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Teaching and discussing about risk: seven elements of potential significance for science education

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ABSTRACT

The present paper takes its point of departure in risk being a relevant content for science education, and that there are many different approaches to how to incorporate it. By reviewing the academic literature on the use and definitions of risk from fields such as engineering, linguistics and philosophy, we identified key elements of the risk concept relevant for science education. Risk is a phenomenon of the future that may be conveyed by our activity, it is something that may or may not take place. Hence, at the core of risk we find uncertainty and consequence. Furthermore, the elements of probability and severity are relevant modifiers of the consequence, as well as both subject to uncertainty. Additionally, in framing, understanding and decision-making on risk, as individuals or society, we need to acknowledge that risk has both objective and subjective components, lying in the interface between knowledge and values. In this paper, we describe how these key elements were derived from the literature and derive a schematic model of the risk concept for the purpose of science education. We further discuss how this model may assist in planning, execution and evaluation of teaching activities explicitly or implicitly involving risk issues.

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1. Introduction

Risk is an important concept in modern society. Indeed, some scholars even go as far as claiming that modern society is characterised by risk; most well-known is Ulrich Beck in his work *Risk society* (1992). We all make risk decisions on a daily basis to avoid or take risks in order to gain benefits. As modernity has seen the introduction of technologies that create risks on a larger scale – risks that are not restricted in time and space – the significance of risk as a concept is increasing (Beck, 1992). This viewpoint is corroborated by

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studies on the use of the term *risk*, such as Zinn (2010) who found an increased use of the term in newspaper reporting since World War II.

The notion of risk and risk assessment is dealt with in a variety of ways in science education (Cerulli, Holbrook, & Mander, 2016; Christensen, 2009; Hansen & Hammann, 2017; Kolstø, 2006; Levinson, Kent, Pratt, Kapadia, & Yougi, 2011; Simonneaux, Panissal, & Brossais, 2013). Risk is often, but not always, included in discussions of and suggestions for curricula aiming at scientific literacy. For instance, Ryder (2001) analysed a large number of case studies of public engagement with science and/or scientists, with the purpose of producing a framework for what content to be included in functional scientific literacy. He identified risk as one of several aspects to consider in teaching about the social and epistemological aspects of science for scientific literacy. Likewise, Millar (2006) described the course structure for a pilot project aiming at developing a curriculum focusing on scientific literacy, in which risk constituted one of six central 'ideas about science'. Risk has also been part of the STS (Science and Technology in Society) movement already from the beginning, either explicitly as in Solomon's (2003) inquiry into what it takes to make issues of risk meaningful in the science classroom, or implicitly through the central idea of including controversial issues in which both scientific and social aspects need to be considered (see for instance Gaskell, 1982). The same may be said about the SSI-literature. Thus, Ratcliffe, Grace, and Cremin (2005) included risk in two of their ten characteristics of a socio-scientific issue, stating that socio-scientific issues 'involve some cost–benefit analysis in which risk interacts with values' and 'may require some understanding of probability and risk' (Ratcliffe et al., 2005, pp. 2–3). At the same time Christensen (2009), in her treatment of risk in science education, noted that the role of understanding risk and making judgements about risk are rarely explicitly addressed in studies on student discussions of and argumentation on socio-scientific issues.

Apart from being treated as a component of overarching frameworks like scientific literacy or SSI there is a body of research in which risk is treated as distinct content in science education in its own right. An early example is a paper by Ravetz (1982) in which he argued in favour of including risk assessment as part of science education. Although Ravetz used 'examples primarily from the "nuclear debate"' (p. 203), he did so in order to indicate 'the principal themes and issues' needed to address in education about risk. In a similar vein, Eijkelhof (1986) argued for dealing with acceptable risk as a content in science education, taking the case of ionising radiation as an example (see also Cross, 1993; Zint, 2001; Zint & Peyton, 2001 and Covitt, Gomez-Schmidt, & Zint, 2005: Enghag & Schenk, 2016). In 1993, Riechard called for including 'risk literacy' as the unifying theme in environmental education and in a recent article, Hansen and Hammann (2017) suggested a working definition and conceptualisation of 'risk competence' and argued for its inclusion in science education.

Yet, the concept of risk has rarely been treated in depth in the science education literature. Our own literature review, although not claiming to be exhaustive, indicates that only approximately half of the studies focusing specifically on risk as teaching content provided a definition of the concept (Schenk et al., 2018). In addition, there was generally no proper discussion of the reasons for choosing a certain definition over another. Two important exceptions are the seminal article by Christensen (2009) and the recent contribution by Hansen and Hammann (2017). As part of her argument for the role of risk in science education, Christensen (2009) provided an overview of different 'conceptions of risk' (p. 212) and concluded that the primary distinction relevant for science education was between 'the scientific/technical conception of risk' and 'subjective framings of risk'. In a similar vein, Hansen and Hammann (2017) distinguished between two 'higher-order paradigms', the realist and the constructivist, to which they referred the different concepts of risk. These two paradigms reflect Christensen's distinction between scientific/technical vs. subjective conceptions of risk.

Together, these two studies contribute important insights concerning certain variability in the use and treatment of risk, with a particular focus on how technical conceptions of risks and subjective aspects of risk are managed in science education. At the same time, in the academic risk management and decision analysis literature, tremendous effort has been put into developing definitions of risk or defending a particular definition or way to operationalise and measure risk. This ongoing academic discussion is still largely unknown in the science education literature, but should have important consequences for teaching about risk in science education. There is general appreciation that the term is used and interpreted in a multitude of ways, both in the technical and non-technical literature, which by some has been pointed out as a potential source of confusion in the communication about risk (Boholm, Möller, & Hansson, 2016). However, there is also increasing recognition that risk as a concept cannot be properly captured by a single definition or operationalisation. Instead, suitability of definitions and operationalisations for the purpose of decision-making depend on context (SRA, 2015).

The present study aims at extending previous work within science education research on the dynamics of the risk concept and its implications for teaching. In particular, we explicitly acknowledge the multitude of definitions, interpretations and uses of the noun risk in everyday as well as technical contexts as treated in the academic risk literature. Through a systematic analysis of this variability in relation to potential consequences for teaching, we provide a model of the concept of risk which can be used for reasoning about teaching as well as research on incorporating risk in science education. This model includes and goes beyond the subjective/technical distinction focused on in previous publications (Christensen, 2009; Hansen & Hammann, 2017).

First, we present an extensive analysis of how risk is treated in the academic risk management and risk decision analysis literature. Second, the findings from this analysis are synthesised into a conceptual model of risk from an education perspective. Third, we offer examples of how this risk model may be used to introduce and/or handle different aspects of risk in science education, concerning teaching and research. We end with a discussion about how the presented model may fit with other works on risk in science education.

2. What is risk?

In this section, we present an analysis of risk as it is used and conceptualised in the academic literature. The analysis was guided by the paper's main purpose, to tease out potentially important characteristics of risk in science education. Through this analysis we identified seven interrelated elements of risk that are important for understanding and discussing risk and are of significance for science education. Below we describe these elements in detail.

The most salient characteristic of the word risk emerging from the literature is that it is highly polysemous, having different technical as well as everyday uses.

In Schenk et al. (2018) we illustrated the polysemy of the word in everyday language with the following three examples of use found in non-technical texts (Boholm et al., 2016; based on Hansson, 2004; 2011):

(a) Risk as an *unwanted event* which may or may not occur.
(b) Risk as *the cause* of an unwanted event which may or may not occur.
(c) Risk as *the probability* of an unwanted event which may or may not occur. May be explicitly or implicitly expressed as quantifiable.

The sentence 'Skin cancer is the most well-known risk of ultra violet light' is an example of (a) risk referred to as an unwanted event, i.e. the event of skin cancer manifesting. An example of (b) risk referred to, as the cause of an unwanted event would be: 'Excessive tanning, especially at young age, is a risk'. Finally, an example of (c) is 'Avoiding sunburns and tanning are efficient ways to reduce your risk of developing skin cancer', in which 'risk' could be replaced with 'probability'. These three examples show that the term risk can be used very differently already in everyday contexts, in which the meaning of the concept is usually not given explicit attention.

In the technical/disciplinary literature, differences in the meaning of risk are even more evident. Althaus (2005) and Renn (1992) review the use of the risk concept in different academic disciplines and both studies illustrate that the ontological and epistemological perspectives vary between disciplines. Having variable understandings of the same word or concept is not an unusual phenomenon, however, regarding risk such variability may hamper communication about risks (Boholm et al., 2016), between laypeople and experts or between experts of different backgrounds.

More importantly for our purposes, however, there have been efforts towards designing transdisciplinary definitions of risk (e.g. Aven & Renn, 2009; Fischhoff, Watson, & Hope, 1984; Rosa, 1998). Aven (2012) presents a classification of risk definitions within different academic fields covering nine classes under which one or more specific definitions of risk can be found. The nine classes and adhering examples of definitions per class are presented in Table 1. For more examples of risk definitions, with references to relevant literature, we refer the reader to Aven (2012).

It can be noted that the everyday use of risk corresponding to (a) and (c) presented above have equivalents in the classes (7) and (2) of Aven's list, respectively. We are not aware of any specialised use of the term risk equivalent to risk (b) from Hansson's (2004, p. 2011) examples. Rather, risk as used in (b) is described in the academic literature as a *risk factor*, in for instance medicine and epidemiology or as a *risk object* in the relational theory of risk presented by Boholm and Corvellec (2011).[1]

From Table 1 it is obvious that risk can be used both in qualitative and quantitative ways. The everyday uses of the term seem to be mainly qualitative in nature. In the analysis by Boholm et al. (2016) non-quantitative senses made up the majority of the instances studied, while strictly quantitative meanings were almost non-existent (Boholm et al., 2016). However, at the same time corpus linguistics makes it clear that even seemingly qualitative uses of risk may be partly understood also in quantitative terms. For instance, 'high', 'low', 'higher', and 'increased' are commonly found collocates in a number of corpora (Boholm et al., 2016; Hamilton, Adolphs, & Nerlich, 2007).

Table 1. An overview of specialised/technical definitions of risk, based on the categorisation of published risk definitions by Aven (2012) and identified key elements.

Aven's class	Example	Quantitative operationalisation?	Elements[a]
(1) Expected value	'Risk' is defined, by most of those who seek to measure it, as the product of the probability and utility of some *future* event (Adams, 1995, p. 30).	Yes	Consequence Probability
(2) Probability of an (undesirable) event	[Risk is] the probability that a particular adverse event occurs during a stated period of time, or results from a particular challenge (Royal Society, 1983, p. 22).	Yes	Probability Consequence
(3) Objective uncertainty	[Risk is] measurable uncertainty [where] the distribution of the outcome in a group of instances is known (either through calculation a priori or from statistics of past experience)' (Knight, 1921, p. 233).	Yes	Probability Consequence
(4) Uncertainty	We define risk as uncertainty of outcome, whether positive opportunity or negative threat, of actions and events[b] (Cabinet Office, 2002, p. 25.).	No	Uncertainty Consequence
(5) Potential/possibility of a loss	Risk is the potential for realisation of unwanted, negative consequences of an event or combination of events to individual groups of people or to physical and biological systems (Rowe, 1975, p. 1).	No	Consequence Uncertainty
(6) Probability and scenarios/consequences/severity of consequences	Risk is equal to the triplet (s_i, p_i, c_i), where s_i is the *i*th scenario, p_i is the probability of that scenario, and c_i is the consequence of the *i*th scenario, $i = 1,2 \ldots N$; i.e. risk captures: What can happen? How likely is that to happen? If it does happen, what are the consequences? (Kaplan & Garrick, 1981).	Yes	Probability Consequence
(7) Event or consequence	Risk is a situation or event where something of human value (including humans themselves) is at stake and where the outcome is uncertain (Rosa, 1998).	No	Consequence Value Uncertainty
(8) Consequences/damage/severity of these + Uncertainty	Risk is uncertainty about and severity of the consequences (or outcomes) of an activity with respect to something that humans value (Aven & Renn 2009).	No	Uncertainty Consequence Severity Activity Value
(9) The effect of uncertainty on objectives	Risk is the effect of uncertainty on objectives (ISO, 2009).	No	Uncertainty

[a]Consequence is used as an overarching term covering also loss, utility, (future) event or outcome (the latter two regardless of whether adverse or not). It should be noted that probabilities can be defined differently, e.g. the distinction between category 2 and 3 (see also Aven, 2012; Hansson, 2011; Kaplan & Garrick, 1981). Uncertainty is in this table designated to all sources and kinds of uncertainty other than those assignable a probability (see also discussion in text).

[b]It can be noted that the sentence directly after this reads: 'It is the combination of likelihood and impact, including perceived importance.'

That specialist uses of the term as well as formal definitions from scholars in various risk related areas include both qualitative and quantitative risk descriptions is important since technical/specialised uses of risk are commonly equated with quantification in the science education literature (e.g. Hansen & Hamman, 2017). In fact, only four of the classes listed in Table 1 cover strictly quantitative risk definitions, whereas remaining five classes contain definitions more or less qualitative in character. Indeed, definitions attempting to capture the concept of risk do not themselves need to be operationalisations of risk (Aven, 2012; Aven, Renn, & Rosa, 2011). In other words, we should allow for a distinction between the *concept of risk* and *how to measure risk* because the suitability of operationalisations of risk, i.e. risk assessment methods, is context dependent (SRA, 2015).

The overview presented above illustrates the variability in the use and definitions of risk within the academic literature. Nevertheless, there are several recurring elements between the different understandings of risk, most frequently *consequence*, *probability* and *uncertainty* (Table 1). It should be noted that we in Table 1, and in the model presented below, use *consequence* as an overarching term intended to also cover loss, event or outcome (the latter two regardless of whether adverse or not). The elements of consequence and uncertainty resonate with Hansson's (2011) two minimal characteristics of the risk concept: '[r]isks refer to undesirable events', i.e. *consequence*, and '[w]hen referring to the risk that a certain event will take place, we imply that it is undetermined or at least unknown whether or not that event will occur' (p. 235), i.e. *uncertainty*. Therefore these two elements can be said to constitute the core of the risk concept. As seen in Table 1, the different classes of definitions either have uncertainty or probability as an element. This is because probability is a means to operationalise uncertainty in quantitative operationalisations of risk. This is connected to the distinction of aleatory uncertainty and epistemic uncertainty. Aleatory uncertainty is caused by intrinsic randomness, such as the rolling of a dice (i.e. the objective uncertainty mentioned in category 3 of Table 1). Epistemic uncertainty is caused by lack of knowledge and can thus (theoretically) be reduced. In the present paper, we draw on this distinction but use the labels probability and uncertainty. Furthermore, we treat probability as one entity, although it should be noted that probabilities can be defined differently, which is reflected for instance in the distinction between category 2 and 3 (Table 1). For further discussion of how the definition of probability affects risk quantifications the interested reader is referred to Kaplan and Garrick (1981), Hansson (2011) and Aven (2012). Thus, we use the term uncertainty to designate all sources and kinds of uncertainty other than those assignable a probability. For instance, one may be uncertain about what the potential consequences are, whether a consequence may manifest or not, as well as regarding the probability estimates for different action scenarios. This relationship between uncertainty and probability also brings up another element, namely *severity* which we see as parallel to probability in that it modifies the consequence and in parallel is subject to uncertainty. More specifically, severity refers to the nature of the consequence, which may be of variable degree of severity. To exemplify, while the manifestation of a disease can be considered a consequence (an adverse event), we can also talk about severity. For instance, coming down with the common cold is a less severe consequence than contracting a malignant melanoma.

Apart from these four elements, the analysis also revealed three additional elements of risk figuring in the academic risk literature, which seem important to consider in a science education context, namely *activity*, *knowledge* and *values*. Although they are not at the core of the risk concept they are important for the contextualisation and understanding of risk issues. Hence, we refer to these as three frame elements in the model.

Although only brought up explicitly in class 8 of Table 1, activity is relevant for several of the classes of risk definitions. The concept of risk is connected to future events that may be affected by our actions (see also e.g. Renn, 1992). The operationalisations of risk presented in Table 1 were designed to provide guidance for action by quantifying the importance of avoiding, mitigating or otherwise managing a particular risk. Furthermore, Beck describes risk as 'a systematic way of dealing with hazards and insecurities induced and introduced by modernisation itself' (Beck, 1992, p. 21). Although this definition does not fit well either with most specialist uses or indeed with everyday uses of risk,[2] it captures the obvious connection between risk and decision-making dealing with insecurities and hazards. Also according to Luhmann (1993), risk is inseparable from considerations, stances and decision-making. Thus the distinction between risk and danger lies precisely in the component of decision-making. Danger is attributed to external factors whereas risk is attributed to the requirement and possibility of making a decision.

The assumption that risk can be managed and is subject to decision-making also leads us to the element of *knowledge* as a basis for decision. Although this is not an element brought up specifically in any of the classes presented in Table 1, access to or the potential to acquire knowledge is an underlying assumption of all. Quantitative risk definitions, or risk operationalisations are aimed at providing a knowledge basis for decisions. Probabilities, although in different ways, are based on evaluations of evidence, as is the identification of potential consequences and appraisals of their severity. Furthermore, epistemic uncertainties can be reduced by further knowledge productions.

However, understanding risk is not an issue of knowledge alone. As seen in class 7 and 8, *values* also come into play (Table 1). A recurring topic in the risk and safety literature is whether risk is objective or subjective. An objective risk concept means that risk is objectively given and determined by physical facts, independent of the observer. A subjective risk concept defines risk as dependent of the observer. Arguments have been made for either point of view and several works discuss the implications of either perspective for risk analysis, management, and communication (Aven et al., 2011; Bradbury, 1989; Hansson, 2011; Otway & Thomas, 1982; Rosa, 1998).

Parallels have been drawn between risk perception[3] and subjective risk, either contrasting risk perception to 'objective risk' (e.g. Riechard, 1993), technical conceptions of risk (e.g. Hansen & Hammann, 2017) or equating it to risk (e.g. Beck, 1992). However, it may be most fruitful to discuss risk as a concept containing both objective and subjective components (Hansson, 2011). The dual nature of risk (i.e. having both subjective and objective traits) opens up for values as integral parts of any decision including risk (compare also to Lee & Brown, 2018), i.e. the notion of adverse events or consequences implies value judgments that need to be made alongside considerations based on knowledge of probabilities and potential consequences. Thus, rather than constituting a defining divide between two overarching frameworks about risk, the objective/subjective-distinction constitutes a duality of risk central to science education as it emphasises the close interaction between knowledge and values.

3. A model of risk from a science education perspective

The analysis presented in Section 2 took its departure from the acknowledged diversity of the concept of risk in both technical and every day contexts, as treated in the academic risk literature. This approach generated no less than seven elements of potential significance. In Figure 1 we combine all these elements into a tentative model for use in science education research and practice. In short, we have placed the core elements *uncertainty*, *probability*, *severity*, and *consequence* at the centre of the risk concept, encased by the frame elements *activity*, *knowledge*, and *values*. Below, we explain the rationale behind the model and justify the placement of the elements within it further.

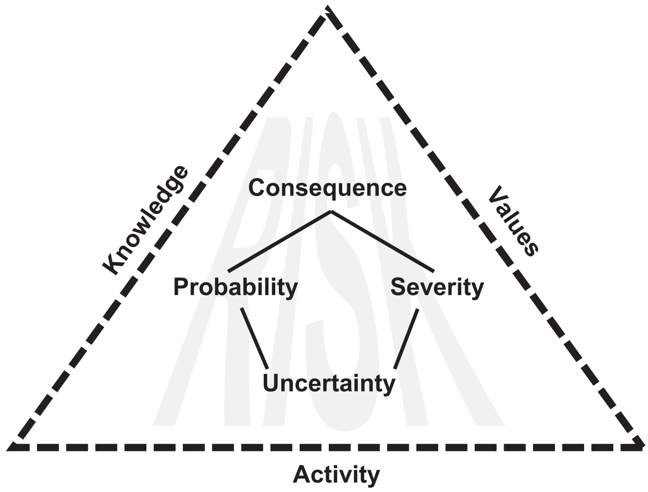

Figure 1 . A schematic representation of the multidimensional concept of risk.

We grant that it is not at all obvious that both uncertainty and probability should be seen as distinct elements of risk. Indeed, as pointed out in Section 2, uncertainty and probability are generally not both included in risk definitions (Table 1). Rather, probability, when included, is an operationalisation of uncertainty. A number of risk descriptions also focus solely on probability (Table 1; Aven, 2012). Risk as probability is, moreover, currently a common understanding in medicine and associated disciplines. Hence, in our daily lives, probability will be a frequently encountered element of applicable risk descriptions, suggesting that of the two elements probability is the most important to raise. However, as seen from the analysis of the risk literature in Section 2, we need to acknowledge epistemic uncertainties as well. In a risk decision situation, we may not only be uncertain about the consequences, but arguably also about the probabilities if such have been determined. Hence, from a science education perspective the distinction between probability and other kinds of uncertainty is, indeed, relevant (Christensen, 2009; Hansen & Hammann, 2017; Ravetz, 1997). Furthermore, rather than presenting probability as a component of uncertainty (cf. the distinction between aleatory and epistemic uncertainty), we wish to present probability as an element also subject to uncertainty (i.e. incomplete knowledge). Hence, in the model we juxtapose probability and severity, both subject to uncertainty, both modifying the consequence.

In the model, the element of activity is placed in the base frame, as a visual starting point for the framing of risk. With this, we wish to acknowledge the close connection between risk and decision-making (although it could of course represent the decision not to take action as well). Activity in the model could be read as human activity that generates risk, such as building a nuclear power plant. Activity could also be read as human activity that aims to manage or mitigate risks, proactively or reactively.[4]

The other two frame elements are values and knowledge. These are paired, as they can be seen as occupying the same epistemological level, while activity is at a different level. Their placement is also intended to signify the interaction of values and knowledge in activities involving risk, together with the fact that risk cannot be reduced to either a matter of objective fact or of subjectivity, but that it has a dual nature of both objectivity and subjectivity.

The frames of the model are represented by dashed lines, there are two figurative interpretations we wish to promote by this design. First, the non-solid lines allow the frame elements to permeate into the understanding of the core elements. Second, these dashed lines should be seen as flexible, knowledge and values are not always equally represented in a risk issue, nor is there any certain balance between the weight of values and knowledge to activity.

As was shown in Section 2, there has been a move in the risk literature towards making a distinction between definition and operationalisation (i.e. quantification and measurement) of the risk. Consequently, the model in Figure 1 is intended to be compatible with a variety of quantitative operationalisations of risk, such as they may appear in relevant risk assessment and risk management applications. The model serves first as an overview of important aspects that may be elaborated on in teaching about risk on the basis of the realisation that the concept is multifaceted and characterised by a diversity of different uses, and second as a reminder that risk issues are not solely issues of facts and numbers, which would, in the words of Hansson (2011) 'rid a complex concept of much of its complexity'. To provide students such an incomplete view of risk would be an undesirable outcome of teaching about risk in science education. The conceptual model of risk in Figure 1 may assist in planning education, as well as further research, so as to acknowledge this diversity and complexity of risk. In the next section, we illustrate how the model may be used to reason about how to include risk in science education.

4. Implications for science education

The model in Figure 1 is intended as a didactic model, in the sense of supporting didactic analysis (Kansanen, 1999; Klafki, 1995; Wickman, 2015) concerning choice and ordering of content in science education.

Thus, the presented model may support teachers' and researchers' analytic and practical treatment of risk in science education because: (1) it offers a set of elements which may be picked and combined in different ways for different educational purposes while, at the same time, (2) it suggests certain relationships between the elements which are not immediately intuitive or self-evident.

4.1. Remembering all aspects of risk

The simplest support that the model may provide teachers and researchers reasoning about how to include risk as a part of science education is as a reminder of the core and frame elements of risk. Consider the very general educational aim that students should understand the concept of risk as well as be able to use the concept in specific situations, for instance be able to discuss risks regarding nuclear power, electromagnetic radiation etcetera. Here, the model suggests that the four core elements (consequence, uncertainty, probability, and severity) will form the basis of such understanding, together with appreciation of the polysemy of the term and, depending on time and ambition, the different risk descriptions presented in Section 2 and Table 1. Moreover, the model suggests that an understanding of the risk concept crucially involves appreciation that both knowledge and values play a part in decision making concerning risk issues, and that such decision making is part of human activities.

4.2 . Increasing the Scope of ideas for teaching about risk

However, the model has the potential to do more than simply work as an external memory of important aspects of risk to include in one's reasoning about risk in science education. In particular, we suggest that the model may inspire and support a wider range of ideas of possible pathways that science teaching involving risk may take, through the suggested relationships between the seven elements.

The frame of the three elements (the triangle: activity – knowledge – values) in the model may be read as offering different possibilities about where to begin science teaching involving risk issues. Thus, moving into the model through the knowledge-frame suggests beginning in certain science knowledge areas, for instance, radiation in physics or gene-technology in biology. Alternatively, moving through the value-frame suggests the possibility of beginning teaching in value-judgments, for instance through value-clarification exercises, and have issues of risk incorporated contingently depending on where students' reasoning goes from there (Lundegård, Arvanitis, & Hamza, 2017). Moving through the activity-frame, in turn, may suggest involving students in broader inquiry into certain societal activities, such as use of mobile phones and their risks.

Whereas the three frame elements may be read as inspiring different points of departure for teaching involving risk, at the same time the model suggests that all three are interrelated. In both scenarios, the activity-frame provides the notion that risk issues need anchoring in authentic activities in which risks may be identified. Moreover, the model illustrates that teaching starting in certain science content (knowledge-frame) needs to find ways to relate that knowledge also to values. And the other way around, teaching beginning in more value-related questions needs to find ways to relate those values to knowledge concerning the specific content of the issue dealt with.

Thus, the triangular frame of the model supports two different but related points of departure for reasoning about how to begin science teaching involving risk: (1) Activity, knowledge, and values as three separate starting points for teaching involving risk. (2) Activity as the basis of any teaching involving risk, which may then take its departure more from a knowledge perspective or more from a values-perspective. And, the need to integrate knowledge and values in risk-related issues.

Once risk issues have been addressed one way or another, the four elements at the core of the model may come into play in different ways in relation to the three elements of the frame. Take, for instance, physics teaching beginning in the content area of radiation and its risk (i.e. moving in through the knowledge-frame). Then, one starting point could be the determination of an acceptable level of ionising radiation for the general population in the event of a nuclear accident (i.e. primarily connecting knowledge to an activity). Here, there are uncertainties with regards to the shape of the dose–response curve at low doses, i.e. how large effects (consequences and their severity) low doses would have or if there is a dose under which no effects are to be expected at all. Therefore, decisions on low-dose radiation risks are influenced by values, e.g. moral and socio-economic considerations (e.g. Eijkelhof, 1986; Howes, 1975), thereby relating back to the third element of the outer frame.

4.3 . Supporting analysis of students' risk reasoning

Yet another potential use of the model may be envisioned, viz., as support for analysing and identifying aspects of risk in student reasoning. For instance, take biology teaching moving into risk through the value frame, as described above with students engaging in value-clarification exercises concerning gene technology (Lundegård et al., 2017). Here, the model may be used by a teacher or a researcher as reference as students engage in deliberations, in which notions of risk may not always be as obvious. Thus, the model may assist in tracing and keeping track of the different aspects of risk in students' reasoning, even where students do not explicitly deal with it. This may offer better opportunities for addressing important points appearing in students' contingently developing reasoning, for teaching as well as research purposes.

4.4 . Teaching about or through risk

The examples given above may be seen as either concerning teaching explicitly *about* risk as well as teaching more implicitly *through* risk. This distinction may also be supported by the model. Thus, teaching about risk may be considered as focusing first on the core of the model, and successively relating these to how risk is used for decision-making, in which case the elements of the frame apply. This is illustrated through the example of radiation, above. Conversely, teaching through risk may be considered as focusing first on the frame of the model, as illustrated with our different examples of beginning in an activity, a certain knowledge area, or in value-judgments.

An example of teaching *about* risk could be the aim to enable students to evaluate risk related arguments. For this, we have to continue taking the polysemy of risk into account, and possibly help students deal with the coexistence of many possible meanings for particular arguments. Depending on the nature of the arguments examined, certain basic knowledge of probability may be invoked. Besides awareness of different ways to express and describe risk, the fact that values come into play in various ways related to the attributed severity of the putative consequences, should help students to analyse and critically discuss arguments on risk-related issues. If students are also expected to perform risk assessments, it will probably be important to help them realise the context dependence of different definitions and operationalisations of risk, and have them apply these to different concrete cases. Knowledge of probabilities should need to be even more detailed, as would knowledge about the actual facts of the matter. Furthermore, settling for a certain decision following an assessment, students should realise how their final judgment constitutes a mix of considerations based on knowledge and values, following the idea of risk as both objective and subjective.

Teaching *through* risk, under which risk can be an explicit or implicit part of the teaching may involve focus on the kind of content known in science education as *science in the making* (Christensen, 2009) and, so, explicitly teach about uncertainty and values, although not directly connected to risk but rather to the knowledge which may possibly inform decisions on risk. In addition, as stated already in the introduction, risk issues lend themselves very well to STS and SSI teaching aiming to encourage student deliberations around questions that are scientific in nature but that cannot be answered solely by traditional scientific methodology. Finally, when focussing on issues connecting to science in the making as well as socio-scientific issues, risk offers opportunities to explore aspects of inquiry and the nature of science, such as interpretation and misinterpretation of data, the tentative character of scientific knowledge, the involvement of values in decisions on what to research in the first place etc. Here, focus is primarily on the knowledge-frame, as well as the interaction between knowledge and values.

5. Discussion

Increasing attention has been directed towards risk as a component of societal decision-making. In a school education where the natural sciences meet social issues, teaching about risk and risk assessment can help students to gain and to structure knowledge, to take a stand and move towards well-founded decisions. However, as mentioned above, risk is a multi-faceted phenomenon and concept, originating in both ontological and situational activities. Incorporating risk in school science education thus poses both challenges and opportunities for science teachers (Christensen, 2009; Hansen & Hammann, 2017; Ravetz, 1997; Schenk et al., 2018).

A major part of the complexity lies in the dual nature of risk as both subjective and objective, requiring interplay between knowledge and values (Figure 1). It is this latter aspect that has drawn the most attention from previous works in the science education field. For instance, Christensen (2009) distinguishes between scientific/technical vs. subjective conceptions of risk and Hansen and Hammann (2017) between the realist and the constructivist paradigm of risk. These works also go more into detail on the psychological literature on risk perception under the headings of subjective conceptions and constructivist paradigms, respectively. The present paper complements these works as it draws much more extensively on the literature of how to define and describe risk. As shown in Section 2 the noun risk is polysemous, i.e. it has many different meanings. These different meanings are found within and between lay uses of the term, in applied expert uses as well as in academic discourse. Hence, and as has also been argued in Schenk et al. (2018), when incorporating risk in teaching, it is essential to be aware of the many different ways of expressing, framing and assessing risks.

In the present paper, we have attempted to extract important elements of risk from the available academic literature on the risk concept that can be useful for science educators (teachers as well as researchers) in guiding students towards relevant knowledge and clarify the different steps in their decision-making. First of all this exercise underscored the versatility and elasticity in the meaning of the concept of risk. In order to design own, qualitative and quantitative investigations of risk-related activities and phenomena, students need access to the multifaceted nature of the concept. Secondly, our exploration highlights a need for teaching to have the context-dependent nature of risk as a starting point, that is to spur students' realisation that the context in which risk is to be assessed affects the approach to risk and risk assessment methods. Finally, teaching about risk also needs to point towards the dual nature of risk as both subjective and objective. In many cases, it is easy to reach consensus on how to quantify risk, but the focal point of such quantification is always dependent on interests beyond the collection and compilation of knowledge. Our analysis indicates that rather than constituting a defining divide between two overarching frameworks about risk, as argued by Christensen (2009) as well as by Hansen and Hammann (2017), the objective/subjective-distinction in fact constitutes a duality of risk central to science education as it emphasises the close interaction between knowledge and values. Drawing on these findings we have created a conceptual model of the risk concept, intended to be used as a tool in the analysis and planning of teaching on risk-related topics in which science meets societal issues. The model incorporates the subjective/objective distinction of previous science education literature on risk, as one of several aspects to consider when including risk in science education.

Hansen and Hammann (2017) extracted three core components of teaching about risk, building on each other to progressively support students' development of risk competency. These were: (1) Scientific knowledge and statistics/probability, including knowledge about the risk issue, basic understanding of statistics and experts' risk judgements as well as reliability of data. (2) Knowledge about science (uncertainty, science in society and science as social practice), moving towards the issue of science in the making and stakeholders' and scientists' role in this. (3) Risk assessment, including risk-benefit analysis, ethical deliberations and decision-making. These core components were identified by Hansen and Hammann from (in order) the realist paradigm, the constructivist paradigm and the combination of the two paradigms. We have followed a similar line of reasoning in the present work; we see the progression from core components (1) to (3) as a sequentially moving deeper into our risk model, starting from the knowledge frame. More specifically, while core component (1) represents a less reflective approach on scientific knowledge, core component (2) with its focus on the nature of science and its limitations moves deeper into the core of the model. Core component (3) is found in the centre of our model. Hence, our model can be used as a support in designing teaching that addresses these three core components of risk teaching.

However, our model also allows for other starting points than the knowledge frame in the progression towards a more complex and complete understanding of risk. Most importantly, our model illustrates how risk is a complex concept and highlights the different elements requiring attention in teaching. In practical terms, when students form opinions regarding potential consequences of a risk issue, they need the opportunity to assess the severity and extent of consequences as well as instruments to assess the probabilities of the different consequences. In the teaching situation this requires us to firstly motivate students to make qualitative assessments of risks connected to different activities. In this step values and moral reasoning are essential as students are to deliberate on the nature of risk and identify relevant aspects of decision-making. Secondly, we need to provide students with quantitative tools for assessing the risks they identified. Simultaneously with these two steps, it is also relevant for students to evaluate the scientific knowledge and basis of risk assessment models, gauging the strengths and limitations of science, exercises that enhance understanding of the nature of science. By means of scientific knowledge the students are given the opportunity to make inter-subjective quantifications and critical analyses, whose point of departure were their own subjective statements. By the very nature of this process, the qualitative and quantitative assessments will develop in a mutual interplay. As shown in this paper, our model of risk may serve as an aide in pointing out elements of risk relevant to bring up in the class room. However, how to practically stage the teaching originating from this model is still to a large degree an empirical question.

Notes

1. Boholm and Corvellec identify three elements in their relational theory of risk: a risk object and an object at risk between which there is a relationship of risk. It is further noted that these elements 'only find their meaning in relation to each other and are constructed simultaneously' (p. 181).
2. Possibly the suitable definiendum in this case would be risk management (as proposed by Boholm et al., 2016) or risk analysis, rather than risk itself.
3. The psychological and sociological literature on risk perception is extensive and is of interest for science education. The differences in risk perception and risk as estimated by risk assessors has in several instances been raised as one argument for the need of addressing risk in science education (e.g. Eijkelhof, 1986; Gregory, 1991; Riechard, 1993; Zint & Peyton, 2001) and is also discussed in more depth by Christensen (2009) and Hansen and Hammann (2017). We will not explore the risk perception literature further in the present work as our focus lies on description of the risk concept, not perception of risks.
4. Risks can be managed proactively through measures such as including safety barriers in a nuclear power plant or wearing protective clothing to avoid over-exposure to UV rays. Reactive risk management means actions taken after an unwanted event, for instance exposure to radiation, has taken place in order to reduce the likelihood of future adverse health effects.

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