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On how to characterize and confront misinformation in a risk context

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ABSTRACT

Misinformation is one of the largest challenges for risk assessment and communication. However, the term *misinformation* in relation to risk has not yet been clearly interpreted by the risk field. Basic definitions of misinformation point to false, incorrect, inaccurate and misleading information. However, when it comes to risk, there is in many cases no reference for what is the truth - the risk magnitude needs to be evaluated on the basis of analysis and judgments. What is judged as misinformation by some, could be seen as adequate information by others. In this paper we reflect on the meaning and scope of the misinformation concept in relation to risk and uncertainty. The main goal is to obtain new knowledge on the topic by relating the discussion to risk science fundamentals, on the understanding, characterization and perception of risk. A structure for a classification of misinformation in relation to risk is proposed. Several measures are also presented to explore how to meet the misinformation challenge in risk contexts.

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1. Introduction

Every day, the media, policy-makers, businesses, the public sector and all of us are challenged with *misinformation*; information that can be labeled as fake news, false, incorrect, inaccurate or misleading. Governments and experts are concerned (see e.g. Harriss and Raymer 2017; Roozenbeeka and van der Linden 2019; Krause et al. 2020; Balog-Way, McComas, and Besley 2020; Montagni et al. 2021). The misinformation is seen as a threat to evidence-based communication and decision-making. Our focus in this paper is on misinformation in relation to risk, but much of the discussion is general and relevant also for other type of settings. As an example, consider the topic of medical treatments to manage a health condition. Patients may seek information from non-medical resources, such as through online resources, to study treatments and risk aspects. Some or many of these resources may be sharing false, incorrect, inaccurate and misleading information, and measures are needed to meet this challenge (such as 'fact-checking' and controlling the access of information). But who are to decide what are facts, correct, and accurate information? For example, a medical treatment can show promising results and be judged safe in some contexts, but not in others. There could be strong economic, social, or political drivers for some information to be highlighted and others to be ignored.

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Science in general stimulates discussion and questions established beliefs and assumptions. There is a balance to be made between encouraging scientific debate and freedom of speech on the one hand and avoiding that people are misled by ineffective or dangerous treatments on the other. The right balance is difficult to find as the 'truth' may not be easily revealed. Science provides justified claims about the truth, not one claim, but typically many reflecting different 'schools' and perspectives. Specifying what are the facts and the correct information, and what are misinformation, is therefore difficult in many cases. There could be thousands of relevant information sources, and selecting some and avoiding or dropping others allows for different messages and conclusions. It is then not obvious what should be labeled as misinformation.

These are the types of issues we will discuss in this paper. We aim at developing new knowledge about the concept of misinformation in relation to risk communication by relating misinformation to different risk perspectives, reflecting on differences in the way risk is understood and characterized. A main difference in perspective relates to the existence or not of an underlying true, objective risk that experts can accurately estimate. If such a risk exists, there is a reference for what is correct and not, which helps determine if the information is false, inaccurate or misleading. However, in practice, such situations are rare. It may be possible to justify the existence of a theoretical true, objective risk, for example associated with a medical treatment, but the estimation is often subject to large uncertainties. The treatment could be relatively new or used in a setting that has not been thoroughly tested. Then we are back to the problems discussed above, with differences in judgments about the risk, among scientists, experts and others. What is misinformation is clearly then more difficult to specify.

For many situations, the idea of an underlying true, objective risk cannot be justified. Climate change risk is an example. Uncertainty becomes a fundamental aspect of risk (SRA 2015; Aven 2020), and the risk measurements and characterizations express these uncertainties. The result is claims about the world (for example climate change), reflecting underlying knowledge and assumptions of the assessors. Again, misinformation is a challenging concept, as there is no true risk to compare. The risk measurements and characterizations need to be discussed, including the supporting evidence (the basis for a belief or statement, in form of data, information, modeling insights, test results, analysis results, etc.) and knowledge (justified beliefs). Presenting some evidence and ignoring others can be viewed as misinformation, but we need to be careful in drawing conclusions about misinformation. There could be different perspectives on the validity of underlying theories and assumptions - theories and assumptions which provide guidance on what are relevant and important evidence. Often there is a selection of evidence supporting some specific beliefs.

The above discussion indicates that the risk perspective influences the way we understand the misinformation concept. We argue in the paper that to adequately address misinformation, it is important to have clarity on how this concept relates to risk. For example, to apply fact-checking, it is essential to understand what facts mean in relation to risk. If there is no truth about risk, how can fact-checking then be justified? The checking can refer to different scientific studies, but the interpretation and selection of these studies are problematic as discussed above. It would require scientific training to review and assess the scientific literature, acknowledging that even highly trained scientists may disagree on the validity of certain findings. As a result, there is large potential for a selection bias in favor of scientific evidence supporting the assessors' underlying perspectives and motivations. We know that science advances as a result of researchers challenging existing thinking. Hence only referring to the beliefs of some scientists would be a dangerous practice if one searches for the best – most justified – knowledge.

The paper is organized as follows. Section 2 presents a structure for classifying misinformation, distinguishing between different risk perspectives. The classification relates to different factors and aspects important for the assessment, characterization and communication of risk. This classification is discussed in Section 3, which also addresses how to confront and reduce misinformation. The final Section 4 provides some conclusions.

2. A structure for classifying misinformation

This section presents a structure for classifying misinformation. In risk communication literature, it is common to distinguish between *misinformation*, m*al-information* and *disinformation*, as different types of information disorder or 'fake news'. Here *misinformation* refers to false information shared without intent to harm (a person, social group, organization or country); *mal-information* is used to express accurate information taken out of context with the intent to harm; and *dis-information*, is knowingly false information shared with the intent to harm (Del Vicario et al. 2016; Mayorga et al. 2020; Wardle and Derakhshan 2017; Balog-Way, McComas, and Besley 2020). In the present paper, we use the concept of 'misinformation' for all of these categories.

In practice it is often difficult, if not impossible, to determine if the information-provider's intent is to harm (mal-information). Consider the case of a medical treatment. A message between the healthcare provider and patient could provide accurate information with the intent to supplement existing information and advocate for a treatment decision. However, there could be some ulterior motive or underlying intent to harm, such as by discrediting a treatment that other professionals believe is promising. It would be challenging to objectively identify the motives of the message. The same types of problems occur when trying to distinguish between misinformation and dis-information. The misinformation concept should not be restricted to 'false information'. The issue is seldom, at least in the risk context discussed in this paper, about the message being true or not, but about selections and representations which can be contested, as will be thoroughly discussed in the following.

The classification system presented below will be based on a distinction between two main categories of misinformation, related to a) risk assessment and characterization and b) risk communication. Risk assessment and characterization refer to the systematic process to comprehend the nature of risk, express and evaluate risk, with the available knowledge (SRA 2015). Risk communication refers to the exchange or sharing of risk-related data, information and knowledge between and among different target groups (such as regulators, stakeholders, consumers, media, general public) (SRA 2015). When referring to key risk science knowledge in the following, a main reference is documents produced by the Society for Risk Analysis (SRA 2015, 2017a, 2017b) and related supporting literature. The SRA documents have been developed by a broad group of senior risk scientists, with input from members of the society.

Table 1 presents the main structure for the classification of misinformation. It is based on a separation between a) and b), as well as between risk perspectives. For clarity, only two risk perspectives are considered, referred to as I and II. The former is based on the idea that there exists a true, objective risk that the analysts and experts estimate. The latter perspective is 'uncertainty-based' meaning that uncertainty is seen as a main component of risk – there is no underlying true, objective risk representing the magnitude of the risk. The two perspectives are discussed in more detail in the appendix.

Osman et al. (2022) provide a study on how people understand the concept of misinformation. Key points are that the concept reflects information that is intentionally designed to mislead, and it is associated with information that exaggerate conclusions from facts, does not provide a complete picture and is presented as fact rather than opinion or rumor. All of these interpretations are covered by the topics addressed in Table 1.

2.1. Type a) misinformation related to risk assessment and characterization

For the risk assessments and characterizations, there are some generic points made, as a result of failure to comply with current risk science knowledge and practice. The aspects listed in Table 1 can be viewed as sources for misinformation. If a basic concept is not properly defined, explained or justified, it can lead to misinformation. For example, presenting the result of a risk assessment using probabilities without explaining what these probabilities mean, can seriously

Table 1. Main structure for classification of misinformation.

	Risk perspective I: There exists a true, objective risk	Risk perspective II: Uncertainty is a main component of risk	Comments
a) Risk assessments and characterizations	Aspects are not in line with fundamental risk science knowledge and practice, e.g. • Basic concepts are not defined, explained or justified • Key assumptions are not reported along with the results • The risk characterizations suppress key risk and uncertainty contributors • Selection of input data to support an agenda • Overconfidence, i.e. having a confidence which is stronger than justified		The reference here is the risk perspective of the assessors
	The concept of a true, objective risk is not explained or justified.	Relatively strong focus on uncertainties	
	The work does not distinguish between the underlying true, objective risk and the estimation of this risk	Relatively strong focus on the subjectivity of the assessment and the characterization of risk	
	Uncertainties in risk estimates are suppressed		
b) Risk communication	Aspects are not in line with fundamental risk communication knowledge and practice, e.g. • Value-laden use of terms • Over-simplification of risk assessments and their results. • Risk assessment results and scientific findings are misrepresented or misinterpreted • Fundamental concepts are not explained • Some risk assessments are highlighted while others are ignored • Restrictions on scientific discourse • Unclear delineation between science and policy-making		The reference here is the risk perspective of the risk communicator
	The interpretation of the risk estimate is not communicated, nor the difference between the underlying risk and its estimate	The risk communication overly focuses on the uncertainties and the subjectivity of the assessment	
	Uncertainties in risk estimates are not communicated	Unclear delineation between professional risk judgments and risk perception, for example communicating risk assessment results as the analysts' perceived risk, or giving too strong weight on people's risk perception	
	Too strong separation between professional risk judgments and risk perception, for example highlighting that the former is science-based and the latter is just feelings and perceptional factors like fear and dread.		
	Confusion about difference between risk knowledge and related decision making, for example communicating the importance of policies based on risk and ignoring the role of management judgment and review		

Type a) misinformation can be rooted in weaknesses, inadequacies, errors, etc. in the professional risk assessments and characterizations. For example, key assumptions are not presented along with the results of the assessment. Type b) reflects misinformation that is more directly linked to the risk communication. For example, media sharing only information supporting a specific political agenda

mislead people when interpreting the result of the risk assessment. Consider reports from the Intergovernmental Panel on Climate Change (IPCC) on climate change risk. It is stated that there is at least 95% probability that most of the global warming trend is a result of human activities (IPCC 2014). However, how to understand this probability is not clear from the IPCC reports (Aven and Renn 2015; Aven 2019). The implication is a potential for misinterpretation and misinformation.

Another issue is key assumptions not being reported along with the results of the assessment. To conduct risk assessments, assumptions are required, for example related to model selection and assumptions. Depending on the assumptions, there can be widely varying results. Not being open and transparent on what these assumptions are, represent a source for misinformation.

A third aspect is risk characterizations suppressing key risk and uncertainty contributors. For example, a risk assessment may present a risk description based on expected values, for example the expected number of fatalities. Using such a metric, risks related to extreme losses may be ignored or given insufficient attention (Paté-Cornell 1996; Haimes 2015; Aven 2012).

Another aspect pointed to in Table 1 is selection of input data to support an agenda. Being a professional risk assessor, there is a goal to have neutrality and not be influenced by ulterior motives or agendas. However, in practice, these goals are not always met. There are often many data sources, and the judgments of relevancy of these sources depend on the assessors' knowledge, but could also reflect the assessors' underlying stances on the issues discussed, such as related to personal value structures.

The fifth and final general point mentioned in Table 1, is overconfidence, i.e. having a confidence which is stronger than justified. The risk assessment balances confidence, expressing for example that an activity is dangerous, with 'humbleness', taking into account that there are uncertainties. The humbleness is a particular issue in relation to the uncertainty-based risk perspective II. As uncertainty is here a main aspect of risk, there is a potential for over-emphasis on the uncertainties. The potential severity of a problem could be overshadowed by the uncertainties. For example, commercial interest could stress uncertainties to an extent that make a dangerous product not easily removed from the store shelves.

Over-confidence is a particular challenge in relation to risk perspective I. Here misinformation may occur if the risk assessment is not clear on the fact that the risk estimations are not risk, but a judgment about risk subject to uncertainties. Limiting the characterizations of the uncertainties to confidence intervals, could be misleading as such intervals address only one aspect of uncertainty – statistical variation related to data. The data could be more or less relevant for the situation discussed, but this issue would not be reflected by a confidence interval - nor would uncertainties in model assumptions.

For this risk perspective, the authority of the risk assessment and its result could be higher than justified as there is a reference to an underlying, true objective risk. By blurring the difference between this risk and its estimate, the interpretation of the assessment and its result could easily be wrong. In some cases, the concept of an underlying true, objective risk is also difficult to define and justify, for example climate change risk. Returning to the IPCC use of the term 'probability of at least 95%' to express that it is very likely that the global warming trend is a result of human activities, it matters a lot whether this is a statement reflecting some objective physical phenomena in the world or whether it is an estimate subject to uncertainties (Aven 2019). As discussed by Aven (2019), the IPCC studies are not clear on this point but indicate in a rather inaccurate way that the probability relates to variation and thus some physical phenomena. In this way the probability statement is given a stronger scientific basis than if we are to interpret the probability as a subjective probability estimate subject to uncertainties (Aven 2019).

We also see this type of imprecision in relation to the distinction between the underlying concept and its measurement in the commonly used ISO standard on risk management (ISO. 2018). For example, according to this standard, likelihood is defined as the chance of something happening, 'whether defined, measured or determined objectively or subjectively, quantitatively

or qualitatively, and described using general terms or mathematically (such as a probability or a frequency over a given time period)' (ISO. 2018). As discussed by Aven and Ylönen (2019) this definition is difficult to understand, as neither 'probability' nor 'chance' is defined. The standard mixes underlying theoretical concepts – like frequentist probabilities – with estimates. For the risk characterization it matters a lot whether the results are about an underlying, true objective risk (probability) or an estimate of this risk (probability).

2.2. Type b) type of misinformation related to the risk communication

Misinformation related to risk communication takes different forms as shown in Table 1. The first point mentioned is value-laden use of terms, for example, using the word 'surge' to describe some quantitative level, suggesting to the audience that the described quantitative level is unacceptably high, discouraging the audience to make their own assessments.

Another example of value-laden use of terms includes wording that implies an idea or perspective has no basis in science, without providing an argument or evidence. This type of behavior can be used to discredit one's opponents. As highlighted in Section 1, science in general stimulates discussion and questions established beliefs and assumptions. While experts may have different conclusions or stances on a scientific issue, this does not justify dissenters to be discredited. As a classic example, consider scientists challenging past civilizations' belief that the earth was flat. What is considered unlikely at some point in time may still happen or be true, as science and expert judgments have limitations in understanding the 'world' and making accurate predictions. Similarly, value-laden terms can also be used to discredit ideas or perspective based on other types of associations, such as whether they have been accepted or endorsed by particular organizations, groups, or scientific disciplines.

Over-simplifying the results of the risk assessments is another type of misinformation, for example by ignoring uncertainties or assumptions. This point is closely related to the next on the list in Table 1: Risk assessment results and scientific findings are misrepresented or misinterpreted. Hansson et al. (2021) provide an example where an Estonian regional news portal late March 2020 published a story titled 'Will the corona epidemic really be over in 2-3 weeks? A British scientist thinks so'. According to this article the leading British epidemiologist, Neil Ferguson, estimated that the epidemic 'will last for 2 or 3 weeks'. It was referred to a publication by Ferguson in the international science periodical New Scientist. However, as noted by Hansson et al. (2021), the New Scientist text actually expressed something very different: that Ferguson was 'reasonably confident' that the UK health service could cope with the spread of the virus when the predicted peak of the epidemic arrived in two or three weeks. The Estonian story clearly misrepresented the words of Ferguson. Hansson et al. (2021) give many other examples of similar type of misinformation in relation to COVID-19, messages that suggested that COVID-19 did not exist or was not severe, that the overall risk of catching it was low, and that the pandemic would end shortly.

Not all cases are as clear as this Estonian regional news portal example. Consider for instance the question about the origin of the Coronavirus. Early 2020, the prominent medical journal, *The Lancet*, published a letter signed by 27 researchers who firmly condemned the idea that COVID-19 did not have a natural origin (Calisher et al. 2020). The letter referred to the idea as a conspiracy theory, and it contributed to a silencing effect on the debate (van Helden et al. 2021). The idea that COVID-19 did not have a natural origin were broadly considered to convey misinformation, i.e. misrepresentation or misinterpretation of current scientific knowledge. Today the question about the origin of the Coronavirus is still debated; non-natural causes are not ruled out (e.g. Maxmen and Mallapaty 2021). It can be discussed whether it was the Lancet letter that represented the misinformation, or the idea that COVID-19 did not have a natural origin.

Another interesting and important example relates to misinformation concerning COVID-19 vaccines. A common health perspective is that this misinformation is fueled by conspiracies and rumors of safety, and the misinformation can strongly influence willingness to follow the recommendations by health and political authorities on vaccination (Montagni et al. 2021). There are, however, many risk issues related to vaccines and vaccinations, related to both the disease and potential side-effects. It is often difficult to decide what are accurate risk characterizations. The authorities may also be biased as they need to balance the need for openness and accurate risk descriptions with the overall goal of getting the majority of people vaccinated. Focus on the risks and uncertainties could scare people from taking the vaccines.

Even though the risk assessment has properly defined all relevant concepts, the risk communication may fail to do so. The reasoning behind this could be that the communicators would like to simplify the results of the assessment. It could also result from inconsistently or imprecisely applying the fundamentals of risk assessment. We refer to the discussion in Section 3 about the IPCC and the probability that most of the global warming trend is a result of human activities.

A main challenge in risk communication is selection of sources. There could for example be many risk assessments conducted for a type of activity, for example a medical treatment. Which studies should then be highlighted? Science often provides a comprehensive volume of findings reflecting a variety of results depending on perspectives and assumptions. For the purpose of a political campaign promoting a specific ('right') view, there will nearly always be evidence available that can be used to serve that purpose. If the 'right' view is to be communicated, the message will be disturbed by science, allowing for uncertainties to be acknowledged and communicated. Institutions exist on the behalf of governments to make overall judgments about what are the most justified knowledge available, but these judgments can be contested as they are to some degree value-based. Simplifying the research message from multiple sources means that some research results could be completely ignored or judged of less importance than other contributions. If the search for a 'right' view is strong, there is a risk that this process will be strongly biased. If media supports this view, they will either contribute to amplify or attenuate the seriousness of the risks, depending on what is the right view. In the former situation, repeated cases and examples will be used to stress the risks, whereas in the latter situation, alternative insights are ignored or given little attention (Kasperson, Pidgeon, and Slovic 2003).

Restrictions on scientific discourse is a current issue in risk communication. An example is newspapers and social media platforms acting as arbiters for what is the truth about scientific issues and practices. In some cases, the media's intention is to secure reliable information, but its restrictions can cause unintended consequences. The restrictions can promote single or few perspectives, undermining the scientific need for critical discourse and discussion. We have seen this clearly demonstrated in related to COVID-19, for example in relation to the issue about the origin of the virus.

As a result, specific views on risk issues can be identified as the only legitimate ones. However, information-seekers may reject the basic pillars that these views are based on despite the fact that the views are referred to as being founded on science. If one view is considered the 'right one', divergent perspectives and research may be removed from communication platforms or made more difficult to trace. Media has the ability to focus on topics, ideas, and discussions that favor particular objectives, which then can influence people, including experts. Such processes can interfere with openness and transparency - which is characterized by an acknowledgement of the limitations of scientific knowledge and a need for a continuous 'battle' between different schools and camps for what are the most warranted statements or justified beliefs within the field of study (Bourdieu and Wacquant 1992). If this 'battle' is removed, there is no real science remaining, but a mixture of science and activism/politics. Openness and transparency is commonly considered a desirable policy of risk communication – it demonstrates respect

for the target audiences and ensures they have the information they need to take risk mitigation actions; it can also help ensure the perceived trustworthiness and legitimacy of the sources (SRA 2017b).

As discussed by Bouder et al. (2015) there has been a change in recent years in the regulatory environment in many areas, in particular in relation to safety, health and environmental issues. The traditional expert-based approach has been replaced by a more transparent and open framework that ensures greater access to data, information and knowledge – a change to a new 'participatory-transparent' thinking with wider stakeholder participation and a trend toward enhancing transparency. People should have the legitimate right to know about the full background of regulatory decision-making. A key driver of this changing policy environment has been the lack of trust in regulators and industry. Bouder et al. (2015) point to the fact that both policymakers and academics agree that transparency is in general something good – if adequately managed, it may improve the communication of benefits and risks. In that perspective, restrictions on scientific discourse, is a highly problematic development.

The tendency to trust in media platforms (both journalism and social media) to perform risk-related assessment and messaging is dangerous, as these risk-related tasks should ideally be performed by experts with the necessary training. The growing practice of media platforms to facilitate sharing of information from non-experts encourages customers of this content to develop their own ideas and beliefs in poorly understood risk-related stances; compromising trust in evidence-based and scientific resources. In many cases, such as related to the COVID-19 pandemic, the actions of the general public play a large role in the magnitude of the risk event, thus the risk attitudes of the general public are critical for risk assessment, management, and communication purposes.

Increasingly, information flow is dictated using algorithms and mined data from multiple technology platforms and other data sources. As information providers gain a vast array of personal information, preferences, and values from studying a user's digital footprint, there is a propensity for information aimed at a user to be catered toward the user's already existing beliefs. Thus, information flows can favor specific stances and ideas while not sharing others. Underlying perspectives, assumptions, and chosen analytic methods within the algorithms may also influence the information flow, when specifying the criteria for selecting what are current and important knowledge about and perspectives on an issue, and what are not.

Finally, Table 1 refers to confusion of science and politics, for example, referring to a policy as science-based when in fact being informed by some scientific findings and ignoring others. The very act of policy-making involves aspects of evidence, judgement, decision-making, and, at times, pursuit of a sufficiently positive public image. Clearly, there are challenges with balancing political activities with the stances of a general public with varying values, stances, information sources, and scientific training.

Next some comments concerning the specific issues listed in Table 1 relevant for the two risk perspectives. If the risk communicator is mainly influenced by a risk perspective of type I, and is seeking to simplify the message from the risk assessments, the result is commonly that the produced risk numbers are presented as the risk – people are misinformed. Uncertainties are suppressed. As an example, think about a risk assessment of a process plant where risk estimates are produced for fatalities among people living close to the plant, as a result of potential accidents. The risk communicator presents the findings from the risk assessment by presenting produced probabilities for various types of events, for example at least x fatalities, and states that these numbers are low and below threshold values for what are commonly considered as safe. The communicator is not stressing that the numbers are estimates of underlying probabilities and risks, subject to uncertainties, nor justifying the existence of these underlying quantities or explaining what they mean. The communicator may be motivated by a conscious desire to demonstrate acceptable risk, but the approach taken could also be a result of a lack of understanding of the importance of being precise on the risk science

fundamentals. Another example is risk characterizations related to vaccines and vaccination, where the analysts highlight the estimates and ignore long term uncertainties and risks.

Risk perception research has shown many examples of what is referred to as misjudgment of risk. This research has shown that when faced with situations characterized by factors such as lack of control, catastrophic potential, delays in effects, new and unknown - often summarized by dread and newness - people tend to raise their risk figures about how likely the actual events are to happen to them, and there is a potential for overreaction (Fischhoff et al. 1978; Slovic 1987; Visschers and Siegrist 2018). Of course, reporting people's actual risk perceptions does not represent misinformation, but if the risk communication presents these perceptions just as feelings and biased judgments, the reporting is imposing value-judgements. There is a potential for misinformation if the communication separate professional risk judgments too strongly from risk perception, for example by highlighting that the former is science-based and the latter is to just feelings and perceptional factors like fear and dread. In contrast to risk perception, professional judgments about risk are not to include feelings. But we also know that risk perceptions can in some cases identify aspects of risk which are not properly reflected by the professional risk assessments. People's concerns could be justified, although the analysts have not yet identified the problem or they have judged it to be unimportant. The point being made is that risk perception is not only about feelings, it can also capture conscious judgements of uncertainties and hence risk. An historical example is the risk related to nuclear power plants, where the experts argued that the risks were relatively small and people's concerns were all about perceptional aspects. However, the risk perception was also capturing important aspects of risk for which the professional judgments at that time basically ignored (Aven 2020; Aven and Bouder 2020).

For perspective II the challenge is more on avoiding a too strong focus on the uncertainties and the subjectivity in the risk assessment results. We can for example think about a case where the risk communicators would like to stress the uncertainties and the weak knowledge supporting the risk assessment numbers beyond a level that are justified from a risk science point of view - the consequences being for example that it is difficult to conclude that the activity considered is safe. Also, these actions may dilute the credibility of the risk communicators. Think again about the vaccination example. Too much focus on the uncertainties could give too strong weight on the risks involved compared to the benefits.

A related potential misinformation for perspective II can occur as a result of unclear delineation between professional risk judgments and risk perception, for example communicating risk assessment results as the analysts' perceived risk, or giving too strong weight on people's risk perception. If the communication too strongly underlines people's risk perception in relation to an activity, and it is not clear on the difference between professional risk judgments and risk perception, there is a potential for misinformation: A too strong risk amplification. As discussed above, it is a judgment call about what is a too strong amplification as the risk perception could reflect also conscious judgments of risk not fully captured by the professional assessments. Yet, an overly strong focus on perceptional factors represents a potential misinformation, which is especially relevant for risk perspective II as the risk concept here is broader and uncertainty is a key element of the risk concept. Theoretically, there is also for perspective II a clear distinction between professional risk judgments and risk perception, but for this perspective misuse is more likely as the knowledge basis for the risk characterizations are broader than typically for risk perspective I.

When building mainly on the risk perspective I, misinformation may also occur if the risk communicator conflates risk knowledge and related decision-making, for example communicating the importance of policies based on risk and ignoring the role of management judgment and review (MRJ). A MRJ is formally defined as the process of summarizing, interpreting and deliberating over the results of risk assessments and other assessments, as well as of other relevant issues (not covered by the assessments), in order to make a decision (Aven and Thekdi 2020). The MRJ is based on the recognition that all assessments have limitations, there are aspects

not fully captured by the assessments. The decision maker needs to take into account *all* aspects of importance for the decision, not only those addressed by the assessments. Most assessments are based on some specific assumptions and beliefs and the decision makers must also consider the validity of these assumptions and beliefs. Stakeholders' values, goals, criteria and preferences provide essential input to the MRJ, but could also strongly influence the definition of the risk issue or problem, as well as the assessments, in particular when performing analyses combining risks, costs and benefits. Returning to the above process plant example, misinformation occurs if the communicators conclude that risk is acceptable or unacceptable on the basis of the quantitative results of the risk assessment. Such a type of misinformation is also possible for risk perspective II, but in general it would be less likely as the perspective highlights the uncertainties and the need for the decision makers to see beyond the risk numbers, i.e. perform a MRJ.

3. Discussion. How to confront misinformation

The discussion in Section 2 is based on a distinction between two risk perspectives I and II, reflecting two important but different stances when it comes to understanding risk. The approach represents a strong simplification of the real world. There exist many different risk perspectives, see e.g Aven (2012). From a theoretical point of view, it is of interest to study misinformation issues when the risk assessors and the risk communicators base their analysis and messages on different risk perspectives as in Section 2. However, in practice, risk assessors and risk communicators to varying degree build their work strictly on a specific risk perspective. The risk science foundation for their work could be weak and represent a mixture of features from different theoretical defined perspectives (Veland and Aven 2013). The structure presented in Section 2 is robust in the sense that many of the misinformation categories are independent of the risk perspective adopted. The specific misinformation elements mentioned in Table 1 that depend on the risk perspectives, are also 'robust' when it comes to the understanding and definition of the risk perspective.

The key point is the distinction between two fundamentally different ways of seeing the world. For risk perspective I, risk exists as an objective property of the activity considered and the risk assessment seeks to estimate this risk. For risk perspective II, uncertainty is a main component of risk. Depending on the degree for which the assessors and communicators tend to base their thinking and practice on these main lines of ideas, the findings in Section 2 are relevant. Suppose for example that a risk communicator lacks a proper understanding of risk concepts, or mixes various risk science ideas about these concepts (Veland and Aven 2013). Then, misinformation of different types is likely to occur even if the risk assessment is based on a strong foundation with precision on concepts, analysis and risk perspective. In the case of a risk assessment built on risk perspective II, a risk communicator with weak knowledge of risk fundamentals would struggle to communicate the results in a meaningful way without extensive support from the risk assessors. As a concrete case, let us return to IPCC example mentioned in Section 2.1. If the probability interval (at least 95%) is to be interpreted as an imprecise subjective (knowledge-based) probability, the associated risk communication is challenging and requires a strong risk science competence to be able to explain these concepts clearly and effectively. For this particular example, the messaging is even more unclear due to weaknesses related to the risk assessment foundation (Aven and Renn 2015; Aven 2018, 2019), and therefore creating potential for serious misinformation issues.

When there is focus on risk perspective I, the risk message is often more clear and understandable as conclusions are made with respect to the 'real risk' of the activity considered. However, the downside is that there is larger potential for misinformation issues. The assessment and communication do not present the real risk, but instead estimates of this risk; and often this is not explained. Justification of the existence of a real risk is also often missing, giving a

false impression that the risk assessment results have stronger authority than can be scientifically defended.

The two perspectives resemble the distinction between a positivistic and social constructivist perspective on risk (Renn 1991; Rosa 1998). There are, however, important differences. When defining the risk perspective I and II, we make a clear distinction between the concept of risk and how risk is measured, described, or characterized. A positivistic perspective highlights the existence of a true and objective risk, an aspect of the world, as shown with risk perspective I. However, risk perspective I acknowledges that the risk measurements, descriptions, or characterizations are judgments made by analysts and hence are not objective. These risk measurements, descriptions, or characterizations are not comparable to the risk perceptions of individuals. According to the social constructivist perspective, risk and risk perception are basically the same. There is no separation between reality and our perception of reality (Rosa 1998). In the same way, risk perspective II differs from a social constructivist perspective as it is based on a clear distinction between risk as a concept, professional judgments of risk, and risk perception. Professional judgments are subjective, depending on the assessors, but follow strict rules according to risk science and do not include perceptional factors like fear and dread as risk perception does. The positivistic idea is rejected, as is the complete relativism of the social constructivist perspective.

Starting from the misinformation types identified in Section 2, we next discuss how we should best meet this challenge. For the risk assessments and characterizations issues, the obvious response would be to strengthen the fundamental risk science knowledge and practice among risk analysts. This leads us to a discussion about training and education in risk science and in particular on risk assessment. The topic is addressed by Thekdi and Aven (2021) and Aven and Thekdi (2022). A key message is this: Today there are rather few study programs in risk science at our universities worldwide. There are many courses on risk-related topics offered in areas like engineering, business, etc., but these courses focus on the application of risk science, not as much on foundational topics of risk science. With increased focus on core foundational topics, there is opportunity to increase professional competencies in risk science, improving standards for high quality risk assessments and characterizations, thereby confronting the misinformation issues listed in Table 1, for example related to the definition, explanation and justification of basic concepts.

To illustrate the problem, consider the notion that risk is defined by expected loss (simplified, risk is equal to probability times loss) as mentioned in Section 2.1. For most situations, using this definition of risk could seriously misinform decision makers because important aspects of risk and uncertainties are not covered. Despite the fact that risk science provides strong argumentation for seeing beyond expected values in risk assessments, practice shows that this risk metric is commonly used in applications. Training in risk assessments highlights various methods that can be used to analyze and calculate risk, but the training may not be updated on current generic risk science knowledge. Risk science today is not broadly recognized as a distinct science, and this generic knowledge is not sufficiently visible to have an impact on the many applied programs and risk courses. To meet this challenge, efforts should be placed on strengthening risk science at our university and colleges, highlighting the current risk science knowledge to benefit for all types of applications and domains using risk concepts, principles and methods.

There can be different views on what is the most suitable risk perspective in a specific context, but clarity on the basic ideas and pillars of a selected perspective is required if the risk assessment and characterizations are to adequately inform decision makers. Many of the misinformation points listed in Table 1 can be traced back to lack of such clarity, for example that the work does not distinguish between the underlying true, objective risk and the estimation of this risk. Again, we consider strengthening the risk education as the most important measure in a longer perspective to meet this challenge.

For the risk communication issues, a similar response is required. Improved training and education is the key to strengthening the fundamental risk communication knowledge and practice. As the items listed in Table 1 indicate, this training and education needs to address specific communication issues, but also basic knowledge on risk assessments and characterizations of risk. As discussed in Section 2.2, to communicate risk, the communicators need to understand the fundamentals of risk and risk assessment. The risk communicators also need to understand the policy and decision-making context in which the risk messages are applied. This motivates education in risk science that provide students with knowledge in different risk related topics, in line with the concept of risk analysis introduced by Society for Risk Analysis 40 years ago capturing risk assessment, risk characterizations, risk perception and communication, risk management and policies on risk (SRA 2015, 2017a). As an example, consider the risk communication challenge in relation to COVID-19. To be able to communicate the risks related to this disease, competence is required on what this risk means, how a proper risk characterization should look like, how uncertainties should be dealt with, what are important issues to take into account when forming risk messages, and how the risk knowledge could best be used in a policy context. One person cannot be an expert on all topics of risk, but a risk communicator should have some basic knowledge in all of them as they are important for understanding the risk and communicate the risk adequately informing the public, experts and others.

Due to the newness of the risk science field, it is a challenge that few degree programs are offered, leaving a market to different types of applied certification arrangements and schemes, for example based on international standards. However, these standards are to large extent based on consensus-oriented processes and not science, refer to discussion in Aven and Ylönen (2019). Hence, care must be shown in equating competence on risk science with knowledge on the substance of a specific standard. For example, the well-known ISO standard 31000 on risk management (ISO. 2018), provides a highly problematic guidance on risk conceptualization and characterization (Aven and Ylönen 2019).

As discussed in Section 2.2, there is a balance between addressing misinformation and promoting discourse. Scientific progress is promoted by challenging current ideas, understanding differences of perspectives, and promoting dialogue. Restrictions on the dialogue related to risk issues can suppress misinformation. However, these acts of suppression may lead to amplification of misinformation in other competing communication channels. Without a balance of perspectives, ideas, and 'truths', a risk-polarized climate can be created, causing information-seekers to increasingly mistrust information sources, recognizing that information-seekers may also be experts or voting citizens who have control over policy decisions. As an example, consider information providers sharing information that aligns with particular values and political stances. The information field outside of a risk context may interpret these issues with a lens that addresses broader concepts such as freedom of speech. These issues are highly relevant for risk science, as a knowledge field on risk and uncertainties, which represent basic pillars for the understanding and communication of scientific processes and results.

The scientific community on risk needs to promote dialogue about risk, noting that scientific ideas and principles should be founded on science, that are independent of political issues. Risk science is about developing concepts, principles, approaches, methods and models to understand, assess, characterize, communicate and handle risk. It is politically neutral, in the sense that it has no political stances. It can be *used* for different purposes, also political, but as risk analysts and scientists, our role is to be neutral. If our work is influenced by our political stances, we can instead be viewed as activists.

It is concerning to the risk field that risk professionals are asked to promote neutrality in a professional setting while also maintaining personal activities as whole individuals with value-based stances on very politically charged issues. It becomes difficult to separate the role as professional risk analyst or scientist versus the personal value-based perspectives. Thus, there are challenges with avoiding all potential misinformation sources of Table 1, but as risk analysts

and scientists this remains our goal. In their statements about ethics, the Society for Risk Analysis (SRA) is clear on this:

- 'Conduct their work with objectivity and themselves with integrity, being honest and truthful in reporting and communicating their research and assessments.
- Abstain from professional judgments influenced by undisclosed conflict of interest and disclose any material or professional conflicts of interest' (SRA 2020).

As community on risk and related concepts, we need to work on clarifying what objectivity and neutrality here mean in practice. The present paper can be viewed as a contribution to this discussion, highlighting different types of misinformation that may conflict objectivity and neutrality in the work conducted. We need as a community to develop more guidelines for 'high quality risk analysis' giving due attention to this type of issues.

Fact-checking instruments have been popular in recent years, trying to verify what are facts and what are not. In relation to risk topics, this is a problematic instrument in many cases. As discussed in this paper, what is a fact or not is not always trivial to decide as a truth may not exist and there are difficult interpretational issues. There are also issues with allowing single actors to decide what is labeled as the truth, as discussed in Section 2. What is required is a type of critical trust, balancing reliance and some degree of skepticism (Poortinga and Pidgeon 2003; Fjaeran and Aven 2021). A blind reliance on the truth being presented by the authorities or other information sources is potentially dangerous; individuals can be misguided. Too much skepticism is of course also dangerous, as important findings and guidance could be ignored. As a community on risk science, we should highlight the importance of finding this balance between reliance and skepticism, in line with basic ideas of scientific discourse.

An illustrating example is the communication in relation to the coronavirus. An issue of great importance but subject to scientific uncertainties, is whether or how a region can achieve herd immunity. Highly respected experts on the virus have gradually updated their views on the basis of scientific developments, but also due to consideration of what people would 'be ready to hear' (NYT. 2020). There are obviously many concerns that need to be taken into account when communicating about risk issues; the goal of full openness and transparency is just one. This fact demonstrates that a critical trust attitude is needed.

4. Conclusions

Misinformation in relation to risk is a challenging concept. There are trivial cases, for example when it is reported that a medical treatment is safe when in fact there are many studies showing the opposite, or when it is concluded that a treatment is not safe having manipulated the underlying data. Looking at the list of misinformation types presented in Table 1, many of them can be seen as trivial in the sense that they are rooted in violations of fundamental risk science and communication standards, for example key assumptions are not reported along with the results and value-laden use of terms. Yet such misinformation is commonly experienced. We argue in this paper that training and education is essential for meeting this challenge. However, there also remain larger issues with information-sharing, promotion of scientific dialogue, and balancing misinformation with suppression of discourse.

As risk analysts, scientists and communicators, there is a code of conduct based on integrity, ethics and professionalism, that seeks the scientifically best risk characterizations and communication messages. This implies awareness of all types of misinformation, and is aimed at avoiding or reducing them to the extent possible. It means clarity of the fundamentals of risk science and in particular on what risk means and how it relates to uncertainty and knowledge.

The risk community needs to promote these values, and react to actors using risk analysis instruments to misinform and misguide people and decision makers. Given the realities, a critical trust attitude is the ideal to balance the need for reliance on science and authorities on the one hand and the need for some level of skepticism on the other. A fundamental feature of scientific processes is scrutiny of current beliefs and assumptions, and hence open dialogue about scientific issues is necessary for scientific progress and development. As individuals we need information about risk from experts, but the experts are not one voice, there are different 'schools' and perspectives. Similarly, individuals making judgments about the magnitude of the risks and concluding what are the best decision, rely on scientific knowledge communication, but are expected to think individually reflecting relevant information and knowledge, as well as personal values.

Finally, there is need to note that the broad issue of misinformation is of importance across scientific disciplines, in addition to risk. While there are benefits and downsides to vetting information flows, disciplines must acknowledge that barriers to information flow have changed drastically in recent years. The communication issues discussed in this paper are not limited to aspects of journalism and social media. For example, even the peer review process of academic publishing can be circumvented, as with the case of online repositories of non-reviewed papers. Similarly, consider academic journals questioning legitimacy of peer reviewed content based on controversy over the use of basic statistical concepts, such as with p-hacking. With increasing access to information and near instantaneous sharing of information, the issues discussed in this paper will continue to grow in visibility and importance. Now is the time to acknowledge and address these issues.

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Appendix

Risk perspectives I and II

This appendix gives some further details about the two risk perspectives discussed in this paper, perspective I and perspective II. Key references are SRA (2015), Aven and Reniers (2013) and Aven (2020).

For risk perspective I there is presumed and underlying true risk, expressing some type of propensity of negative consequences due to the activity considered. This propensity is in general not always easy to give an exact interpretation, but it is commonly expressed by frequentist probabilities and probability models. For example, in the medical treatment case mentioned in Section 1, there is a risk related to side-effects, defined by the fraction of people experiencing side-effects when using this treatment. The risk can also be defined by a probability distribution of the severity of the side-effects, for example expressed by the number of fatalities. To be more specific, let N be the number of fatalities as a result of side-effects in the defined period of time. Then risk can for example be defined by the frequentist probability that N is greater than n, for different values of n. In general the frequentist probabilities are unknown. Using statistical methods and risk analysis, we estimate the frequentist probabilities and address uncertainties related to what are the true values of these probabilities.

In many situations frequentist type of probabilities are difficult to justify. Think about the frequentist probability that the global temperature increase will exceed 2 degree Celsius above the pre-industrial level within a ten year period. However, this statement has no meaning, as we cannot repeat the world over and over again under similar conditions which is required to define a frequentist probability (Aven 2020).

Risk perspective II rejects the idea that there exists an underlying, true objective risk. Uncertainty is a main component of risk. It is acknowledged that the magnitude of the risk and risk characterizations in general are assessor dependent and can to very degree capture and adequately represent and express the uncertainties. Intuitively the risk according to perspective II is the potential for negative consequences of the activity considered. If climate change is the issue, and life on the earth the activity, there is risk as there is a potential for damages and loss related to human life and health, the environment and economic values due to climate change. Thus the risk concept captures two basic elements: consequences of the activity and associated uncertainties about what these consequences will be. Risk assessment is about predicting these consequences and assessing the uncertainties. The assessment reflects the knowledge of the assessors, and as knowledge is justified beliefs (SRA 2015), it can be more or less strong and even wrong. To adequately describe or characterize the risk, probabilities (subjective, knowledge-based) – precise or imprecise - can be used to measure the uncertainties and express degrees of belief. The knowledge supporting the probabilities should however always be added, as well as judgments of the strength of this knowledge. A subjective probability can always be assigned, however the basis for it can be more or less strong. When frequentists probabilities and probability models can be justified they can also be used in perspective II. The quantities do not then express risk, but an unknown fraction of an infinite population of repeated similar situations.