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On the gap between theory and practice in defining and understanding risk

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A B S T R A C T

The risk concept is used in all types of situations and applications, ranging from technology to medicine and security issues. Many definitions of the concept exist, and there is an ongoing discussion on what is the most suitable way of defining and understanding the concept. In recent years, several overriding frameworks have been developed, aiming at providing conceptual clarity and structure and including most of the existing definitions as special cases. A key feature of these frameworks is that uncertainty is a main component of risk. Risk science literature and recognized societies and organizations have actively promoted these frameworks and definitions. Nonetheless, applied risk analysis and management is characterized by all types of definitions and understandings of risk, many that go back to conventions made several decades ago. It can be argued that there is a considerable gap between contemporary risk science knowledge and the practice of risk analysis and risk management in these areas. This paper discusses why we have this gap, why it is important to close it and how this can be achieved. A main goal of the paper is to refute the claim that the gap is due to a disconnection between risk science and the application of risk science.

1. Introduction

The author of the present paper conducted numerous risk assessments in the 1980s and 90s in the Norwegian petroleum industry. As risk analysts, we followed well-established practices for conducting the risk assessments. A cornerstone of the practices was probabilistic analysis based on detailed models and calculations, with results in the form of risk metrics like PLL (potential loss of lives) and FAR (fatality rate). We defined and characterized risk by these metrics. Assumptions were included in an appendix, for example expressing that no hot work activity will be conducted and no rotating equipment will be in use in the operational phase, and the planned maintenance program will prevent equipment deterioration for the time interval considered.

We had the 'know-how knowledge' of how to conduct risk assessments; we were skilled risk assessors according to current practice in that industry. However, the quality of this practice could be questioned. For example, we did not really address uncertainties. Some general statements about uncertainty were always made, but uncertainty was not discussed in any thorough and systematic way beyond the probabilities and expected values presented and the listing of the assumptions made. The issue of potential surprises and the unforeseen was not addressed. Considerable risk science knowledge existed at this time about these issues. We did not, however, possess that knowledge when conducting the risk assessments. We lacked this 'know-that knowledge'.

This example serves as a point of departure for the present paper. In our studies, there was a gap between risk analysis and risk science knowledge and how risk was assessed and characterized. Such gaps existed then, and they exist today. This relates to many aspects of risk analysis and science (covering risk understanding, risk assessment, risk communication and risk handling). The focus of this paper is on the definition and characterization of risk – the risk understanding. In the 1980s and 90s, it was common to think of risk as a function of probabilities and consequences, especially in technology and engineering contexts, but other types of definitions were also common, as discussed for example in Aven (2012a). Several of these alternative perspectives pointed to uncertainty as a fundamental aspect of risk. Also, when risk was defined based on probabilities, uncertainty was highlighted to properly conceptualize and describe risk; see for example Kaplan and Garrick (1981) and Paté-Cornell (1996). Returning to the example above from the 1980s and 90s, we as analysts gradually become aware that our practices were not updated with respect to the then current risk science knowledge. At the same time, we struggled to find theory and frameworks that we could use to meet the challenges we faced in our practical risk assessment and management work. We identified a need for research that could better guide us on how to conceptualize and characterize risk.

Since then, new knowledge – in the form of concepts, principles, frameworks, approaches and methods – has been developed, meeting the challenges then raised about how to improve the understanding of risk. Theories and frameworks have been developed that aim to provide conceptual clarity and structure, integrating existing definitions and perspectives. One such theoretical framework is described by work conducted by the Society for Risk Analysis (SRA) (SRA 2017, 2018a,b), founded on research conducted over the last 20–25 years (see, e.g., Rosa

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1998, IRGC 2005, Renn 2008, Aven and Kristensen 2005, Aven and Thekdi 2022).

Now, questions have been raised regarding the extent to which current practices are in line with current risk science frameworks (e.g., Røyksund and Engen 2020, Heyerdahl 2022, Zio 2018, Aven, 2020). A gap has been identified between contemporary risk science knowledge and the practice of risk analysis and risk management, when it comes to understanding of the risk concept. The present paper looks more closely into this issue; it discusses what this gap is about, why it exists, why it is important to reduce or close it and how this can be achieved. There are many reasons for the gap between theory and practice. To a large extent, the theoretical frameworks developed are a result of needs identified in practice. The developments have been motivated by applications and conducted in close collaboration with users. So why is it so challenging to connect the theories and frameworks to the applications and daily risk assessment activities?

Considerable scientific work has been carried out on the relationship between theory and practice. The challenges concerning – and tensions between – theory and practice represent a common issue, relevant to many types of disciplines and fields (e.g., Weick 2001, Kaufman 2003, Van de Ven and Johnson 2006, Roth et al 2014). We seek new insights for the risk field by using this knowledge, as well as general insights provided by change management. The risk field and science can be seen as comprising two main areas: generic risk analysis and science, and applied risk analysis and science (SRA 2018a, Aven, 2018). The theoretical frameworks referred to above contribute to generic risk analysis and science, whereas a specific risk assessment that is conducted constitutes applied risk analysis and science. In the above example from the 1980s and 90s, applied risk analysis and science raised questions about generic risk analysis and science knowledge. The result was research and development in generic risk analysis and science, aiming to meet the challenges raised in applications. From this research and development, new theory for how to understand and characterize risk – with guidance for the applications – is provided. As such, it can be argued that there has been a close connection between applied and generic risk analysis and science on this issue.

The paper is organized as follows. Section 2 provides a short summary of relevant risk science knowledge, highlighting risk definitions and characterizations. Section 3 gives an overview of the practice of risk analysis and risk management when it comes to risk understanding. Then, Section 4 discusses issues as introduced above concerning the gap between theory and practice, with a focus on clarifying what this gap is about and what we can and should do to reduce this gap. Finally, Section 5 provides some conclusions.

2. Risk science knowledge

In science, there is always a discussion about what is the most justified knowledge. So, also, for risk science and concerning the question about how to understand the concept of risk. The present paper builds strongly on recent documents by the Society for Risk Analysis (SRA, 2017, 2018a,b) and related scientific work. The SRA papers have been developed by a group of senior risk researchers and analysts with different types of competencies, with input from members of the society. However, other frameworks and perspectives will also be discussed in the coming analysis.

The present paper discusses risk theory in relation to practice, which requires clarity on what this theory is. Section 1 and the previous paragraph provide some background for why the SRA-related work constitutes a relevant platform for this discussion. SRA is a worldwide society on risk analysis and risk science, and the fact that broad consensus has been established on some key concepts and principles, gives the work authority as a scientific perspective defining what theory means. As noted above, the discussion in the paper also covers other perspectives, but it would have been difficult to discuss the gap between theory and practice without having a specific perspective as the point of departure for the discussion.

The SRA documents refer to different definitions of risk and different ways of describing risk. In its broadest form, risk can be conceptualized as (C,U) or (A,C_A,U), where C are the consequences of the activity considered, U associated uncertainties (what will C be), A events, and C_A consequences given the occurrence of A. Following this conceptualization, risk can be described by (C',Q,K) or (A',C_A',Q,K), where A' and C' are the specified events and consequences, respectively, C_A' the specified consequences given the occurrence of A', Q is a measure or description of uncertainty, and K is the knowledge that the risk assessment is based on. Commonly, Q is represented by probability P – precise or imprecise – but it is also recommended to add judgments of the strength of the knowledge (SoK) supporting the probability judgments. Using this terminology, we can see risk as the combination of an event's risk contribution (A,U) and vulnerability (C,U|A). See Appendix A for further details explaining this risk perspective. Appendix B presents a list of symbols used in this paper.

This set-up provides a pillar for a risk framework for risk science covering knowledge on understanding, assessing, characterizing, communicating and handling risk (e.g. SRA 2017, 2018,a,b, Aven and Thekdi 2022). Many other risk definitions and frameworks exist. Here is a short resume, to a large extent based on Aven (2012a).

A considerable number of publications refer to the triplet (A,C,P), interpreted as for (A,C,U) but with probability in place of uncertainty. The perspective is founded on quantification of risk, using probability. A common basis for this perspective is the quantitative risk definition introduced by Kaplan and Garrick (1981) – the triplet covering scenarios (events), their consequences and related probabilities. In some cases, the focus is on a specific type of event, and risk is then understood as the probability of this event.

A related perspective sees risk as an expected value. It goes back to Abraham de Moivre more than 300 years ago (de Moivre, 1711) and summarizes the probabilities, using the centre of gravity of the probability distribution of C. The definition is considered appropriate in some cases, as the expectation approximates the average when considering a number of similar activities (by the law of large numbers). A variant of this definition is the expected (dis)utility, E[u(C)], where u is a (dis) utility function reflecting the decision maker's risk aversion or risk-seeking attitude.

It is also common to refer to risk as event & vulnerability, event & exposure & vulnerability, and multiplications of these factors suitably interpreted (e.g., SRA 2017, Peduzzi et al 2009), where the event is referred to as a hazard or threat.[1] Using the (A,C_A,P) terminology, risk is considered a combination of the event A and the vulnerability, typically expressed by (C,P|A) or E[C|A], i.e., the probability distribution of the consequences, given the occurrence of the event, or the expected consequences, given the occurrence of the event, respectively. To multiply the event and vulnerability, the event is replaced by the probability of occurrences of the event, P(A), leading to an unconditional expected value equal to P(A) × E[C|A], tacitly assuming that we can ignore the probability of two or more events in the time interval considered. Similar formulae are established using the exposure concept, for example, an expected value taking the form P(event occurring) × P (exposure of object | event occurring) × E[damage | event and exposure].

In security contexts, it is common to consider risk through the triplet threat, values and vulnerability (Amundrud et al 2017, PST 2023). Using the (C,U) terminology introduced above, values are implicitly defined by the consequences, as these consequences – and the vulnerabilities – are

[1] In this paper hazards and threats, when suitably phrased, are considered examples of events A. Theories and frameworks exist distinguishing between risk sources and events, where the hazards and threats are seen as risk sources, see for example Aven (2012b). For the purpose of the discussion in the present paper, this distinction is not considered critical.

with respect to some values. Hence, the approach is basically about threats and vulnerability (A & V). The vulnerability concept captures aspects of uncertainty/probability related to C; consequently, these definitions see beyond (A,C_A). The literature also refers to definitions of risk based on A and C. Examples includes the Rosa (1998) definition, which basically expresses that risk is A, and the IRGC (2005) definition, which relates risk to C; see discussion in Aven et al (2011) and Aven (2022), which also discuss related definitions.

In economics and business contexts, particularly for investment projects, it is common to refer to risk as uncertainty, and the variance is used as a metric to express the uncertainty. It is also common to distinguish between risk and uncertainty using Frank Knight's understanding of these concepts (Knight 1921). Following Knight, risk is present when an objective probability distribution can be obtained; otherwise, we face 'uncertainty'.

Risk research also refers to risk as the same as risk perception (Jasanoff 1999, Douglas and Wildavsky 1982). Beck (1992, p. 55) concludes that "because risks are risks in knowledge, perceptions of risks and risk are not different things, but one and the same.".

Finally, a reference is made to a pragmatic perspective that provides no recommendations on how to define and understand risk but argues that different situations call for different approaches. This perspective acknowledges that there are different views on how to understand the concept of risk and has no ambitions to integrate these or provide general recommendations on how risk should be conceptualized or described. Different researchers and applications need to choose the perspectives found appropriate in the situation considered.

From a risk science point of view, it can be argued that there should be continuous research aiming at developing the best – the most justified – knowledge on relevant issues, including the way risk should be conceptualized and described. As such, it can be argued that this pragmatic perspective does not acknowledge risk science as a generic science aiming to develop such knowledge. Alternatively, the perspective can be seen as acknowledging risk science as a contributor to improved knowledge on these issues but leaving it up to the individual analyst or application to select the definition or framework to adopt in a specific case, seeing recommendations and practices established as equally informative as risk science insights.

Considerable research has been conducted to justify the (C,U) type of risk perspective. Arguments are provided for why this type of conceptualization is preferrable to, for example, the alternative perspectives referred to above. It is beyond the scope of the present paper to give a full account of the argumentation; the reader should consult, for example, Aven (2012a, 2021, 2023a). The argumentation is based on quality evaluations capturing aspects like validity and usefulness. Validity relates to the degree to which we actually measure or characterize what we set out to measure or characterize: here, the risk. Uncertainty is an aspect of validity, as it relates to potential deviations between unknown quantities and the related estimated, predicted or assigned associated quantities. Usefulness concerns the degree to which the definition or framework adopted serves the purpose of the study in the context in which it is to be used. Key points to consider here are the degree to which the perspective used provides a suitable platform for communication of the seriousness of the risks and provides relevant decision support. Another criterion used is the degree to which the definitions and framework are in line with daily language concerning risk and related concepts.

In the coming sections, we will, however, point to some of the main arguments used. A key message is that the (C,U) risk perspective is a general framework which includes most of the other perspectives and definitions as special cases, stressing that different metrics and characterizations are needed to adequately express risk in specific situations. To define risk in general as expected value is difficult to justify, but acknowledging the expected value as a metric that can be informative in some cases is something else.

It can be questioned whether it is in fact a strength of a theory (perspective or framework) that it is general and including others as special cases. If the generality makes it vague without sufficient details to make it useful in practical situations, the theory would not be attractive. It can, however, be argued that the (C,U) perspective meets this challenge, by its clear separation between the concept and its description. When it comes to the concept, there are some underlying generic ideas supporting the perspective, motivated by the fact that risk is a generic term used in all types of applications. For the description, the perspective allows for and stimulates different ways of assessing, measuring and characterizing the risk, reflecting the specific situation considered. In this way the theory is flexible and inclusive, but at the same time it is restrictive in the way that it builds on these fundamental ideas. Science stimulates discussions of these ideas. 'Allowing' all applications to develop and define their own risk conceptualization and characterizations would be counterproductive in the same way that it would be for for example mathematics and statistics not developing generic, fundamental knowledge on concepts, principles, theories, models, approaches and methods.

3. The practice of risk analysis and risk management, with respect to risk conceptualization and characterization

Today, there is no broad agreement on how to define and understand the risk concept; all the definitions referred to in Section 2 are used. Papers and books on risk – and practices of risk assessments and other studies of risk – use different definitions and compute risk in different ways. There are differences between application domains, like engineering, health, business, climate change, etc., but also within these domains, different understandings of the risk concept are seen. The trends presented in Aven (2012a) are still considered appropriate for describing the developments in definitions and understanding over the years. Today, we find risk definitions based on (C,P), (A,C_A,P), A, C, (C, U), (A,C_A,U) and more, including pragmatic perspectives that provide no recommendations on how to define and understand risk – the idea being that different situations call for different approaches.

The ISO 31000 standard on risk management (ISO 2018) is commonly referred to and used in practice. It is based on an uncertainty-based perspective on risk. This standard defines risk as "the effect on uncertainty on objectives". Although questions can be raised about the precision level of this definition (Aven and Ylönen 2019), it supports the idea that uncertainty is a main component of risk, and probability is a tool used to express this uncertainty. There is no scientific foundation justifying the ISO risk definition, as there is for the (C,U) framework, yet it is commonly referred to in applications and even in scientific publications. The ISO 31000 standard states that risk is usually expressed in terms of risk sources, potential events, their consequences and their likelihood. As such, the standard points to a risk characterization similar to (A,C_A,P). Likelihood is then 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). The standard emphasizes that likelihood is meant to be broadly interpreted, in contrast to a more narrowly interpreted mathematically based probability concept.

As discussed in Aven and Ylönen (2019), the uncertainty characterizations guidance in the standard is not scientifically sound. In the standard, likelihood is defined through 'chance', but the 'chance' concept is not defined. The ISO standard mixes underlying theoretical concepts – like frequentist probabilities – with their estimates, as well as specifications of subjective (knowledge-based) probabilities. There is a gap between the ISO recommendations on this point and the risk science characterizations (A',C_A',Q,K). ISO 31000 basically refers to the same approach for describing risk as that in the 1970s and 80s, despite considerable new knowledge developed in risk science on this topic in recent years.

Among practitioners, there are different understandings and views concerning what risk means and how it should best be characterized. Below, two examples are provided, the first from security applications, the other from the petroleum industry. The examples have been selected as they provide informative illustrations of some of the key issues addressed in the paper.

Heyerdahl (2022) has interviewed security professionals and civil servants, most of them working with risk assessment policy (public or as standards) and/or conduct risk assessments. Only a few of the interviewees had an academic education in risk studies. Many of the interviewees were skeptical about using probabilities, the main argument being that the information and knowledge needed to specify them are lacking: the probabilities cannot be estimated in a meaningful way.

Considering threat and vulnerability (A&V), the focus is on the vulnerabilities and what one can do to deal with the threats. This gives strong incentives for implementing security measures, which is appreciated by some of the interviewees. Security professionals think that if vulnerabilities are present, these will be exposed, and measures are consequently needed. As such, the terms 'possibility' and 'potential' are more adequate than probability. Enemies will look for weaknesses and use them. Security as a concept is commonly seen as absence of unwanted incidences. Looking into the future, there is, however, uncertainty about this absence; hence, we are led to the risk concept capturing consequences (undesirable events) and uncertainties.

However, other interviewees find that, without addressing the threat probabilities, risk is judged too high, and it is difficult to justify that some threats should be disregarded because they are so unlikely. The threats could have severe consequences, but it could be difficult and/or very costly to implement vulnerability-strengthening measures. Among security practitioners, it is common to express the view that some values should be protected no matter what. However, this perspective is easily refuted, as certainty is not possible – and measures significantly reducing the vulnerabilities could be extremely costly in some cases – if possible at all.

The next example is from the petroleum industry, following up the discussion in Section 1. In 2015, the Petroleum Safety Authority Norway (PSA-N) changed the definition of risk from (C,P) to (C,U), using the terminology from Section 2. According to the PSA-N (2016), the main reason for the change was to contribute to an improved understanding of risk in the industry by obtaining a stronger focus on and highlight of uncertainties and knowledge aspects of risk in risk assessment and risk management processes (Røyksund and Engen 2020). Through the new definition, the PSA-N aimed at obtaining a better match between the intentions of the regulations and the industrial practice. PSA-N (2016) pointed to a practice of rather 'mechanical' assessments based on probabilities and expected values, ignoring or giving too little consideration of uncertainties, for example as a result of deviations from assumptions. The PSA-N has introduced the new risk definition in the guidelines of the regulations, as a way of influencing the industry through means rather than applying legally-binding regulatory requirements.

The change in risk perspective has changed the industry practice to varying degrees (Røyksund et al 2016, Røyksund and Engen 2020). Both authorities and industry have faced challenges in implementing the new definition, for example on how to assess and characterize the risk in line with the new perspective. A key question discussed has been the degree to which uncertainty should be assessed and treated in the risk assessment and, in particular, how uncertainty would affect the use of risk acceptance criteria. To meet these challenges, PSA-N and the industry have developed relevant guidance (e.g. ON 2015, 2017a,b, PSA-N 2016, 2018), and many 'roll-out' events and activities have taken place to inform and discuss the definition and its implications for the practice of risk assessment and management.

Yet the degree to which practice has changed is open to discussion. A factor used to explain the problems of implementing the new definition is the difference in risk perspective between the petroleum regulation guidelines and industry standards. Some of these standards build on a traditional probabilistic understanding of risk. Another factor is the lack of clarity on the operationalization of the uncertainty-based risk perspective into the regulatory strategies and industrial risk management (Røyksund and Engen 2020). The change was referred to as 'merely an adjustment' but, at the same time, as important for the proper assessment and management of risk. If the change was 'merely an adjustment', there would be low expectations of the change being particularly influential for the regulatory practices. But why then make the change at all? The other view expressed that the change represented something new, with strong implications for how to conduct and use risk assessments. This latter view is illustrated by regulatory audits that concluded on non-conformity due to lack of systematic assessments and treatments of uncertainty (Røyksund and Engen 2020).

Finally in this section a remark about the discrepancy often found in practice between how risk is claimed to be defined and how it is actually reported in the assessments. It is common for example to see risk formally defined as an expected value, but the risk assessments describe risk using FN-curves and risk matrices which are not warranted by the risk definition. The discussion in this paper is concerned about both dimensions, the claims and the actual approach. What matters the most is of course the actual assessments and reports. When there is a discrepancy of this type, it is commonly a result of a lack of or a weak risk science foundation, as was the case in the example from the 80s and 90s referred to in Section 1. Uncertainties are often analyzed and discussed in the risk assessments, even if there is seemingly no trace of uncertainty in the definition of risk. The term 'seemingly' is here used, because, if for example risk is defined by an expected value or using probabilities, uncertainty is in fact reflected as probability P is a measure of uncertainty. However, if the risk definitions are built on frequentist probabilities, the risk assessments produce estimates of these probabilities and uncertainties of these estimates then need to be analyzed and discussed for the assessments to be solid and informative. In practice such analyses and discussions are conducted to varying degree. Using a frequentist probability basis for the risk conceptualization and characterization, we are led to an alternative risk perspective to the (C,U) perspective. This perspective is applicable only in some situations as frequentist probabilities cannot be defined for unique events. The strengths and weaknesses of this risk perspective is thoroughly discussed in Aven (2012a, 2021, 2023a).

4. The gap between theory and practice: What it is about, why is it important to close it and how this can be achieved

There is a gap between theory and practice in many, if not all, disciplines and fields. Risk analysis and risk science are not an exception. The previous sections have provided examples of what this gap is about. This section aims to provide a more thorough and deeper analysis of the issue. The section also discusses why it is important to close/reduce this gap and how it can be achieved.

4.1. What is the gap about?

To be able to provide clarity on what the gap between theory and practice is about, there is a need to clarify what theory and practice refer to. As discussed in the previous sections, there are no straightforward answers.

4.1.1. Risk science theory

If we consider theory as risk science knowledge, the term refers to the best knowledge – the most justified beliefs or statements – available on the conceptualization and characterizations of risk. The present study considers this knowledge to be represented by the SRA documents, and related research, as discussed in Sections 1 and 2. For all sciences, there is discussion on what is the best knowledge; however, for the purpose of the present study, it suffices to use this understanding of risk science as the basis for the discussion. Using this reference for theory, the paper allows for a comparative discussion between theory and practice. The discussion will be specific on some of the issues addressed but, for the most part, general, with insights also applicable to other interpretations of the theory used as a reference. For the petroleum example discussed in previous sections, the SRA documents and related theory for the risk conceptualization and characterization represent a natural point of reference, as the regulation guidance is based on the (C,U) risk perspective.

4.1.2. Practice

Next, we need to clarify what is the practice we would like to compare the theory with. In general, we can say that the practice is the way that risk is conceptualized/characterized in specific applications. The literature shows that this practice varies considerably across application areas and uses, as discussed in Section 3. The following examples of current practices will be used to illustrate the discussion:

- Risk is seen as probabilities and expected values (probability times consequences) (4.1)
- Risk is described by traditional risk matrices, which for each event specifies one category of consequences and one for probability (4.2)

Risk science theory warns against these two stands, to adequately understand and describe risk (see Sections 4.1.3 and 4.2), yet they are common in practice. The approaches (4.1) and (4.2) are used in different context and settings, ranging from large quantitative risk assessments to job safety analyses. The coming discussion considers the full spectrum of applications.

4.1.3. What creates the gap between theory and practice?

The generic literature on knowledge theory and practice (e.g., Rynes et al 2001, Van de Ven and Johnson 2006) refers to different perspectives for understanding the gap between theory and practice. The traditional one frames the issue as a knowledge transfer problem, see Fig. 1. This perspective is based on the assumption that the practice (knowledge of how to do things) in a professional domain is to a large extent derived from scientific knowledge. The gap problem is thus one of translating and diffusing scientific knowledge into applications (Van de Ven and Johnson 2006). Following this perspective, questions need to be raised as to whether the academic work is not in a suitable form or not useful for the practitioners. Reversed, it can be questioned whether organizations and practitioners are not aware of relevant research and are not learning fast enough to keep up with the changing times (Weick 2001).

For risk science and its applications, considerable work has been conducted on philosophical questions about the existence (ontology) of

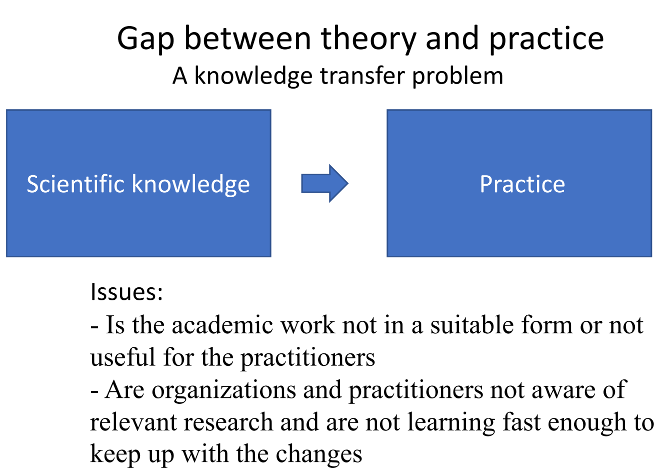

Fig. 1. The traditional perspective for understanding the gap between theory and practice: A knowledge transfer problem.

risk (see, e.g., Aven et al 2011, Solberg and Njå 2012, Ylönen and Aven 2023). This work can be viewed as foundational for the theory development but of less importance for the practitioners who are concerned about how to assess and describe risk in specific settings. From a theoretical point of view, the risk science distinction between the concept of risk and how it is measured or described, i.e., between (C,U) and (C',Q, K), is critical, but for the practitioner it is not. The practitioner would like to know how risk should be characterized with the new risk perspective and, particularly, how it deviates from the established methods (e.g., 4.1 and 4.2). Considerable academic work has, however, been conducted to meet this challenge. Papers and books today provide examples of methods that can be used to characterize risk according to the (C,U) perspective (e.g., Milazzo and Aven 2012, Aven, 2013a, Aven and Thekdi 2022). Compared to earlier practices based on probabilities, the new perspective highlights the need to provide judgments of the strength of the knowledge (SoK) supporting the likelihood judgments and to implement approaches for identifying potential surprises relative to the available analyst knowledge. Ways of addressing risk related to deviations of assumptions are also developed (e.g., Berner and Flage 2016). Alternatives to the traditional risk matrices are suggested, which include the (SoK) dimension.

As such, the degree to which the new knowledge is not in a suitable form for the practitioner can be discussed. Whether they find the suggested ideas and methods useful is a different and more difficult question to answer. What a practitioner finds useful depends on inter alia the degree to which the person finds the information convincing. Hence, the issue is also a matter of persuasion – to influence the thought and conduct of one's listeners (Van de Ven and Johnson 2006). To Aristotle, persuasion is about: (1) logos – the message, its argumentation and especially its internal consistency; (2) pathos – the power to stir the emotions, beliefs, values, knowledge and imagination of the audience so as to elicit empathy, not only sympathy; and (3) ethos – the credibility, legitimacy, and authority that a presenter both brings into and develops over the course of the argument or message (Barnes, 1995). Logos, pathos, and ethos together form the persuasiveness of the communication.

The publications from recognized researchers in international highly ranked journals provide ethos, and the arguments in these publications contribute to logos. There may be some elements of pathos in written texts, conference presentations, teaching and practical guidance, but to appeal to people's feelings and emotions is not what scientists have been trained to do. The author of this paper finds the (C,U) risk perspective appealing as a rational framework for how to conceptualize and characterize risk which integrates and makes sense of nearly all other perspectives on risk. But there is also a pathos dimension for me – the elegance and beauty of the theory. Practitioners may not experience this dimension, as they see and value not the theory but only the methods being used to assess and characterize risk.

An alternative to the knowledge-transfer problem perspective is to see 'practical knowledge' as a distinct mode of knowing in its own right (Van de Ven and Johnson 2006). Following this thinking, we can make a distinction between fundamental knowledge and practical knowledge, in line with the separation between generic risk analysis (science) and applied risk analysis (science), as introduced in Section 1, see Fig. 2. As commented by Van de Ven and Johnson (2006), the purpose of the practical (applied) knowledge is knowing how to deal with the specific situations and cases, whereas the purpose of the scientific (generic) knowledge is knowing how to see specific situations and cases as instances of more general phenomena and processes. Think of a risk analyst conducting risk assessments in a company. The assessments are based on assumptions, and the analyst keeps track of these assumptions and develops ways of studying how they influence the risk assessment judgments. The analyst is not familiar with any theory that explains how this can be systematically done. The analyst develops new practical knowledge. This knowledge is then hopefully transferred to the fundamental generic knowledge, is further developed and contributes to the

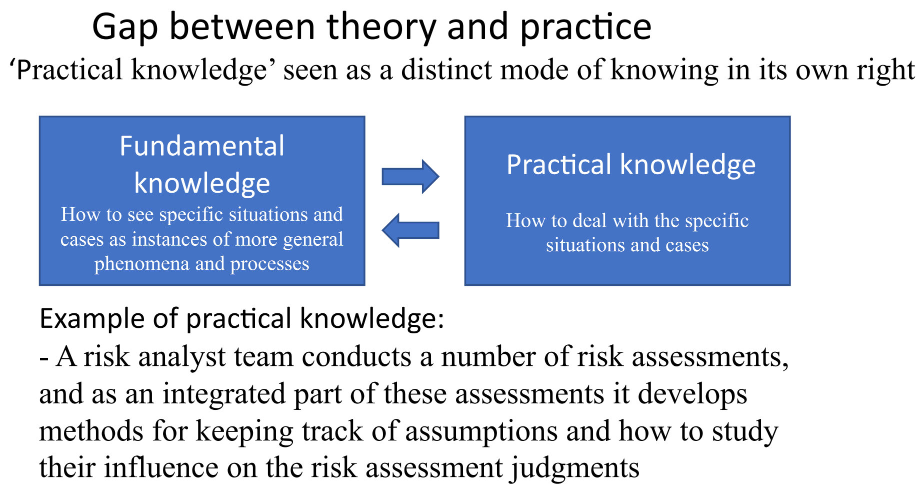

Fig. 2. An alternative perspective for understanding the gap between theory and practice: Seeing practical knowledge as a mode of knowing in its own right, leading to a distinction between fundamental knowledge and practical knowledge, similar to the separation between generic risk analysis (science) and applied risk analysis (science).

general theories of the discipline, similar to the illustrating petroleum example presented in Section 1.

As such, there is a strong interaction between theory and practice (generic risk analysis/science and applied risk analysis/science). Theory guides practice, practice develops knowledge and stimulates theoretical knowledge generation, which in turn improves theory.

The close link between theory and practice is reflected in the well-known statement that "There is nothing so practical as a good theory", which is attributed to the social scientist Kurt Lewin and dates back to the 1940s. Lundberg (2004) provides a discussion of this statement which is highlighted as relevant for analysis in this paper. Lundberg points to two different types of theory, one guiding knowledge discovery, the other improving practice and performance, see Fig. 3. These two types of theory are based on different mindsets – sensemaking. We refer to the former as a descriptive approach and the latter as a prescriptive approach. The descriptive approach is focused on discovery and the improvement of knowledge. In the case of anomalies being observed, inquiries are conducted with the aim of modifying or reformulating the approach. The prescriptive is based on the application of rules and procedures, meeting defined goals. If discrepancies are observed, actions are taken to reduce or solve the problem. A main conclusion by Lundberg (2004) is that Lewin's claim can be justified; because conceptual descriptive frames are a requisite for sensemaking, the more accurate, focused and verified the frame, the better the sensemaking is likely to be – for practitioners, for everyone.

The theory on risk conceptualization and characterization, for example (C,U)=(C',Q,K), is about both approaches. The basic ideas underpinning the (C,U)=(C',Q,K) framework are mainly descriptive theory development, but there is also considerable research on how to use this framework in practice, as discussed above. Examples include the use of alternative risk matrices, covering strength of knowledge judgments in addition to probability and consequences or covering probability and strength of knowledge judgments for a fixed consequence category (Aven, 2020, Aven and Thekdi 2022). Challenges in applications motivated the (C,U)=(C',Q,K) framework development, and descriptive and prescriptive sensemaking have been closely integrated. Practitioners have a mindset that biases them towards a prescriptive approach. They appreciate specific methods to apply, rather than abstract concepts and philosophical reflections. The (C,U)=(C',Q,K) theory and framework is strong on philosophy but can still be seen as somewhat underdeveloped on methods and procedures for practical implementation.

To understand why there is a gap between theory and practice, change management also provides relevant knowledge. This knowledge field points to, for example, factors that can contribute to resisting change (e.g., Godbole 2017), see Fig. 4. One such factor is *not understanding the rationale for change*. With a well-established practice, based on, for example, (4.1) and (4.2), practitioners may struggle to understand the need for a change. The methods used have been a pillar for risk assessment education and standards for years. The practitioners may acknowledge that the approaches adopted have some limitations and weaknesses, yet they are considered useful instruments capturing the essential aspects of risk. The idea that uncertainty is a main component of risk is, for many practitioners, difficult to comprehend. It is easier to see risk as some property of the system or activity considered, and probability (i.e., frequentist probability, SRA 2017) is the way of defining this property. According to this view, a process plant has an inherent objective risk level that is not affected by the analysts obtaining more information. The uncertainty-based risk perspective changes this

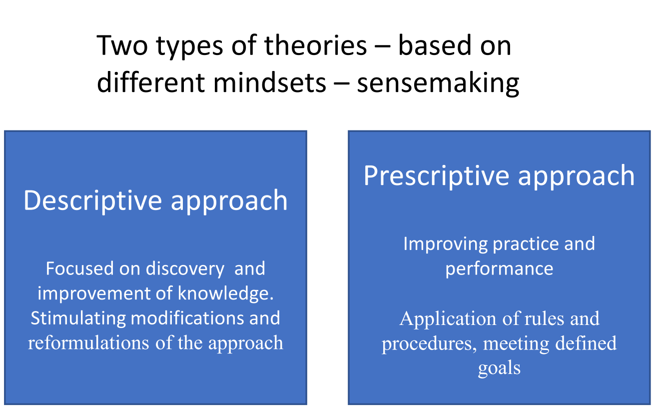

Fig. 3. The two different types of theory, one guiding knowledge discovery, the other improving practice and performance (based on Lundberg 2004).

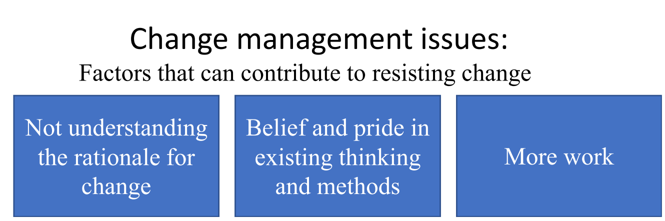

Fig. 4. Factors that can contribute to resisting change (based on Godbole 2017).

thinking, by rejecting the notion that there is an underlying objective risk that the risk assessment is to accurately measure. In line with this perspective, the consequences are objective and uncertain, and the risk assessment aims to measure and characterize the uncertainties. To understand this perspective takes time when one has, for years, been practicing this probabilistic way of thinking about risk. The differences in perspectives are fundamental.

Another factor contributing to resisting change, closely linked to not understanding the rationale for change, is *belief and pride in existing thinking and methods*. Many risk analysts have their training from universities and courses justifying a perspective in line with (4.1) and (4.2), and they have practiced and promoted this perspective for years in applications. They acknowledge that some of the tools they use – like (4.1) and (4.2) – are not perfect, yet they are judged as simple and representing a sufficiently accurate approximation to the problem at hand. People – including decision makers – are familiar with the tools, and this ensures informative and effective communication of the relevant risks. Their organizations and industry have built standards and guidance documents based on this thinking and methods. To them, the system works, so why make changes that could mess things up and introduce new risks? Supporting an uncertainty-based perspective on risk means to acknowledge that their way of doing things has been insufficient, with flaws, and potentially misleading decision makers. The analysts may fear that their authority and power will be reduced or challenged, when leaving the established knowledge and methods. If the change is considered fundamental for how to conduct risk assessments, the resistance to the change would naturally be stronger than if it is to be seen as a minor adjustment in terminology and thinking. Returning to the PSA-N example in Section 3, the authorities' change to the (C,U) perspective was partly communicated as such an adjustment, which could explain why many practitioners were able to justify working with risk in basically the same way as before. The change did not really challenge existing thinking and methods used.

The belief in existing thinking and methods can also be based on a conscious judgment of what is a proper weight to be given to uncertainties in risk management. A probability and expected value-based perspective can be viewed as giving less weight to uncertainties than an uncertainty-based perspective. Clearly, if (C,U) is adopted, a stronger focus on uncertainties would be the result, compared to a perspective where a definition in which the risk is equal to expected loss is used. Hence, protection could be easier to justify.

An often-cited reason for resistance to change is that it would create *more work* (Godbole 2017, Kanter 2012). The changes may relate to rewriting existing guidance and standards, but the main point here is the perception that the uncertainty-based perspective requires additional analyses compared to the existing practices. This is true in the sense that the perspective requires that the knowledge dimension is more thoroughly addressed in the risk assessment compared to existing practices; however, if the analysis on this dimension is properly planned and implemented, there need not be a big difference in workload. It would not take more time to analyze and present the risk using an alternative risk matrix highlighting probability and knowledge strength, compared to a traditional risk matrix presenting probability and consequences assignments. This requires of course that the risk analyst is familiar with the approach and methods. Clearly, it will take some time to obtain the same efficiency as when conducting traditional analyses. In a transition phase, more work will thus be required from the analysts.

4.2. Why it is important to close the gap?

Risk science provides the best (most justified) knowledge available on concepts, principles, approaches and methods for understanding, assessing, characterizing, communicating and handling risk. This knowledge is produced by generic and applied risk analysis and risk science, and their interaction. Clearly, if practice is not in line with this best knowledge, we should try to reduce it and close it. One should say the same thing if theory were not to meet the best knowledge. Considerable theoretical work is published that could be seen as poor risk science, if the reference is contemporary knowledge in the field. We see, for example, many publications and books promoting the use of expected values as a general way of describing risk, despite the strong arguments provided against this approach (Pate-Cornell, 1999, Haimes 2015, Aven 2012a, 2020).

Thus, from a risk science and continuous improvement perspective, there should be no discussion about the need to reduce and close gaps between theory and practice. Using knowledge that is not the most justified and most current – for example, adopting (4.1) and/or (4.2) – means that risk could be seriously mischaracterized and decision makers misinformed. A decision alternative could be considered preferable based on expected values, but not when taking into account its potential for severe consequences. This potential may be suppressed or attenuated, if risk is equated with an expected value. Risk science stresses the need to address the uncertainties related to extreme events and consequences, using not only probabilities but also judgments of the strength of knowledge supporting these probabilities. In addition, the potential for surprise needs to be addressed. Similarly, the use of traditional risk matrices (4.2) could conceal the spectrum of consequences associated with a decision alternative, as well as considerations of the strength of the knowledge supporting the probability judgments.

These examples provide arguments why current practice can mischaracterize risk and misled decision makers. If we review incidents occurred worldwide, many of these can be traced back to poor risk management and governance, but it is difficult to assess to what extent application of contemporary risk science knowledge would have avoided the incidents. Risk science is challenging in this sense, measuring its quality using hard performance data is not normally possible. Yet, there is a need to address the issue of what is the best knowledge to use, to ensure high quality risk handling.

As discussed in Section 4.1.3, practitioners acknowledge that their approaches and methods – such as (4.1) and (4.2) – have limitations, but they are still considered attractive in practice, as they are simple, reasonably accurate and people are familiar with them. As a response to this thinking, the present paper argues that these methods are not reasonably accurate in general. In practice, there will always be a balance to be made between simplicity and accuracy, but it is difficult to see how (4.1) and (4.2) can pass any quality test for adequately describing risk in most cases, as discussed above and in, for example, Aven (2012a, 2020). The claim that these approaches and methods are simple to understand and communicate can indeed be questioned. In fact, analysts often struggle to explain what the basic underlying ideas supporting (4.1) and (4.2) are. There are, for example, issues linked to explaining what probability means and how the consequence assignment in the risk matrix should be interpreted, as only one value is used.

The example of including the Strength of Knowledge (SoK) judgments in risk matrices (Section 4.1.3) can be used to illustrate this discussion. Some practitioners may find the use of SoK judgements theoretically justified, but too complicated to use in particular settings; the main problem being that the matrix would include three dimensions instead of two, which would be more difficult to communicate and not necessarily improve the risk understanding for the decision makers and other stakeholders. As a response to this argumentation, several points should be made. Firstly, alternative approaches have been developed to include the knowledge dimension of risk, in particular two-dimensional matrices covering probability and SoK judgments only. The consequences dimension is then fixed, typically with a specification of a severe category. Secondly, it can be discussed to what extent it complicates the risk assessment and communication to include the SoK judgments, if properly planning the work and having the right competence and attitude, as discussed in more general terms in Section 4.1.3. Thirdly, the arguments and rationale should be the most important issue: Not including the SoK dimension means that an important aspect of risk is not included in the characterization and communication of risk, which can seriously hamper the risk understanding. If this is disputed, arguments need to be provided. That is how science works and develops. There will, of course, always be considerations of efficiency in analysis and communication matters, and research is needed to obtain new insights and find the overall best approaches, see Section 4.3.1.

For the petroleum industry example presented in Section 3, reducing and closing the gap between theory and practice is also about regulation compliance. However, the main motivation for the change from the (C, P) risk perspective to (C,U) – and also then efforts to bridge the gap between theory and practice – is to improve the risk understanding and through that enhance related risk communication and decision-making.

For the security example discussed in Section 3, being in line with contemporary risk science knowledge means to use frameworks that acknowledge the security community's concerns and focus on values and vulnerability but, at the same time, are able to adequately take into account uncertainties and knowledge aspects and in this way strengthen the decision support on the implementation of risk-reducing measures and the use of resources. The security community commonly ignores the uncertainty and knowledge dimension of risk, which could lead to serious mischaracterizations of risk (e.g., Aven, 2013b). Amundrud et al (2017) show how the security framework based on threat and vulnerability (A&V) can be incorporated into the (A,C,U) risk framework.

4.3. How can we reduce or close the gap?

If we are to reduce or close the gap between theory and practice, we first need to acknowledge that there is a gap and that it is important to reduce/close it. If this is not the case, changes will not occur. Section 4.1 pointed to some factors that could explain why there could be a lack of momentum and drive to make changes and enhance the risk conceptualization and characterizations. In the present section, we presume that there is some understanding of the importance of improving the practice and also willingness to make changes, at least in some parts of the organization. The question is then what we should do to obtain the best results.

Many types of measures have the potential to contribute to reducing/closing the gap. In view of the analysis in Section 4.1, the present paper would like to suggest and highlight the following measures:

(a) Technology advancements and research
(b) Further development of guidance on how to implement the theories, for example how to characterize risk using the (C,U)-(C',Q,K) perspective.
(c) Conducting seminars, workshops, etc. where the goal is to characterize risk and improve the understanding of risk in specific situations/cases, covering both risk scientists and practitioners.
(d) General efforts to strengthen the education and training on risk at universities and colleges.

4.3.1. Technology advancements and research

New technology provides opportunities for research and development contributing to bridging the gap between theory and practice. Risk analysis and risk science knowledge is today to large extent formulated in standard paper and book format, with limited use of modern advanced computer-based tools to illustrate and understand ideas, concepts and principles. The opportunities for using new technology are many. An example is Interactive Learning Platforms, which combine theoretical concepts with practical applications, using simulations, virtual labs, and interactive exercises. Virtual Reality and Augmented Reality create immersive learning experiences, enabling users to relate real-life scenarios to abstract theories and concepts. Another example is Gamification, which is a technique in which game elements are incorporated into a process to motivate users. Most people like a challenge or a competition, and there is clearly a potential for development of such tools and elements to improve the understanding of risk concepts and principles. As a final example, think about the many possibilities for developments that Artificial Intelligence (AI) gives. There is a huge potential in using AI to for example adaptive learning, to analyze users' strengths, weaknesses, and learning styles. It is, however, outside the scope of the present paper to give further details on how AI and other technological systems can be used for this purpose, helping bridging the gap between theory and practice.

There is a need for more comprehensive research with collaboration across traditional disciplines. This includes, in particular, social science methods, interviewing practitioners, regulators and experts on issues relevant for developing suitable concepts, principles, models, theories, approaches and methods to understand, assess, communicate and handle risk, in general and for specific applications. Together, risk scientists and social scientists can obtain interesting insights on these issues. More research is also needed to empirical test different concepts, approaches and methods in practical settings. Such testing has been conducted to some degree, but not enough. For example, risk analysts and scientists need to collaborate closely with ICT (Information and Communications Technology) and pedagogical experts to evaluate different ways of conceptualizing and describing risk, giving due attention to the knowledge aspects of risk, also surprises and the unforeseen. 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, approaches and method, and stimulate modifications and innovations in the theory development. As such it can contribute to bridge the gap between theory and practice in risk analysis.

To bridge the gap between theory and practice, one can argue schematically that either theory needs to be moved toward practice or vice versa. The paper has argued that we need both processes. The discussion in Section 4.2 highlights the need for practice improvement, but as the example in the introduction section from the 80s/90s indicates, the issue is also about the theory enhancing. This is also underlined in Section 4.1.3, when pointing to practical knowledge (applied risk analysis) as a mode of knowing in its own right. There is a close interaction between the practical knowledge and the fundamental knowledge. The research and development ideas referred to above in this Section 4.3.1 can be viewed as mainly motivated by the needs of the practitioner, but the work is also expected to lead to or stimulate theoretical advancements. As a field and science, there should be a continuous drive for improvements on both theory and practice. The best way of ensuring this is to conduct both fundamental and applied research, highlighting also integrated research as illustrated above with the testing example.

This type of research should specifically look into different settings, to identify the most suitable risk conceptualizations and descriptions, reflecting different conditions and factors defining these settings. The (C,U)-(C',Q,K) risk perspective is general, applicable to all types of situations, but from a practical point of view, it is important to search for proper adaptations supporting the specific challenges of the settings studied.

On some topics, there are competing theories - there are different perspectives and schools of thought - and the issue of bridging the gap between theory and practice becomes more complex as there are multiple gaps, refer to Sections 2 and 4.1.1. The present paper has focused on one main reference for the gap – the SRA documents and related research – but looking into the theory–practice gap issue when considering other references and perspectives would also be interesting. It is task for future research.

4.3.2. Guidance development

As discussed in Section 4.1.3, it can be argued that Lewin's claim can be justified, if the theory is sufficiently focused and specific. That means changing the focus from the concepts to the methods to be used, from the fundamental risk ideas and concepts to how, in practice, to measure or describe risk. Contemporary risk science considers uncertainty as a main component of risk, and there is also growing support for this idea in practical contexts, influenced by risk science efforts and, particularly, the ISO 31000 definition of risk, as commented on in Section 3. However, ISO 31000 does not provide a theory on risk characterization that adequately follows up the uncertainty-based risk definition. According to ISO 31000, risk is described by consequences and probabilities (C,P) but without including the knowledge aspects critical for the proper understanding of risk; refer to discussion in Section 4.1.3. Risk science has provided some guidance through the strength of knowledge concept and methods aiming to take into account potential surprises and the unforeseen. As mentioned in Section 4.1.3, more research is needed to develop and test out methods that could be used to characterize the risk addressing these knowledge aspects. A challenge then would be to reach out to practitioners with these methods. The practitioners do not read scientific papers. Standards and guidance documents are needed. ISO standards are strongly influential, but changes in these standards are difficult to obtain, and the processes are slow and ad hoc, with varying levels of interactions with scientists (Aven and Ylönen 2019). In organizations and industries, there are, however, many types and levels of standards and guidance documents. Some of these could be difficult to influence, for example for an international company with a strong central unit providing guidance and requirements for all its activities worldwide. Others, however, are easier to update, if there are adequate incentives for making changes and there are people with the vision and drive for such changes to occur.

In the petroleum example, the regulator has a common practice – in line with the internal control principle which highlights functional requirements – to avoid specifying how the industry is to implement regulatory changes. The result is typically that changes take time to implement and there is a phase of development and testing before satisfactory solutions are obtained. Some of the problems experienced in the industry as a result of the change to the (C,U) perspective – refer to Section 4.1.3 – can be traced back to this practice. The authorities have produced some guidance documents and organized some conferences on the topic, but it can be argued that more specific guidance documents on methods, with concrete examples, would have been helpful for the industry. Although the industry now is in a different position on the matter than it was in 2015, such documents could still be useful.

For the security example, guidance documents are also needed, providing approaches that integrate ideas from security and risk science. Amundrud et al (2017) outline some ideas, but more work is needed. A challenge in this context is the difference between uncertainty and probability: you face uncertainty, and you measure or express uncertainty by means of probability. Many people, scholars and practitioners struggle to see the difference between these two concepts. Many struggle also with the probability concept – to understand the meaning of and difference between a frequentist probability and knowledge-based (subjective) probability. Only the latter expresses uncertainty. A frequentist probability is a measure of variation in populations – a model that needs to be estimated. These are fundamental concepts that all people working with risk need to understand. Unfortunately, that is far from the case today, among both academics and practitioners. As well as guidance documents, other measures are needed, as discussed in the following.

4.3.3. Conduct seminars, workshops etc

The guidance development discussed in Section 4.3.2 needs to be followed up with seminars, workshops, etc., where risk scientists and practitioners work together on real-life and constructed cases, and the aim is to understand risk. These cases should cover a broad set of situations relevant to the practitioners. Think again about the petroleum example. Then the cases should look into risk assessments, ranging from job safety analysis to quantitative and semi-quantitative risk assessments conducted in the planning stages of a technical development project. By working together, theoreticians and practitioners need to obtain joint understanding of the problem at hand, discussing what risk means and how it could/should be conceptualized and characterized. This requires clarification of key terms, like uncertainty, knowledge and probability, and the difference between underlying ideas (concepts) and measurements/ estimations/characterizations, to say something about the magnitude of the risk. Experienced facilitators, with both theoretical and practical competence, are needed for this work. Working on such cases would improve the participants' understanding of risk, and ideas for how to practically deal with various issues and assumptions would be suggested and tested out. In this way, practical guidance would be developed, as discussed in Section 4.3.2, see also Bjerga and Aven (2016) and ON (2015, 2017a,b). To be concrete, think about a terrorism security context, where the participants are to discuss the following questions/tasks:

(a) Identify relevant assets/values
(b) Identify threats, describe potential scenarios
(c) Assess uncertainties by using probability (imprecise, knowledge-based, subjective) for threats/scenarios and strength of knowledge judgments
(d) Assess consequences of these threats/scenarios and associated uncertainties, by using probability (imprecise, knowledge-based, subjective) and strength of knowledge judgments; assess vulnerabilities
(e) Review assumptions and potential deviations from these. Perform a study to identify potential surprises.
(f) Characterize risk building on elements a)-e) and how measures and factors affect the risk.

We see the tasks are in fact generic and applicable to all types of situations. The list provides the core of the theory but allows for different ways of implementation. The aim of the work is to use the cases to develop ideas and methods for how to carry out the implementation. This work will be guided by risk science knowledge but also allow for and stimulate new and alternative ways of dealing with the questions and issues.

4.3.4. Strengthen the risk education

Risk is not broadly acknowledged as a distinct discipline and science, although efforts are made toward this end (SRA, 2017, Aven, 2018). Risk is addressed in disciplines like engineering, business, health, security, etc. but then as a field and topic supporting these disciplines. The result is that each discipline, to a large degree, develops its own theories and practices. Risk science, as defined by SRA (2017) and Aven (2018), aims to establish the best (most justified) knowledge and practices across all disciplines. With a strong risk science, the different disciplines could apply this knowledge and avoid inventing the wheel over and over again. Education and training programs could then be based on this knowledge. It would be a strong measure to bridge the gap between theory and practice, from a long horizon perspective.

We are, however, far from this state today. And it will clearly take time to build a strong and influential risk science. Yet, it needs to be addressed as an issue and a goal. We need champions to take the lead and promote risk science at our universities. There are success stories, but still there are not enough risk science programs to have a global influence on risk analysis practices. This paper encourages risk and safety professionals to take initiatives to strengthen the education and research on generic and applied risk science at our universities and colleges. The present author recalls that it was enthusiastic industry people that contacted his university and requested the development of risk and safety study programs. The university leadership was skeptical but accepted the plans when it experienced strong support from its academic staff and also received external funding. These initiatives were the beginning of a development of risk and safety education and research at the university, which from the start have highlighted both theory and practice but, in particular, generic risk science, to ensure that students' knowledge is current and relevant to different types of applications. A key point made is that risk science programs and research are not being offered without some risk professionals having visions/goals and working hard to realize these.

5. Conclusions

This paper has discussed the issue that there is a gap between contemporary risk science knowledge on conceptualizing and characterizing risk and the practice on these topics. More specifically, it has been a goal to discuss the claim that the gap is due to a disconnection between risk science and the application of risk science.

The main conclusion of the paper is that this claim cannot be justified. Contemporary risk science has been developed as an integrated process between theory and applications, between generic and applied risk analysis/science. Much of the motivation for the theory developed comes from applications and the problems encountered in working with real-life situations. Observations were made that the then current practices lacked a scientific foundation, and important aspects of risk and uncertainties were not addressed or given sufficient weight. This does not mean, however, that there is not a theory–practice gap issue – there is the potential for many improvements. Still, practice is characterized by varying levels of sound theoretical thinking and methods. There is a gap, and it is serious, as strong arguments exist showing that many of the current methods lead to mischaracterizations of risk and the misguidance of decision makers. The paper identifies and looks into several reasons for why practice is not updated on the new knowledge and why it is difficult to obtain changes, including *not understanding the rationale for change, belief and pride in existing thinking and methods, and more work* as a result of the change. The paper acknowledges that more research can and should be conducted to provide suitable guidance on how to conduct the risk characterizations in line with the new knowledge. The risk theory is conceptually challenging, with philosophical issues raised about risk, but these issues are not essential or critical for the practitioners, who look for specific methods and procedures for how to conduct the risk assessments and characterizations. This research needs to be conducted with close collaboration between theory and practice, for example in seminars with theoreticians and practitioners, working together on concrete cases and seeking to improve the risk understanding by adequate risk conceptualization and descriptions.

Practice needs theory, as strongly highlighted in, for example, quality management (Deming, 2000) – without theory there is no reference for what is good or bad and how to learn from experience. And the paper supports Lewin's well-known statement that "There is nothing so practical as a good theory". Risk research needs to continue its developments concerning risk understanding, as there are still issues to be discussed, particularly related to the practical use of this theory. The paper has aimed at providing new insights on these issues, as well as providing concrete suggestions for how to reduce/close the gap between theory and practice.

CRediT authorship contribution statement

Terje Aven: Conceptualization, Investigation, Methodology, Validation, Writing – original draft, Writing – review & editing, Formal analysis.

Declaration of Competing Interest

The author declares that he has no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. The (C,U) risk perspective

The (C,U) perspective is based on a distinction between the concept of risk and how it is measured or characterized. In its broadest form, risk – linked to an activity (for example an investment, the operation of a technical system or life on the earth) – captures as a concept two dimensions: i) the consequences C of the activity with respect to the values and concerns of interest and ii) associated uncertainties U (what will C be), for short referred to as (C,U). Commonly, the focus is on the negative or undesirable consequences C, but the framework allows for considerations of all types of consequences, which is important, as the outcomes could turn out to be positive. From this general definition of the risk concept, the magnitude of the risk is measured or characterized in a risk assessment, using different metrics and descriptions. Probabilities and expected values are typically used. In the most general form, risk is described by specifying the consequences (C') and representing or expressing the uncertainties (Q), based on the available knowledge K. We write (C',Q,K). Note that C is the actual consequences occurring, whereas C' are those specified in the risk assessment. It is important to distinguish between C and C', as the assessment could overlook some events, meaning that important risk contributors could be ignored or downplayed. Commonly, Q is represented by probability P – precise or imprecise – but it is also recommended to add judgments of the strength of the knowledge (SoK) supporting the probability judgments.

In many cases, it is appropriate to split the consequences C into events (A) and related effects/consequences (C_A) given the occurrence of A, leading to risk being defined by (A,C_A,U) and described by (A',C_A',Q, K), with obvious interpretation. Using this terminology, we can see risk as the combination of an event's risk contribution (A,U) and vulnerability (C_A,U|A). Hence, vulnerability is the combination of consequences and associated uncertainties given the occurrence of an event. Think about the risk related to fires in a building. Then A is the event that fire occurs and C_A the consequences given the fire. The vulnerability can be seen as the risk given the fire and could, for example, be measured or described by a probability distribution of fatalities given the fire, with SoK judgments.

Appendix B

List of risk-related symbols used in the paper:
C: The consequences of the activity studied.
U: Uncertainty (what will C be?).
A: Actual events occurring.
C_A: The consequences when A is given.
Q: A measure or description of uncertainty.
P: Knowledge-based (subjective) probability.
K: Knowledge.
SoK: Strength of knowledge.

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