BRIDGING POLICY DEBATES ON RISK ASSESSMENTS AND MATHEMATICAL LITERACY

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The aim of this theoretical paper is to generate discussions on why to develop mathematical literacy and critical thinking related to risk assessments and how. The paper presents ideas and key points from the academic literature on science for policy related to uncertainty and risk assessments. These are elaborated and exemplified. I further show that these match aspects of mathematical literacy and related literature on research in mathematics education. Perspectives from the two academic communities are then combined, resulting in a framework for increasing competences useful for public participation. The theoretical foundation of the framework constitutes the starting point for a series of future research questions and research projects.

INTRODUCTION

We are facing tremendous challenges in society, covering scarcity on food and energy supplies and pollution of various kinds and sources. Science is given an important role in finding solutions to these problems, yet 'facts' are occasionally disputed with scientific advice at the centre of debate. The academic literature on science for policy has responded to this situation, and increased attention is given to the handling of uncertainty in science for policy in situations characterised by high stakes and diverging interests. Experts' common handling and communication of uncertainty through quantitative measures, as for example risk assessments, probability distributions, error bars or safety factors, are argued to be insufficient for sound decision making in such situations.

From a democratic viewpoint, challenging policy issues benefit from an engaged public. Facts are often presented in numbers and thus require mathematical literacy. In the next section of the paper, I present some background information and research on mathematical literacy that is linked to active citizens and critical thinking. The proceeding section provides examples where risk assessments have been disputed and briefly discuss these by demonstrating some key points from the academic literature on uncertainty in science for policy. The paper finally presents a framework for increasing mathematical literacy and critical thinking where perspectives from the two academic fields are combined. The ultimate aim of the framework is to enhance mathematical literacy to strengthen public participation where risk assessments are at the centre of policy making. At present, the framework rather serves as an instrument for theoretical discussions as a basis for a range of planned research projects on democratic and critical thinking. I consider the framework quite general, targeting students at any level of educational institutions, from primary school to teacher education institutions.

CRITICAL DEMOCRATIC COMPETENCE

UN describes literacy, including mathematical literacy, as a condition for critical awareness and which can stimulate participation and ensure increased influence on society. PISA 2003 and 2006 (OECD, 2003; OECD, 2006) defines mathematical literacy as: " [...] an individual's capacity to identify and understand the role that mathematics plays in the world, to make well-founded judgments and to use and engage with mathematics in ways that meet the needs of that individual's life as a constructive, concerned and reflective citizen" (OECD, 2006, p. 72).

The Norwegian National Curriculum reflects the societal needs in terms of mathematical literacy. It highlights the competence to "understand and critically evaluate information, statistical analyses […] to understand and impact processes in society" (Ministry of Education and Research, 2006). Further, the curriculum includes statistics, functions and graphic representation together with practical problem framing.

Mathematical literacy, including some definitions of statistical literacy (Ben-Zvi & Garfield, 2004), is closely linked to the development of critical democratic competence; the ability to criticize, evaluate and analyse applications of mathematics in society (Blomhøj, 1992, 2003). Blomhøj (1992, 2003) argues that mathematical modelling can increase the development of critical democratic competence, amongst others. The modelling process can be described as consisting of the following phases: a) Framing the problem, b) defining the boundary (the choices of what to include and what not to include in the model), c) mathematization (developing the model by describing the system/situation with mathematical concepts and language) d) the mathematical analyses (the mathematical calculations or representation from applying the model), e) interpretation and evaluation of the model results, and f) evaluation of the model's validity (Blomhøj, 2003). All phases demand critical and skilful evaluation, as they all include some kind of choice with no officially "correct" answer. Reflections during the process may result in revisiting certain phases of the process. As indicated, mathematical modelling will often stand in contrast to the rather common perception that science and mathematics produce one particular answer which is exact and correct. The acknowledgement of this is in itself a step towards critical democratic competence.

Research on school children working with aspects of mathematical modelling reveals children's development of critical thinking relevant for the modelling process (see for example Hansen, 2009, 2010). The process of developing risk assessments resembles the modelling process, but needs to include the sampling and data phase. This phase also demands critical and skilful evaluation. Watson introduces three tiers in statistical literacy: 1) understanding terminology, 2) understanding terminology in a social context and 3) critical awareness (Watson, 1997), where the third tier can be associated with critical democratic competence. Literature on educational research on critical democratic competence includes risk assessments related to nuclear power plants (Alrø, Blomhøj, Bødker, Skovsmose, & Skånstrøm, 2006).

In my opinion, increased awareness and understanding of the limitations in risk assessments of societal concern can help improve the quality of public debate. Citizens cannot be expected to understand complex mathematical calculations, but insights in the modelling or sampling process may help understand uncertainty aspects in the process. I now turn to the academic literature on science for policy and present key aspects related to uncertainty and risk assessments. The purpose is to discuss how these perspectives can be utilised in developing mathematical literacy and critical thinking related to risk assessments in schools and in teacher educations, which is addressed in the last section of the paper.

UNCERTAIN SCIENCE FOR POLICY

Science is often seen as a key factor to solving societal problems, and indeed, science has developed genetically modified organisms to increase food production and great effort is put into developing green technology. In addition, science often plays an advisory role in developing policies related to environmental risks, for example related to greenhouse gas emissions or fisheries.

While science has long been seen as 'truth' seekers, where science feeds the policy makers, we now eventually see that scientific 'facts' are disputed. The discussions around whether global warming is real and whether it is manmade are examples of this. It is argued that the nature of problems science is asked to provide advice for has changed considerably. Now scientists also have to deal with complex systems, of which knowledge and data are scarce, and where the issue at hand is controversial with great values at stake (Funtowicz & Ravetz, 1993). A consequence of these challenges is that some policy processes have become more open, where cross-sectoral approaches, stakeholder involvement or public hearings have influenced policy making.

Risk assessments often play an important role in decision making, for example in fisheries management, managing permissions for petroleum exploitation and managing permissions for nuclear power plants. In such cases, risk is generally defined as the probability of an unfortunate event multiplied with its effect. I now briefly present some discussions on existing risk assessments to demonstrate potential challenges with risk assessments in general.

Wild capture fisheries management is often based on risk assessments, where a management principle is to keep the probability of depleting a fish stock low. In general there are too many fishing vessels compared to the amount of fish, so that fishing needs to be restricted. Fisheries scientists provide risk assessments, and lack of trust is common between advisors, managers and the fishing industry. Several problems with calculating risk have been addressed (Hauge, 2011). First, the probability calculations are based on uncertain assumptions, ranging from the ability to predict what species fishermen catch to assumptions on environmental conditions, which often vary from one year to another and may be impossible to predict so that it adds relevance. Second, the relevance of the one, single event of consequences chosen from the event space has been questioned. It is further argued that these uncertainties are downplayed by the science community, although this may indeed not be the intention (Hauge, 2011).

The question of opening Norway's northern offshore areas to petroleum production has been a long and heated political debate in Norway because the areas host some of the worlds' largest fish stocks and bird colonies. A central issue has been the development of risk assessments, which are defined by the multiplication of the probability of a major oil spill by its environmental impact. There has been disagreement between the petroleum sector on one side and the fisheries and environmental sector on the other side, on which of the previous blowouts are relevant for calculating the size of a major oil spill. Further, the relevance of these risk assessments have been questioned due to the quite narrow scope of defining both the event and the impacts (birds, marine mammals and two fish species) (Hauge et al., 2012). The risk assessments represent only a limited interval in a continuous event space. This means that only events with extremely low probabilities are included and that few impacts are assessed. The debates have centred on the quality of the risk calculations rather than their scope and relevance. The risk assessments have thus defined what issues are plausible to discuss and criticize.

Similar problems are discussed regarding the risk calculations of meltdowns in nuclear power plants. The empirical basis for calculating the probability is argued to be weak since few power plants are based on comparable technologies. In addition, experience has shown that accidents are often initiated by a combination of two or more simultaneous events which in isolation are quite harmless. However, due to the complexity of power plants they have caused unpredictable occurrences, which have been challenging to interpret for the operators (Perrow, 1999).

My last example is from IPCC (International Panel on Climate Change). They do not operate with risk assessments as defined above, but they use the term 'likely' based on probability calculations: "Most of the observed increase in global average temperature since the mid-20th century is very likely due to the observed increase in anthropogenic greenhouse gas concentrations" (International Panel on Climate Change, 2012). 'Very likely' refers to a probability assessed to be above 90% (IPCC, 2012). Sceptical proclamations to climate change are not uncommon, and for a non-expert it is challenging to weigh 'evidence'. Yet, the uncertainty in, for example, IPCC's temperature predictions should be apparent for an interested reader, as IPCC can inform us that these are based on emission scenarios and a "hierarchy of models". The latter implies that several research groups around the world produce temperature predictions, and that a weighted average is chosen as the 'most likely' one.

There are several similarities between these examples: i) they all represent great values at stake: monetary value, nature, life style and identity, ii) reputable scientific communities produce advice iii) scientific advice has great influence on public debate and/or on policy making, iv) scientific advice is associated with substantial uncertainty, and v) advice or predictions are presented with hyper-precision, understood as numbers appearing much more certain than what the associated uncertainty would imply (Funtowicz & Ravetz, 1994).

Funtowicz and Ravetz argue that situations where stakes are high and 'facts' are uncertain require post-normal science, where quality in science is defined as both good, peer-reviewed science and as fit for purpose, where peer reviews are supplemented by extended peer reviews (Funtowicz & Ravetz, 1993). Although science may be 'truth seeking', traditional scientific questions and methods may not be relevant for a specific policy problem. Uncertainty should therefore be specifically addressed, and stakeholders, including the public, should evaluate the relevance of scientific input to policy and decision making (Funtowicz & Ravetz, 1993; Funtowicz & Strand, 2007). However, scientists and engineers are usually not trained to address uncertainty in other ways than probability distributions, error bars or safety factors.

In response to this situation, several frameworks have been developed to enhance relevance by articulating values and the qualitative aspects of uncertainties. The following list covers essential issues related to these:

a. Mapping values at stake (van der Sluijs et al. 2005a, 2005b, 2008).
b. Mapping potential risk bearers, which may depend on the final policy (van der Sluijs et al. 2005a, 2005b, 2008).
c. Uncertainty in the translation from a policy problem to a scientific question: whether the scientific problem answers the policy question or only part of it, and whether it is neutral to values and risk bearers (Walker et al. 2003).
d. The sources of uncertainty, referring to data, methodology, underlying assumptions, and the scope of investigation (Walker et al., 2003).
e. Characteristics of the uncertainties: for example whether uncertainty can be represented by measurement error or whether it involves unknown aspects, implying that uncertainty cannot fully be quantified. Another characteristic would be whether the uncertainty is reducible (Funtowicz & Ravetz, 1990; Wynne, 1992; Walker et al., 2003).
f. Extended peer-review (Funtowicz & Ravetz, 1993; van der Sluijs et al. 2005a, 2005b, 2008).

Uncertainty in framing the policy problem as a scientific problem is perhaps an unusual concept. However, the relevance of scientific framings has been questioned in all four examples above: whether managing single stocks are possible when fishermen catch a mixture of species (Hauge, 2011), whether the developed risk assessments are relevant for managing risks in petroleum exploitation (Hauge et al., 2012), whether single event accidents are characteristic for nuclear power plant accidents (Perrow, 1999) and whether all the efforts of reducing uncertainty in IPCC's temperature predictions will be helpful for policy making. In these examples, the event space is continuous, making a comprehensive risk analyses more or less impossible, forcing pragmatic choices to be made. These choices influence policy debates in ways people may not be aware of, which again can have political consequences. For example, the probability of a certain oil spill size is incredibly low, which again becomes an argument for opening areas for permitting exploitation.

The purpose of addressing characteristics of uncertainties is that numerical results accompanied by error bars, or other quantified uncertainty measures, do not communicate the soundness of the knowledge base. Appropriate data or knowledge may not be available, demanding more or less qualified guesses. Such choices have been taken, for example, in modelling global temperature development: assessing historic temperatures, deciding data point grids, deciding which physical processes to be left out in the model, etc. Uncertainty aspects like these cannot be reflected in quantified uncertainty measures and need to be addressed in addition. Frameworks are developed for this purpose (see for example Walker et al., 2003).

It has been questioned whether science gets devaluated through emphasizing uncertainty and involving non-experts as peer-reviews. Devaluation is not the intention, and it can be argued that a more extensive way of addressing limitation of scientific advice could rebuild trust in science. Most people support science, but it needs to be kept in mind that it is impossible to provide exact and precise answers to policy questions like the four above. Scientists and experts often need to narrow the scope of their investigations, and such choices may have political and value implications.

From a democratic viewpoint, policy issues like the four above benefit from an engaged public. The public may not grasp the complex mathematics or science behind predictions or advice, but the public may be competent in raising relevant questions to knowledge production and understand the nature of associated uncertainties and its societal consequences.

CRITICAL DEMOCRATIC COMPETENCE RELATED TO RISK

A question imperative to the paper is how educational institutions can work with the concept of probability and risk in order to improve mathematical and statistical literacy related to societal questions where risk assessments influence policy making and decisions. I now present a framework for developing critical democratic competences, but which also can serve as a starting point for theoretical discussions on planned research projects. The framework consists of three rather complementary approaches. The first is to conduct risk assessments, the second is to work with statistical concepts through issues presented in the media, and the third is to discuss risk assessments in light of the above list of value and uncertainty questions.

Conducting risk assessments requires both statistical and modelling competences and are activities closely linked to Blomhøj's modelling process (see above). Through first-hand experience on developing and applying models for calculating unfortunate impacts and models for calculating probabilities of unfortunate events, the student is trained in developing mathematical arguments. She further experiences that choices and evaluations need to be made in every phase of the process, thus gaining insight in associated uncertainties. The ambitions on which parts of this process are to be addressed, and how, may of course vary. And probabilities do not need be linked to unfortunate events in order to archive valuable insights.

The benefit of working with media issues is threefold: i) motivation, ii) conceptual understanding of statistical concepts and reflecting on the process behind quantified probabilities and impacts, and iii) experience with, and the habit of, discussing issues presented in the media. Probability, event space, stochasticity and stochastic variable are all challenging concepts. Internet offers a rich spectrum of issues related to statistical concepts, graphical representations of data and to quantified measures. I also find it valuable for students to work with different categories of the probability concept, for example: every day speech, probability calculations based on symmetry examinations and probability based on frequency calculations (categories taken from Lysø, 2010). Students can search for relevant issues on internet and define the stochastic variable related to the issue, the event space and other concepts, but they can also practice on discussing what kind of data has been used and how conclusions have been made. The point is not to find the right answer to what data has actually been collected, but rather to discuss challenges in gathering relevant data and dealing with complex problems.

The third approach is to discuss risk assessments presented in the media while exploiting the list in the above section on Uncertain Science for Policy. Again, the purpose is not to find the correct answers to the list, but to gain insight in what questions might be relevant in understanding values and uncertainties associated with the risk assessment. The students can thereby act as extended peer-reviews. This approach is perhaps the most challenging approach for the teacher and requires skilled teachers. A solution to this challenge could be to cooperate with relevant experts, maybe risk assessors, either at the teacher education level or in schools.

These three approaches to increasing critical democratic competence of students, specifically related to risk assessments, are partly complementary. The first facilitates an experience that mathematics is not necessarily about searching the one and only correct answer, but that choices need to be made based on reason and best guesses. The second generates deeper understanding of statistical concepts and allow training in applying these in the “real world”. The third approach seeks to gain insight in how uncertainty and values are linked in risk assessments and what sort of questions can be asked to illuminate value and uncertainty issues.

These approaches partly correspond with Watson’s three Tiers of developing quantitative or statistical literacy (Watson 1997, 2004). The first approach may require some familiarity with terminology, but could still be a way to increase understanding at all Tiers. The second approach is closely linked to Tier 2 as the aim is to increase understanding of terminology within social contexts. The third approach is obviously on critical awareness. Barbosa divides the uses of mathematical modelling in schools into three categories: *modelling as content*, *modelling as vehicle* and *modelling as critic* (Barbosa, 2006), and the framework presented in this paper falls mainly within the third category.

Although all approaches seek to enhance insights in the process of developing risk assessments, they do so from slightly different angles. They are partly complementary because the focus and activities differ. I consider insight in these as valuable for understanding not only the concept of probability and risk, but also the kind of choices scientists are facing when producing risk assessments. The framework consisting of the three approaches looks quite ambitious, but may not necessarily be so. For some students, it may be sufficient to focus on smaller parts of the framework, while engaged students may work more comprehensively and in depth. Also, risk assessments can be linked to other school subjects, facilitating multi-disciplinary approaches. This framework, and discussions around it, will form a basis for planned research projects related to critical democratic competences, involving teacher students, primary schools and lower secondary schools. As these projects evolve, I expect the framework to be changed and refined.

As a final remark, I find it important to emphasize to students that we can be critical to risk assessments, not because we expect scientists and experts to cheat or to perform badly, but because they are often required to give answers to problems to which solid conclusions cannot be expected. The scientists and experts involved are often the best in their field, and they provide valuable knowledge, but you may need to be critical to the context in which this knowledge is used.

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