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PERSPECTIVE

Risk literacy: Foundational issues and its connection to risk science

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Abstract

A new research area is developing, risk literacy. The term "risk literacy" basically refers to one's ability to understand and evaluate risk, in order to support and make appropriate decisions. In this article, we discuss how risk literacy relates to risk analysis/science with its topics of risk fundamentals (concepts), risk understanding, risk assessments, risk characterizations, risk perception, risk communication, and risk handling (covering risk management, risk governance, and policies on risk). We question how issues and research topics addressed in risk literacy relate to risk analysis/science knowledge, particularly on risk understanding. The main conclusion of the article is that risk literacy addresses an important topic—from both a theoretical and a practical societal relevancy perspective—and brings the potential for many additional developments and further insights if the topic is better integrated with risk science knowledge more broadly.

KEYWORDS
foundational issues, risk literacy, risk science

1 | INTRODUCTION

We all face risk in our daily lives—health risk, transportation risk, security risk, financial risk, and many others. Risk literacy is about understanding and evaluating these risks, in order to make proper decisions—it is about how to accurately interpret and act on information about risk and uncertainties (Cokely et al., 2012; Gigerenzer, 2012; Lusardi, 2015; Nikiforidou et al., 2012; Richard, 1993; Risk Literacy, 2023; Till, 2014). Its focus is on individual risk and decisions for researchers and professionals in fields like business, health, and law, as well as members of the public and children and young people. Considerable risk literacy work addresses public health issues, but the term is general and the literature includes examples from a variety of application areas, including finance, transportation, and ecological risks.

As an example, think about a disease and a statement expressing that the probability of contracting it is 0.1%. What does this statement mean? Is the number high? In what way would this information influence my decisions, for example, when it comes to vaccination? These are questions that are addressed in work on risk literacy. Considerable interest has been devoted to this area in recent years, mainly by psychologists. The focus has been on probabilistic and quantitative thinking.

Understanding and evaluating risk, and risk-related decision-making, can all be seen as core subjects of risk analysis and risk science. "Risk analysis" is here understood in a broad sense in line with a long tradition in the Society for Risk Analysis (SRA) to cover risk assessment, risk characterization, risk perception, risk communication, and risk management (which includes risk government and policies on risk) (SRA, 2015), or reformulated as in SRA (2017a), to cover fundamentals (concepts), risk assessment, risk perception and communication, risk management and governance, and solving real risk problems and issues. Risk science refers to the most updated and justified knowledge—in the form of concepts, principles, theories, models, approaches, and methods—for understanding, assessing, characterizing, communicating, and managing risks with applications (Aven, 2018a; Aven & Zio, 2014; Hansson & Aven, 2014). It is also about the *practice* that gives us this knowledge. To simplify,

TABLE 1 Definitions of some key literacy concepts.

Term	Definition
Risk literacy	- How to understand and evaluate risks, in order to make proper decisions - How to accurately interpret and act on information about risk and uncertainties
Science literacy	- An individual's knowledge and understanding of scientific concepts, phenomena and processes, and their ability to apply this knowledge
Health literacy	- The ability/capacity to obtain, process, and understand the basic information and services needed to make appropriate health decisions

the article refers in the following to risk science, meaning risk analysis and risk science.

The fact that risk literacy can be considered covered by risk science constitutes the point of departure for the present article: There is a potential to strengthen the risk literacy work by including risk science knowledge currently not addressed by this work. In addition, vice versa, research on risk science can be enhanced by better incorporating insights obtained into risk literacy.

As an example, think about the use of probabilities to express risk. Risk science explains how probabilities are to be interpreted, and how they relate to risk, uncertainty, and knowledge. Risk literacy can use this insight in its research, to obtain alternative and broader theoretical frames and explanations, for example, when performing tests on how people understand, evaluate, and handle risks. Reversed, risk literacy knowledge on statistical numeracy issues provides fundamental insights useful for characterizing and communicating risk assessment results.

When referring to risk science knowledge, the main source will be concepts and principles summarized by documents produced recently by the SRA (SRA, 2015, 2017a, 2017b) and related scientific work. The SRA documents have been developed by a group of senior risk analysts and researchers with different types of competencies, with input from members of the society.

Risk literacy is closely related to science literacy and health literacy, see Table 1. There are many definitions of the science literacy term, but basically it refers to an individual's knowledge and understanding of scientific concepts, phenomena and processes, and their ability to apply this knowledge (e.g., Feinstein, 2011; NASEM, 2016). There have also been many suggestions for defining health literacy (e.g., Berkman et al., 2010; CDC, 2023; NASEM, 2016). The main idea of the concept relates to the ability/capacity to obtain, process, and understand the basic information and services needed to make appropriate health decisions. There is a considerable literature on both science literacy and health literacy.

Risk is a key scientific concept, and understanding science is also about understanding risk. As such, the risk literacy field provides input to science literacy knowledge. Vice versa, science literacy work provides input to risk literacy. It can be discussed whether risk literacy is to be seen as a subfield of science literacy, as there are aspects of risk literacy that are not really about scientific concepts and information, at least for some interpretations of science. Consider, for example, the issue about how to interpret and act on a risk signal in a situation characterized by large uncertainties. Thus, when pointing to a potential for risk science work to strengthening risk literacy, it may include also science literacy but not necessarily.

Similarly, it can be argued that risk literacy work provides input to health literacy knowledge, and health literacy work provides input to risk literacy. Restricting risk to health issues, risk literacy can be viewed as a subfield of health literacy.

The article is organized as follows. Section 2 clarifies what risk literacy is relative to basic topics of risk science, following up on Section 1. Four topics are studied in detail: the concept of risk, probability and knowledge, risk understanding and evaluation, and risk decision-making, all topics central to the concept of risk literacy. Section 3 discusses how to proceed to better integrate risk literacy and risk science and provides some conclusions. Suggestions for how to follow up the theoretical analysis and findings of Section 2 are presented, including a list of potential topics for conducting empirical risk literacy research (Table 2) based on these findings. The present work points to theoretical risk science knowledge that provides opportunities for further risk literacy research and development.

This perspective article can be viewed as conceptual risk research, as in Aven (2018b), covering concepts, principles, theories, models, approaches, and methods, for understanding, assessing, communicating, and handling risk. Reasoning and argumentation are the key instruments. As discussed in MacInnis (2011), this type of research builds on elements such as identification, revision, delineation, summarization, differentiation integration, advocating, and refuting. The following examples illustrate these elements for the research in this article:

- Identification: To identify risk literacy–relevant topics where risk science knowledge can provide new ideas and perspectives.
- Revision: To reinterpret the definition and understanding of the risk literacy concept.
- Delineation: To clarify what risk literacy includes and not, and how risk literacy is linked to related concepts such as health literacy and science literacy.
- Summarization: To state the main issues and points concerning risk literacy and risk science knowledge.

- Differentiation: To distinguish between alternative definitions and interpretations, for example, on the concepts of risk and probability.
- Integration: To build the article on a perspective on risk science allowing for the integration of risk literacy knowledge and risk science knowledge.
- Advocating: To argue for the rationality of seeing risk literacy knowledge as providing input to risk science, and vice versa.
- Refuting: To rebut the idea that risk literacy is mainly about understanding probabilities and numbers.

As mentioned above, the SRA documents (SRA, 2015, 2017a, 2017b) and related research provide the reference when referring to contemporary risk science knowledge. There is clearly a subjective element in deciding what this knowledge covers; this is recognized, but a reference is required to clarify the premises for the discussion and conclusions made.

2 | CLARIFYING WHAT RISK LITERACY IS RELATIVE TO THE BASIC TOPICS OF RISK SCIENCE

This section discusses the risk concept, probabilities and knowledge, understanding and evaluating risk, and risk decision-making.

2.1 | The risk concept

In risk literacy work, reference is made to different ways of understanding the concept of risk, but the main focus is on risk as probability together with impact (e.g., Cokely et al., 2012; Till, 2014). The risk framework adopted aligns with the well-known Knightian dichotomy between risk and uncertainty (Knight, 1921), where risk relates to known, objective probabilities, whereas uncertainty covers situations where such probabilities cannot be derived—the probabilities need to be assigned or estimated on a subjective basis. The risk literacy work is strongly linked to economic and psychological theory on decision-making under risk, which is mainly concerned with quantitative probabilistic and statistical analysis and thinking.

The risk concept is fundamental to the understanding of risk literacy and the related research. How to properly understand and evaluate risk depends on what risk is. Risk science has devoted considerable efforts to studying the conceptualization and characterization of the risk term, using different types of criteria, including how various definitions match typical daily-life phrases, validity (to what degree one measures or characterizes what one sets out to measure or characterize, here risk) and usefulness (the degree to which the concept serves the purpose of the study in the context in which it is to be applied). As the present author reads the literature, the conclusion is that there is a need to see beyond the Knightian perspective on risk, to properly address risk. In general, we face risk related to an activity when there is a potential for undesirable consequences of the activity, which means that uncertainty is a key component of risk (Aven & Thekdi, 2022; SRA, 2015). Probability is a way of expressing or characterizing these uncertainties, but probability is just a tool and does not capture all relevant risk aspects. By making a distinction between the concept of risk and how it is measured and described, questions will be asked regarding how good the risk measurements and descriptions are. These questions relate to, for example,

- the amount and relevancy of historical data, the reasonability of assumptions made, and the accuracy of models used (2.1).

Traditional statistical methods are, to varying degrees, able to reflect risk and uncertainties associated with such questions. As an example, think about the coronavirus risk of March 2020; early risk assessment studies indicated a death rate of 1:100 if strong measures were not implemented (Adam, 2020; Biggs & Littlejohn, 2021). Risk literacy is about understanding and evaluating numbers like this, in order to make proper decisions. However, this cannot be meaningfully done without also taking into account uncertainties. From a risk science perspective, 1:100 can be viewed as a prediction of the fraction of people that will die due to the coronavirus, and, to reflect the uncertainties, different types of uncertainty intervals could be used. Risk science provides knowledge about how to do this, taking into account factors referred to in the statement (2.1). The point made is that interpretation and evaluation of the numbers cannot be meaningfully conducted without understanding how the numbers relate to risk, which aspects of risk are reflected, and which are not. Adding an uncertainty type of interval would improve the risk characterization, but there is also a need to extend the understanding and evaluation beyond this interval, as it is not able to reflect all aspects of the uncertainties. The issue is discussed in risk literacy work but is typically restricted to quantitative probabilistic perspectives. Risk science considers all types of frameworks that are relevant to characterizing the risk, also including quantitative and semi-quantitative ones (e.g., Aven & Thekdi, 2022; SRA, 2015, 2017b).

Considerable risk literacy work is focused on public health issues, where risk is traditionally associated with frequentist probabilities—the fraction of people of a large population having a specific feature. We will discuss this in more detail in Section 2.2. The key point made by risk science is that—to adequately understand and evaluate risk and properly support decision-making—it is necessary to see beyond probabilities, for both frequentist and subjective types.

2.2 | Probability and knowledge

Probability is a key term in the risk literacy literature, but it is seldom precisely defined. In most cases, it is tacitly

understood that probability refers to a frequentist probability. Formally, a frequentist probability of an event A is the long-term fraction of times the event A would occur, if we could repeat the situation considered over and over again infinitely. The probability is normally equated with fractions in large populations of similar units for which the event A occurs. The probability relates to the future, but in practice a sharp distinction between the unknown future fraction and observations is not made. In theory, the distinction captures the difference between the probability and the estimation of this probability. To properly interpret the numbers (e.g., the ratios, fractions, percentages, or decimals), this distinction is essential, as risk relates to the future, and there is a fundamental gap between what we have observed and what could occur. For situations with huge volumes of relevant data, vagueness or imprecision on this point is not a problem, as the data provide accurate estimates of the future fractions.

However, in many situations today, there are uncertainties regarding the degree to which the data would provide good predictions for the future. The world is changing in many ways, and stable processes are hard to find outside test laboratories. Different approaches can be used to characterize and communicate the uncertainties, as discussed in the previous section. Risk science provides guidance. Risk literacy cannot be achieved without adequately addressing the uncertainties. Restricting the risk literacy issue to historical frequencies alone could seriously misrepresent the risk and misguide decision makers.

Risk literacy work has traditionally focused on health issues, where large populations of similar units can be defined. However, understanding and evaluating risk to make proper decisions is relevant to all types of applications, including when frequentist probabilities are not relevant or easily justified. If the risk of a particular patient is the center of attention, averages, as expressed through frequentist probabilities and their estimates, may be of less interest. Still, probability can be used to express risk, but this would be a different type of probability compared to frequentist probabilities. Whereas the latter probabilities reflect variation, the former type of probability expresses uncertainties and degrees of belief—we call them subjective or knowledge-based probabilities. Given the knowledge available, a physician could, for example, express the probability that a patient will completely recover following a specific treatment to be 0.90. Risk science explains how to interpret this type of probability (Aven & Reniers, 2013; Lindley, 2006; SRA, 2015). An urn type of illustration is commonly used: The physician's uncertainty and degree of belief in this event (full recovery) being true is comparable with randomly drawing a red ball out of an urn comprising 10 balls of which 9 are red. If the statement had referred to a probability of at least 0.90, either 9 or 10 balls would be red, the assessor would not like to be more precise. We speak about an imprecise probability.

Many issues that are linked to this type of probability are discussed in risk science, for example, the link between the probability and the supporting knowledge. Here, knowledge refers to justified beliefs, founded on data, information, tests, modeling, argumentation, etc. The probability cannot be seen as separate from the knowledge and its strength. For the decision makers, it matters a lot whether the probability is assigned based on strong or weak knowledge. There is a transformation from the knowledge to the probability, which is more objective for imprecise than precise probabilities, but less informative. The question about information value is also about the knowledge supporting the probability assignment. Think, for example, about a probability specified on the basis of one expert with rather limited competence on the topic discussed. Then, an objective transformation could be obtained from the expert's judgment to an imprecise probability, but the strength of the knowledge could still be poor and highly subjective. For the risk interpretation and evaluation, it is essential to know this.

There is an opportunity for risk literacy work to discuss issues linked to these probabilities and related knowledge. The main question would be to explore and research how people interpret, evaluate, and act upon risk, given this type of risk perspective in different settings. Different types of applications could be studied, including security and climate change. Based on this type of work, normative guidance could be provided on how the probabilities and knowledge should be presented. Risk science is concerned with such questions, but more research is needed, and contributions from the risk literacy field are highly welcome. One particular issue that would be interesting to study is how knowledge strength is and should be expressed. Common approaches relate the strength of knowledge to factors that include the following (Aven & Thekdi, 2022; Flage & Aven, 2009; refer also to the statement (2.1) in Section 2.1): the reasonability of the assumptions made, the amount and relevance of data/information, the degree of agreement among experts, the degree to which the phenomena involved are understood and accurate models exist, and the degree to which the knowledge K has been thoroughly examined (e.g., with respect to unknown knowns; i.e., others, but not the analysis group, have the knowledge). As risk researchers, we should ask how such factors are interpreted and to what extent they capture the essential aspects of knowledge.

Subjective probabilities have not been much addressed in the risk literacy literature. Different types of interpretations exist (Aven & Reniers, 2013), and it is common to relate these probabilities to Bayesian analysis. However, such probabilities exist and can be used without placing them in a Bayesian updating context, where posterior subjective probabilities are derived on the basis of subjective prior probabilities and probability models. For a risk setting, knowledge-based probabilities, together with the supporting knowledge, represent a key tool for expressing uncertainties and degrees of belief. Bayesian updating can be useful in some situations but not in others. The main problem is the fact that probability models may not be justified. Bayesian analysis also lacks judgments of the strength of the knowledge (Aven, 2020).

Risk science aims at clarifying these issues, but making proper and easily understandable risk characterizations is not

straightforward. Risk literacy studies could provide valuable insights in this regard.

2.3 | Understanding and evaluating risk

Risk literacy is about understanding and evaluating risk. The understanding depends on how the concepts of risk and probability are interpreted, and how these concepts are measured or described, as discussed in Sections 2.1 and 2.2. There is an additional component, risk perception, meaning a subjective appraisal of risk that can involve social, cultural, and psychological factors (SRA, 2015). People may perceive the risk as high because they dislike the uncertainties and fear the potential consequences. Such aspects are not reflected in professional risk judgments. Considerable research has been conducted showing the type of factors that influence people's risk perception. A key finding is that, in many cases, people tend to overestimate risks, depending on factors like dread and newness (Kahneman, 2011; Slovic, 1987, 2016). The reference for this type of conclusion is typically historical data. Examples commonly referred to are terrorism risk and side-effect risk related to vaccination. Based on the data, the probability of an undesirable event could be judged as minuscule and the risk as negligible, and vaccine hesitancy, for example, would be to assign an inordinately high "decision weight" to this tiny risk/probability (Aven, 2015). The problem with this analysis is that the individual risk is not determined by hindsight, observing historical numbers. At a given point in time, an objective risk metric for a specific person does not exist. The statement that the individual risk is minimal can be questioned, as risk relates to the future and the future is not known. Hence, care must be shown in concluding that the associated behavior is wrong or irrational (in a wide sense of the word), as a way to determine the truth about risk at the decision point does not exist. In many cases, there is no well-defined objective probability that can be used as a basis for a proper decision weight. The type of thinking referred to fails to take into account the uncertainty dimension of risk. Risk science provides insights into these issues that are critical for the proper understanding of the risk.

Differences between expert judgments about risk and people's risk perception are commonly explained by the fact that people's risk perception is influenced by feelings, in contrast to professional judgments about risk. Risk science makes it clear that people's risk perception can also capture conscious judgments of uncertainties (Aven, 2015). Many examples can be provided, where uncertainties were ignored by the professional risk assessments but covered by the lay people's risk appraisals. A good example is the risk related to nuclear power plants in the 1980s and 1990s (Aven & Thekdi, 2022; Goble, 2021).

Risk science provides clarity on these issues, by showing the importance of uncertainties and the related knowledge when measuring and describing risk (Aven & Thekdi, 2022; SRA, 2015, 2017a). In many cases, people may have good reasons for questioning issues linked to these uncertainties. If the risk analysts build their risk judgments on a "narrow" perspective on risk, they may be tempted to downplay such questioning, considering it to be influenced by feelings and not the result of conscious judgments of uncertainties and risk.

In general, it can be argued that the knowledge gap between experts and laypersons is widening, as the world becomes increasingly more complex which requires special competence and insights. The above discussion shows that laypeople's risk judgments and perceptions could still provide useful input to understanding risk and making proper decisions. Proper frameworks are needed to adequately take into account risk perceptions in risk management and governance. Risk science develops and presents such frameworks (e.g., Renn, 2008).

The risk literacy work is to a large extent founded on the risk perception and decision analysis school of thought, with a strong foundation in psychology. Research on risk perception is an integral part of this work, with considerable focus on biases in people's risk judgments. There is an opportunity for further insights by extending this work to also cover risk science knowledge on alternative risk perspectives that can explain differences between risk perception and professional risk judgments, as discussed above.

Risk evaluation can be seen as the process of determining the significance and acceptability of the risk (SRA, 2015). Is the risk high or too high? The discussion in this section has shown that the risk evaluation would strongly depend on the risk understanding. But there are additional factors to be taken into account. If we conclude that the risk is too high and unacceptable, we need some references. These references could be common established standards in society or risk levels that are normally accepted. There is a risk associated with driving a car, and if you accept this risk, it will be difficult to argue that the risk of traveling by a commercial airliner would represent an unacceptable risk from a professional risk assessment point of view. We can all agree about the health risks related to smoking, but still some people accept the risk. It is about differences in values. The risk evaluation becomes more challenging when the uncertainties are large, as then there is a need to give weight to the importance of the uncertainties. The weight is about values, and they differ between people.

Risk science provides knowledge on risk evaluation along these lines, which should also provide a basis for the risk literacy work. If the focus is on cases like travel by plane, the discussion would be rather simple, as the knowledge supporting the risk characterizations is so strong. However, in many situations in society, there are considerable uncertainties, and the risk evaluation becomes more challenging.

Risk science considers the risk evaluation as a stage of the risk assessment. The risk assessment is conducted by the risk assessor, who often is different than the decision maker. If the risk assessor is not the same as the decision maker, there is a leap between the risk assessment and the decision-making. This gap is commonly referred to as the decision maker's review and judgment (DRJ)

(Aven & Thekdi, 2022; Hertz & Thomas, 1983). It 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 & Thekdi, 2022). The DRJ is based on the recognition that not all aspects are fully captured by the assessments—all assessments have limitations. Risk science distinguishes between risk evaluation, as conducted by the assessor, and the DRJ, conducted by the decision maker. Clarity on the difference between these two evaluations is critical for the consecutive decision-making, to be discussed in the following section. Again, the present article argues that there is a potential for risk literacy work to develop enhanced analyses building on risk science knowledge—here, this separation between these two types of evaluations.

2.4 | Risk and decision-making

Risk literacy highlights the decisions; it is about understanding and evaluating risk to make *proper decisions*. But what is a proper decision when facing risk? Consider the following example (inspired by Aven, 2023).

You wake up and feel dizzy. You have not experienced this type of dizziness before. You had planned to go on a long drive today, but now you think this trip should be canceled, as driving in this condition would be risky. You assess the risk to be too high.

You think about specifying some probabilities, but it is difficult, as the knowledge about this dizziness is so weak. But let us assume that you nevertheless assign the probability of a car crash to be at least 10% if you choose to drive. It is an imprecise probability, yet you consider the assignment rather arbitrary and lacking rationale.

In risk science, the reasoning associated with not driving can be said to be based on weight given to the precautionary principle. The principle applies when we are faced with potentially serious consequences of an activity, such as the car trip here, and there is fundamental, "scientific" uncertainty related to what these consequences will be (SRA, 2015). In that case, the principle expresses that measures must be taken to reduce the risk or refrain from carrying out the activity. In the car example discussed here, it is the last thing you choose to do. The key is that you do not know what causes this dizziness, and you do not want to drive until it is gone. You decide to take it easy for a day and consult a doctor if the dizziness does not disappear during the day. The uncertainties can be referred to as fundamental because you do not know what is causing the dizziness.

Most people would probably agree that this is a sensible strategy for dealing with this situation. It is about understanding and evaluating risks to make proper decisions, and hence about risk literacy. However, it is not the typical case addressed by the risk literacy literature, as there is not much data. This example demonstrates the need to see the decision aspect of risk literacy in relation to risk science and the topic of management policies and strategies.

Next, let us consider a case where there is considerable data, on the COVID-19 disease and the related vaccine. Risk literacy is about understanding and evaluating the risk of getting ill (and potentially dying) due to COVID-19 and the risk related to side effects of the vaccines, and then making adequate decisions, for example, on whether to take the vaccine or not. Numbers are presented to characterize the risks, but providing guidance on what to do clearly needs considerations beyond the numbers, as discussed in previous sections. The acceptance of the vaccine has been based on testing, and there are well-established methods for how to conduct these tests using statistical theory. The common approach used is randomized trials, where the participants are assigned to either the treatment or the control group. The statistical analysis compares the probability of an event occurring (infection, serious illness) in the treatment group in relation to the probability of the event in the control group. Risk literacy provides knowledge on how to interpret this type of analysis. It is an important task, as it is not trivial for people who are not statisticians. Based on this guidance, people will be better informed to make a decision. Many examples exist where this type of guidance changes attitudes and behavior; see, for example, Rebitschek et al. (2022).

In practice, understanding and evaluating the risk is more difficult than interpreting the statistical data and concepts. One issue is potential long-term effects that the tests do not reflect, whereas another is the different variants of the virus, leading to uncertainties about the validity of the original tests for the future. Consider the following example from Norway in December 2021. The focus was on the omicron variant, and the Norwegian Institute of Public Health (FHI, 2021) conducted a scenario analysis that laid an important basis for the government's COVID-19 treatment in early 2022. The scenario analysis showed four scenarios for how many hospital admissions there could be in Norway in the coming months due to the coronavirus. The numbers were all high, and the two most serious scenarios gave alarming figures. If these were to prove correct, it was clear that strong measures would have to be taken.

It turned out that the actual hospital admissions did not match these scenarios very well. The scenarios were too pessimistic—the two most serious were nowhere near the actual number hospitalized. From a risk professional point of view, the analysis was problematic because it presented four scenarios without relating these to risk, probability, knowledge (strength of knowledge), and assumptions—the four scenarios could be perceived as having the same importance. The strong uncertainties were highlighted, but, summarizing the key message, the FHI (2021) report showed a risk characterization in which two out of four scenarios were extremely worrying. Differences in probability and strength of knowledge were not adequately described and communicated. The analysis was based on a critical assumption that the consequences of the omicron disease were almost as serious as those of the delta variant. This was, however, a

very pessimistic assumption. Studies in South Africa showed that omicron was far milder in consequence than the delta variant.

Risk science is concerned about situations like this, and how risk should be best characterized and communicated. Had the study been based on a stronger risk science foundation, risk would have been presented in a completely different way than it was—far more nuanced. One can speculate as to whether this would have changed the government's and people's decisions, but there are good reasons to believe so. There is no doubt that many people, including young people, chose to take a vaccine booster as a result of the authorities' strong recommendations at this time. Now, one can ask whether these recommendations came as a result of mischaracterization and miscommunication of the risks we faced at the time.

Risk literacy is, per definition, concerned with this challenge, how to understand and evaluate the risks. It addresses the issue of interpreting the scenarios and all the supporting data and information, and that also includes evaluations of the degree to which the scenario approach adequately characterizes the risk. Hence, risk literacy is concerned with the same basic questions as risk science. Guidance on taking the vaccine based on the FHI (2021) report was problematic, as risk was not properly characterized.

The risk literacy literature focuses on understanding and evaluating risk, in order to make proper decisions. Although risk communication is not highlighted, it is a closely related topic as the above example illustrates. Risk communication provides insights on exchange/sharing of risk-related data, information, and knowledge between and among different target groups (such as regulators, stakeholders, consumers, media, and general public) (SRA, 2015). For some key references summarizing current risk communication knowledge, see Balog-Way et al. (2020), Burger et al. (2022), and Aven and Thekdi (2022).

The issue of communicating uncertainty with the public has been thoroughly discussed in the literature (see Balog-Way et al., 2020). Research points to advantages and pitfalls communicating uncertainties. The main benefit pointed to is that the uncertainty communication contributes to enhancing transparency, increasing legitimacy and credibility, and helping building public trust. Other researchers argue, however, that the uncertainty communication may do the exact opposite, unintentionally eroding public trust, reducing confidence in messengers, and decreasing transparency by hiding issues under complex risk information. Burger et al. (2022, p. 2468) indicate that people who have the responsibility of communicating with the public commonly express not to focus on uncertainty.

The risk communication literature provides an extensive knowledge source for dealing with this issue. In all sciences, there are discussions about what is the most justified knowledge. The present author will argue that uncertainty needs to be communicated if risk is to be communicated, as uncertainty is the main component of risk (Aven & Thekdi, 2022). The question is not about including uncertainty, but how to do this in the best possible way. Risk science discusses this issue and provides guidance (e.g., Aven & Thekdi, 2022; Balog-Way et al., 2020; Burger et al., 2022). The COVID-19 pandemic has demonstrated the need for uncertainty to be adequately communicated to the public. We have seen many examples where health officials and politicians have presented risk statements completely ignoring uncertainty, for example, expressing that vaccines prevent you from becoming infected and getting COVID-19. Such statements are highly misleading, as the situations considered are not deterministic.

The fact that likelihoods and knowledge change over time represents a challenge for the risk communication, and related decision-making. An example is the risk related to the COVID-19 during the period 2020–2022. Health experts struggled to characterize and communicate what risk levels people were facing beyond historical data. How would new virus variants and vaccines influence the risk? These are difficult questions to answers, but risk science provides useful input, reflecting changes in knowledge. However, seldom or never have we experienced informative risk levels being communicated at press conferences and other public settings where the COVID-19 risks were addressed.

3 | DISCUSSION AND CONCLUSIONS

As the present author reads the risk literacy literature, it is strongly influenced by (i) probability theory, data analysis and statistics, and (ii) risk perception research and decision analysis, in addition to pedagogical knowledge on how to present different types of information. This is not surprising, as most people working on risk literacy seem to be psychologists, and (i) and (ii) are two common frameworks used by psychologists. The present article argues that there is an opportunity to enhance the risk literacy work by building on risk science knowledge. This knowledge extends beyond (i) and (ii) in many ways. Section 2 has pointed to some examples where there is a potential for new insights, by building on concepts, principles, theories, models, approaches, and methods studied in risk science.

Current risk literacy work focuses on the interpretation of probabilistic and statistical terms, biases in risk understanding leading to errors in reasoning, and poor decision-making. Risk science provides additional knowledge on the fundamentals of risk, related in particular to the concept of risk and its characterization, and associated risk handling and communication. These fundamentals are not captured by (i) and (ii). Compared to the standard setup of the risk literacy, the risk science knowledge provides new perspectives on risk situations characterized by a lot of data, as well as situations where such data are lacking. The risk science knowledge opens the door to risk literacy discussions for situations with varying levels of uncertainty. In practice, uncertainty is a key factor in understanding risk. The frameworks commonly used by the risk literacy work have been based on Knightian thinking that

TABLE 2 Examples of topics for conducting empirical risk literacy research following up the conceptual findings identified in Section 2.

Suggested aspect to address in empirical research	Comments
Seeing uncertainty as a key component of risk	See Section 2.1
Clear and precise definitions of probability	See Section 2.2
Using the urn model to explain a subjective probability	See Section 2.2
Seeing risk characterizations as dependent on assumptions	See Sections 2.1, 2.2, and 2.4
Include judgments of the strength of knowledge supporting the probabilities	See Sections 2.1 and 2.2
Clarifying the difference between professional judgments of risk and risk perception	See Section 2.3
The difference between risk evaluation as a part of a risk assessment, and a risk evaluation conducted by the decision maker (decision maker's review and judgment)	See Section 2.3
How the precautionary principle influences the decision-making	See Section 2.4
Seeing scenarios in relation to risk	Refer to the COVID example in Section 2.4

reduces the scope and applicability of risk judgments. To be able to use risk literacy knowledge on current issues, uncertainty needs to be taken into account beyond uncertainties of probabilistic parameters. Risk science builds on a perspective where uncertainty is a component of risk. This perspective has implications for the risk characterization, risk communication, and risk handling, as indicated by the discussion in Section 2 and thoroughly studied in the risk science literature.

In this way, risk literacy work can be strengthened. Conversely, work on risk science can be enhanced by better incorporating risk literacy knowledge. Understanding and evaluating risk to make proper decisions is a core topic of risk science. Risk literacy has provided valuable insights on this topic, especially on analysis and experimental work testing ways of visualizing risk and pointing to pitfalls in the understanding and handling of risk. The present author considers the work in relation to children and young people to be of special importance. It should be a goal for risk science to better incorporate risk literacy work into study programs, textbooks, and research. With improved interactions between risk literacy and risk science more broadly, the knowledge on understanding and evaluating risk to make proper decisions can be substantially improved. Initiatives should be taken to develop research projects and activities involving researchers and analysts from both risk literacy and risk science traditions, to address issues and topics as discussed in this article.

The above discussion also applies to science literacy and health literacy. To read and understand scientific information and results—in general and for health applications in particular, there is a need for clarity on basic concepts like probability, uncertainty, knowledge and risk, and their relationships; and risk science provides insights on this that extends beyond what is commonly seen in science and health literacy contexts. Vice versa, there is also a potential for developing new insights on risk science, using science literacy and health literacy knowledge. In contrast to the risk literacy that has an individual view focus, the scientific literacy and health literacy also highlight organizational and societal perspectives (CDC, 2023; NASEM, 2016). As for all scientific fields, there are different stands within the science literacy field on science and the scientific process, and in particular on how nonscientist should think in relation to these issues (e.g., concerning scientific facts, scientific methods, and uncertainty). Risk science provides perspectives to the discussion with its work on fundamental issues linked to knowledge and uncertainties, and how to adequately represent and express these concepts, challenging the ideas underpinning some of the stands of the science literacy field. The risk perception discussion in Section 2.3 illustrates the point. Scientists claim the risks are low by reference to scientific studies, but according to risk science, the issue of understanding risk extends beyond interpreting the numbers produced in the quantitative risk assessments.

The scientific literature includes many articles integrating science literacy and risk perception knowledge (e.g., Kahan et al., 2012). These contributions are rooted in both science literacy and risk science. There is a potential for related research studies that also include other aspects of risk science than risk perception, including fundamental topics of risk science as have been focused in the present article. An interesting research question would be how science literacy impacts not only risk perception, but also risk science more broadly.

It is to be acknowledged that there is a gap between what we know (risk science knowledge) and what the public, elected officials, and journalists know and understand. The article has addressed many issues that are relevant to bridging this gap. More specifically, the article makes the following suggestions:

(1) Conduct empirical research using conceptual findings as discussed in the present article, including tests addressing issues as in Table 2.
(2) Use of new technology to support research and development in the field, in particular tools for visualizing and communicating risk and uncertainties.
(3) Development of a special issue of *risk analysis* addressing how to explain risk and uncertainty to elected

officials, journalists, public audiences, etc., and in particular how to use graphics, tables, etc. for this purpose.

(4) Development of SRA guidance documents on such topics, in line with the SRA (2015, 2017a, 2017b) articles.

(5) Call for surveys about risk literacy, addressing current issues (e.g., related to climate change, health, or technology) and building on risk science knowledge as discussed in Section 2.

Concerning (1), Section 2 has pointed to several theoretical issues that should be followed up by empirical work. Tests should be conducted, for example, to see how people interpret and understand a risk concept where uncertainty is the main component, and if a change in the risk definition influences the decision-making. Another interesting topic is to study how precision on the probability concept can influence the risk literacy. The testing will give input on what works in practice and what the main challenges are. It will give feedback on the applicability of the concepts, principles, models, and methods as well as stimulate modifications and innovations in the theoretical developments. In this way, it can contribute to bridging the gap between theory and practice in risk science.

When it comes to (5), the point is to improve our knowledge about how people interpret and understand risk and related concepts. To be successful in this, it is essential to base the studies on a strong risk science platform, which clarifies the meaning of all relevant concepts and their relationship. There is a need for close collaboration between experts on risk literacy, risk communication, and risk science fundamentals.

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