Chapter 19

How to handle knowledge uncertainty: learning and teaching in times of accelerating change

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Abstract

This chapter describes the urgent need for enhancing 'uncertainty competences' in children due to the complex (environmental) challenges that face humanity. Young children are already confronted with knowledge uncertainty. It is important to teach them how to deal with it. A model is presented showing different pathways a learner can take while confronted with the need to make a decision in the presence of too little, enough, or too much knowledge uncertainty. Nine competences are distinguished that help a person to tolerate and to reduce knowledge (un)certainty: being able to accept not knowing what will happen; reflect on one's own or other's beliefs and being able to change personal beliefs; find and evaluate information; judge the credibility and cognitive authority of information sources; reason; respond in accordance with the underlying probabilities; assess one's own ability to achieve a desired outcome; engage a supportive network; formulate a plan of action to deal with uncertainty. The role of education in enhancing these competences is explored. Promising learning methods are discussed per competence. Suggestions are made for further research, including the need to analyse children's frames, devise measuring tools, and examine the maturational components of the development of uncertainty competences.

Introduction

Which expert should I believe about the causes of climate change? What's the point of turning off the lights, without knowing if it has any effect at all? The need to equip citizens with competences required to handle the increasingly complex environmental challenges of our time, such as climate change, has never been more evident (Kroeger *et al.* 2010, UNEP 2010). Examples displayed daily in the media, show us that the political and ethical impacts can be enormous. They illustrate that humanity is entering what some refer to as 'post-normal times': times filled with uncertainty, contested (scientific) knowledge, high levels of complexity, and the need for re-assessment of our value systems (Funtowicz and Ravetz 1993). An overload of uncertainty can lead to a state of paralysis (Lertzman 2012). This chapter describes the pressing need for enhancing 'uncertainty competences' in children and explores the role of learning and teaching. It provides a preliminary framework for handling knowledge uncertainty.

Although uncertainty is of all ages, the sort of uncertainty we are now facing is rooted in complexer and more far reaching dynamics in science and society. Studies regarding decision-making processes under uncertainty tend to focus on audiences such as politicians, policymakers and the general public (Marx *et al.* 2007). Children have been largely ignored. Yet, it is unlikely that these problems will be solved in the near future; any preparation we can provide now will be of significant benefit later in life. Preparing people for decision making processes related to these challenges requires developing uncertainty competences: specific sets of skills, knowledge, attitude and abilities needed to deal with uncertainty, ambiguity, and complexity in diverse contexts. Examples include 'being able to assess knowledge authorities' and 'being able to formulate a plan of action when dealing with uncertain information' (Beck *et al*. 2007, Gregory 1991, Metz 2004). Being able to deal with complex and uncertain knowledge is often seen as a premise for sustainable development (Mayer and Tschapka 2008, Remmers 2007). Experts cite it liberally while talking about Education for Sustainable Development. But how exactly do you teach someone how to deal with uncertain knowledge? This is the central question addressed in this chapter.

Why focus on children?

Questions arise about the way in which knowledge uncertainty related to these issues should be communicated to children without them becoming disheartened and indifferent. The body of scientific knowledge regarding this issue is relatively meagre. Some experts assert that children should not be confronted with complex and problematic environmental challenges (Sobel 1996, 2007), as they aren't sufficiently developed cognitively and emotionally. However, as children are confronted with these complex issues especially via television and the Internet, whether we like it or not, children require appropriate support (C. Armstrong, personal communications). So how do we prepare our children for a future filled with uncertainty? What role can education play in this preparation?

In the past we shielded children consciously and unconsciously from uncertainty, thinking that children would not be able to handle it. "The general tendency from the classical instructional design perspective was to recommend the elimination of ambiguity, in the interest of clarity and efficiency in instruction" (Visser and Visser 2004). However, a growing body of research suggests that children are capable of far more sophisticated mental processing (Beck 2007, Metz 2004). Perhaps a new paradigm, in which uncertainty with respect to facts and decisions can be discussed without hesitation, is both feasible and necessary. Godin goes one step further saying: "The obligation of the new school is to teach reasonable doubt. Not the unreasonable doubt of the wild-eyed heckler, but the evidence-based doubt of the questioning scientist and the reason-based doubt of the skilled debater" (2012, p. 25). This new way of looking at the abilities of young learners, as well as acknowledging the need for the acquisition of uncertainty competences, could have profound consequences for primary education.

Uncertainty, risk and ambiguity

The word 'uncertainty' means different things in different contexts (Van Asselt 2000). This relates directly to the way in which people frame knowledge (Aarts and Van Woerkum 2006, Goffman 1974). Scientists tend to view uncertainty as an intrinsic component of scientific inquiry. It is seldom possible to know enough to declare something a 'certainty'. For scientists, uncertainty points the way towards further research. Policymakers and the general public, on the other hand, tend to view uncertainty as a non-appreciated 'lack of knowledge' (ibid.). Risk is sometimes referred to as 'measurable uncertainty', however, according to Knight (1921) 'true uncertainty' cannot be measured or quantified .

Grenier *et al*. (2005, p. 594) state that "ambiguous situations involve novelty, complexity, insolubility, unpredictability and uncertainty with a set of cognitive, emotional and behavioural reactions [as result]". They further say "individuals who are intolerant of ambiguity are unable to tolerate the present situation which they experience as threatening. Individuals who are intolerant of uncertainty will consider it unacceptable that a future negative event may occur" (ibid., p. 596). Defined this way we can say that ambiguity refers to the properties of a stimulus (situation) itself, whereas uncertainty refers to both the immediate situation and its implications for the future and the need to react or make a decision.

Knowledge and knowledge authorities

Knowledge includes "facts, information, and skills acquired through experience or education; the theoretical or practical understanding of a subject." (Oxford Dictionaries 2012). We often find ourselves dependent on the knowledge of others about events that are distant from us in time, place (Wilson 1983) and/or comprehension. These sources can be referred to as 'knowledge authorities'. The more we are dependent on what Wilson calls 'second-hand knowledge', the more we have to "rely on, or believe in, that others are capable of delivering information in a reliable or credible way" (Andersen 2004, p. 11). It is important to develop the ability to judge the credibility and cognitive authority of these information sources.

Knowledge uncertainty

To explore the concept of 'knowledge uncertainty' we will use the example of eight year old Jonathan. At school Jonathan's teacher engages her pupils in a discussion about energy use and climate change. She concludes the days' lesson by telling her pupils that from now on they will turn off all the lights every time they leave the classroom. In doing this they will help fight climate change. However, Jonathan is left puzzled and does not really understand how leaving on the lights contributes to climate change. Can he really make a difference? What is the right choice? Jonathan's confusion may have been caused by his teacher providing:

- ambiguous/confounding evidence; and/or
- too complex information

In the case of confounding evidence, some crucial information is lacking (Schulz and Bonawitz 2007). Perhaps the teacher left out information she found too difficult for the children to understand. In a second scenario the teacher tries to explain how electricity is usually produced by burning fossil fuels, which leads to high CO_2 emissions, which in turn contributes to climate change. The knowledge the teacher is sharing is too complex for Jonathan to understand.

The perceived 'knowledge uncertainty' could also originate from two other sources. Usually Jonathan doesn't doubt his teacher's explanations. But a classmate contradicts the teacher. Her father is a professor of electrical engineering and he says that indeed the climate is changing, but turning off the lights whenever you leave the room is not going to change that. It might even be a more unsustainable action, as lamps that are switched on and off all the time have a lower life expectancy. Who should the little boy believe? He has limited means to verify the reliability either of his teacher's remark or what the father of his classmate said. Jonathan might have difficulty judging either:

- the trustworthiness of the knowledge authority; and/or
- the reliability of the information

Individuals follow rules and strategies, both referring to the cognitive process used to solve problems and make decisions. Strategies may be learned explicitly or deduced from experience (Jansen *et al*. 2002). When a person needs to make a decision to act upon given information her or she can find themselves confronted with 'knowledge uncertainty'. The example demonstrates that perceiving knowledge uncertainty is a highly individualized experience. What one person experiences as uncertain knowledge, for instance, because he doesn't know the source, could be experienced as certain knowledge by someone else who does recognize the source and judges it as trustworthy. Similarly, what is considered complex knowledge by one person, could be experienced as uncomplicated by another.

Theoretical framework

Decision-making involves an iterative learning process. When a learner has to make a decision while being confronted with knowledge uncertainty he or she can follow different pathways. The model in figure 1 presents different pathways for handling this uncertainty. It is made up of five layers. In the example Jonathan wonders if from now on he will or will not turn off the lights (the *event* which confronts a person with a decision to be made). Jonathan is too uncertain to make a decision (experienced *degree of knowledge uncertainty*). The issue of climate change makes him feel uncomfortable and he wonders if what he does really makes a difference (*cognitive, emotional and/or behavioural effect*). His teacher could tell him that it is a good question. She could also suggest places where he could look for answers (*teaching strategy* to acquire the necessary competences). In this way she models an effective way to deal with knowledge uncertainty. Jonathan follows her advice. Then he makes his *decision*.

Learners can travel down alternative pathways corresponding to their degree of knowledge uncertainty: too little, enough or too much. How this uncertainty is experienced relates to a person´s level of uncertainty tolerance. Individuals have different uncertainty thresholds, comparable to the dissonance thresholds discussed by Wals (2007). What is stimulating to one person can be frightening to another. Traveling along the pathways the level of experienced (un)certainty is reduced sufficiently to make a decision. Sometimes people have to make a decision even though it would seem that their level of knowledge uncertainty has not been sufficiently reduced. The model presented in this chapter is built on the premise that a person will not be able to make a decision if the level of experienced uncertainty is too high.

Enough uncertainty motivates learning

We all need some stimulus to make decisions and act accordingly. This requires at least a minimum amount of uncertainty. Dewey explains how thinking and producing true knowledge starts from feelings of uncertainty and requires a questioning attitude (Dewey 1916). In 1956 Festinger coined the well-established concept 'cognitive dissonance'. It represents the discomfort caused by holding conflicting cognitions (e.g. ideas, beliefs, values, emotional reactions) simultaneously. Dissonance is an uncomfortable state. The theory of cognitive dissonance proclaims that people have a motivational drive to reduce dissonance by altering existing cognitions or adding new ones to create consistency. Dissonance is also reduced by avoiding further knowledge after a decision has been made. A strongly related concept is that of 'cognitive disequilibrium' which refers to the internal conflicts a child experiences when differences between current beliefs and new information lead to a disequilibrium, which in turn motivates the child's progress through various stages of development (Piaget 1952, Stonewater and Stonewater 1984).

Too little uncertainty blocks learning

Experiencing too little uncertainty can hinder learning (Ritchhart and Perkins 2000) and deeper level processing and may lead to feeling a lack of personal relevance or to boredom. Jonathan might decide that the whole issue of climate change is a problem for grown-ups to deal with if his teacher doesn't make his decision relevant by connecting the event to his life world. In the case of boredom, it is important to make the decision-making more interesting by adding some element of surprise which fuels the students' curiosity. It is often thought that something 'new' has to be introduced to keep the learner motivated. However, researchers have found that adding some uncertainty by presenting young learners with confounded information regarding a stimuli whose causal structure is ambiguous can be very motiving in its own right. Learners continued exploring the stimuli until they understood how it worked (Schulz and Bonawitz 2007). It was only then, that they became interested in the new stimuli.

It seems relevant to examine another subcategory of too little uncertainty: complacency. Does 'no uncertainty' equal 'certainty'? Intuitively you might think that making a decision while being confronted with certainty is clear-cut and easy. However, it is often so that it should not be. Information sources frequently have a hidden agenda, in the light of which it can be important for them to frame knowledge as certain, when in fact it is not. The debates about climate change provide an obvious example. The opposite also occurs when things that have a high probability of happening are framed as uncertain to reduce dissonance (e.g. regarding health related risks). It can therefore be as important to be able to question certainty as to deal with uncertainty. Both rely on an understanding of the dynamic quality of knowledge. Of course it can be essential in a particular situation to frame a message as (more) certain in order for people to understand it and to act appropriately (CRED 2009). However, when people are better at handling knowledge uncertainty, at least some knowledge authorities will have less incentive to frame knowledge as indisputable. Bear in mind that asking questions may lead to answers, and new questions, possibly creating so much uncertainty that a person cannot reach a decision after all. It is all about striking the right balance.

Too much uncertainty blocks learning

Too much uncertainty can lead to cognitive, emotional and/or behavioural overload (Grenier *et al*. 2005). Experienced stress is a function of an individual's appraisal of a situation and how he copes with it (Greco *et al*. 2000). When confronted with too much knowledge uncertainty three distinct pathways can be followed, each involving the development of different uncertainty competences. These are competences that reduce uncertainty, competences that assist in tolerating uncertainty and competences that limit one's awareness of knowledge uncertainty. Although limiting uncertainty is a way of coping and creating a sense of control, it does not aid in optimizing learning. Nonetheless it is common practice. When teachers decide that information about e.g. climate change is too difficult for their students to understand, they often simplify and/or omit information. They are modelling that uncertainty should be avoided by taking uncertainty out of the learning context. The student not only does not learn to handle uncertainty but is confronted with too little to prompt learning.

Uncertainty Competences

Dynamic qualities "are necessary for a new perspective on the world, allowing us to be flexible, appreciate other people's opinions, to abandon known paths and seek new ones" (Mayer 2003, p. 5). Gregory (1991) discusses critical thinking skills that children need to develop with regard to health safety issues and the associated uncertainty. Pigozzi (2008, p.11) presents a list of 'learning capabilities of the 21st century' which includes "critical thinking and problem solving skills, further specified into 'reasoning, recognizing and questioning patterns; dealing with uncertainties; analysing, synthesizing and evaluating information' and 'information, media and technology skills". Godin (2012) asserts that people need to learn to be "comfortable being wrong, comfortably verbalizing a theory and then testing it." Indeed Some *methods of reducing uncertainty* can lead to a sense of control. However, it is also important to *learn to tolerate uncertainty* and to remain open to new information. Learning to tolerate uncertainty makes it easier to learn how to reduce uncertainty and vice versa. The following list of uncertainty competences is not necessarily complete. It is intended to initiate a thoughtful discussion about uncertainty competences.

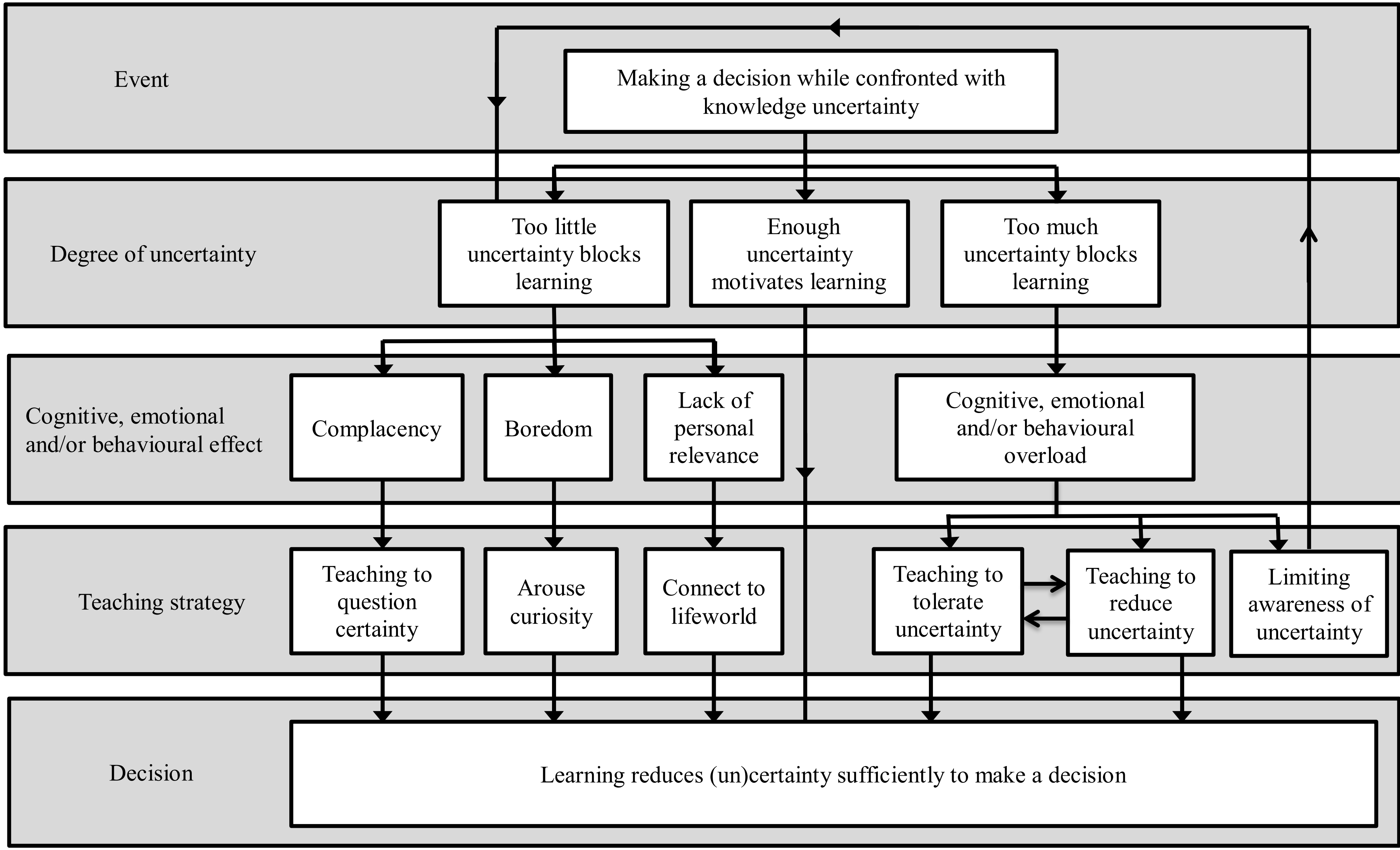

Figure 1: Pathways for handling knowledge uncertainty

Learning to tolerate uncertainty

The two competences in this category comprise a close weave between skills and attitudes. Letting go of the need for certainty, and having the ability to adapt to change and generate new knowledge are central to learning to tolerate uncertainty. A second competence that deserves to be mentioned is the ability to change personal beliefs which may facilitate a positive attitude regarding an uncertain situation. Of course one can always reflect on the situation and decide to view it negatively, but acknowledging the power of belief-making (Gelatt 1989, Kaufman 1999) and maintaining a flexible mindset can be important skills that support decision making in the face of uncertainty.

1. Being able to accept not knowing what will happen;
2. Being able to reflect on one's own or other's beliefs and being able to change personal beliefs

Learning to reduce uncertainty

Seven competences can be distinguished that assist in reducing knowledge uncertainty.

3. Being able to find and evaluate information
4. Being able to judge the credibility and cognitive authority of information sources
5. Being able to reason (inductive and deductive reasoning)
6. Being able to respond in accordance with the underlying probabilities
7. Being able to assess one's own ability to achieve a desired outcome
8. Being able to engage a supportive network
9. Being able to formulate a plan of action to deal with uncertainty

What teaching methods are available to develop uncertainty competences?

1. Embracing uncertainty

How do you get someone to embrace something like uncertainty when he has a strong aversion to it? Teachers can discuss the positive qualities of uncertain knowledge with their students. DeRoma *et al*. (2003) speak of providing students with a rationale highlighting the benefits of raising tolerance of ambiguity. They also stress the importance of modelling ambiguity-tolerance in the classroom by showing its affinity with exploration and risk taking. In addition, training which makes use of a gradual increase in the level of uncertainty can initiate the process of desensitization or habituation (ibid., Doherty and Clayton 2011). Another approach entails practicing 'mindfulness' a concept that has its origins in Buddhist meditative traditions. It views mindfulness as a tool with which a person can enhance awareness of his or her 'moment-to-moment experience'. Moss *et al*. (2008) state that mindfulness may be described as the practice of 'safe uncertainty'. It can assist with accepting, for example, anxiety caused by an ambiguous situation. Mindfulness can also be seen as a goal. Ritchhart and Perkins (2000) speak of 'nurturing the disposition of mindfulness'. In other words allowing feelings of uncertainty to be present.

2. Reflection skills and a flexible mindset

Gelatt (1989) describes the concept 'positive uncertainty' in relation to counselling. When adjusted to an educational context this term refers to a decision framework that helps students deal with change and ambiguity, accept uncertainty and inconsistency, and utilize the non-rational and intuitive side of thinking and choosing. He explains that changing one's mind will become an essential skill (in the future). Special attention should be given to the process of reflecting on one's beliefs and the ability to change them (Kaufman 1999). Reflective learners are receptive to feedback and able to adapt appropriately (Fraser *et al*. 2001).

3. Finding and evaluating information

It is important for learners to acquire 'information technology skills' for effective information gathering, for example, by using search engines on the Internet and catalogue systems in libraries. Gregory (1991, p. 282) writes that "many children will tend to take account only of the information that is readily at hand". A special aspect of finding required information is the ability to delay interpreting ambiguous input in order to gather disambiguating evidence. Beck *et al*. (2007) describe that children until about seven years of age are inclined to make a quick judgment even though the information remains confounded. "We experience uncertainty when we believe that any number of possible answers may be correct" (Gregory 1991, p. 278). Learners need to be taught how to question the knowledge sources they are using and to assess whether the information they find is sufficient to solve their 'problem'. To avoid cognitive overload (Van Merriënboer *et al*. 2003) for (novice) learners, attention should be paid to the number and complexity of information sources the learners are required to examine. Both characteristics can be gradually increased as the learning process progresses. As learners become more skilled at gathering information, it's important to confront them with the often contradictory sources and suggest ways for them to judge their content.

4. Assessing knowledge authorities

Closely related, but not entirely the same as finding and evaluating information, is the assessment of knowledge authorities. It is important to learn to ask questions about the interests of the people and organizations 'behind' information sources. What are their (hidden) goals? What do they base their opinions on: peer reviews, double blind research experiments and/or anecdotal evidence?

Another interesting dimension to the discussion of knowledge authorities is that of the generational divide between children and their educators (Sacks 2006, Wilson and Gerber 2008). The different generations are said to acquire and process information differently. This theme was popularized by Boschma and Groen (2007). For example, the introduction of Internet, they propose, often left generation Xers feeling disillusioned and confused with the disappearance of former 'knowledge authorities' (parents, teachers, scientists, books, etc.). The children and youth in schools and colleges today are growing up with Internet and learning quickly that there is more information available than one can process and that information sources can disagree. Perhaps for them knowledge and truth have a more temporary character. Do today's children learn to handle knowledge uncertainty automatically by growing up in an age in which their umbilical cords are already plugged into Internet?

5. Reasoning abilities

People use different tools to choose one decision over another. 'Deductive reasoning' starts out with a theory, then a hypothesis that can be tested, observations collected to address the hypotheses and finally a confirmation or a rejection of the original theory. In a deductive reasoning problem there is only one logically valid answer. If Jonathan is given the two premises " all dogs bark" and "Rex is a dog", there is only one logical deduction. Rex is a dog, all dogs bark therefore Rex must also bark. Had Jonathan been told instead "Rex is a cat" and "all cats bark" and then asked "does Rex bark" the correct deduction would again be that Rex must also bark (Goswami 2004). 'Inductive reasoning' starts out by observing, detecting patterns and regularities, formulating a tentative hypothesis, exploring this hypothesis and finally developing a theory. When there are gaps in our knowledge, we have to reason by induction. Generalizing on the basis of a known example, making an inductive inference from a particular premise, or drawing an analogy are all examples of inductive reasoning at work.

6. Understanding probabilities

When people talk about probability assessment images involving adults in complex situations such as stock markets, politics and gambling come to mind. More and more evidence, however, is coming to light regarding infants already perceiving statistical patterns in their environment (Goswami 2008). We will examine assessing risks and recognizing and questioning patterns from a physical and then a more cognitive-mathematical perspective.

Risk assessment is concerned with estimating risks, the reward for achievement, and the seriousness of failure (Jambor 1986). Estimating these factors is learned and improves with experience. Jambor focuses on the learning benefits of physical activities. Through play and exploration of their environment children encounter numerous challenges that involve decisions for risk-taking behaviour (ibid.). Jambor makes suggestions for the development of safe play environments that at the same time harbours risk and challenges.

With respect to the 'cognitive-mathematical' perspective, Kazak and Confrey (2007) suggest that students' informal conceptions of probability and distribution can be developed through a sequence of tasks. Using simulations to model natural probability distributions where students build upon previous experiences can lead to informative discussions of probability and statistics. "Children are given very little guidance as how to express the terms 'doubt, confidence, probability and likelihood' numerically or interpreted in a consistent sense" (Gregory 1991, p. 278). Spending time in the classroom comparing students' verbal and mathematical interpretations of uncertainty can enable clear communication about the probability of a future event. Students develop a better understanding of such important concepts as calibration and overconfidence. "When individuals have only a vague notion of probability, their ability to think about the consequences and to choose among alternatives suffers. They will be prone to well-known biases: probabilities with a high likelihood are viewed as certain and events with a low probability may be forgotten" (ibid., p. 279).

7. Assessing your own abilities

It is important for a person to be capable of realistically judging his own competence level in a particular situation. Assessment *as* learning emphasizes assessment as a process of metacognition (knowledge of one's own thought processes). It involves learners in the process of looking at their own learning and reflecting on their own abilities. With instructor guidance, modelling, and through focused activities, learners are encouraged to think about and assess their learning process. Teachers have the responsibility of creating environments in which students can become confident, competent self-assessors by providing emotional security and genuine opportunities for involvement, independence, and responsibility. Students need clear criteria and many varied examples of what good work looks like. Helpful learning methods are, for example, in-class discussions of learning points, teacher feedback, self-assessment checklists and learning logs (WNCP 2006).

8. Engage a supportive network

If someone is uncertain about a decision and does not possess sufficient competences to make a decision, it may be of great importance to be able to activate a supportive network. Though networks are not a new development in themselves, think of church groups, guilds and unions, actively forming networks seems a part of growing up in the 21st century. Indeed youth these days seem to be plugged in 24/7. Nonetheless, it is not just about knowing a lot of people, or knowing 'the right' people, it is also about getting them interested and committed to help you with your decision-making. Because networking is an important part of most careers and indeed life in general, it is an important skill to teach. Using classroom games and teambuilding exercises, can be an effective way to enhance networking skills.

9. Formulating an uncertainty action plan

When people are faced with knowledge uncertainty associated with complex environmental problems, it can be essential to develop action plans based on, for example, the Precautionary principle (Petersen 2002). The principle states "that if there is an indication that a certain activity may be harmful to humans or the environment, that activity should be abandoned" (ibid., p. 1). According to Van Merriënboer *et al*. (2003, p.6) "although 'part-task approaches' can be effective in preventing cognitive overload, they are not very suitable for learning complex tasks" such as the development of action plans. This requires coordination and integration of constituent skills. Van Merriënboer *et al*. (ibid.) suggest whole-task approaches in which "instruction starts with the most simple but authentic case that a professional might encounter in the real world". One example is 'problem based learning'. In this approach students learn through facilitated problem solving. They are confronted with a complex and realistic problem for which there is no single correct answer. Students work in collaborative groups identifying what they need to learn in order to solve the problem. A plan is made to divide tasks and decide how useful information will be gathered. Facilitator should discuss the inherent uncertainty of planning. During the process students adjust their planning according to the chain of events. While searching for solutions, students master e.g. problem solving skills, decision making, self-directed learning and collaboration skills (Hmelo-Silver 2004). The teacher facilitates learning by providing scaffolding, modelling a positive attitude towards an uncertain, open-ended process and providing feedback (Schmidt *et al*. 2011). In addition to the uncertainty related to content, experienced knowledge uncertainty could also be due to procedural or task ambiguity and complexity if, in other words, the instructions aren't clear enough or the learner does not (yet) have the abilities to proceed effectively (Van Merriënboer *et al*. 2003).

Discussion

Uncertainty and knowledge uncertainty have been examined and an attempt made to define the competences required to deal with them. The emerging model was created by drawing upon research from different disciplinary fields, such as developmental psychology, cognitive and decision sciences, neurocognitive sciences, education for sustainable development, education sciences and instructional design. It has been shown that uncertainty is not in itself negative, but rather something that sparks learning processes. Striking the right balance between too much and too little uncertainty is essential. Learners need to be guided along the different pathways for handling knowledge uncertainty. Specifying the different uncertainty competences is the first step towards a better understanding of the development of these competences in children. Some of the competences are already familiar in educational settings (e.g. being able to find and evaluate information, judging knowledge authorities and reasoning), others are less well known (e.g. being able to embrace uncertainty and to engage a supportive network). ‘Uncertainty education’ should be an integral part of ‘education for sustainability’. Although learning how to handle uncertainty is frequently mentioned in this context, in practice it does not yet seem to get the attention it deserves. Much research still needs to be done. Here are some suggestions.

A detailed analysis of children’s frames with regard to knowledge uncertainty is essential to developing guiding principles to facilitate the design of learning environments and learning methods conducive to the acquisition of uncertainty competences. Do they perceive knowledge uncertainty as frightening, exciting or perhaps unnecessary for children to concern themselves with? What about the difference in frames between children and between children and adults? How do children’s frames change over time? And how do children perceive the lack of ‘ultimate knowledge authorities’?

The conducted literature search reveals many possibilities for enhancing skills and attitudes through (primary) education. It becomes clear that integrating ‘uncertainty education’ does not have to involve an entirely new set of learning methods and activities. Developing uncertainty competences is not an isolated topic on a teacher’s already packed agenda. It is important to find ways to integrate it in the existing curriculum. Each competence deserves a further and in-depth analysis of the most effective and practical instructional designs for its development.

A challenge for the future will be to develop measuring instruments with which the development of uncertainty competences can be described and perhaps even quantified. For example, learning to embrace uncertainty may be correlated to a decrease in ‘the intolerance of uncertainty’. The ‘Intolerance of Uncertainty Scale (IUS) is currently one of the most favored measuring instruments which could be employed (Comer 2009, Grenier *et al*. 2005).

It may well be that there is a maturational component to the development of particular uncertainty competences. For example, according to Delfos (2005) there is a turning point in the development of abstract thinking in children around the age of seven and Beck (2007) describes how children around the age of seven become better at dealing with ambiguous situations by delaying their response. Different authors explain that “young children tend to over-estimate their knowledge under conditions of uncertainty, to a much greater extent than older children and adults” (Fay and Klahr 1996, Klahr and Chen 2003). The maturation of the nine uncertainty competences deserves further exploration because it may provide preconditions for the development of learning methods and learning environments. It is important to investigate in which cases it is useful to spend valuable teaching time and resources aimed at the development of these competences. Which competences would develop naturally during the child's development without active engagement by teachers (Piaget 1967) and which could benefit from specific support?

The combined efforts of researchers and teachers are needed to provide useful guiding principles for the development of learning environments and teaching methods conducive to the development of uncertainty competences. Some initial thoughts are that such learning environments need to…

1. incorporate uncertainty – uncertainty as context
2. contain clear boundaries and ground rules, making it safe enough for students to take risks and openly reflect on what they believe (Fraser *et al*. 2001)
3. include open-ended curricula (no single answer questions)

It is too early to extend the emerging framework with such guidelines. We first need to learn more about the children's frames, and the maturational, as well as the educational, components of learning and teaching how to handle knowledge uncertainty. This calls for further literature research and strong empirical research.

"*Uncertainty and mystery are energies of life. Don't let them scare you unduly, for they keep boredom at bay and spark creativity*."

R. I. Fitzhenry

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