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Communicating scientific evidence: scientists', journalists' and audiences' expectations and evaluations regarding the representation of scientific uncertainty

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Abstract: Although uncertainty is inherent in scientific research, it is an often neglected topic in public communication. In this article, we analyze how scientists and journalists think they should communicate about the uncertainty of scientific evidence in public, and whether their real-world communication meets laypersons' demands and expectations. For scientists and journalists, our analyses are based theoretically on an expectancy-value model and empirically on two representative surveys. Laypersons' expectations and evaluations are analyzed using qualitative in-depth interviews. Results show that scientists and journalists widely agree that scientific uncertainty should be pointed out in their communication. Nonetheless, while scientists show a clear inclination toward the media and hope that uncertainties will not be dramatized or misused, journalists on the other hand have a strong audience orientation and hope to stimulate critical reflection on scientific findings. For audiences, however, media coverage about scientific uncertainty is of less interest. They clearly expect fact-oriented information on the use of technology in everyday life.

Keywords: science communication, scientists-journalists-audience interactions, scientific uncertainty, expectancy-value model, mixed-method-approach, biotechnology

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1 Introduction

One characteristic of scientific evidence is that it is more or less *uncertain*, since ambiguity and conflict lie in the nature of the scientific process (e.g., Popper, 1959). However, in public communication of science and technology, scientific uncertainty has frequently been neglected. "The ongoing struggles that occur between scientists over the definitions or significance of scientific and technological phenomena are often placed in the background when communicating findings to the public", so that, in general, "uncertainty is stripped out of the [public] discourse" (Ebeling, 2008, p. 336). For scientific laypersons though, information regarding uncertainty can be especially relevant in fields in which scientific evidence is regarded as (highly) tentative, and in areas where laypersons must base their decisions on the available information, for example, in politics, as private consumers, or regarding medical treatment. One such domain is emerging technologies in the field of life sciences (e.g., Nowack et al., 2012).

Following the concept of a *medialization* of science by Weingart (2005), the reasons as to why the portrayal of scientific uncertainty has been neglected thus far in media coverage may be found in the science and/or in the journalism . The concept addresses the relation between science, the media, and the public as well as essentially describing two developments: science, is increasingly oriented to the expectations of the media, whilst the media display an increased interest in science. From Weingart's perspective, science adapts to the logic of the media and thereby tries to influence the portrayal of science within the media. The main reason as to why scientists would act in such a way is to increase their social legitimacy and reputation. For this reason, scientists might avoid communicating scientific uncertainty if they are worried about unsettling the public. However, scientists might also explicitly focus on scientific uncertainty in order to meet the criteria of journalistic selection, and increase the probability of getting media coverage of their research. On the other hand, journalists act as gate keepers who select information on the basis of certain criteria such as individual preferences, selection routines, the news organization influence, but also based on beliefs regarding their audience (Shoemaker, Vos, and Reese, 2009). The representation of scientific uncertainty in biotechnological research in the media might therefore also depend on how relevant journalists evaluate specific information will be perceived by their audience.

In reference to the concept of medialization of science, the *key question* of the present study is how scientists and journalists think they should communicate the uncertainty of scientific evidence to the public, and whether their real-world communication meets laypersons' demands and expectations. We first

compare how scientists and journalists perceive scientific (un)certainty in biotechnological research and analyze their attitudes toward pointing out aspects of uncertainty in their public communication based on an expectancy-value model (Ajzen, 2006; Fishbein and Ajzen, 2010). These perspectives are then compared with laypersons' expectations regarding the presentation of scientific evidence and their evaluation of TV science reports. To take into account the perspectives of these three groups of actors involved in science communication – scientists, journalists, and the public –, the analyses require multiple data sources. Scientists' and journalists' perspectives are analyzed on the basis of two representative surveys among German scientists active in biotechnological research and science journalists reporting on such issues. Laypersons' expectations toward, and evaluations of, real TV science shows on nanotechnology – as an example of a technology emerging from biotechnological research – are examined using qualitative in-depth interviews. Nanotechnology was used as an example for biotechnological research to reduce the complexity of the subject for the audience study.

2 How scientists, journalists, and audiences deal with scientific uncertainty

Degrees of uncertainty are a central feature of science as research findings are always provisional from the logic of falsification (Popper, 1959). Research and knowledge gaps, limitations of existing research, or contradictory findings are factors that contribute to scientific uncertainty (Schneider, 2010). Conversely, scientific certainty is increased upon confirmation of hypotheses and replications of research results (Bromme, Prenzel, and Jäger, 2014). Scientists, as experts in a certain domain, may assess degrees of uncertainty, for example, by reviewing existing research. In contrast, scientific laypersons, largely (have to) rely on media communication of scientific insights including information regarding uncertainty (National Science Board, 2014). Regarding their possibilities to assess scientific evidence, science journalists probably fit somewhere in-between.

Within *academia*, uncertainty of scientific evidence may lead to regular discussions among researchers. In public, however, scientists seem to carefully weigh the possible benefits and risks of referring to uncertainty in their research, even though research has shown that they are willing to disclose uncertainty in general (e.g., Post, 2016). Benefits that scientists expect from pointing out uncertainty include enhancing their chances of receiving funding for fur-

ther studies (e.g., Tsfati, Cohen, and Gunther, 2011), the promotion of their public recognition and authority (Mellor, 2010), and finally, the education of lay-persons about the state of research (Peters, 2014). There are several possible risks that scientists seem to be sensitive to when addressing aspects of scientific uncertainty and conflict in public. Some of these are that journalists might dramatize, or interest groups might misuse this information (see Brechman, Lee, and Cappella, 2009; Maille, Saint-Charles, and Lucotte, 2010; Post, 2016; Tøsse, 2013), that journalists might not be interested in "uncertain" research findings (Dudo, 2013), or that scientists' open communication might have negative consequences concerning the audience. For example, the audience might question the authority of the scientist, lose trust and become more skeptical (Besley and Nisbet, 2013; for a summary, see also Post and Maier, 2016). To sum up, it seems that scientists communicate about scientific uncertainty strategically, thereby adapting their communication to the media, which could be a hint toward an increased medialization of science, as well as to the audience. However, it is still open as to which orientation is stronger. Furthermore, since the material that scientists and university press offices provide to journalists is the most important factor triggering journalistic coverage of scientific topics (Schwartz, Woloshin, Andrews, and Stukel, 2012; Stryker, 2002), scientists' attitudes and behaviors have a significant impact on the depiction of scientific uncertainty in public communication. Given their crucial role in the process of science communication, it is important to further analyze the expectations of scientists in reference to the consequences of their communication, and their perceptions of journalists' and laypersons' expectations.

Journalists who adhere to the criteria of high-quality journalism (Grimm and Wahl, 2014; for a critical discussion, see Maier, Rothmund, Retzbach, Otto, and Besley, 2014) are expected to describe research gaps and controversial opinions in public communication about science (Schneider, 2010) without overstating, downplaying, or dramatizing facts (Guenther, Froehlich, and Ruhrmann, 2015), for example, by pointing out the limitations of case studies or unsystematic summaries (Bromme, Prenzel, and Jäger, 2014). Nonetheless, research has shown that media often neglect uncertainty in their coverage (e.g., Ashe, 2013; Cooper, Lee, Goldacre, and Sanders, 2012; Heidmann and Milde, 2013; Stocking and Holstein, 2009). Their representation of science is influenced by general individual preferences, work routines and organizational resources (Dunwoody, 1999; Stocking and Holstein, 2009). Moreover, journalists' individual concepts and perceptions of scientific evidence (e.g., Dudo, Dunwoody, and Scheufele, 2011), as well as perceptions of audience expectations, affect their representation of scientific uncertainty (Amend and Secko, 2012; Schneider, 2010; Stocking and Holstein, 2009). However, the relevance of jour-

nalists' perceptions of scientific uncertainty, their intention to mention uncertainty-related aspects in public communication, their perceptions of consequences from this communication and of scientists' and laypersons' expectations toward them have not yet been thoroughly analyzed.

Studies explicitly concerned with the question of what kind of expectations *laypersons* have regarding the depiction of science and technologies, especially scientific uncertainty, are rare and the findings mixed. In general, research findings from education and psychology suggest that motivational as well as cognitive processes can impede the choice of, and the engagement with, science-related information (for summaries, see Maier et al., 2014; Smith, Fabrigar, and Norris, 2008). Regarding motivational processes, it has been shown that exposure to science information, and particularly to information regarding scientific uncertainty, can be promoted by accuracy motivation, for example, if individuals have a strong need for cognition (Winter and Krämer, 2012). On the contrary, "defense motivation can enhance selective exposure to one-sided ['certain'] scientific information that is in line with preexisting attitudes and beliefs" (Maier et al., 2014, p. 92), for instance, if individuals have a strong need for cognitive closure (Fischer, Schulz-Hardt, and Frey, 2008). In addition, credibility and information quality seem to promote people's openness to uncertainty-related information (e.g., Hart et al., 2009). Looking at cognitive processes, it has been shown that cognitive overload presents an important obstacle for science communication as it can lead to a drop in motivation and attention (for a summary, see Maier et al., 2014). Suggestions on how to prevent information overload refer, for example, to journalistic ways of structuring media content as well as to the integration of narrative elements (see Maier at al., 2014). These general research findings nicely frame the few specific research findings as regards laypersons' expectations concerning information on scientific evidence in emerging technologies.

With respect to motivational processes, it becomes apparent that scientific laypersons want to be informed about scientific uncertainty in technological fields (Frewer et al., 2002). However, they hardly differentiate between different types of uncertainties (Miles and Frewer, 2003).[1] It has also become apparent that laypersons value information about scientific uncertainty differently – positively or negatively (Wiedemann and Schütz, 2008): For some people ac-

1 Miles and Frewer (2003) differentiate seven types of uncertainties: uncertainty about who is affected, temporal uncertainty (uncertainty about past and future states), measurement uncertainty, uncertainty due to scientific disagreement, uncertainty about the risk to humans after measurements with animals, uncertainty about the extent (or 'size') of the risk, and uncertainty about how to deal with (specifically, how to reduce) the risk.

knowledging scientific uncertainty can make a source seem more credible; for others, it can lead to the scientists being perceived as incompetent (Johnson, 2003; Johnson and Slovic, 1995; Wiedeman, Löchtefeld, Claus, Markstaler, and Piet., 2009). Additionally, information about scientific uncertainty can decrease the perceived comprehensibility of news reports on science (Wiedemann et al., 2009). In terms of cognitive processes, the study by Corbett and Durfee (2004) shows that laypersons' assessments of uncertainty of scientific findings depend on the characteristics of the story, such as the contextualization of earlier scientific work (Corbett and Durfee, 2004). However, all in all, research on laypersons' expectations toward news reports on scientific uncertainty has played a marginal role in science communication research so far. Furthermore, the findings at hand are unclear concerning the question as to what kind of media coverage laypersons expect and how they evaluate different ways to account for uncertainty in public communication.

This is the starting point of our empirical study. We aim at analyzing the process of science communication, focusing on the public communication of aspects of scientific uncertainty while taking into account the three dominant groups of actors in this context: scientists, science journalists, and laypersons receiving information about science (see Figure 1). Using the example of *biotechnological research*, we explore scientists' and journalists' perspectives and mutual references in the sense of the medialization concept of science communication based on a simplified expectancy-value model. Following the theory of planned behavior (Ajzen, 2006; Fishbein and Ajzen, 2010), we assume that their communication is determined, among others factors, by a) their anticipations of positive and negative consequences (behavioral beliefs) and b) by their perceptions of the expectations other communicators and the public have towards them (normative beliefs).[2]

The audience study incorporates this point and examines the extent to which perceptions of scientists and journalists correspond with the expectations of the public. As an exploratory study, it examines laypersons' expectations towards the portrayal of scientific evidence in the media. In a second step, the analysis turns to the question of whether or not media depictions meet the expectations of the audience. The study contributes to the empirical

2 Additional aspects specified in the theory of planned behavior (Ajzen, 2006; Fishbein and Ajzen, 2010) are perceptions of the circumstances (control beliefs), and perceptions of norms as part of normative beliefs. Due to space restrictions, however, in this article we focus on the categories relevant for the interactions between the three groups of actors. For additional but separate analyses of scientists' and journalists' communication intentions, see also Guenther, Froehlich, and Ruhrmann (2015), Guenther and Ruhrmann (2016), and Post and Maier (2016).

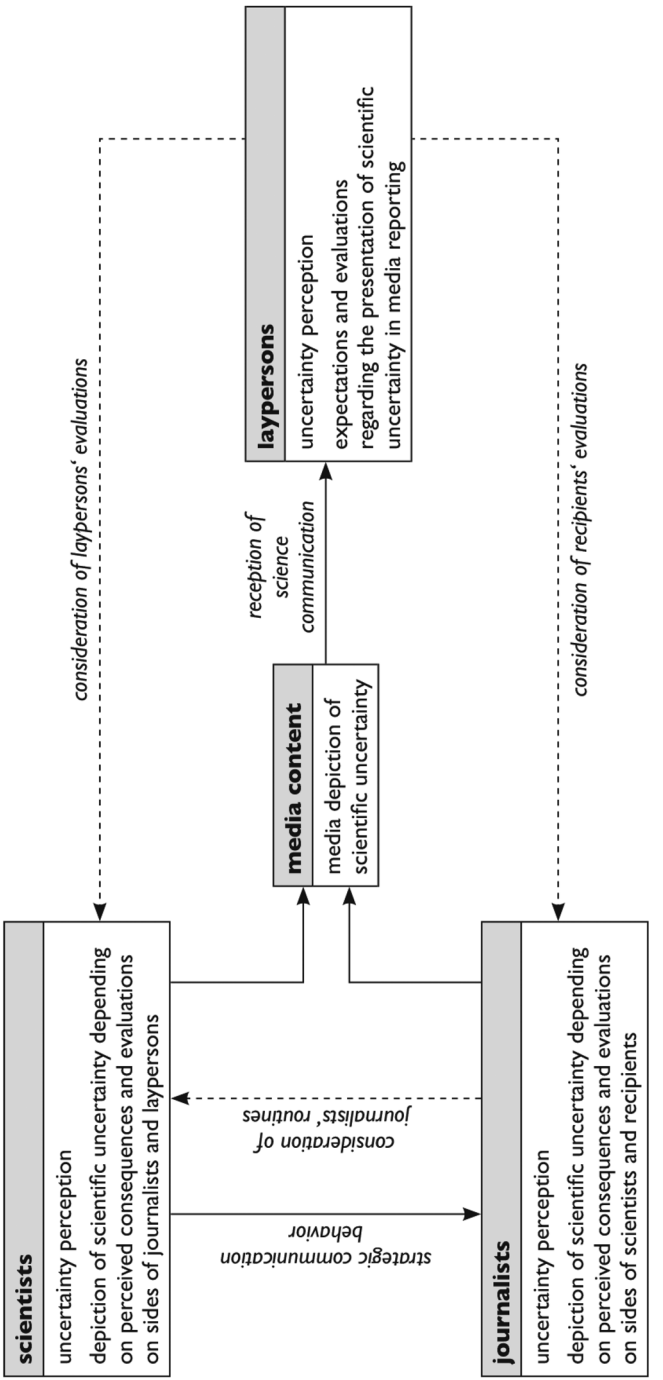

Figure 1: Scientists', journalists' and laypersons' expectations and evaluations of the representation of scientific uncertainty.

analysis of the quality of science journalism from an audience point of view (Loosen and Dohle, 2014) by detailing the demands of laypersons regarding quality media coverage of scientific topics (Scholl, Malik, and Gehrau, 2014; van der Wulff and Schoenbach, 2014).

For all three groups, we start by assessing the perceptions of scientific uncertainty. From the communicators' (scientists and journalists) viewpoint, we analyze their attitudes toward communicating about scientific uncertainty in public. We further compare how scientists and journalists perceive the consequences of their communication of uncertainty and of audiences' expectations toward them with how laypersons perceive and evaluate examples of actual TV science shows. The goal of this investigation is not to investigate the different actors' rationales of dealing with scientific uncertainty but to compare their assessments of scientific uncertainty and their attitudes toward communicating it.[3] The audience study focuses on TV science shows, as television is still the most popular medium for science information in Germany, and TV science shows are an established component of the German TV landscape. The Eurobarometer (European Commission, 2013) has shown that about 50 % of German citizens find television to be the most reliable medium for science information, followed by newspapers (23 %) and the internet (10 %).

Due to the explorative character of our study, we pose the following research questions:

[RQ1] How do scientists and journalists assess scientific (un)certainty in biotechnological research?

[RQ2] Do scientists and journalists think they should address aspects of scientific uncertainty in their public communication?

[RQ3] Which consequences do scientists and journalists expect from communicating scientific evidence and how do they evaluate these consequences?

[RQ4] Which expectations (from other communicators and the public) do scientists and journalists perceive, and are they willing to meet these expectations?

[RQ5] Which expectations do laypersons have regarding media representations of scientific uncertainty?

[RQ6] How do laypersons perceive and evaluate the presentation of varying degrees of scientific evidence in the media?

3 For more detailed analyses of journalists' and scientists' rationales to communicate uncertainty, see Guenther and Ruhrmann (2016), and Post and Maier (2016).

3 Methods

3.1 Data collection

As previously mentioned, our analysis is based on a mixed-method approach. To assess scientists' and journalists' perspectives, we rely on representative telephone surveys which are founded on earlier qualitative studies (Guenther, Froehlich, and Ruhrmann, 2015; Maier, Post, Barkela, and Retzbach, under review). In order to identify the relevant German *scientists* conducting academic biotechnological research, we used the database of the German Research Foundation (DFG), which includes all scientists that had received funding since 1999. Using a keyword search, we selected 424 scientists who had received funding since 2006 for biotechnological research projects.[4] Interviews were conducted in early 2014. We aimed to complete 100 interviews with scientists and stopped telephoning upon completion of this number. Of the 424 scientists, 51 were ineligible due to retirement, illness, research stays abroad, or lack of expertise. Ten were unreachable or not traceable. Of the remaining 363 scientists, 29 % (n = 105) completed the survey. Forty percent (n = 145) explicitly refused to participate. In most cases, scientists refused to participate because of a lack of time or because of travel. No refusal was due to explicit skepticism toward the survey or the topic. Upon completion of the 105th interview, 31 % of the scientists (n = 113) had not been reached due to absence from the workplace or busy phone lines.

For the *journalists*' survey, the names and contact data of German science journalists working as permanent editorial staff or as freelancers were collected from media outlets (e.g., websites), professional data bases, and journalists' associations (see Guenther and Ruhrmann, 2016). In total, our database contained contact information for 1,249 science journalists. The research team made initial contact via e-mail and phone with all journalists included in the database in early 2014 to explore the specific profile and willingness to participate in the study. Only journalists who spent more than a third of their total working time on science issues, and who had already reported on biotechnological research were invited to participate in the study. 392 journalists who were contacted fulfilled these criteria, 185 of whom refused to participate in the study, and five interviews were used as a pre-test for the final version of the questionnaire. In sum, 202 surveys were completed with science journalists who report on biotechnological research.

4 The keywords used were biotechnology, nano-biotechnology, bio-sciences, life-sciences, bio-medicine, nano-medicine.

Due to the stronger explorative character of the *audience study*, a qualitative approach was chosen for this part of the study, and 20 qualitative interviews were conducted in February 2015, each lasting about 90 minutes. Participants were recruited using a quota sampling plan based on age, gender, education, interest in science and research as well as interest in nanotechnology. The interviews included questions on expectations regarding the depiction of scientific uncertainty in the media as well as the evaluation of three actual TV reports about different areas of research and applications in the field of nanotechnology that were shown during the interviews. These TV reports were taken from a media sample of TV science reports from the years 2010 and 2011 that had been content-analyzed beforehand (Heidmann and Milde, 2013)[5] and which varied in their depiction of scientific uncertainty: Report 1 presents a medical treatment of sepsis using nanoparticles to clean the blood. Scientific evidence is depicted as rather certain. Report 2 about nano products presents the scientific evidence as mixed but also leaning towards certainty. Report 3 presents risks and benefits of nanotechnology and describes scientific evidence as rather uncertain. The interviews were conducted by trained interviewers, audio-recorded, and entirely transcribed. The transcripts were analyzed using content structuring on the basis of statements and arguments made by the participants (Schreier, 2014). The participants' statements and arguments were summarized and assigned to categories, which were either developed deductively based on the state of research or were formulated inductively (Mayring, 2008). The advantages of this additional inductive approach are that aspects not included in the literature so far could be included and specified within this study.

3.2 Measures

Scientists' and journalists' *perceptions of uncertainty* in biotechnological research were first measured using single-item questions that asked to what extent they thought that knowledge in their main field of research (scientists) and reporting (researchers) was uncertain. The degree of scientific uncertainty was measured on a Likert-scale from 0 "hardly uncertain" to 10 "very uncertain". Regarding their *attitudes toward mentioning scientific uncertainty*, scientists

5 The media content analysis was based on all thematically relevant media reports found in weekly newspapers, science magazines, and TV science reports in Germany. In the content analysis, the depiction of scientific uncertainty was coded. The codebook is available on request from the authors.

were asked whether they would find it appropriate to mention the uncertainty of scientific evidence when talking to a journalist (scale from 0 "very inappropriate" to 10 "very appropriate"). Journalists were asked how they evaluate scientific uncertainty if it is depicted in their reports (scale from 0 "very negative" to 10 "very positive"). In addition, scientists were asked about which *aspects of uncertainty* they would mention if talking to a journalist, and journalists were asked whether they would mention the same aspects in their reports. Specifically, they were asked how likely they were to mention a) research gaps, b) scientific controversies, and c) doubts regarding research findings (scales from 0 "very unlikely" to 10 "very likely"; see Stocking and Holstein, 2009). Regarding the *perceived outcomes* of their depiction of scientific uncertainty, scientists were asked how likely they thought their communication would contribute to a) citizens becoming more critical regarding biotechnological research and b) journalists losing interest in the topic. Journalists were asked how likely they thought that their reports would contribute to their audience a) becoming more critical, b) becoming more uncertain, and c) thinking more about the issue (scales from 0 "very unlikely" to 10 "very likely"). Following an expectancy value model (Ajzen, 2006; Fishbein and Ajzen, 2010; Guenther, Froehlich, and Ruhrmann, 2015; Post and Maier, 2016) both scientists and journalists were then asked to *evaluate these outcomes of their communication* on a scale from −5 "very negative" to +5 "very positive" (for a more detailed explanation of this and the following measures, see the Findings section). Finally, scientists and journalists were asked whether they were *expected* to mention scientific uncertainty and how important it was for them to comply with such expectations. Scientists were asked whether a) journalists and b) the public expected them to address scientific uncertainty; journalists were asked whether a) scientists and b) the public expected them to refer to aspects of uncertainty (scales from −5 "expected not to mention uncertainty" to +5 "definitively expected to mention uncertainty"). Their willingness to comply with these expectations was measured on scales from 0 "not important" to 10 "very important".

To analyze the expectations and evaluations of the laypersons, a semi-structured guideline was developed. The *expectations* of the participants were determined by two questions. First, they were asked which expectations they had towards the portrayal of nanotechnology on TV. Then, the participants were given a definition of scientific uncertainty to standardize the idea of the concept.[6] On the basis of this definition, participants were asked how scientific

6 The definition of scientific uncertainty was: "Especially in new fields of research, very often science is still at a very early stage. It is always possible that the scientists are still uncertain about a lot of things. For example, research results may contradict each other, without the scientists even knowing why. Or not enough studies have been conducted, so that one cannot

research should be portrayed in media reports: as rather certain, uncertain, or a mix of both. Participants were asked to choose one of these alternatives and to explain their decision. The *evaluation* of the three TV reports was assessed immediately following the reception of each report. The participants were asked whether they considered the portrayal of scientific evidence to point to certainty, uncertainty, or a mix of both. They were also asked to explain their choice and to evaluate the portrayal.

4 Findings

4.1 Scientists' and journalists' views

[RQ1] addresses scientists' and journalists' perceptions of scientific (un)certainty in biotechnological research. The results show that scientists as well as journalists are similarly ambivalent on the question of the (un)certainty of biotechnological research having mean values of $M = 4.77$ ($SD = 2.38$; $N = 101$) for scientists and $M = 4.88$ ($SD = 2.02$; $N = 191$) for journalists ($t(290) = -.42$; $p = .678$).

[RQ2] refers to scientists' and journalists' attitudes toward mentioning scientific uncertainty. Scientists report finding it adequate to point out scientific uncertainties when talking to a journalist ($M = 7.20$; $SD = .62$; $N = 103$), and journalists would evaluate a report pointing out scientific uncertainties also quite positively ($M = 7.07$; $SD = 2.85$; $N = 180$; ($t(281) = 0.46$; *n.s.*). In order to measure respondents' intentions to disclose aspects of scientific uncertainty, we asked scientists and journalists which aspects of scientific uncertainty they would mention in a conversation with a journalist (question for scientists) or in a media report (question for journalists). Our findings reveal significant differences only for one aspect: journalists are significantly more inclined than scientists to mention scientific controversies (see Table 1). Also, in sum, it seems rather likely that they would also mention aspects such as knowledge gaps and scientific doubts in their reports. Scientists are, furthermore, quite willing to point out knowledge gaps but a bit less likely to mention controversial scientific issues; however, they are more ambivalent about whether or not to mention scientific doubts.

Following the expectancy value model, [RQ3] asks which consequences scientists and journalists expect from their communicative behavior and how they

be entirely certain that, for example, a new type of medicine or a new technique really works. So, one can say that very often research results are only provisional and uncertain."

Table 1: Intention to mention aspects of scientific uncertainty in public communication.

	Scientists **M** **(*SD*; *N*)**	**Journalists** **M** **(*SD*; *N*)**
Knowledge gaps	7.20 (2.59; 105) $t(301) = .10$; $p = .922$	7.17 (2.51; 198)
Controversial issues	6.50 (2.73; 103) $t(302) = -2.10$; $p < .05$	7.15 (2.47; 201)
Scientific doubts	6.06 (2.79; 104) $t(301) = -1.40$; $p = .163$	6.53 (2.77; 199)

Ratings on scales from 0 ("very unlikely") to 10 ("very likely").
Note: Scientists are significantly more likely to mention research gaps than to mention controversial issues ($t(104) = 2.767$, $p < .05$) and scientific doubts ($t(104) = 4.507$, $p < .001$). There is no significant difference between their readiness to mention controversial issues and scientific doubts ($t(102) = 1.618$, $p = 0.109$).
Journalists' willingness to mention knowledge gaps and to mention controversial issues do not differ ($t(198) = .060$, $p = 0.952$). However, they are more likely to mention knowledge gaps ($t(196) = 3.661$; $p < .001$) and controversial issues ($t(199) = 3.858$; $p < .001$) than to mention scientific doubts.

evaluate these consequences. For instance, scientists were asked to first rate the probability that citizens would become more critical about biotechnology if they mentioned scientific uncertainty in their communication. This likelihood scale ranged from 0 ("very unlikely") to 10 ("very likely"). Then they were asked to rate this consequence (citizens becoming more critical) as very negative (–5) to very positive (+5).[7] For the analysis, we multiplied the estimated likelihood of each consequence by how it was rated by the journalists and

7 According to Ajzen (2006), it is unclear whether perceived likelihood should be measured on bi- or unipolar scales. According to him, one has to figure out whether respondents assess likelihoods on an objective or subjective, i.e. evaluative metric. We reasoned that, in the context of strategic communication, actors perceive likelihoods of consequences on an objective, that is, non-evaluative metric. In other words, we presume that they perceive (un)desired but highly unlikely consequences as neutral or irrelevant with respect to their behavior (see Ajzen, 2006, pp. 10). For example, we reason that if a communicator thinks that particular consequences will not be produced by pointing out uncertainty, that communicator will not be enthusiastic about pointing out uncertainties. However, he or she will not have a problem with it either.

Table 2: Evaluation of the consequences of communicating scientific uncertainty.

	Estimated likelihood of consequence [0; +10]	Evaluation of consequence [−5; +5]	Expected value of pointing out scientific uncertainty [−50; +50]*
Scientists' perceptions:			
Citizens become more critical.	6.66	.68	4.80
	(2.23)	(2.49)	(17.24)
Journalists lose interest.	4.76	−1.51	−7.14
	(2.73)	(2.09)	(12.45)
Journalists' perceptions:			
Audience becomes more critical.	6.02	3.93	24.32
	(2.69)	(1.45)	(15.19)
Audience becomes more uncertain.	5.16	−1.89	−8.98
	(2.37)	(2.50)	(14.76)
Audience thinks more about the issue.	7.00	4.44	31.38
	(2.10)	(.94)	(12.40)

* Estimated likelihood of consequence × Evaluation of consequence.
Mean values, standard deviations in brackets.
Scientists: max. $N = 102$; Journalists: max. $N = 202$.
Scientists think that it is significantly more likely that citizens become more critical than that journalists lose interest ($t = -6.990$; $df = 100$; $p < .000$). They think it is significantly more negative when a journalist loses interest than when citizens become more critical ($t = -10.573$; $df = 100$; $p < .001$). Overall, mentioning uncertainty has a significantly higher value for them with regards to citizens' attitudes than with regards to journalists' interest ($t = -9.637$; $df = 100$; $p < .000$).
Journalists think that it is significantly more likely that their audience becomes more critical than more uncertain ($t(184) = 3.518$; $df = 183$; $p < .01$); however, they think it is more likely that the audience will think more about the issue than become more critical ($t(188) = -6.554$; $df = 187$; $p < .001$) or more uncertain ($t(191) = -7.872$; $df = 190$; $p < .001$).
Regarding evaluations, the outcome that the audience becomes more critical is seen more positively than the outcome that the audience could become more uncertain ($t(187) = 27.339$; $df = 186$; $p < .001$). That the audience could think more about the issue is seen as more positively than them becoming more uncertain ($t(192) = -5.984$; $df = 191$; $p < .001$) or them becoming more critical ($t(195) = -.351$; $df = 194$; $p < .001$). Overall, journalists assigned highest values to the outcome that their audience thinks more about the issues, in comparison to both the audience could become more critical ($t(195) = -6.123$; $df = 194$; $p < .001$) or become more uncertain ($t(192) = -31.998$; $df = 191$; $p < .001$); they also rate the outcome that the audience could become more critical higher than they could become more uncertain ($t(187) = 27.339$; $df = 186$; $p < .001$).

scientists. Through this procedure, values between –50 (high likelihood of very negative consequence when pointing out scientific uncertainty) and +50 (high likelihood of very positive consequences when pointing out scientific uncertainty) can be obtained.

For scientists, pointing out scientific uncertainty has a slightly positive value with regard to people becoming more critical (see Table 2). In other words, scientists have some hope that acknowledging scientific uncertainty will increase people's skepticism towards biotechnological research. In contrast, their pointing out uncertainty has a slightly negative value with regard to journalists' interest. This means scientists have modest concerns that journalists might lose interest if they point out scientific uncertainty. However, considering that, theoretically, values could range between –50 and +50, the magnitude of scientists' positive and negative ratings of the consequences of their communication behavior is small.

For journalists, pointing out scientific uncertainty has clearly positive values with regard to the hope that their audience will deliberate more about the respective issue and – similarly to the scientists – that their audience will become more critical towards biotechnological research (see Table 2). Journalists, to a significantly lower degree, fear that the audience could become more uncertain.

The same procedure was applied in order to assess how scientists and journalists deal with expectations that journalists (question for scientists), scientists (question for journalists), and the public (question for both groups) have regarding their communication of scientific uncertainty [RQ 4]. We first asked whether the particular groups expected them to communicate scientific uncertainty (–5 "xyz thinks I should not at all mention uncertainty" to +5 "xyz absolutely thinks I should mention uncertainty") and then multiplied these perceptions by their ratings of how important it was to them to fulfill such expectations (0 "not important" to 10 "very important").[8] Our findings show that scientists perceive that journalists, as well as the public, expect them to mention scientific uncertainty, and although they think that it is important to fulfill these expectations to a certain degree, they generally do not perceive strong pressure from either journalists (see Table 3) or the public.

8 We reasoned that whereas expectations not to mention uncertainty have negative values, expectations to mention uncertainty have positive values, while a low level of pressure to comply has rather neutral and a high pressure to comply has high values.

Table 3: Perception of pressures to communicate scientific uncertainty.

	Perceived expectations to communicate uncertainty [−5; +5]	Importance to comply with expectations [0; 10]	Perceived pressure to point out scientific uncertainty [−50; +50]*
Scientists' perceptions of:			
Journalists' expectations	2.08	3.66	6.83
	(2.26)	(2.94)	(13.53)
Public's expectations	1.64	4.69	6.28
	(2.58)	(3.12)	(16.35)
Journalists' perceptions of:			
Scientists' expectations	−.16	4.96	1.04
	(3.14)	(3.10)	(19.54)
Public's expectations	.29	7.12	2.63
	(2.86)	(2.55)	(22.85)

* Perceived expectations to communicate uncertainty × Importance to comply with expectations [−50; +50].
Mean values, standard deviations in brackets.
Scientists: max. $N = 102$; Journalists; max. $N = 202$.
Scientists think that journalists expect them to point out uncertainty significantly more than the public ($t = 17.810$; $df = 100$; $p < .000$). They think it is significantly more important to comply with the public's expectations than with journalists' expectations ($t = 3.924$; $df = 101$; $p < .001$). Overall, there is no significant difference in the pressures they perceive to mention uncertainty from journalists and the public ($t = .413$; $df = 101$; p = .687).
Journalists do not think that their audience expects them to represent uncertainty more than scientists do ($t(180) = -1.135$; $df = 179$; $p > .05$). However, their motivation to comply with the expectations of their audience is higher than their motivation to comply with the expectations of scientists ($t(195) = -9.229$; $df = 194$; $p < .001$). Taken together again, they do not perceive stronger pressures from their audience than from scientists ($t(181) = .061$; $df = 180$; $p > .05$).

Journalists score even lower than the scientists; they do not really feel any pressure from scientists or their audience to point out uncertainty. However, the importance of complying with the expectations of the audience is slightly higher than is that of the scientists.[9]

9 We computed OLS regressions explaining journalists' and scientists' intentions to communicate uncertainty to the public by their above-mentioned behavioral beliefs about it and their perceptions of expectational pressure. However, both regression models were not significant. Detailed analyses of journalists' and scientists' rationales for communicating uncertainty have

4.2 Laypersons' expectations

We asked the participants what expectations they had when watching televised reports about nanotechnology [RQ5]. On this very general question, none of the interviewees explicitly mentioned information on the degree of scientific (un)certainty. Some participants mentioned aspects that might be related to uncertainty; for instance, they often asked for background information about funding and research institutions. However, the discussion of scientific evidence for the audience played only a minor role. More important expectations were that the information presented is up-to-date, accurate and trustworthy (e.g., "*has to be correct and based on verifiable facts*", 20,36).[10]

When provided with the definition of scientific uncertainty, participants responded differently. Some audiences expected the presentation of uncertainty, while others rejected such information. A third group tended to differentiate and expected information on uncertainty under specific conditions. The reasons participants gave for their choices are manifold and more or less related to the scientific process. Those who expected to be informed about scientific uncertainty offered rationales such as: "*There are no indisputable scientific results"* (20,53). Therefore, scientific evidence should be depicted as "*rather uncertain because things are still developing"* (10,101). Others explicitly referred to the subject and stated that "*nanotechnology research is incomplete. A TV report has to discuss this*" (16,727). While these statements refer to the scientific process itself, other participants were interested in uncertain research findings because they show where research is headed "*and thereby people are informed about future developments"* (18,86).

In contrast, there were participants who explicitly did not want to be informed about uncertain research findings in science TV shows. Some considered uncertain findings to be a sign of unfinished research and, therefore, not scientific (16,117); others acknowledged that scientific evidence can be uncertain but criticized the public release of uncertain findings as misinformation of consumers (19,112). Trustworthiness was another important factor: "*I believe more in reports when the results have been checked and proven*" (6,101). Other people demanded reliable information that enabled them to make decisions in a complex world: "*I, as a layperson, can't deal with assumptions and uncertainty because I am not qualified to get a coherent overall picture*" (1,99). Some even

been published elsewhere (Guenther & Ruhrmann, 2016; Post & Maier, 2016), which is why, in the present paper, we chose a comparative descriptive rather than an explicative perspective.

10 Interviews were structured in paragraphs. To retrace quotes, we labeled them with an interview ID and a paragraph number.

Table 4: Laypersons' expectations, perceptions and evaluations regarding scientific uncertainty.

Laypersons expect …	… no presentation of uncertain evidence. Reasons: "*unscientific", misinformation of consumers, untrustworthy, unsettling.*	… presentation of uncertain evidence. Reasons: *part of scientific work, to be informed about open questions, academic controversy, current state of research.*
Laypersons perceive …	… presentation as certain if … mentioned by the actors or the journalist (voice over), test-series are successful, replication studies exist.	… presentation as uncertain if … mentioned by the actors or the journalist (voice over), laboratory settings are shown, long-term and field studies are missing.
Laypersons evaluate …	… perceived certainty … rather positive.	… perceived uncertainty … ambivalent – positive & negative.

went one step further and assumed "*that uncertainty will unsettle society*" (6,99).

Aside from clear-cut positions for or against the presentation of information about uncertain research findings, a third group of participants offered more differentiated expectations. Some explained that they would like to be informed about particular uncertainties such as open questions or academic controversy (10,134; 9,114). Some participants were interested in the current state of research and wanted to know about certain as well as uncertain results because "*a certain result can be disproven someday*" (15,66). Similar to our findings above, some people demanded that journalists should explicitly state when findings are uncertain: "*When results are not one hundred percent certain, it must be clearly pointed out*" (15,66).

4.3 Laypersons' perceptions and evaluations of uncertainty depiction in TV reports

[RQ6] asks how laypersons perceive and evaluate the depiction of varying degrees of scientific evidence in the media. During the interviews, participants watched three TV science reports in which scientific evidence was presented differently: as certain, as mixed but leaning towards certainty, and as uncer-

tain. After each report, we asked how the participants perceived the presentation of scientific evidence and how they evaluated it.

Even though scientific evidence was presented differently in the reports, the majority of participants perceived the presentation of scientific evidence as uncertain in all three. The important reasons for such a perception were that research was "*only conducted as a laboratory test*", (4,124) that "*long-term research is missing*" (17,143) or that scientists "*contradict each other*" (12,207). Others interpreted the presentation of scientific evidence as uncertain since "*the interviewed scientist said: 'Our research is not finished'*" (5,179). Some noticed if the voice-over mentioned uncertainty. Other participants came to quite differentiated evaluations and described the research findings as "*only provisional*" (8,125). They believed in the certainty of first results but noted that additional long-term and field studies were needed. However, others also recognized scientific *certainty* in the reports. Some noticed that certainty was pointed out by emphasizing the existence of "*replication studies*" (13,143). Others explained that basic research seems to be finished because "*test-series were successful and therefore implementation is possible*" (10,162). The last statement mentions aspects of laboratory research and is noteworthy because – as shown above – other participants in general considered laboratory research to be a sign of uncertainty. While these evaluations are based on scientific criteria, other participants simply based their assessment on the *credibility of actors* and assumed that these sources tell "*the truth*" (14, 107) and would not report wrong information. People attributed this credibility not only to scientists but also to other relevant actors, such as non-governmental agencies.

After discussing how laypersons perceived the portrayal of scientific evidence in the TV reports, we asked them to *evaluate* this presentation. It is remarkable, first, that participants in most cases evaluated the media presentation of science as positive and, second, that the reasons for this evaluation referred to many things other than the depiction of scientific (un)certainty. Relevance ("*important research in order to help mankind*", 6,146; "*based on examples from everyday life*", 16,204), quality of explanations, and technical features ("*fully comprehensible; with the animated graphics it gets imaginable*", 1,147) are examples of such criteria.

If participants referred to the presentation of scientific evidence, the following can be observed: those who perceived scientific evidence to be depicted as *certain* evaluated this positively as they believed in the credibility of reports and actors ("*they said what they discovered and it is proven*", 13,147). There were no negative evaluations if the depiction of evidence was perceived as certain. If participants perceived scientific evidence as uncertain, evaluations were mixed. If a technology's potential was stressed, evaluations were positive

(e.g., "*it was shown what could be possible but also pointed out that this is not the final result*", 5,113). However, other participants claimed that uncertainty presentations "*unsettle"* (6,223*)* or "*raise false hopes among the people who are not as critical as myself*" (1,129).

5 Discussion and conclusions

In this article, we analyzed how scientists and journalists think they should communicate about the uncertainty of scientific evidence in biotechnological research and whether their real-world communication meets laypersons' demands and expectations. Our findings first show scientists' and journalists' moderate willingness to point out uncertainty to the public (see Figure 2): scientists and journalists agree that existing knowledge gaps should be mentioned but are both relatively hesitant to point out scientific doubts. Moreover, for journalists, controversial issues have a high news value in science reporting (see also Guenther and Ruhrmann, 2013).

Regarding the consequences they expect from their communication behavior, scientists are a bit worried that journalists might lose interest in a topic if the uncertainty of scientific evidence is pointed out. Journalists, on the other hand, seem to believe that their reporting of scientific uncertainty will stimulate laypersons to think more about the topic, leading audiences to become more critical of biotechnological research. In reference to the expectations of each other among the actors, while scientists perceive some pressure from journalists – who presumably expect them to communicate about uncertainty to a certain degree – journalists feel very little external pressure. In sum, these findings support the medialization thesis by Weingart (2005) from the scientists' perspective. Their perceptions of consequences as well as external pressures are directed towards the media. The journalists, on the other hand, show a much stronger audience orientation, hoping for positively valued effects on their audiences and not perceiving any external pressures. This finding supports the notion that science journalists see themselves not just as neutral 'disseminators' of facts or as mediators between scientists and the public but also as able to develop proactive roles by attempting to enable critical reflection on scientific findings (e.g., Maier et al., 2014; Meier and Feldmeier, 2005; Stocking and Holstein, 2009).

The question as to whether scientists' and journalists' ideas regarding laypersons' expectations and evaluations of their communication are correct was undertaken in the third part of the paper. The qualitative reception study shows

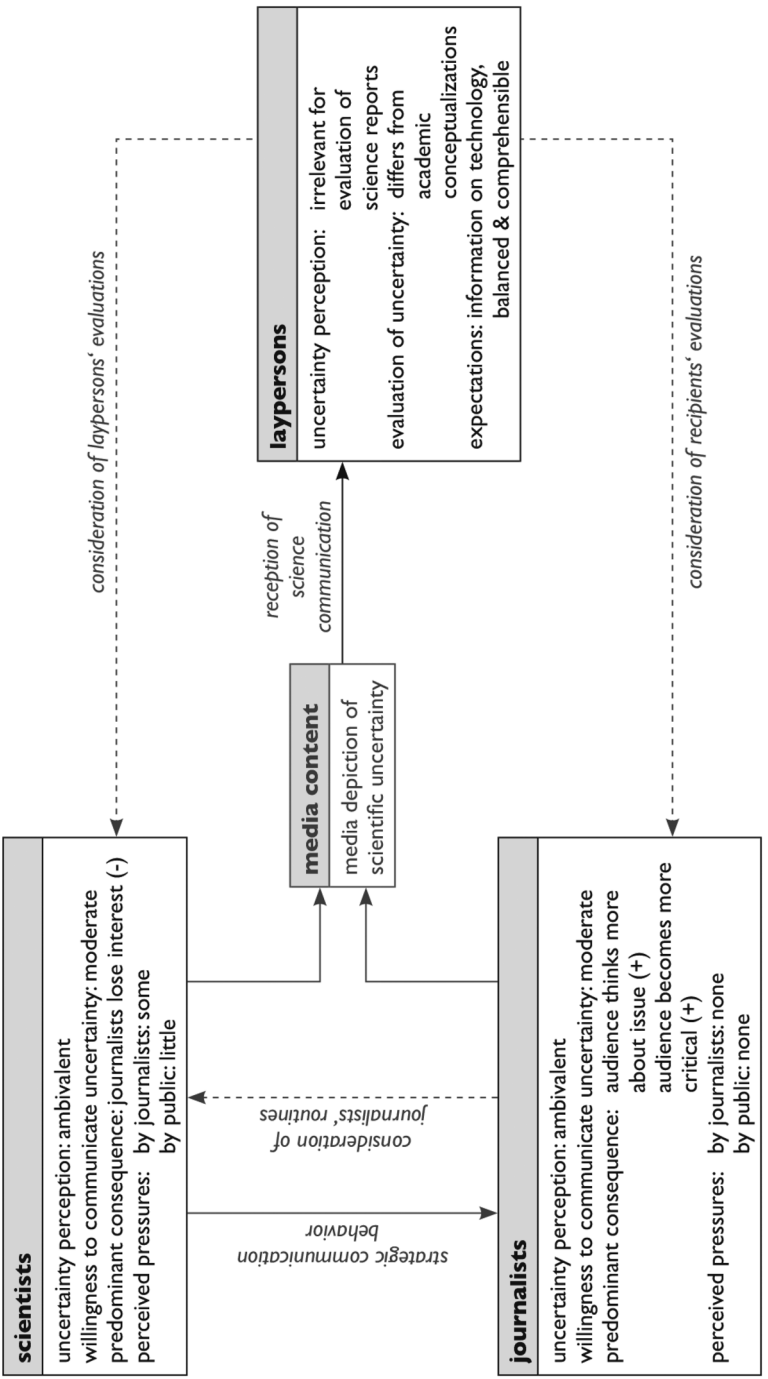

Figure 2: Results: Scientists', journalists' and laypersons' expectations and evaluations of the representation of scientific uncertainty.

that the participants only referred to the portrayal of scientific uncertainty as an expectation of media science coverage when they were sensitized to this concept. Then, laypersons provided arguments for and against the portrayal of scientific uncertainty. Their major argument in favor of open communication was that uncertainty is part of the research process, and that such communication also provides information on desiderata and possible venues for future research. Arguments against uncertainty communication were that it seems "unscientific" and that it damages the credibility of the report and of science as a whole. This predominant notion is in line with former research findings (Johnson, 2003; Wiedemann et al. 2009). All things considered and based on the findings of this explorative study, the portrayal of scientific uncertainty seems to more or less disturb people and make it more difficult for them to come to day-to-day decisions.

We also found that laypersons' evaluations of news reports often differ from expert ratings. Most laypersons rated scientific evidence as uncertain in all three treatment conditions as their criteria were only partly in line with the academic conceptualization. Furthermore, they did not assess the general proposition of the report, but instead referred to single creative aspects, for example, pictures of laboratory settings. Another indicator for scientific (un-) certainty for laypersons was how authentic the protagonists seemed to be. When comparing laypersons' judgments with the expectations of scientists and journalists towards their audience, it becomes clear that the communication about scientific uncertainty is much less important to laypersons. Their major interest focused on information about the use of technology in day-to-day life. Preferably, the media reports should be fact-oriented, balanced and comprehensible. As laypersons' perception and evaluation of scientific uncertainty differed fundamentally from that of scientific experts, many people will only perceive the depiction of scientific uncertainty in media coverage if journalists explicitly emphasize it.

The comparison of scientists' and journalists' views and laypersons' expectations and evaluations regarding the communication of scientific uncertainty was the goal of this paper. Integrating the perspectives from all three groups of actors involved in science communication based on the different levels of theoretical and empirical evidence is a major challenge and also suggests the need for future research. From the audience standpoint, additional representative surveys should seek to replicate our findings regarding laypersons' expectations toward, and evaluations of, science communication taking into account science-related attitudes, information/media evaluations as well as recipients' characteristics. From the viewpoint of the communicators of science-related information, this study only considers two groups of actors, scientists and jour-

nalists. However, many more actors are involved in the process of science communication (see, e.g., Maier et al., under review; Post and Maier, 2016) whose interactions, interdependencies and different rationalities should be granted more attention in future studies.

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