication content that is based on the up-to-date expert knowledge, and focused on people's decisions, thus meeting the maxims of quality and relation (Table 1).

2.2. Descriptive research

Descriptive research aims to identify how people think about the topic under consideration, their concerns about it, and how they make decisions about it (Bruine de Bruin and Bostrom 2013; Morgan et al. 2002). Involving descriptive research in the development of communications formalizes audience participation, aiming to identify potential content that is most relevant to their decisions and the wording they prefer to describe it. As such, undertaking descriptive research should make it more likely that a communication meets the maxims of quantity, relation, and manner (Table 1). Typically, the descriptive research involves semi-structured interviews and follow-up surveys. Like the normative research, the descriptive research will benefit from the involvement of technical scientists and social scientists. The former can make sure that the relevant questions are asked, and the latter can make sure that the questions are asked in a way that participants understand.

2.2.1. Semi-structured interviews

Semi-structured interviews aim to identify which beliefs exist in the target audience, and their preferred language for describing those beliefs. Semi-structured interviews therefore begin with general questions on the topic, which allow interviewees to raise those topics that they deem relevant. For example, Bostrom and colleagues (1994) conducted semi-structured interviews about climate change that started with "Tell me all about the issue of climate change" followed by open-ended questions that asked participants to provide definitions, explain exposure and effects processes, as well as judgments and decisions about climate change.

This interview procedure aims to encourage interviewees to express their full set of beliefs in their own wording, without being influenced by interviewers' preferred conceptualizations (Bruine de Bruin and Bostrom 2013). Interviewers are trained to implement the 'active listening' interview technique developed for patient-centered counseling (Kvale and Brinkman 2009; Spradley 1979). This interview technique treats interviewees as collaborators, and uses extensive follow-up questions so as to encourage interviewees to explain their views. Interviewers are taught to maintain a non-judgmental tone, even if interviewees make seemingly incorrect, ill-advised or morally questionable statements. Instead, they stress their goal of learning from the interviewee how they view the topic under consideration. As with expert consultation, confidentiality should be provided so that participants feel less hesitant to share potentially controversial points of view (Knoll 2010).

A main limitation of interviews, however, is that they are labor-intensive and therefore costly. In addition to spending 30-90 minutes with each interviewee, researchers need to have the interviews transcribed and carefully coded for the topics that are raised. Rather than recruiting a large representative sample, it is therefore recommended to recruit a small but

diverse sample of participants (Bruine de Bruin and Bostrom 2013; Morgan et al. 2002). To be cost-effective, it is recommended to stop recruiting new interviewees when the 'saturation' point is reached (Glaser and Strauss 1967). Saturation refers to the finding that the number of new ideas shared by each additional interviewee levels off after a certain number interviews. Typically, sample sizes of 10-15 interviews are justified because no more new ideas are generated by continuing to recruit (Guest et al. 2006; Morgan et al. 2002).

2.2.2 Follow-up public perception surveys

Because interviews tend to be conducted with relatively small samples, they are better suited for identifying which beliefs are held, than for identifying how common they are (Bruine de Bruin and Bostrom 2013). Follow-up surveys can provide a cost-effective strategy for obtaining data from larger samples, thus providing the statistical power needed to identify the prevalence of identified beliefs, relationships between beliefs and behaviors, and how these findings vary between sub-groups in the population. For example, after interviews about climate change revealed that participants thought all pro-environmental behaviors (e.g., including reducing air pollution, recycling) would benefit climate change (Bostrom et al. 1994), follow-up surveys confirmed significant correlations between endorsing climate change mitigation actions and endorsing unrelated pro-environmental behaviors as strategies for mitigating climate change (Read et al. 1994).

Although surveys can easily be conducted with large sample sizes, semi-structured interviews are needed to inform their design (Bruine de Bruin and Bostrom 2013). Indeed, surveys should include questions about the topics that experts deemed relevant (as identified in the normative research) and that non-experts deemed relevant (as identified in the interviews), in wording that the interviewees used in the interviews. For example, the follow-up surveys by

Read et al. (1994) would likely not have included questions about pro-environmental behaviors unrelated to climate change, if initial interviews had not alerted the researchers to non-experts' confusion between climate change mitigation actions and generally good environmental practices (Bostrom et al. 1994).

Thus, the combined findings from the semi-structured interviews and the follow-up surveys will identify topics that are most in need of being addressed to improve people's decisions, and the wording that would be most likely to be understood (Bruine de Bruin and Bostrom 2013; Morgan et al. 2002). These findings thus provide communicators with insights regarding the information that is most relevant, and how to present it in an understandable manner. As a result, descriptive research is needed to develop communications that meet the maxims of quantity, relation, and manner (Table 1).

2.3 Prescriptive research

The third step of the mental models approach is prescriptive research, which involves the development of the communication. It should build on the normative and the descriptive research findings, so as to meet the maxims of quality, quantity, relation and manner. That is, the normative research will have identified the scientific evidence experts deem relevant to people's decisions. Rather than covering all of the scientific evidence, it should focus on those facts that can address the most common misunderstandings that drive people's behavior, as identified in the descriptive research (Bruine de Bruin and Bostrom 2013; Bostrom et al. 1992; Morgan et al. 2002). The communication should also provide strategies for overcoming common barriers to implementing decisions, as revealed in the descriptive research (Bruine de Bruin and Bostrom 2013). As noted, only if the normative research indicated that specific actions will be beneficial to the entire population is it may be ethically defensible to combine this

information-based approach with persuasive messages or 'nudge' behavior-change interventions (Brewer 2011).

The content of the communications should be written at a level that is suitable for the intended audience, so as to meet the maxim of manner. Language for the communications can be adapted from the interviews conducted for the descriptive research. We recommend that communications be written at 5th-6th grade reading levels, because that can increase recipients' understanding without harming their perceptions of the communications' quality (Wong-Parodi et al. 2013). The Flesch-Kincaid readability statistic can be used to assess the reading level needed to understand the presented text, and has been applied to evaluate the readability of surveys (Velez and Ashworth 2007), insurance policies (Dubay 2004), medical consent forms (Tait et al. 2005), and patient education (Daraz et al. 2011; Finnie et al. 2010). This statistic has been reliably correlated with other established measures of readability, such as average word familiarity and passage length (Golinkoff 1975-1976; Kesselman et al. 2007; Ley and Florio 1996; Spyridakis and Standal 1987; Surber 1992; Tuinman 1973). Word processing programs such as Microsoft Word can be set to assess the Flesch-Kincaid readability as part of their grammar and spelling check.

After drafting communication materials, it is generally recommended to conduct user-testing, in which members of the intended audience are asked to read materials aloud while providing their evaluations and suggestions for improvement (Jääskeläinen 2010; Morgan et al. 2002). Both during the think-aloud session and afterwards, users may be asked to comment on the complexity of the wording and the usefulness of any recommendations, as well as on graphic design features such as text lay out and images, as well as formats for presenting risk and uncertainty (Bruine de Bruin and Bostrom 2013; Wong-Parodi and Strauss 2014, Schapira et al.

2001). Such user testing may also identify unintended issues that may undermine the effectiveness of the communication. For example, it has been suggested that warnings to prepare for heat waves may be more effective if they target the whole population rather than just 'vulnerable older adults,' because even people over the age of 70 may object to being referred to as 'old' and may not perceive themselves as vulnerable (Abrahamson et al. 2009). Thus, involving intended audience members through user testing may help to design communications that they perceive as acceptable and trustworthy, and useful for applying to their decisions.

Subsequently, any user-recommended revisions will need to be approved by technical experts to make sure that the simplified content still reflects the relevant science accurately (Wong-Parodi and Strauss 2014). Several iterations between user-testing and expert input may be needed to reach a point at which users judge the content to be clear and acceptable, while the technical experts deem it accurate. This iterative process is designed to meet the ethical need to design communications that align with audience members' concerns and values, while remaining trustworthy and truthful to the science (Persson et al. 2015). Versions of the same communications can also be evaluated experimentally to identify which ones respondents find most understandable, acceptable, and useful (e.g., Wong-Parodi et al. 2013; Canfield et al. 2015; Taylor et al. 2015). Thus, the development of communications requires a participatory process with intended audience members. It also requires an interdisciplinary team of technical experts, who provide the scientific information, and social science experts, who aim to design materials so that they meet audience members' wants and needs. In doing so, the prescriptive research aims to meet the maxims of quality, quantity, relation, and manner (Table 1). Yet, systematic evaluation of the communication is still needed to test whether it is actually effective in improving recipients' understanding and informing their decisions.

2.4. Evaluation research

The fourth step of the mental models approach is evaluation research, which involves systematically testing whether a communication is effective, in terms of achieving specific outcomes (Figure 1). Hence, evaluation research seeks to meet the maxim of proven effectiveness (Table 1). Measured outcomes may include understanding of the topic, attitudes towards policies, intentions to implement specific actions, perceived efficacy to implement specific actions, and actual observations of implemented actions (Davidson 2005). They may also include measurement of trust and emotional responses, especially if those issues have arisen in the prescriptive research as relevant to recipients' responses. Trust and emotions affect judgments of risk, perceptions of the communication, and willingness to implement recommended behaviors (Bruine de Bruin et al. in press; Bruine de Bruin and Wong-Parodi 2014; Cvetovich et al., 2002; Slovic 2000).

To draw causal conclusions about the effect of a communication on these outcome measures, it is typically recommended to conduct a randomized controlled trial (Kaptchuk 2001). A randomized controlled trial is an evaluation study in which participants are randomly assigned to a group that received the designed communication or to a control group (Kaptchuk 2001). In large samples of participants, the randomization should ensure that, at the baseline, the communication group and the control group are similar in demographic background, initial understanding, interest in communications, willingness to change behavior, and other potentially relevant characteristics. If, after receiving the communication, recipients perform better than controls on various outcome measures of interest, it can be concluded that the communication was the cause of this change.

One question that often arises about this type of evaluation study design is what information should be provided to the control group. In part, the answer to that question depends on the types of statements designers hope to make about their communication. If they want to claim that their communication is better than the best available alternative, then the control group should receive the best available alternative. However, if the best available alternative is hardly ever used, it might be better to compare the communication group against a control group that receives the most common alternative. If most people actually tend to receive no communications at all, then it might be defensible to give the control group no communication. Because participants in no-communication control groups tend to be less motivated to remain enrolled in a study due to lacking interactions with the researchers, it might be better to give them materials on a completely unrelated topic (Siddiqui et al. 1996).

Another question that often arises is whether a control group is necessary at all. Including a control group means paying for participants who are not even receiving the communication. However, without a control group, it is difficult to assess whether the communication caused any changes in any of the measured outcomes (Downs 2011). If recipients of a communication improve on understanding or another outcome measure, it may be the case that those improvements reflect learning from other sources during the time of the study, such as exposure to media messages. If so, it remains unclear whether improvements may also have been observed among people who had received no communication, as would be the case in a no-communication control group. A comparison of the communication group to a no-communication control group therefore allows for conclusions about whether the communication leads to more improved outcomes as compared to a control group (even if the control group also improves.)

To avoid having to run a control group, some communicators choose to compare participants of their communication evaluation study with people who did not participate at all (Downs 2011). Here, the problem is volunteer bias, such that those who signed up from the study are more motivated to engage with the presented communications than those who did not sign up (Davis and Krishnamurti 2013) thus leading to serious overestimations of the effectiveness of a communication.

Thus, evaluation research is needed to meet the maxim of proven effectiveness (Table 1). Once it has been shown that a communication is effective, it can be disseminated. The evaluation of the communication's effectiveness need not stop there. Audience responses may need to be tracked over time, because communications may need to be updated as beliefs or 'mental models' change. Moreover, even the success of the dissemination can be evaluated (O'Connor et al. 2015; Downs 2011). Such process evaluation assesses how well a communication reaches its intended audience. Process evaluations may include counts of how many brochures are downloaded from a website, or consumer surveys that ask people whether they have seen the communication (Downs 2011). Such data can help communicators to understand which audiences are reached, and generate ideas for targeting audiences that seem to be under-served.

3. Conclusion

Climate scientists face the ethical need to provide understandable and useful information to non-experts about their climate change predictions, and what people can do in terms of mitigation and adaptation. However, climate experts may struggle to meet the maxims of effective communications, which require that they are accurate, concise, relevant, clear, and

tested for effectiveness (Table 1). The mental models approach offers a systematic way to develop communications (Morgan et al. 2002). As noted, this approach involves four steps: 1) normative research, which aims to identify the relevant information from experts to inform non-experts' decisions; 2) descriptive research, which aims to characterize how individuals make their current decisions; 3) prescriptive research, which aims to design communications to help individuals to make more informed decisions; and 4) evaluation research, which aims to test how well communications work, in terms of informing recipients' decisions. The process requires collaboration between relevant technical experts (such as climatologists, atmospheric scientists, and marine scientists), social scientists, and members of the intended audience (Bruine de Bruin and Bostrom 2013; Morgan et al. 2002). This evidence-based approach to developing communications meets the maxims of effective communications (Table 1).

The mental models approach to risk communications also incorporates the three recommendations made by Nihlén Fahlquist and Roeser (2014) for developing ethically responsible communications. Their first recommendation is that the procedure for developing risk communication be participatory, including different stakeholders as well as members of the general population. As noted above and in in Figure 1, the normative research seeks input from a diverse expert panel and the descriptive research seeks input form members of the intended audience. Both procedures are designed to uncover a wide range of beliefs, including those that oppose mainstream scientific views. Their second recommendation involves ethical deliberation about the content of the risk communication. The prescriptive research phase of the mental models approach includes continued input from non-experts so that the communication content addresses what they deem useful to their decisions, in a manner that they deem acceptable and understandable. Finally, the third recommendation is to systematically examine the unintended

effects of communications on recipients' values, emotions, or trust in communicators (Nihlén Fahlquist and Roeser 2014). The evaluation research step of the mental models approach is designed to test effects of communications on recipients' experienced outcomes, including understanding and decisions, as well as those that have emerged as relevant in the earlier steps of the mental models approach. Hence, the mental models approach provides a systematic methodology for designing communications that aim to give people information they want and need to make more informed decisions, while helping to meet ethical requirements for communication design.

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Table 1. Maxims of effective communication (adapted from Grice, 1975, 1978)

Maxim of effective communication	What it means	How the mental models approach addresses it
Maxim of quality	Accurately represent the scientific evidence	Normative and prescriptive research
Maxim of quantity	Communicate no more than is needed to help the target audience with their decisions	Descriptive and prescriptive research
Maxim of relation	Present information that is relevant to the target audience's decisions	Normative, descriptive, and prescriptive research
Maxim of manner	Use language that is understandable to the target audience	Descriptive and prescriptive research
Maxim of proven effectiveness	Disseminate communications that have been tested and deemed effective	Evaluation research

Fig. 1 Overview of the mental models approach to developing communications (adapted from Bruine de Bruin and Bostrom, 2013).