Testing Stakeholder Engagement in Ecological Risk Analysis: A Case Study of Genetically Modified Maize and South African Biodiversity

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Abstract

Ecological risk analyses (ERA) are traditionally conducted by a narrow range of biological scientists with limited stakeholder involvement. Different knowledge types and epistemologies necessary for understanding how stressors move through complex socio-ecological systems are generally excluded, as well as broader societal concerns of interested or affected parties. Calls for stakeholder engagement in ERA aim to address such deficiencies, but little real-world evidence exists on: 1) how to design participatory ERAs, 2) how ERA results change with inclusion of diverse participants, and 3)how to facilitate social learning fundamental to such collaborative endeavors. Social learning occurs when people engage with each other and share diverse perspectives and experiences to develop a common framework of understanding and foundation for collective action. Such learning is critical for efficacious participatory ERAs because participants must engage with different disciplines, epistemologies and worldviews to understand socio-ecological systems in which risks manifest, how the risk situation occurred, and then develop joint support for specific risk governance actions. I tested a participatory ERA process specifically designed to engender social learning through open communication, constructive conflict and extended engagement, in two workshops analyzing potential impacts of genetically modified (GM) maize on South African biodiversity. Workshop 1 involved four biologists, who were then joined by 18 diverse participants in Workshop 2, and I compared the ERA process and results between the two. Workshop 2 participants generated a larger and more comprehensive set of hazards and a more in-depth understanding of the agro-ecological system, creating a robust information base for the final risk assessment. Social learning occurred, as participants engaged with new information and diverse perspectives, began thinking systemically and modified their risk perceptions of GM maize. Participants did not, however, develop a shared understanding of the ERA process or highest priority risks to biodiversity. These results suggest that it is possible to implement participatory ERAs that generate useful risk-relevant information, and carefully designed participatory processes can produce social learning about other stakeholders, complex socio-ecological systems, and the topic of risk in short time periods. However, longer engagement is needed to build a shared understanding of the risk situation and possible solutions. Such learning-focused participatory ERAs should help transform risk governance from an unreflective approach (e.g., using risk assessments conducted by a small set of experts focusing on the stressor's most obvious attributes) to a reflexive approach, which not only aims to widen the scope of impacts evaluated but also considers how societal values and norms influence the conception and handling of risk.

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Introduction to the dissertation

Ecological risk analyses (ERA) aim to identify and estimate threats to natural systems, and their results often support decisions on how to manage human activities and technological development (Burgman 2005). Such analyses are typically conducted by experts using scientific information as the primary input, and opportunities for stakeholder or public engagement are limited to just before final decisions are made. Such analyses generally exclude different perspectives, knowledge, and epistemologies useful for understanding many of today's complex risk situations, which are increasingly arising when stressors like non-native species and emerging technologies enter interconnected socio-ecological systems. There are growing calls for greater stakeholder involvement to address such knowledge deficiencies, as well to allow more citizens to engage in issues that interest or affect them and build their support implementation of risk management actions (NRC 1996). However, there is little empirical evidence on the following questions: 1) how to design an ERA with genuine and substantive stakeholder involvement, and 2) whether and how such stakeholder involvement affects the content and outcomes of an ERA. These information gaps led to the dissertation research reported here, which investigates both questions, as well as the extent to which group learning and communication—or social learning—can result from participatory ERAs.

The case study of ERA of genetically modified (GM) maize in South Africa came about as the South African National Biodiversity Institute (SANBI) began to implement a 2004 legislative mandate to develop a national monitoring program for evaluating potential impacts of GMOs on the nation's biodiversity. SANBI developed a partnership with the University of Minnesota's NSF IGERT on Risk Analysis for Introduced Species and Genotypes to design an ERA process to help structure an evaluation of which interactions between biodiversity and GM crops are of most concern to monitor or research. Furthermore, SANBI recognized the importance of including stakeholders in this ERA process, as much of the biodiversity in and around agro-ecological systems is understood best by those living and working in such systems. GM crops have also generated controversy in South Africa, and SANBI anticipated interest in the process of identifying monitoring and research endpoints. South Africa also has a strong commitment to public participation in decision-making, and SANBI is similarly committed to these ideals. For these reasons, South Africa was an ideal place in which to conduct research on how to engage stakeholders in an ERA process and evaluate the outcomes of such involvement.

Conservation Biology is a problem-driven field concerned with studying the Earth's biodiversity and developing practical methods for protecting it from threats. Soulé (1985) pointed out that the discipline is often concerned with viability of whole systems (both the social and the ecological), and is characterized by an interplay between the social and natural sciences. ERA is a tool useful for identifying threats to biodiversity, but is just beginning to be applied to evaluate living or novel stressors entering complex socio-ecological systems. Conservation Biology can therefore benefit from advances in stakeholder engagement in ERA, as a way to better incorporate diverse types of knowledge and experience necessary to understand the type and magnitude of threats to biodiversity systems and to engage interested and affected parties in designing and implementing socially *and* biologically relevant solutions.

This dissertation is comprised of three chapters, each of which is written for publication in a different peer-reviewed journal with one or more co-authors. The first chapter reports testing and results from the design and implementation of a participatory ERA process to evaluate potential threats to South African biodiversity from GM maize. The second chapter complements the first, by investigating the extent to which the design of such a participatory ERA can engender social learning between diverse participants and the role of group learning outcomes in a successful participatory ERA. The third chapter applies the theory of reflexity to the process of risk analysis and investigates how social learning-focused participatory ERAs can move risk governance from a prevailing unreflective approach toward a more reflexive one which also assesses the role of societal values and norms in influencing the conception and handling of risk.

CHAPTER 1: Testing Stakeholder Involvement in Environmental Risk Analysis: A Case Study of Biodiversity Risk Assessment in South Africa

Environmental risk analysis (ERA) is traditionally conducted by biological scientists with limited stakeholder involvement. Such an approach often excludes different knowledge types and epistemologies necessary for understanding the social and biological complexities inherent in biodiversity conservation. We describes implementation and results of a highly participatory ERA process, addressing two research questions: 1) how does one implement a scientifically rigorous ERA process, using formal risk assessment tools, with stakeholder involvement at all steps; and 2) how does the involvement of diverse stakeholders change the ERA process, information, and conclusions? We conducted two participatory ERA workshops in South Africa, to analyze potential impacts of genetically modified maize on biodiversity. The first workshop involved only four biological scientists, who were joined by 18 diverse participants in the second, and we examined the ERA process and results between the two. Diverse stakeholders generated a larger and more comprehensive set of hazards, creating a more robust information base for the final risk assessment. Assessment endpoints and risk acceptance criteria should be defined with stakeholders just prior to a separate technical exposure and effects analysis. Human activities in the system influence the type and magnitude of risk; this information should be gathered using culturally appropriate methods and incorporated by stakeholder representatives in the formal ERA. Results suggest it is possible to develop a participatory analytic deliberative approach to ERA and increase transparency of risk decision-making by exposing the logic and rationale for decisions made at different steps in the ERA process.

INTRODUCTION

The loss of biodiversity--the variability among living organisms and the ecological complexes of which they are part--is one of the most pressing global environmental problems, as decreasing biodiversity impairs ecosystem functioning and the services that ecosystems provide to society (Hector 2007). Understanding the concept of biodiversity requires thinking across ecological levels and recognizing the interconnectedness inherent in ecosystems. Analyzing threats to biodiversity begins with understanding indirect drivers of change (e.g. technology, population growth) and direct drivers (invasive alien species, pollution, and land use changes), and how their impacts move through ecosystems (Millennium Ecosystem Assessment 2005). Such sophisticated analyses are aided by the inclusion of different types of information and perspectives, as considerable relevant ecological knowledge exists outside formal scientific disciplines (Reid 2006).

Involving stakeholders (interested and affected parties) in environmental decision-making is an obvious way to incorporate a wide range of knowledge and perspectives. Local environmental knowledge is particularly useful when investigating ecological systems characterized by a paucity of scientific data and long histories of community-led management (Berkes 2000; Grimble 1997). Stakeholder involvement also upholds principles of good governance: people have the right to participate in solving problems and making decisions that affect or otherwise interest them (Wondolleck 2000). Furthermore, stakeholder involvement offers a way to maintain transparency and garner trust in the environmental problem solving process, which in turn can make it easier to implement management strategies. Including those who contribute to or are affected by biodiversity loss can help develop a clearer understanding of the source of threats and develop appropriate and feasible responses.

Environmental risk analysis (ERA) guides the structured evaluation of threats to species, natural communities, and ecosystem processes (Burgman 2005). Traditional ERAs are technical processes, conducted by experts with scientific inputs. Environmental risk analysis began in the field of ecotoxicology, in which methods were first developed for assessing, approving and auditing pollutants and toxicants in a regulatory system (EPA 1998; NRC 1983). More recently, ERA has been used to evaluate more complicated biological stressors such as invasive species, genetically modified organisms (GMOs), and biological control agents. Various frameworks and sets of terminology exist, but ecological risk analyses traditionally follow three linear phases: *problem formulation, exposure and effects analysis, and risk management*. Problem formulation involves determining conceptual models of the system and choosing assessment endpoints. Exposure and effects analysis involves identifying co-occurrence of the stressor with assessment endpoints, and the resulting effects on the assessment endpoints. The integration of exposure and effects from the stressor generates a risk estimate and comprises the risk assessment step of a risk analysis. The results of the ERA are often then communicated to interested parties, limiting stakeholder involvement to a public commentary period just before a risk-related policy decision is made.

Policy makers and practitioners are beginning to recognize that traditional, linear ERAs do not adequately address today's complex environmental problems for several reasons (Renn 2008; NRC 1996). First, traditional ecotoxicology techniques are not well suited for investigating living organisms entering complex ecosystems. For example, it is difficult to determine a traditional pollutant dose-response relationship for a potential invasive species entering a river basin. Second, traditional ERA results are often contested, and risk management procedures are therefore difficult to implement. Because of these deficiencies, there are increasing calls for a different approach to ERA, that incorporates stakeholders into the process of analysis and deliberation (Kapuscinski et al 2007; Hart 2006; Burgman 2005; NRC 1996; Fiorino 1990). Stakeholder involvement has improved the knowledge base, trust and durability of other environmental decisions (McDonald 2008; Eamer 2006; UWCALS 2005), and it is reasonable to expect similar results from their inclusion in ERA (Renn 2008; Hope 2007).

Participatory risk analysis frameworks have emerged in the last decade, aiming to operationalize stakeholder involvement throughout the process (Nelson et al 2009; Renn 2008; Hayes et al 2007; Renn 2005; AS/NZS 2004; Jones 2001; USPCC 1997; NRC 1996). However, reports of real-world implementation of such participatory processes are limited (Carey et al 2007; Kellett 2007). There is clearly a need for empirical evidence to address two main questions. First, *how does one implement an ERA with stakeholder involvement at all steps?* Second, *can a participatory process generate useful ERA information?* The research reported here addresses these questions by testing a participatory qualitative ERA framework used to examine potential risks to biodiversity from genetically modified (GM) crops in South Africa. We investigated the effect of stakeholders by comparing the ERA process and outcomes between two workshops: one with four biological scientists, and one with 22 diverse participants. Results provide policy makers and practitioners with tested guidance on implementing such processes and possible results one can expect from a participatory ERA.

THE SOUTH AFRICAN CONTEXT

South Africa's government recently mandated the South African National Biodiversity Institute (SANBI) to monitor for potential impacts of commercially approved genetically modified organisms (GMOs) (i.e. those released into the environment) on the nation's biodiversity (Republic of South Africa 2004. SANBI expressed interest in using a risk analysis approach to determine highest priority interactions between genetically modified (GM) crops and biodiversity, in order to help its monitoring program focus on interactions with the highest risk to biodiversity. SANBI was motivated to include stakeholders for several reasons. First, South Africa has a strong national commitment to public involvement in government decision-making. SANBI was similarly committed to involving stakeholders in the design of its monitoring program, especially since the adoption of GM crops has a high public interest and the scientific community is still debating the potential risks of GM crops and the methods for detecting risks (NRC 2008; Snow 2005). Second, SANBI's leadership realized that understanding and analyzing the complex topic of biodiversity and agro-ecosystems requires a diversity of expertise and perspectives.

PARTICIPATORY ERA FRAMEWORK

Design of ERA Framework and Process

We modified the highly interactive environmental risk assessment framework of Hayes et al (2007) to suit the analysis of a complex agro-ecological system by a diverse group of stakeholders. This framework is founded upon and elaborates on a previously recommended approach (NRC 1996) of iterative analysis and deliberation, and involves relevant stakeholders and experts throughout the ERA. We reviewed ERA literature and solicited advice from risk assessment experts to choose rigorous, but technologically simple, risk analysis tools. The authors also combined insights from research on adult collaborative learning (Daniels and Walker 2001; Kolb 1984) and advice from a professional facilitator to structure the tools into a qualitative ERA framework (Figure 1-1) designed to promote group learning and cohesion.

We then implemented the qualitative participatory ERA framework in two workshops hosted by the South African National Biodiversity Institute in Pretoria, South Africa in 2008. Workshop 1 (WS1) contained four biological scientists, who were joined by 18 diverse participants in Workshop 2 (WS2). Both workshops were facilitated by an experienced, scientifically knowledgeable facilitator from the USA, who acted as a neutral outside party (Kaner 2007). The lead author conducted semi-structured, in-depth interviews with each participant after each workshop, exploring the usefulness of the ERA process for investigating highest priority interactions between GM crops and biodiversity, whether participants found the ERA tools easy to use, the presence of diverse knowledge and perspectives, and improvements for future ERA workshops. The steps of the ERA process and implementation are described below; the process for WS1 is described in detail, and modifications made in WS2 are described at the end of each ERA process section (Table 1-1).

Define boundaries and scope of the analysis

We established the geographic and legislative boundaries of the ERA before the workshops. Defining the scope of the ERA helped identify participants, limit analysis specifically to impacts on biodiversity, and narrow the focus from an unwieldy country-wide analysis of all GMOs to one crop in a smaller region. The National Environmental Management Biodiversity Act of 2004 mandates that SANBI monitor the impacts of GMOs on biodiversity (Republic of South Africa 2004), thereby excluding the consideration of human health, social and economic impacts from our analysis. The original mandate did cover biodiversity important for agricultural productivity, so this was included in the analysis. Of the three GM crops cultivated in South Africa, we chose GM maize engineered to resist pest insects (specifically the MON810 line expressing the *Cry1ab* protein from the soil bacterium *Bacillus thuringiensis*); this protein is toxic to certain larval *Lepidoptera* species (e.g., maize stem borers). This line has been cultivated the longest in South Africa (>10 years), and the research and agricultural community is familiar with it. We limited the analysis to Mpumalanga Province, which has relatively good biodiversity data (Ferrar and Lotter 2007), and where over 50% of cultivated maize is MON810 (personal communication, van den Berg, 2008).

Identify and engage stakeholders

Stakeholder engagement is important in ERA to define the risk analysis problem, ensure that diverse types of knowledge and epistemologies are considered during the ERA process, and develop appropriate risk management solutions which are more likely to be accepted by the broader community (AS/NZS 2004; NRC 1996). In general, people should be involved if they have information that cannot be gained in other ways, or if their participation is critical to ensuring successful execution of subsequent initiatives built upon the analyses (Bryson 2004).

We define stakeholders in this study as persons interested in or knowledgeable about the topic of GM crops and impacts on biodiversity, and those who may be affected by SANBI's monitoring program. Our definition includes scientists, because they are an interested group whose knowledge, insights, perspectives and skills are necessary for a risk analysis (NRC 1996). We recognize that many risk analysis frameworks see scientists serving in a separate advisory role. It is important to note that the scientists who participated in this study varied greatly in terms of seniority, employer, cultural and educational backgrounds, personal interests, opinions about risk, and involvement with GMOs (e.g., some conduct research on environmental effects of GMOs while others had no knowledge about GMOs).

We chose the four biological scientists to participate in WS1 for their integral involvement in South African biotechnology development, risk assessment, and biosafety research. They are part of a small group of experts who normally provide risk assessment expertise on GMOs in South Africa; therefore, we believe the process and results of WS1 are comparable to what a traditional group of South African biotechnology experts might generate if they were to use our participatory ERA framework.

We used the following questions to identify main categories of stakeholders for WS2:

1) What scientific disciplines and professional training are relevant to an assessment of GM maize agriculture and biodiversity?

2) What groups of people are interested in GMOs?

3) Who are relevant policy makers and regulators of biotechnology?

We used a nonrandom snow ball sampling technique to identify relevant stakeholders, by which initial subjects suggest additional subjects with relevant knowledge or interest in GMOs (Spreen 1992). Due to constraints in workshop time and facilitation, WS2 participation was limited to 22 people (Figure 1-2). The workshop did not include all possible stakeholder groups (e.g., consumer groups, health professionals) because we were constrained by SANBI's legal mandate to focus on biodiversity.

We contacted each potential participant individually to introduce SANBI, its GMO monitoring mandate, the purpose of the workshop, and how someone with their background was instrumental for developing the ERA and monitoring program. Our goals were to avoid overlapping expertise, to have equitable representation in terms of race and gender, and to select persons able to engage in a fairly scientific, English language-based risk assessment process. If the person agreed to participate, we described the workshop process in detail, either in a face-to-face meeting (most common) or via phone.

Farming communities were represented by the provincial level Department of Agriculture and Land Affairs extension officers, as it proved extremely difficult to identify interested farmers with the necessary scientific literacy and English language skills (and many farmers were occupied with planting season). Mpumalanga Tourism and Parks Agency is responsible for the sustainable management and promotion of tourism and nature conservation in the Province, and its staff provided zoological and aquatic systems knowledge. Persons from policy and research think tanks, universities, and government research agencies provided additional social and biological knowledge in areas including agricultural economics, ecology, conservation biology, entomology, plant pathology, and soil science. The environmental NGO community and the biotechnology industry (international and national) were also represented. The Department of Agriculture, Forestry and Fisheries (formerly Department of Agriculture), which is responsible for the regulation of GM crops, and the Department of Environmental Affairs (formerly Department of Environmental Affairs and Tourism), each sent an observer to WS2, but chose not to directly participate.

Before WS2, we provided each participant with a packet of extensive reading materials describing basic genetic modification techniques, commonly-stated benefits and risks of GM crops, the biology of maize and a list of 80+ peer-reviewed research articles investigating the effects of GM maize on various organisms and ecological processes. We decided that a reading packet was the most efficient way to address the varying knowledge about biotechnology among the participants. We did not use workshop time for educational presentations, as half of WS2 participants knew a great deal about biotechnology and such a presentation would not have been the best use of their time.

Furthermore, it proved difficult to identify a truly neutral party to give such a presentation, which was critical to minimize the perception of bias on SANBI's part. We also encouraged attending biotechnology experts to explain key concepts as they emerged during the workshop, augmenting information from the reading packet.

Implementation of ERA Framework

The facilitator led the workshop participants through the steps of our ERA framework, as described below.

Develop conceptual models

Conceptual models help define the understanding of a system, including biotic, abiotic, and socio-economic parts and their relationships, and provide a method for reflection on the complexity of the system being analyzed. Hazard identification and assessment depends on constructing an appropriately detailed conceptual model (Hayes et al 2007). The first activity of each workshop was for each participant to hand draw a mind map, a type of conceptual model in which major topics or categories flow from a central image (Budd 2004) of a participant's conception of a GM maize cropping system, its socio-biological components, and relationships between them. Participants then shared their conceptual models with the group. With the help of the facilitator, participants developed a group mind map of the maize agro-ecosystem on a whiteboard in the front of the room, aggregating variables from each person's individual map. The maps expressed the rich diversity of perspectives about maize cropping systems and the interconnectedness of biological and social components (Figure 1-3). The mapping exercise functioned to stimulate systemic thinking by participants at the genetic, species, ecosystem and ecological process level. The conceptual maps were not used to define precise relationships between ecological components, as they sometimes are.

Create farmer practice matrix

Participants in WS1 identified the need to understand, early in the ERA process, the different types of South African farmers and farming practices to help contextualize the interactions and risk estimates identified in subsequent ERA steps. Participants with hands-on farming knowledge in WS2 enabled the group to create a "farmer practice matrix" (Table 1-2). The group identified three types of farmers: *subsistence, low input and high input*. A variety of farming practices (e.g., irrigation, post-harvest maize storage, and disposal of crop residues) were analyzed by farmer type.

Hazard identification

Hazard identification systematically identifies a wide range of interactions between a stressor and environmental components. A hazardous interaction has the potential to cause harm to things that humans value. Hazard identification provides the foundation for a rigorous risk assessment by ensuring that as many interactions as possible are identified early in the ERA process, and that final risk estimates are based on as much information as possible. Stakeholder involvement is particularly important at this step, as diverse information and perspectives are thought to provide a more complete understanding of the system under analysis. Stakeholders can also help inform monitoring efforts by highlighting where and when to look for potential risks (Hayes 2004).

Hazard matrices are useful for capturing hazards with multiple effects and for investigating new technologies introduced into complex systems, and can utilize a diversity of knowledge types (e.g., on-the-ground experiences and scientific data). We built a hazard matrix template before WS1, and participants collectively filled it with direct and indirect interactions between stressors and a range of biodiversity components (Table 1-3). Stressors identified by participants in WS1 were Bt toxin, Bt transgene, insecticide, absence of refugia, and abiotic and biotic factors. Biodiversity components were aggregated into biologically functional groups (e.g., non-target *Lepidoptera* larvae, insectivorous birds, adult soil beetles).

Prior to WS2, the scope of SANBI's mandate was clarified and we removed humans (e.g., consumers, farmers, laborers) as a biodiversity component, and two stressors (absence of refugia[1] and abiotic and biotic factors). This slightly revised matrix informed the hazard identification process in WS2, where the larger group refined the list of stressors and biodiversity components, revised interactions indentified in WS1, and added new ones from their areas of expertise. Several WS2 participants felt that the use of the word "hazard" raised undue alarm in many people, so we used the word "interaction" instead during the rest of the workshop.

Prioritize hazards

Hazard identification identifies a long list of hazards, which requires prioritization to generate a more manageable list for further analysis (Hayes et al 2007). WS1 participants used a multi-criteria decision tool to individually vet the list of hazards against a set of biodiversity-related criteria (Table 1-4). Hazards that met the most criteria were compiled from each participant, generating a prioritized list of 16 (from an original list of 355) for further analysis via risk estimation.

[1] Refugia are areas of non-GM crops, which serve to slow down the target pest's evolution of resistance to the Bt toxin and function as habitat for non-target organisms.

Prior to WS2, SANBI staff clarified their mandate and working definition of biodiversity, resulting in refining the criteria to focus on impacts at different ecological levels. In WS 2, participants could use the multi-criteria decision tool to prioritize hazards for further analysis. We gave participants who had difficulty applying the tool to all hazards the option of choosing a subset of hazards either in their field of expertise or in which they were personally interested.

Estimate risk

Risk estimation determines the likelihood of the hazardous event, and the consequences should it occur (Burgman 2005). In both workshops participants used a risk estimation worksheet (Table 1-5) to individually generate semi-quantitative risk estimates for a selected set of hazards. We provided WS1 participants with one geographically-specific, evidence-based likelihood table (Table 1-6) and seven tables scoring consequences at multiple ecological levels (e.g., genetic, population, ecosystem) (Table 1-7). Each participant in WS1 completed individual risk estimations for all 16 priority hazards, by multiplying likelihood and consequence scores to generate “risk scores”.

We compiled each participant’s risk scores and facilitated deliberation about the scores’ ranges. Participants identified sources of uncertainty (primarily incertitude--or lack of knowledge about effects of the Bt toxin or transgene on biodiversity components) surrounding the risk estimations, clarified misunderstandings about terms and hazardous interactions, and provided new information. The range of risk scores narrowed as participants revised their estimates.

Participants in WS2 reviewed and edited the likelihood and consequence tables from WS1, with the biggest change being the addition of a “zero” consequence category.

Participants could now assign a risk score of "zero" to hazards if they felt Bt maize posed no risk to biodiversity. Each participant estimated the likelihood and consequence of up to 10 hazards (chosen using the multi-criteria prioritization process, or in their field of expertise or personal interest). The facilitator worked through several example risk estimations to illustrate the range of scores, how they could be narrowed, and possible sources of uncertainty. Additionally, WS2 participants noted how farming practices might change risk scores. Farming practices mentioned included spraying of pesticides (which is an additional stressor on many organisms), disposal of crop residues (which impacts duration of Bt toxin in the environment), and amount and proximity of refugia.

Determine assessment endpoints and risk acceptance criteria

We tested the feasibility of determining assessment endpoints and risk acceptance criteria early in the ERA process (after conceptual modeling) as proposed by (Hayes et al 2007). Assessment endpoints represent higher-level environmental components chosen by stakeholders as valuable to protect or manage. Assessment endpoints can be economically important or endangered species, a community, or ecosystem (EPA 1998). Risk acceptance criteria aim to quantify levels of change people are willing to accept in assessment endpoints (e.g., >10% population decline in a beneficial insect species is unacceptable). WS1 participants identified high-level concepts like "non-target organisms", "aquatic ecosystems", and "culture" as valuable to protect, as they had not yet unpacked these components; that happened in the next step (hazard identification). Because WS1 participants were not able to identify succinct assessment endpoints or risk acceptance criteria during early stages of the ERA, we removed this step from the process in WS2.

MAJOR OUTCOMES OF THE PARTICIPATORY ERA PROCESS

Comparing workshops provides insights about the *products* of a highly participatory ERA, and lessons on the *process* of such an ERA. The addition of stakeholders to our qualitative ERA greatly increased the amount of information germane to identifying potential risks of GM maize to South African biodiversity, and we discovered that involving diverse stakeholders requires a great deal of up-front time and effort. Major findings are presented below, in the form of quantitative analysis of information resulting from the workshops and selected interview responses from participants in both workshops.

Exploring products of the participatory ERA

Increased hazard identification

Diverse participation in the ERA process not only increased the number of total hazards, but also broadened the scope of biodiversity interactions considered. There was a 102% increase in the number and type of hazards identified in WS2 as compared to WS1 (Table 1-8). Hazards associated with vertebrates, soil organisms and microbes showed the greatest increase. Five participants argued during the workshop and post-workshop interviews that such a thorough investigation of interactions was overkill, resulting in “Ecology 101” instead of succinct identification of important interactions for monitoring. However, other participants appreciated the opportunity to examine interactions between the environment and GM maize at a depth not previously attempted. Eighteen of 22 participants indicated they learned the most during hazard identification, because of the breadth and detail of information analyzed. A scientist who participated in both workshops gives his take-home message on diverse participation during hazard identification:

> "…it just shows you how complicated the system is. It shows you that we have an extreme lack of knowledge. And that knowledge groups consider their part, I wouldn't say more important, but everybody has his expertise. You cannot compile this type of thing without different people. It would be skewed."

Recognition of the value of different types of knowledge

Diverse participants contributed different types of expertise and knowledge to the ERA process, to develop a real-world picture of Bt maize and its place in agro-ecosystems. A scientist who participated in both workshops described the value of this added dimension:

> "I've always been aware of the potential interaction that can exist between Bt maize and the environment. But what I was very grateful to take away from [WS2] is now I've been able to hear experts on the ground say that 'this is happening and that's happening'. And that to me was very very useful. It's enriched my understanding of the environmental interactions, and I am very grateful for that."

Non-scientists also felt their knowledge was valuable for informing the ERA process. An agriculture extension officer recognized valuable scientific information from other participants, but defended the importance of his experiential knowledge:

> "…his general knowledge is quite good. But I told you the last time, it's Google knowledge. And Ms. Smith[2] is Google knowledge. Because she was immediately asking 'didn't you read up?' Why should you read up? That wasn't the purpose. If you wanted us to read up on all those things, you could have done the study yourself. That's how I feel. So it was good to come forward with your own ideas."

Deepened understanding of the complexity of biodiversity

Participants noted that the diversity of perspectives and different types of knowledge in WS2 deepened their understanding of the complexity of relationships in an agro-

[2] All participant names have been changed to protect their identity.

ecological system, and enhanced their ability to conceptualize and analyze the whole system. An agricultural economist describes his observations in WS2:

> "…it was very interesting to see how the other people view the whole interaction on the different…elements in maize production. This again goes back to what your special focus is. I look at this as about more of the inputs and the different variability in the inputs. Whereas the other people probably never talked about fertilizers or something like that, and just looked at insects. And it was interesting to see everyone, the different…all the different people you brought together and their views of the whole…the holistic thing."

An agriculture extension officer explains how his thinking of the environment as a whole led him to re-evaluate his approach to analyzing potential impacts of Bt maize on biodiversity:

> "Prior to the workshop I thought of little possible risks. But now, also accommodating the opinions of the different interest groups, not just the agricultural production, also thinking of the environment as a whole. I began to feel that we need to ascertain negative impacts on the other organisms, even those that we as producers might feel comfortable getting rid of. Because they are all part of the system. And we need to deal with them responsibly."

Challenges in generating a focused set of priority hazards

WS2 participants were unable to complete hazard prioritization using the multi-criteria spreadsheet, whereas WS1 participants had no problems. This difference is due to both the lack of knowledge by many of the stakeholders, and the design of the prioritization tool. Many WS2 participants grew frustrated when trying to evaluate whether the hazards met prioritization criteria, because they did not know enough about the mode of action and effects of the Bt toxin, or how transgenes behave within the maize plant and when they enter the environment. A biologist explains the difficulty encountered:

> "I think it boils down to the fact that one would be looking at all the interactions, and trying to say which one is more important than the other. Now the problem

> with doing that is that you can only be able to prioritize that you know. That you have got more information about than those that you don't...I wouldn't be able to prioritize large mammals. Because I don't have much information on that. If I look at that, I don't know much about them. To be able to downgrade them or put them up there, to me that was very difficult. I wouldn't be able to do it."

Further compounding their frustration was the fact that the prioritization process was not built to incorporate uncertainty; each participant had to provide a binary, Yes/No answer to the criteria. While some of the "experts" on biotechnology (e.g., the developers of GMOs) had no problems completing the spreadsheet, we agreed with other participants' requests to stop the prioritization process.

Challenges generating risk estimations

WS1 participants generated a more precise set of risk estimates, while WS2 risk estimates were widely divergent across hundreds of hazards. In WS1, 16 priority hazards were analyzed by all four participants, and the range of risk scores narrowed to provide a concise set of highly likely, highly consequential hazards for SANBI's monitoring and research program. In WS2, not all hazards received risk estimates, and furthermore estimates were extremely divergent (e.g., one hazard could receive a "zero" risk score from one participant and a "25"—the highest possible score—from another). We did not have time to transcribe and organize 200+ risk scores during the workshop and we were not able to narrow the range of risk scores through analysis and deliberation as in WS1. Figure 1-4 shows an example of the full range of risk scores between workshops for the same hazard, and it illustrates the divergence of risk estimations likely to emerge from a diverse group of stakeholders. The divergence was due to a lack of scientific studies, and limited knowledge among participants, about the likelihood and consequences of many of the identified hazards (e.g., insectivorous birds and Bt toxin).

Participants' prior beliefs about the risk of a stressor can influence risk scores (Burgman 2005). We hypothesized that "pro" GM crop participants (five self-identified participants) would consistently give low risk scores, and "anti" participants (three self-identified participants) high scores. We examined the three participants whose scores were biased toward two extremes: two participants (one "pro" and one "neutral") assigned lower scores, and one participant ("anti") assigned higher risk scores (Table 1-9). One "pro" participant did not turn in risk scores. Our limited data do not support the hypothesis that "pro" GM participants were prone to giving consistently low risk scores, and "anti" participants did not all give high risk scores. We found that incorporating multiple persons from the same stakeholder interest group may provide a way to counter motivational bias, as they may not always share the same attitude toward the risk posed by a given stressor.

Exploring the participatory ERA process

Involving diverse stakeholders

Engaging diverse stakeholders face-to-face and at the start of an ERA process was a groundbreaking endeavor in the field of biotechnology risk assessment. Substantial resources are needed to identify and build rapport with stakeholders, particularly when investigating controversial topics and working with populations who are unaware of the environmental problem. The lead author spent six months identifying the final 22 participants, meeting each one personally, and allaying various and on-going concerns about the structure, purpose and topic of the ERA workshops. Although not all interested and affected parties chose to participate (e.g., seed distributors, farmers unions), final representation was quite broad; indeed when asked to identify missing parties, participants had limited suggestions. The most common recommendations were to include more molecular biologists to elucidate how the transgene is inserted into the maize genome and functions thereafter, and to include more farmers as they have an excellent grasp of the realities of maize cultivation and conditions in agricultural fields and surrounding environment.

Facilitation

The strength and success of the workshops was influenced by high quality facilitation. Participants noted that the facilitator "cared for the process" and created space for culturally appropriate, respectful communication, and allowed participants the freedom to offer information and opinions for consideration by the group. Our facilitator offered two particularly unique skills: he was scientifically literate in natural resource management and ecology and could keep the group's efforts focused on biodiversity, and he was integrally involved in developing the process and tools, so understood how they worked and results we desired. His distinctive skills were critical for successfully moving 22 diverse participants through multiple days of scientific deliberation about a complex and controversial issue. The success of future participatory ERAs will depend greatly on the quality of facilitation.

Disagreement with the use of ERA to inform SANBI's monitoring effort

WS2 participants differed in their opinion of the ERA process' utility for helping fulfill SANBI's monitoring mandate. Most participants were generally favorable, as was this civil society representative:

> "It was interesting getting a diverse group together. I think especially in the area of biosafety, which is such a new area, that South Africa really needs to have people who are thinking more holistically about it. And such a workshop does help."

Four of the 22 participants in WS2 strongly disagreed with using an ERA approach to determine which interactions are of enough concern to monitor. One biotechnology developer explained his or her discomfort:

> "I guess for me it was a case in learning how not to go about it. You certainly can't go into that level of analysis for every single GM [crop], in every single Province. It's completely unrealistic. I think that one needs a better way of doing it that does not tie a huge group of people down for three and a half days for one [GM crop]."

Several of four participants felt the best approach would be to build the monitoring program around indicator species commonly used to test the effects of toxins in ecosystems (e.g., daphnia crustaceans and springtail insects (Stark 2004). Although these four participants freely expressed their discomfort with the ERA process throughout WS2, they did complete the entire exercise.

Definition of assessment endpoints and risk acceptance criteria

Defining assessment endpoints in the early stages of such a participatory ERA did not work, even though many current ERA frameworks suggest that this is the best placement. First, defining assessment endpoints and risk acceptance criteria is controversial, and the group has not yet built the necessary rapport to engage in a constructive, highly value-based deliberation. Second, valuable time will be spent identifying valued biodiversity components later eliminated during hazard prioritization. The same logic applies to the determination of risk acceptance criteria: a very contentious topic tackled early is likely to hinder the building of group rapport, use valuable time needed for other ERA tasks, and initial valued components will be eliminated at later steps.

Multiple consequence tables and non-probabilistic likelihood table

We aimed to reduce linguistic uncertainty pervasive in qualitative ERAs (Hayes et al 2007) by specifying different ecological scales and categories of consequence. Biodiversity can be examined at multiple levels: genes, species, ecosystems, and landscapes, as well as ecological and evolutionary processes, and a thorough ERA should evaluate risks at all levels. To facilitate such an evaluation, we created multiple consequence tables, building upon the few other qualitative ERAs also evaluating risk on multiple ecological levels (Campbell 2007; Fletcher 2004). We added GM maize-specific consequences: genetic diversity and agricultural productivity. For example, the hazard "Spiders x Bt toxin" could receive consequence scores at the level of 1) species richness and composition, 2) populations, and 3) ecosystems. This multi-level approach is more specific than many qualitative assessments, where, for example, a consequence of "severe" magnitude is defined as: "Impact that will cause a detectable effect in local ecosystem factors. Recovery time measured in months to years"(IRC 2001). The latter description uses underspecified words like "impact", "detectable effect", and "ecosystem factors", and context dependent words like "local".

Furthermore, we removed categories of magnitude (e.g., negligible, severe, catastrophic) from the consequence tables, as such words are vague and context-dependent, and assign value judgments to consequences which are not shared by all participants. For example, an ecologist might consider a 10% species richness and composition decline in farm field margins “severe”, while a farmer might see this as a “negligible” change. We focused instead on quantifying the level of change one might see and assigning it a consequence score that could be contextualized during stakeholder deliberation.

We aimed to further reduce linguistic uncertainty by not assigning ranges of probabilities or categorical likelihood values to the likelihood table. Many qualitative ERAs use likelihood tables describing categories of likelihood of the hazardous event as “almost certain”, “likely”, and “moderate” (Fletcher 2004; Van Lenteren 2003; Crawfod 2000). Some of these tables go the additional step to quantify the likelihood of occurrence, either as probabilities, percentages (e.g, 11-50%), or number of times/per period of time (e.g., once per six months) (IPCC 2005). Language-based likelihoods are rife with all types uncertainty (linguistic, variability, and incertitude), and calculations are not necessarily associative and may not consistently preserve the meaning of terms (McCarthy 2007). Indeed, we attempted to develop a more quantitative likelihood table prior to the workshops, and abandoned the effort due to unresolved interpretations of probabilities, opinions on how to define “likely”, “almost certain”, etc. We instead developed a likelihood table which depended on the strength of the evidence of the hazard occurring (Table 1-6).

DISCUSSION

This participatory ERA process generated a rich set of information important for underpinning a risk assessment, and modifications should improve the rigor of certain steps, particularly the human practices analysis, hazard prioritization and identification of assessment endpoint and risk acceptance criteria. A key strength of our process was the structured exploration of a complex agro-ecological system, incorporating a diversity of disciplines, types of knowledge, and perspectives. Including stakeholders aided generation of a more comprehensive set of hazards. However, only WS1 participants completed hazard prioritization and generated refined risk estimates. They were able to successfully analyze and deliberate about scientific information because they were part of a small group with less divergent viewpoints about GM crops and concomitant risks, and they agreed that the ERA process was a useful endeavor. Nonetheless, results from both workshops illustrate that qualitative, participatory ERAs can help elucidate which interactions between a biological stressor and a complex ecosystem are of concern. This information can then be used in a quantitative risk assessment, presented to policy makers to inform risk management decisions, or to inform a research or (in the case of South Africa) monitoring program.

Involving stakeholders in an early problem formulation process may help alleviate discomfort expressed by some WS2 participants (e.g., about the utility of an ERA approach and how the objective of developing a monitoring program was framed). All ERAs start with a "problem formulation" step, in which stakeholders should ideally be involved to help ensure that the ERA addresses concerns relevant to what they value (NRC 1996) (see Nelson et al 2009 for methodologies). Stakeholders can then help define the boundaries and scope of the analysis. SANBI had previously received the legislative mandate to develop a monitoring program and this constrained stakeholder involvement in problem formulation (i.e., the problem was that a monitoring program needed to be developed using a strict definition of biodiversity) and boundaries and scope definition. If stakeholders had been involved in problem formulation, this would have provided a basis for subsequent deliberation on the optimal method for designing a monitoring program. An ERA approach could be a valuable option, particularly when investigating data-poor situations where novel technologies are being introduced. Alternatively, participants might have chosen a set of well-known indicator species as appropriate monitoring endpoints. It is also possible that stakeholders would not define the boundaries and scope of the ERA so narrowly; they could perhaps choose to examine a larger geographic area or multiple GM crops. Future studies are needed to examine whether stakeholder involvement at earlier steps of the ERA increases participant buy-in and saliency of the results to a wider variety of stakeholders.

Human practices in the system under analysis should be elucidated more thoroughly before the formal ERA process. Local production practices, environmental knowledge, or cultural practices should be investigated in culturally sensitive ways, and resulting information brought into the ERA by trusted stakeholder representatives. Informal engagement in small working groups, or individual dialog and visits to field sites, may work best to collect information in some situations. In others, focus groups, interviews or surveys might be appropriate. How best to collect and integrate non-traditional technical knowledge into a participatory ERA is an important research area, as such information is vital to understanding how humans interact with the system, how their activities influence the type and magnitude of risk, and possible risk management strategies.

The controversial and highly value-laden process of defining assessment endpoints and risk acceptance criteria should happen after hazard prioritization, and investigate a smaller set of high priority hazards. Stakeholder deliberation can explore why certain hazards are important and which attributes or quantities are ideal assessment endpoints (e.g., species composition, total population numbers). Risk acceptance criteria, or degrees of change people are comfortable with (including no change), can also be elucidated. Assessment endpoint and risk acceptance preferences then inform a more rigorous risk assessment conducted by a technical team after the stakeholder workshop. Risk assessment requires exposure and effects analysis, the quality of which can be improved by access to published literature, quantitative analysis, and time to carefully construct estimates. Such an external risk assessment process is likely to be less frustrating and balance strengths of the technical participants and other stakeholders. Risk assessment results should then be presented and deliberated upon by the entire stakeholder group, perhaps in a second workshop.

We have produced empirical evidence that it is possible to develop a participatory analytic deliberative approach to risk analysis, and, based on our findings, have provided advice on how to structure such approaches. Our conclusions are more broadly applicable to the analysis of different types of stressors and environmental effects, beyond our study's focus on GMOs and biodiversity, and they should be tested using more diverse participants in more legally flexible situations. Certainly participatory processes can be more controversial, less efficient and slower than purely expert-run ERAs. Nonetheless, they are necessary for understanding the complex systems which affect and are affected by most environmental problems. Furthermore, authentic participatory processes contribute to increasing the transparency or traceability of risk-related decisions by exposing the logic and rationale for various decisions made at different steps in the ERA process. We recognize that the feasibility of involving stakeholders in ERA will vary from case to case and nation to nation, and we provide our observations and conclusions from this South African case to assist scholars and practitioners in future participatory ERA endeavors.

Table 1-1. Summary of ERA steps, the success of each, and major changes between Workshops 1 (WS1) and 2 (WS2

ERA step	**WS1**	**WS2**	**Success**	**Key changes in WS2**
Conceptual mapping	x	x	Worked well in both workshops	None
Farmer practice (FP) matrix	NA	x	WS1 identified the need to understand farming practices, leading to the addition of the FP matrix in WS2	NA
Hazard identification	x	x	Worked well in both workshops	Minor changes to adhere to the scope of SANBI's mandate (e.g., removing humans as a biodiversity component)
Hazard prioritization	x		Worked well in WS1; step halted in WS2 at request of participants	Refined the prioritization criteria to focus on impacts at different ecological levels
Risk estimation	x	x	Worked well in WS1; time constraints prevented analysis and deliberation in WS2 about the divergence of risk estimates	Participants were allowed to choose hazards of interest or in their field of expertise instead of everyone estimating a prioritized set; addition of "zero" as a consequence score; farming practices explored for how human activities and choices change potential risk of GM crops; no time for group analysis and narrowing of range of risk scores
Identification of assessment endpoints and risk acceptance criteria	x	NA	Did not work well in WS1; not implemented in WS2	NA

Table 1-2. Illustrative segment of the farmer practice matrix created in WS2. South African farmers were divided into three categories based on access to inputs (e.g., credit, implements, seeds). Participants explored different maize farming practices, which varied by type of farmer. Information generated is comparative; famers with "xxx" are three times as likely to use the practice as ones with "x".

Farming Practice	**Subsistence Farmers**	**Low Input Farmers**	**High Input Farmers**
Plants Bt maize	x	xx	xxx
Plants hybrid conventional maize	xx	xxx	xxx
Plants conventional open pollinated maize	xxx	xx	x
Plants landrace maize[3]	xxx	x	x
Plants refugia[4]	x	xx	xxx
Saves seeds	xxx	xx	x
Shares seeds	xxx	x	
Fertilizes	x	xx	xxx
Intercropping of other plants	xxx	xx	
Controls for pathogens	x	x	xxx
Maize storage	On the cob	On the cob	In silos
Planting	By hand	By machine	By machine
…			

[3] Landrace maize is grown from seeds which have not been systematically selected and marketed by seed companies or developed by plant breeders.
[4] Refugia are areas of non-GM crops, which serve to slow down the target pest's evolution of resistance to the protein toxin by serving as habitat absent the toxin for the non-target organism.

Table 1-3. Sample of hazards identified in WS2. Participants identified interactions between stressors (columns) and biodiversity components (rows), completing an analysis of possible interactions between the agro-ecological system and GM maize. An “X” denotes a direct interaction (e.g., the organism consumes the stressor), and an “I” denotes an indirect interaction (e.g., the organism eats another which consumed the stressor). Both types of interactions are sometimes possible (denoted by “IX”). WS1 used the same process, but with a slightly modified set of biodiversity components and stressors.

	Stressors										
Biodiversity components	Toxin in planted seeds	Toxin in leaves	Toxin in stem/stalk	Toxin in roots	Toxin in silks	Toxin in pollen	Toxin in cob	Toxin in decaying matter	Transgene in pollen	Transgene in kernel	Tansgene in soil
Non-target arthropods											
Mites	IX	IX	IX	IX	IX	IX	IX	IX	IX	IX	IX
Spiders		I		I	I	I		I	I	I	I
Ladybirds		I			I	I				I	
Hymenopteran parasitoids		I	I		I	I	I			I	
Honeybees						X			X		
Non-target maize pests											
Aphids		X	X		X						
African bollworms		X			X	X				X	
Stinkbugs			X		X					X	
Leafhoppers		X									
Vertebrates											
Rodents		I	IX	X			X	X		X	
Insectivorous mammals	I	I	I	I	I	I	I	I	I	I	I
Carnivores	I	I	I	I	I	I	I	I	I	I	I
Fish		I	I	I	I	IX	I	I	I	I	
Microbes											
Endophytes	X	X	X	X	X	X	X	X	X	X	X
Epiphytes											X
Viruses	X	X	X	X	X	X	X	X	X	X	X
Plants											
Landrace maize									X		
Non-GM maize									X		
Striga parasitic plant				X							X
…											

Table 1-4. Segment of an individual multi-criteria hazard prioritization worksheet used in WS2. Participants used the spreadsheet to individually prioritize hazards from the hazard matrix based on four biodiversity-specific criteria (top row). Each participant weighted the criterion out of a possible 100 points, allowing greater importance to be placed on a specific criterion. Each participant answered "yes" (1) or "no" (0) for each hazard, for each criterion. Hazards that met the most criteria (i.e. had the most "yes" answers) were analyzed in more detail in the next ERA step: risk estimation. WS1 used the same prioritization process, but with slightly modified biodiversity criteria.

	Criteria				
	Could the interaction or relationship negatively impact genetic diversity?	Could the interaction or relationship negatively impact a species population?	Could the interaction or relationship negatively impact ecosystems?	Could the interaction or relationship negatively impact organisms important for sustaining agriculture?	*Total weight*
Weight	*40*	*30*	*25*	*5*	*100*
Mites x Bt toxin	0	0	0	0	*0*
Mites x transgene	0	0	0	0	*0*
Mites x insecticide	1	1	1	0	*95*
Spiders x Bt toxin	0	1	0	0	*30*
Spiders x transgene	0	0	0	0	*0*
Spiders x insecticide	0	1	0	0	*30*
Ladybirds x Bt toxin	0	0	0	1	*5*
Ladybird x transgene	0	0	0	0	*0*
Ladybirds x insecticide	0	1	0	1	*35*
Endophyte x Bt toxin	0	1	1	0	*55*
Endophyte x transgene	1	1	1	0	*95*
Endophyte x insecticide	0	0	0	0	*0*
		…			

Table 1-5. Risk estimation worksheet used in WS2. Participants chose up to 10 hazards and estimated the likelihood and consequence of the interaction, generating risk scores. The consequences were analyzed at different levels of biodiversity. Participants also considered how farming practices might impact the likelihood and consequence scores and identified areas of uncertainty in their estimates. WS1 used a similar worksheet, minus questions on farming practices.

<table>
<tr><td>Hazard #</td><td colspan="3">Description of Interaction</td></tr>
<tr><td rowspan="8">Likelihood Table 1
Likelihood Score:</td><td>Consequence Scores</td><td>Consequence Tables</td><td>Risk Scores (L x C)</td></tr>
<tr><td></td><td>Table 2 Genetic Diversity</td><td></td></tr>
<tr><td></td><td>Table 3 Agricultural Productivity</td><td></td></tr>
<tr><td></td><td>Table 4 Species Richness/Composition</td><td></td></tr>
<tr><td></td><td>Table 5 Species Populations</td><td></td></tr>
<tr><td></td><td>Table 6 Ecosystems</td><td></td></tr>
<tr><td></td><td>Table 7 Habitat</td><td></td></tr>
<tr><td></td><td>Table 8 Trophic Interactions</td><td></td></tr>
<tr><td colspan="4">Explanation for Likelihood Score (Please describe exposure pathway)</td></tr>
<tr><td colspan="4">What are key areas of uncertainty in your analysis of this interaction?</td></tr>
<tr><td colspan="4"></td></tr>
<tr><td colspan="4">How do farming practices influence your analysis?
1) How do farming practices increase or decrease the likelihood of the interaction?
2) How do farming practices increase or decrease the consequences of the interaction?</td></tr>
<tr><td colspan="4"></td></tr>
</table>

Table 1-6. Likelihood table used in both ERA workshops. The likelihood of a hazard was based on weight of evidence; those hazards known to be occurring in the geographic area of analysis (Mpumalanga Province) received a higher score than, for example, a hazard observed in studies outside of South Africa.

Likelihood Score	Description
1	Never heard of it occurring, but this interaction is theoretically possible (biologically or socially)
2	Uncommon, but this interaction has occurred elsewhere (e.g., evidence from studies outside of South Africa)
3	This interaction is possible in South Africa (e.g., evidence from studies in other South African maize growing areas)
4	The conditions in Mpumalanga Province are conducive to the interaction occurring
5	This interaction is occurring or has occurred in Mpumalanga Province

Table 1-7. Two of the seven tables used to examine consequences of hazards at multiple ecological levels. Table 1-7a defines categories of consequences for species richness or composition. Table 1-7b defines categories of consequence at the trophic level. WS1 used the same consequence tables, minus the consequence score of "0", which was added at the request of WS2 participants. Consequence tables not shown: genetic diversity, agricultural productivity, populations, ecosystems, and habitat.

a.

Consequence Score	Description for Species Richness or Composition[5]
0	No change in species richness or species composition No loss of species or populations No local extinctions
1	Change in species richness or species composition not readily detectable (<10%) Recovery is expected in days (for microbes)
2	Change in species richness or species composition are <20% Recovery is expected in days to months No local extinctions
3	Change in species richness or species composition are <30% Recovery time in months to years Loss of at least one species or populations Local extinction events
4	Change in species richness or species composition are <70% Recovery time in years to decades Loss of several species or populations Multiple local extinction events; one regional extinction
5	Change in species richness or species composition are >70% Recovery is not expected Loss of multiple species of populations Local extinction events Global extinction of at least one species

[5] **Species richness:** the number of species in a given area. **Species composition:** the relative abundance of different species (or of different functional groups of species).

b.

Consequence Score	Description for Trophic Interactions[6]
0	No significant changes in trophic level species composition observed No change in relative abundance of trophic levels (based on biomass) Changes in trophic interactions not measureable against background variability
1	Minor changes (<10%) in relative abundance of trophic levels (based on biomass) <10% reduction of population abundances for top predator species Recovery expected in days to months No loss to keystone species
2	Measurable changes (<30%) in relative abundance of trophic levels (based on biomass) <30% reduction of population abundances for top predator species Recovery expected in years to decades Loss of keystone species populations No loss of primary producer populations
3	Major changes (<70%) in relative abundance of trophic levels (based on biomass) <70% reduction in of population abundances for top predator species <30% reduction of population abundances for primary producer species Recovery is expected in centuries Loss of keystone species populations Changes in trophic levels Loss of primary producer populations Local extinction events
4	>70% change in relative abundance of trophic levels (based on biomass) >70% reduction of population abundances for top predator species >30% reduction of population abundances for primary producer species Recovery is not expected Loss of trophic levels Potential trophic cascades resulting in significant changes to ecosystem structure, alteration of biodiversity patterns, and changes to ecosystem function Significant local extinctions
5	>90% change in relative abundance of trophic levels (based on biomass). >90% reduction of population abundances for top predator species >50% reduction of population abundances for primary producer species. Recovery is not expected Loss of trophic levels Potential trophic cascades resulting in significant changes to ecosystem structure, alteration of biodiversity patterns, and changes to ecosystem function Significant local extinctions

[6] **Trophic interactions** are represented by a food chain, which organizes specific organisms by their distance from primary producers, and by food webs, which detail the feeding interactions among all organisms in an ecosystem.

Table 1-8. Summary of the number of hazards (interactions between a specific biodiversity component and a stressor) generated in the two ERA workshops. Additional stakeholders increased the understanding of the components and relationships in a Bt maize agro-ecosystem. As a result, twenty-two new components of biodiversity were added in WS2, and 364 additional hazards were identified.

Categories of Biodiversity Components	**Stressors**	**# of Hazards Identified in Workshop #1** *(4 scientists)*	**# of Hazards Identified in Workshop #2** *(22 diverse participants)*	**% Increase in Hazards Identified btwn Workshops**
Plants (e.g. weeds)	T, O*, A^	4	38	850
Domestic animals	B, T, A^	2	14	600
Livestock	B, T, A^	9	56	522
Soil organisms	B, T, A^	8	26	225
Microbes	B, T, A^	32	83	159
Aquatic species	B, T, A^	24	59	146
Vertebrates	B, T, I, R*, A^	82	198	141
Non-target maize pests	B, T, I, R*, A^	31	55	77
Non-target insects	B, T, I, R*, A^	138	178	29
Target stemborer	B, T, I, R*	11	12	9
Humans+	B	14	NA	NA
Total		**355**	**719**	**102**

B= Bt toxin in all maize life stages (germination to mature kernel, below ground parts, and post-harvest residues); T= Transgene (throughout the plant and in soil); I= Insecticide; R= Lack of Refugia; O= Other abiotic/biotic stress; A= Additional aspects of the transgenic construct (e.g., promoters).
+ Denotes biodiversity component *removed* by SANBI before WS2.
*Denotes stressors *removed* by participants in WS2.
^Denotes stressors *added* by participants in WS2.

Table 1-9. Summary of risk scores for all participants in WS2, along with self-identified attitude towards GMOs. Not all persons opposed to the technology consistently gave high risk scores, nor did proponents consistently give low scores.

Participant	Stance towards GMOs	Number of Risk Estimates (n)	Average	Std
A	Anti	70	17.50	5.76
B	Anti	59	8.31	6.89
M	Anti	42	3.02	4.44
E	Pro	21	4.67	0.66
H	Pro	67	4.40	5.54
R	Pro	70	1.14	2.58
S	Pro	56	1.05	2.03
T	Pro	98	0.20	0.89
V*	Pro	NA	NA	NA
C	Nuanced	47	6.77	6.52
G	Nuanced	35	4.63	3.34
I	Nuanced	53	3.64	4.70
J	Nuanced	62	3.21	4.38
L	Nuanced	37	3.11	3.41
O	Nuanced	63	2.25	4.10
Q	Nuanced	63	1.52	3.15
U	Nuanced	28	0.00	0.00
D	Unsure	56	5.41	5.23
F	Unsure	50	4.90	2.57
K	Unsure	56	3.14	3.50
N	Unsure	63	2.70	2.82
P	Unsure	56	1.61	4.06

*Participant V did not turn in risk estimates after the exercise.

Figure 1-1. Participatory ERA framework for stakeholder involvement (adapted from Hayes et al. 2007). For the 2008 ERA of GM maize and biodiversity in South Africa, identification of boundaries, scope and stakeholders occurred prior to workshops, and all steps inside the inverted triangle occurred during workshops. Results of this research led us to modify or add the following steps (denoted by dashed lines): Human practices matrix development and incorporation, assessment endpoint and risk acceptance criteria identification, risk estimation by a technical team. We also recommend reconvening stakeholders after the risk estimation (oval below the inverted triangle).

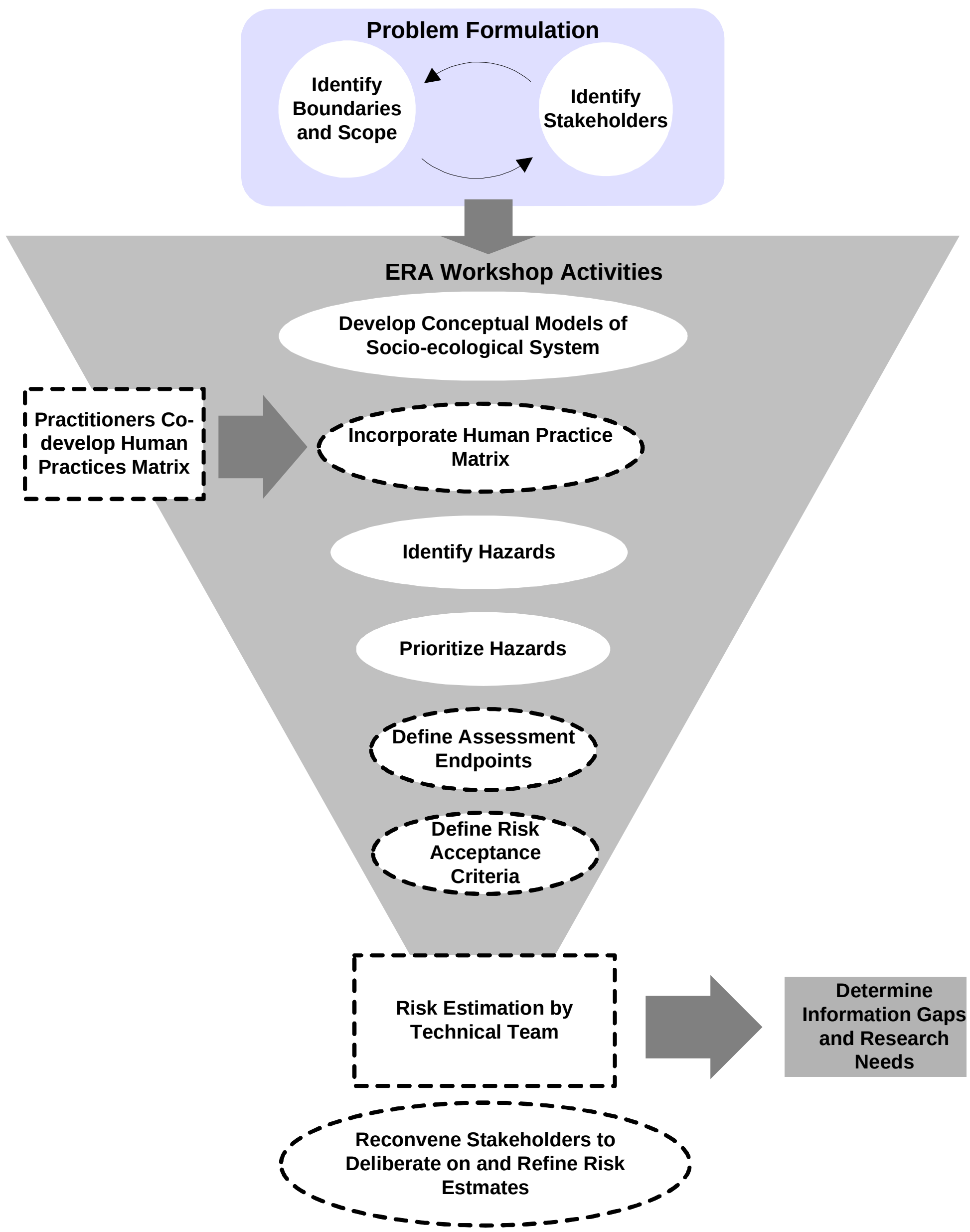
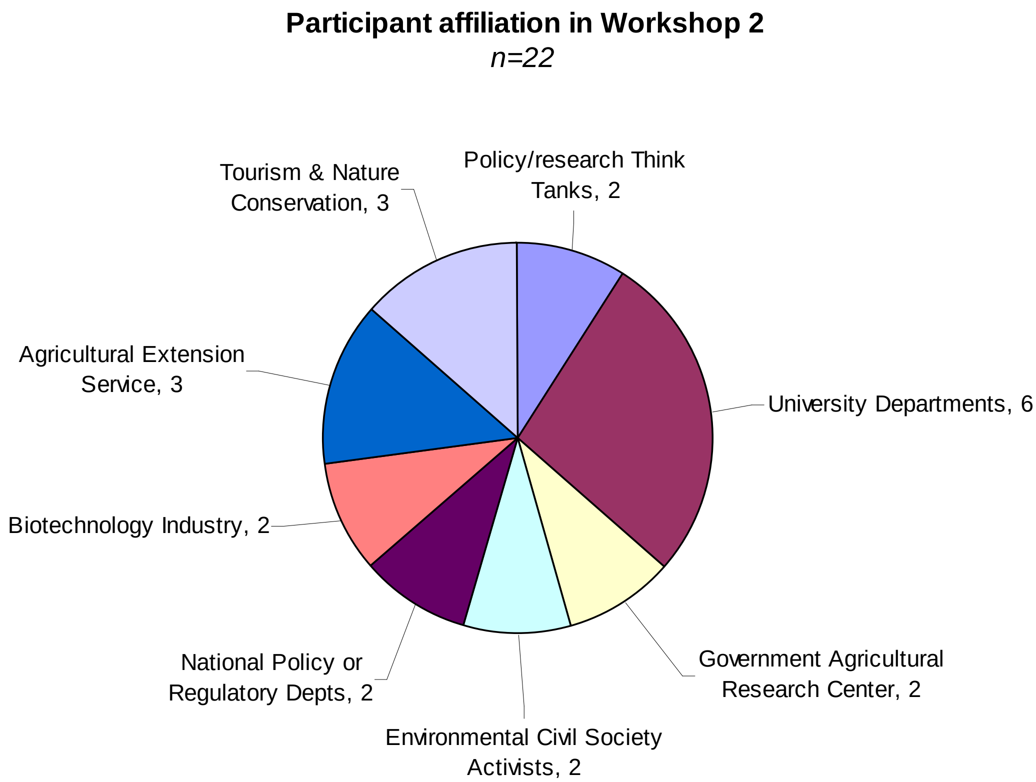


Figure 1-2. Affiliations of WS2 participants. The four participants in WS1 were affiliated with universities (2), a government ag research center (1), and a policy think tank (1).



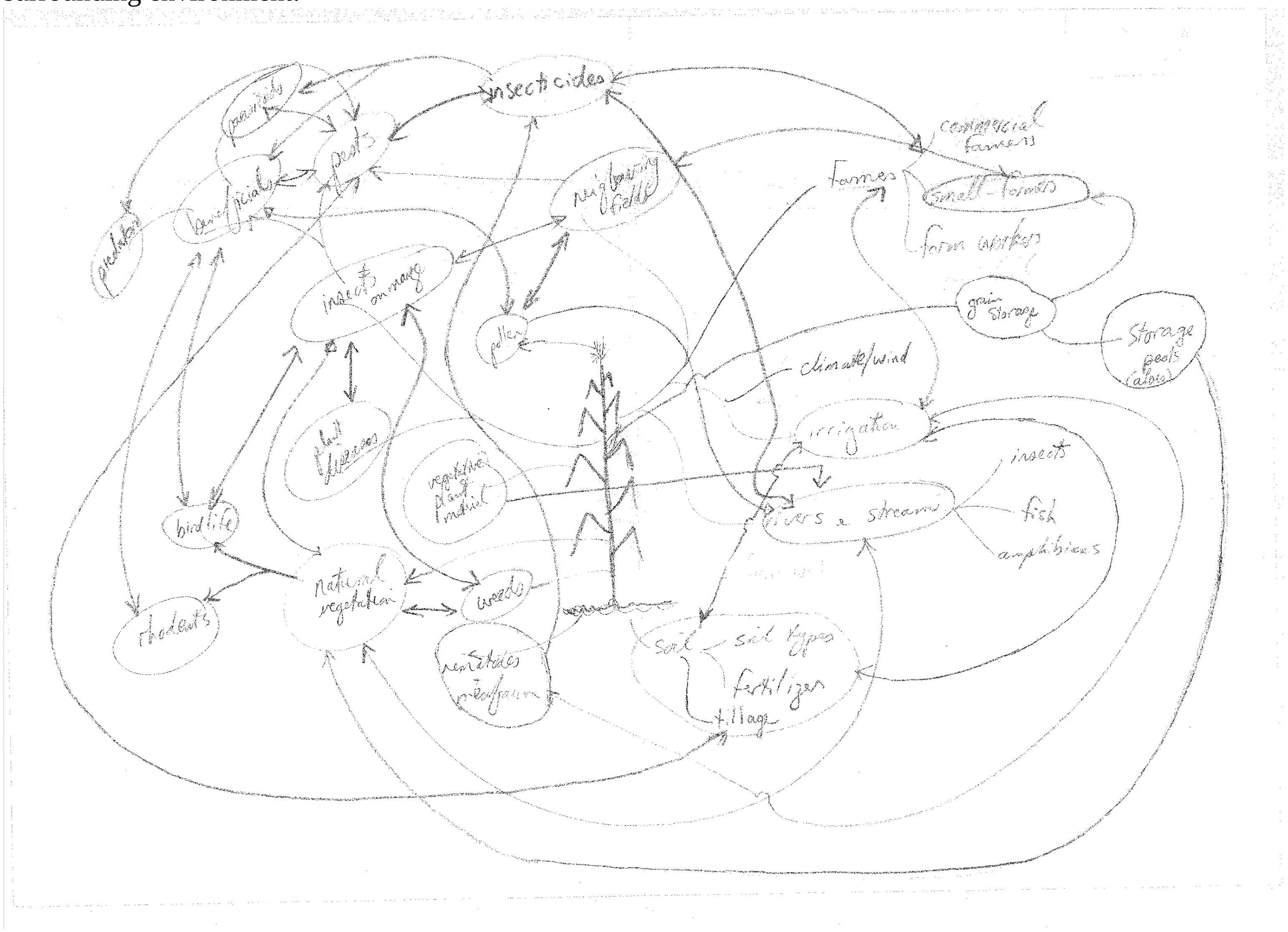
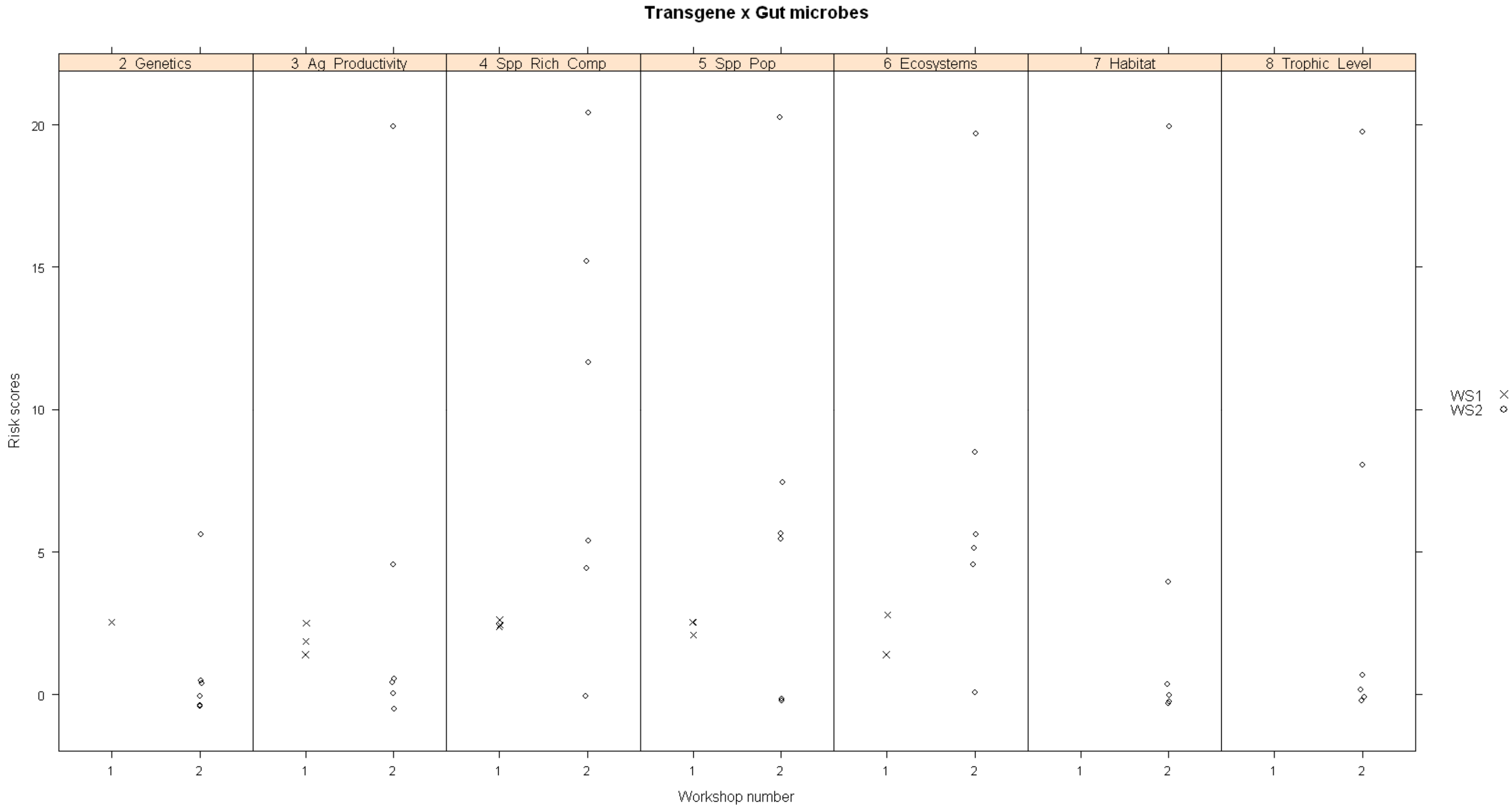


Figure 1-3. Example of individual mind map created in the ERA workshop, showing the relationships between Bt maize and the surrounding environment.

Figure 1-4. Example of the number and range of risk scores generated by workshop participants between Workshops 1 and 2, for the hazard “transgene x landrace maize”. Labels at the top of the columns correspond to tables that participants used to estimate consequences at different ecological levels. Risk scores were generated by multiplying the likelihood of the hazard (on a 1-5 scale) with its consequences (on a 0-5 scale). Participants chose ecological levels they deemed important, and therefore risk estimates were not completed for all levels.



CHAPTER 2: Social learning in biotechnology environmental risk analysis

Social learning is critical in participatory environmental risk analyses (ERAs), because investigating complex socio-ecological systems in which many risks reside depends on learning diverse knowledge and perspectives. The social component occurs when people engage with each other and share diverse perspectives and experiences to develop a common framework of understanding and a foundation for collective action. Efficacious risk-related decisions also rely on social learning outcomes, which include collective understanding of how the risk situation occurred and joint support for specific solutions. We investigated social learning among 22 diverse stakeholders during a 3.5-day participatory ERA workshop evaluating potential threats from genetically modified (GM) maize to South African biodiversity. Participants evaluated the ERA process as containing components and attributes important for engendering social learning, such as diverse participants, open communication, constructive conflict management and extended engagement. We found that social learning occurred, as participants engaged with new information and diverse perspectives, began thinking systemically and modified their risk perceptions. Participants did not, however, develop a shared understanding of the ERA process or highest priority risks. Carefully designed participatory processes can produce social learning about other stakeholders, complex socio-ecological systems, and risk in short time periods, but longer engagement is needed to build shared understanding of the risk situation and how to resolve it.

INTRODUCTION

Social learning is a promising concept for sustainably managing complex socio-ecological systems. It describes the process whereby people share, re-frame, and integrate knowledge with their personal experiences, and then work to create a joint foundation for collection action (Schusler et al. 2003). This concept is increasingly being studied in collaborative approaches for natural resource management (Steyaert and Jiggins 2007; HarmoniCOP 2005), where the challenge to managing systems is less about finding an optimal solution and more about ongoing learning and adaptation by communities (Tompkins and Adger 2004; Campbell et al. 2001). Developing flexible and adaptive communities requires that diverse actors be able to effectively deliberate, negotiate and make decisions, and social learning facilitates these communicative actions. Pahl-Wostl et al. (2007) claim that social learning increases adaptive capacity of society by enabling sustained processes of attitudinal and behavioral change by individuals through interaction and deliberation.

The concept of social learning was first developed in studies on individual learning through the imitation of role models (Bandura 1977) and experiential learning by adults as they form and reform ideas by testing them against prior experiences (Kolb 1984). It is now being studied in the collaborative management of natural resources and socio-ecological systems (Steyaert and Jiggins 2007; Maarleveld and Dangbegnon 1999). Current scholars still conceptualize social learning as based on social processes and group learning dynamics, but they also focus on how these processes lead to technical and relational outcomes (Pahl-Wostl et al. 2007; Pahl-Wostl and Hare 2004). Such learning is understood to occur from participation (Bouwen and Taillieu 2004), and knowledge is created through the *transaction* between objective (substantive) and subjective (emotional) life experiences by individuals (Blackmore 2007). Social learning can therefore only be achieved by active participation (Nicolini et al. 2003) and is characterized by interaction among multiple, inter-dependent stakeholders (Ison et al. 2007). This interaction with others is very important because social learning involves creating new relationships and transforming adversarial ones as people learn about character and trustworthiness of others and develop new networks and norms (Schusler et al. 2003).

Scholarship from education and public policy identifies a multitude of factors capable of influencing social learning. Education scholars Johnson and Johnson (1999) have long recognized elements necessary for collaborative classroom learning, which generally include good communication skills, reinforcing each person's connection to the group, and opportunities for reflection. Policy makers acknowledge that social learning takes place in a natural (the physical learning environment or "situation") and social context (the cultural, political, and institutional constraints on participation and group learning) (Valve 2006). Factors influential for social learning related to natural resource management include the roles of stakeholders, motivation and skills of leaders and facilitators, and openness and transparency of the participatory process. Scholars studying collaborative environmental problem solving also identify that an individual's learning style, the safety of their environment, and the immediacy or relevance of the issue to their lives influences a person's capacity to learn in group settings (Daniels and Walker 2001).

Social learning and environmental risk analysis

Muro and Jeffrey (2008) encourage investigating and defining situations in where promoting social learning is appropriate. The field we chose to investigate is environmental risk analysis (ERA), which traditionally utilizes expert-generated evaluations of risks to individuals, species and ecosystems to support environmental management decisions (Burgman 2005). There are growing calls for ERA to become a more participatory, recursive process (Kapuscinski et al. 2007; Renn 2005; NRC 1996) and to involve stakeholders as a way to include different types of knowledge in the analysis, involve persons in decisions that interest or impact them, and decrease the likelihood that resulting decisions will be contested. In addition, there are efforts to incorporate stakeholder contributions into new ERA methodologies (Nelson et al. 2007; Nelson et al. 2004). The role of social learning is not considered in the few published examples of participatory ERAs (e.g., Dana et al. in review; Carey et al. 2007).

It is important to foster social learning in participatory ERAs, as participants must consider and navigate diverse knowledge and epistemologies about the socio-ecological system under analysis, grapple with competing viewpoints on issues of risk, and jointly create and support risk management strategies. Many risk debates arise from fundamental disagreements over values and perceptions, and solutions depend more on understanding and negotiating social constructions of risk than analysis of scientific information (Gregory et al. 2006). This is not to say that scientific information is excluded in a participatory ERA; instead it becomes one of several inputs (NRC 1996). Indeed, Slovic (1987) argues that a risk analysis will succeed only when it becomes a two-way, participatory process of communication and negotiation between experts and the public, not a traditional expert-driven process where results are only communicated to the public at the end.

Our case study investigates a participatory ERA of the potential risks of currently cultivated genetically modified (GM) crops to South African biodiversity. An ERA of genetically modified organisms (GMOs)[7] is particularly interesting to evaluate for its ability to engender social learning, because participants will have to grapple with the fact that the biotechnology is controversial, scientifically complex and its environmental impacts are uncertain (Snow 2005). The technology is also characterized by polarized debates and diverse opinions and perspectives about its utility and risk (Marris 2001). Partly because of GMO's public controversy and ecological uncertainty, there is support for ERA of GMOs to include more transparency and stakeholder participation (Nelson and Banker 2007; Glover et al. 2003), particularly at the beginning of the analysis when formulating the issue or problem that the technology is trying to address. Nelson et al. (2009) propose a problem formulation and options assessment (PFOA) process that involves multiple stakeholders—interested and affected parties—and scientists, functioning as a venue for social learning about GMOs and other emerging technologies. This interactive problem formulation is a first step in an ERA of GMOs that can then be repeated at critical stages in the ERA as new information becomes available. Our work contributes to and goes beyond this scholarship by studying stakeholders' social learning throughout an in-depth risk analysis process. Our findings illustrate the challenges of social learning about risk with diverse participants in a complex agro-ecosystem.

[7] Any organism that possesses a novel combination of genetic material obtained through the use of recombinant DNA technology. Common GMOs include agricultural crops genetically modified for greater productivity or resistance to pests or diseases (CBD 2000).

METHODS

We chose a case study approach as a way to undertake an in-depth exploration of the characteristics, perceptions and values of a group of stakeholders about biotechnology and risk (Yin 1984). We used a multiple method approach to gather data related to social learning, using interviews, written surveys and evaluation worksheets. We describe the case setting, how participants were chosen, data collection methods, and analysis plan below.

Case Description

South Africa's government recently mandated the South African National Biodiversity Institute (SANBI) to monitor for potential impacts of approved genetically modified organisms (i.e. released into the environment) on the nation's biodiversity (Republic of South Africa 2004). SANBI expressed interest in using an ERA approach to determine highest priority interactions between genetically modified (GM) crops and biodiversity, in order to help its monitoring program focus on interactions with the highest risk to biodiversity. Monitoring looks for realized risks (or lack thereof) in the environment. SANBI was motivated to include diverse participants in the ERA process for several reasons. First, South Africa has a strong national commitment to public involvement in government decision-making. SANBI was similarly committed to involving stakeholders in the design of its monitoring program, especially since the adoption of GM crops has a high public interest and the scientific community is still debating the potential risks of GM crops and the methods for detecting risks (Andow and Hilbeck 2004). Second, SANBI's leadership realized that understanding and analyzing the complex topic of biodiversity and agro-ecosystems required a diversity of expertise and perspectives from different stakeholders. Of the three GM crops cultivated in South Africa, we chose to analyze GM maize engineered to resist pest insects such as corn stem borers.

SANBI collaborated with the University of Minnesota's National Science Foundation Integrative Graduate Education and Research Traineeship (IGERT) program in Risk Analysis for Introduced Species and Genotypes to develop and implement a risk assessment approach to structure the analysis of interactions between GM crops and biodiversity. The IGERT program is comprised of an international community of risk analysis experts and students conducting research to improve ERA and develop workable solutions to policy questions and problems affecting management of introduced species and genotypes (including GMOs). The lead author first developed the ERA process with the IGERT community and refined it upon arrival in South Africa. She also trained SANBI staff in risk analysis techniques, coordinated logistics of implementing the participatory ERA and contributed to the South African research community investigating invasive species and risks of GMOs.

Who participated?

We defined stakeholders as persons interested in the topic of GM crops, and those affected by SANBI's monitoring approach. Scientists were included as an important stakeholder group. There are three common roles for scientists in an ERA: scientists as experts who conduct the entire analysis, scientists as advisors to a group of stakeholder participants, and scientists as one category of stakeholder. We subscribe to the third definition as scientists are an interested group whose knowledge, insights, perspectives and skills are necessary to complete an iterative, analytic-deliberative risk analysis (NRC 1996). Furthermore, the scientists who participated in our ERA varied greatly in terms of seniority, employer, cultural and educational backgrounds, personal interests, opinions about risk, and familiarity with GM crops (e.g., some were key researchers on environmental effects of GMOs while others lacked any knowledge about them) (Figure 2-1).

The provincial level Department of Agriculture and Land Affairs extension officers represented farming communities, as it proved extremely difficult to identify interested farmers with the necessary scientific literacy and English language skills (and many farmers were occupied with planting season). Mpumalanga Tourism and Parks Agency is responsible for the sustainable management and promotion of tourism and nature conservation in the Province, and its staff provided zoological and aquatic systems knowledge. Persons from policy and research think tanks, universities, and government research agencies provided additional social and biological knowledge in areas including agricultural economics, ecology, conservation biology, entomology, plant pathology, and soil science. The environmental NGO community and the biotechnology industry (international and national) also sent representatives. The Department of Agriculture, Forestry and Fisheries (formerly Department of Agriculture), which is responsible for the regulation of GM crops, and the Department of Environmental Affairs (formerly Department of Environmental Affairs and Tourism), each sent an observer but chose not to directly participate.

We used a nonrandom snow ball sampling technique to identify relevant stakeholders, by which initial subjects suggest additional subjects in relevant areas of expertise (Spreen 1992). We asked the following questions to identify main categories of stakeholders for the ERA workshop:

1) What scientific disciplines and professional training are relevant to an assessment of GM maize agriculture and biodiversity?

2) What groups of people are interested in GMO risk assessment?

3) Who are relevant policy makers and regulators of biotechnology?

We contacted each potential participant individually to introduce SANBI, its GMO monitoring mandate, the purpose of the workshop, and how someone with their background was instrumental for conducting the ERA and developing a monitoring program. If the person agreed to participate, we described the workshop process in detail, either in a face-to-face meeting (most common) or via phone. SANBI covered workshop participant's travel, lodging and daily expenses; beyond this, participants were not compensated. We explained to all participants the purpose of the research, how their confidentiality would be protected, and the various research activities involved. Each participant verbally consented to participate and received a one-page description of the research purpose and activities. Workshop time and facilitation constraints limited final workshop participation to 22 stakeholders. Our goals were to avoid overlapping expertise, to have equitable representation in terms of race and gender, and to choose persons able to engage in a fairly scientific, English language-based risk assessment process.

Design and implementation of participatory ERA framework

We took a recently published conceptual framework for a participatory ERA process (Hayes et al. 2007) and adapted it for real-world implementation in South Africa. We drew upon ERA literature (e.g., Burgman 2005) and solicited advice from risk analysis experts to choose rigorous, but technologically simple, tools that could be used by a diverse group of stakeholders to analyze a complex agro-ecosystem. We also combined insights from experiential and collaborative learning literature (Daniels and Walker 2001; Kolb 1984) to create different types of exercises throughout the ERA to capitalize on participants' different learning styles and keep them engaged over multiple days. We implemented this participatory ERA process in a 3.5-day multi-stakeholder workshop hosted by SANBI in Pretoria, South Africa in November, 2008 (Dana et al. in review). An experienced, scientifically knowledgeable facilitator from the USA facilitated the workshop.

Conceptual framework used to evaluate social learning

We chose two main categories by which to evaluate our participatory ERA for social learning: the *process* itself, and the *outcomes* of the process (Figure 2-2). Key *process components* important for engendering social learning are: facilitation, diverse participants and a democratic structure. Facilitation is required to guide participants through the process, provide space for all participants to contribute, and keep the process focused. Diverse participation increases the amount of new information, epistemologies, and worldviews about which other participants can learn. A democratic structure ensures that participants feel they have the opportunity to contribute and that their contribution is respected and incorporated in the process.

Process attributes emerge based on the quality of the process' components, and include: time for extended engagement, diverse knowledge, unrestrained thinking, constructive conflict, and open communication. Extended engagement allows participants to have more in-depth conversations and continue learning from others outside of formal workshop activities, and, if participation is diverse, a variety of expertise and epistemologies present should provide opportunities for broadening participants' understanding of diverse perspectives and worldviews. Encouraging unrestrained thinking stimulates participants to think outside the boundaries of traditional professional or disciplinary topics, and open communication happens when participants feel comfortable asking questions, contributing knowledge, listen respectfully and are open-minded to different types of information. Finally, constructive conflict occurs when participants can voice and challenge divergent opinions respectfully and productively.

We chose to evaluate six short term *outcomes* of social learning: whether participants 1) learned new information, 2) became knowledgeable about other perspectives and worldviews, 3) experienced new or transformed relationships with others, and 4) began to think systemically. Understanding complex socio-ecological systems surrounding GM agriculture requires learning new information, perspectives and worldviews. New or changed relationships between participants influence the cohesion of the group, the quality of interactions and the capacity for other collaborative endeavors related to the environmental problem. Systemic thinking refers to participants' ability to envision connections and feedback loops between different socio-ecological components, how these connect into a holistic system, and how actions at one level may sometimes have unanticipated or unintended consequences on another (Seiffert and Loch 2005).

We also evaluated several medium-term outcomes in terms of whether participants 5) developed a shared understanding of the problem being addressed, the workshop process and outcome, and 6) changed their perceptions about the risks of GM crops. A shared understanding by participants about why they are gathered together, the collaborative process and its outcomes is important to ensure participants understand what they are jointly working towards and generate a sense of unity around and ownership of the final product. Such a sense of shared understanding is important for creating consistent solutions that can be adjusted and adapted as needed (Maarleveld and Dangbegnon 1999). Changing perceptions of risk is a social learning outcome specific to our ERA case, but it represents a more general measure of whether participation in a collaborative process can change persons' perceptions or opinions upon learning new information, perspectives and worldviews. Such shifts in opinion may reflect whether participants feel better informed or signal the direction or level of support for final solutions.

Other long term social learning outcomes such as increased trust, a community of practice[8], behavioral change or new policy directions are also possible (Muro and Jeffrey 2008; Mostert et al. 2007; Wenger 2003). Such substantive changes take longer time to materialize, are impacted by a variety of factors, and can be difficult to attribute specifically to social learning. Therefore, evaluations of outcomes can begin by examining the participatory process itself and incremental changes that are easier to

[8] Communities of practice are groups of people who share a concern or a passion for something they do and learn how to do it better as they interact regularly (Wenger 2003).

achieve in a shorter time horizon, such as changes in knowledge and relationships, as indicators of nascent social learning, in events as small as a workshop (e.g., Schusler et al. 2003).

Data collection methods

First, the lead author conducted 22 *semi-structured interviews* before and 22 after the workshop with each participant. Pre-workshop interviews began roughly two months before the workshop, and all post-workshop interviews were conducted 5-30 days afterwards. We conducted 34 of the total 44 interviews in-person, with the rest via phone, and audio-recorded all. Interviews ranged in length from 18 minutes (pre-workshop) to 2+ hours (post-workshop). There were 20 and 26 questions in the pre- and post workshop interviews, respectively; all questions were open-ended. We chose open-ended questions because they helped build rapport with interviewees and allowed participants to articulate complex ideas about risk and biodiversity and reflect upon their personal experiences with the social dynamics during the ERA.

Second, each participant completed a one-page *learning evaluation* at the end of each day during the workshop (5-10 minutes in length), where participants could answer up to five open-ended questions about what they learned, what they tried to communicate and how it was received, what worked well and what they would improve. Third, all participants completed a written *survey* at the end of the workshop (20-30 minutes in length) to evaluate the ERA process. Participants rated eight attributes and components of the workshop and the group's achievement of social learning outcomes on a scale of 1-5. The final three questions were three open-ended asking what they learned, how well the tools worked and what they would improve. Lastly, the lead author *observed* the context of participants' interactions and where they encountered problems with the process during the workshop. We also made *video recordings* of workshop proceedings, but did not use them in our analysis.

Data analysis

We drafted an analysis framework prior to coding and defined key categories of social learning responses to search for. We used QSR International's NVivo8 software to transcribe and code three sources of data for each participant: responses to open-ended questions in pre- and post-workshop interviews, daily evaluation sheets, and the final workshop survey (Appendices I-IV). The coding process was iterative; we refined the details of each social learning category after coding 5-10 interviews and both authors periodically discussed trends in emerging responses. Responses to open-ended questions were often lengthy and difficult to extract data from, and they did not always contain exact responses to a specific social learning component, attribute, or outcome. Therefore, we looked for multiple pieces of evidence of social learning within each participant's set of data, and gathered composite responses across participants. We selected several interviews with extensive, complex text and another social learning scholar external to the project applied our codes independently. She helped confirm that there was similarity in coding patterns, and general agreement about the intent of interview text.

FINDINGS

The ERA process contained the necessary components and attributes to engender social learning, as evaluated by workshop participants. Short term social learning outcomes occurred in terms of participants learning new knowledge and perspectives, with some participants changing their perceptions about risks related to GM crops. Participants did not achieve a shared understanding of the purpose of the workshop, the ERA tools, and final monitoring endpoints. We discuss these findings below, starting each section by presenting end-of-workshop survey ratings and then responses from open-ended interview, survey and daily evaluation sheet questions as evidence.

ERA process components

All three components received average ratings of four and above on a five-point scale in end-of-workshop survey evaluations (Table 2-1). A month later, in open-ended interview questions, *facilitation* was deemed successful by the majority of participants (Table 2-2). Participants specifically mentioned that the facilitator kept the process democratic and helped focus them. Though participants did not explicitly comment on the *diversity of participants*, more than half mentioned the diversity of knowledge present, particularly the "on the ground" type. As one environmental group participant commented:

> "The work of the people on the ground was also very illuminating in the sense of what their field observations were. Whether it's termites eating residual parts of the maize or whether it was maize seed coming up in animal feces around the field. Field observations, or whether it was [Tourism and Parks participants] noticing that storks would feed on germinating seeds. Those kinds of observations are very useful, and that's really part of the monitoring program."

In terms of the *democratic nature* of the process, half the participants noted there was opportunity and enough time for everyone to contribute, and specifically mentioned their and others' unique contributions. Some noted that they were in a learning role or were ambivalent about how their contributions were received. Even though most participants were positive about their contributions, some noted that they limited themselves because they wanted to save time and avoid criticizing others, or lacked knowledge to contribute. The presence of regulatory authorities as observers and not full participants bothered several people, and impacted their evaluation of the process as democratic. As one participant explained:

> "I found it very uncomfortable that [Department of Environmental Affairs and Tourism] was there as an observer but they didn't give any input. It is kind of like they are, not spying, but ah…I don't know why? I was not curious. It was actually more negative thing. …I didn't trust it. I was dubious of, suspicious. I was suspicious, I must be honest."

ERA process attributes

All five social learning attributes received a score of 3.5 or higher on a five-point scale in end-of-workshop surveys (Table 2-1). A month later, again in open-ended interview questions, over half of the participants mentioned the great *diversity of knowledge* present at the workshop (Table 2-2). One environmental organization participant noted:

> "…some people definitely brought gems to the table. Things which people wouldn't have considered. A field extension officer perhaps wouldn't have been thought of as a suitable expert in GMOs, wouldn't have been consulted, yet they brought quite a lot of knowledge to the table, which was very useful."

Some noted that important types of expertise were missing, especially farmers. For instance one scientist noted that farmers are "the people on the ground who know how <the maize> is operating, and if there are changes in biodiversity, they are usually the first people who are going to pick it up". Participants identified particular areas of helpful scientific expertise they would have liked to have seen, including someone to better explain the genetic engineering process, principles of risk analysis, and pollination biology. *Unrestrained thinking* did not emerge as a strong attribute in open-ended responses; quite the opposite, as the majority of participants who mentioned anything related to this topic (10 out of 22) commented that the structured nature of the ERA process was restrictive. Only the first step of the process, conceptual mapping—where participants drew mind maps of the maize cropping system—was mentioned as promoting creative thinking. *Extended engagement* happened during the workshop, as the majority of participants mentioned how helpful it was to have informal discussions during teas, lunch, and evening gatherings. Furthermore, unprompted, 14 participants reported seeking out and asking questions of, or teaching and guiding, other participants, evidence of social engagement necessary for social learning. A government agricultural researcher noted how his thought process shifted after engaging with others:

> "I found myself at lunch time either having things explained to me, or explaining things. And then going back to the meeting and saying: 'Just now that's how my thoughts [were] running, and now I've changed direction in a sense'. And so the whole time…it was a learning process…"

Open communication occurred, with over half of participants noting that people listened, contributed and were open to new information. But a few individuals noted instances that they perceived as negative, when certain individuals grumbled or sighed at others' comments, or when some participants' ideological arguments started to dominate. A fair amount of *constructive conflict* occurred, as just under half of participants noted that when instances of disagreement and divergence of opinion appeared, they were accommodated or resolved. A few participants realized that conflict around ideological beliefs about GMOs was not going to be resolved and they gave up trying to reason with those whom they felt held such beliefs.

Social learning outcomes

Through open-ended interview responses, surveys and daily evaluation questions, participants identified short term outcomes of social learning, such as new information learned, knowledge of different perspectives, and systemic thinking (Table 2-3). Transformation of relationships and a shared understanding of the purpose of the workshop and its final outcomes did not occur (Figure 2-3).

The majority of participants reported learning *new types of information* about the process of maize genetic engineering, farming practices, and the diversity of environmental components GM maize can interact with. Half of participants identified that they learned about others' *perspectives* on the subject of risk and that these differences were important and to be respected. A few participants reported *new relationships*, and about a third of all participants noted *transformed impressions* of others after interacting at the workshop, but not necessarily transformed *relationships*. In particular, impressions about the environmental NGO participants improved based on their behavior and contributions, and those of the biotechnology industry worsened.

Participants appear to have begun *thinking systemically*, as at least a third of them expressed new appreciation for the complexity and interconnectedness of the agro-ecological system, a bigger picture of agricultural production and the broadness of potential impacts of GM maize. One agricultural extension officer explained how his thinking changed:

> "Prior to the workshop I thought of little possible risks. But now, also accommodating the opinions of the different interest groups, not just the agricultural production, also thinking of the environment as a whole. I began to feel that we need to ascertain negative impacts on the other organisms, even those that we as producers might feel comfortable getting rid of. Because they are all part of the system. And we need to deal with them responsibly." (P14)

Some participants *changed perceptions of risk* of GM maize to biodiversity as a result of participating in the ERA workshop. Of those whose perceptions changed, most reported being more concerned about the potential risks. A few participants felt that the risks were less or that the issue had become more complicated for them.

Participants did not develop a *shared understanding* of the purpose of the workshop, the ERA process, and the final outcomes. More than half of participants responded that there was no shared understanding of the workshop's purpose (i.e., the problem they were gathered to solve), with responses evenly split between "to determine what to monitor" or "to test a risk assessment model". Participants were equally unclear about how the steps and tools of the ERA process linked together and helped SANBI move toward the end goal of developing a GMO monitoring program. Finally, a little more than half felt there was a shared understanding of what interactions between GM maize and biodiversity to monitor at the end of the workshop. The inability of participants to achieve these different levels of shared understanding impeded joint support for a decision on what was most important to monitor in terms of impacts to biodiversity and influenced the cohesion and unity of the group's activities during the workshop.

A small set of participants from industry, environmental, and key university research programs articulated a few, longer-term social learning outcomes. Some believed there was increased buy-in or legitimization of the process by having diverse stakeholder groups participate, as explained by a government agricultural researcher:

> "Not necessarily the workshop, but for any system that gets put in place, you need this participatory thing because I think there's just greater acceptance for the project that comes out. Even if you disagree with it you still feel that you had a say and you could have said, and may have disagreed. But if somebody just draws up the [monitoring program] and says 'this is what we are going to look at', I think some people on principle will say 'yeah, but..'"

A few identified that they built capacity to conduct better ERAs for biotechnology projects and developed new research collaborations to investigate risk-related questions. Furthermore, some felt that priority research directions were identified and validated by the larger community of stakeholders. A university researcher summarizes this sentiment:

> "And so I walked away with a feeling of 'well there's a lot that needs to be done, but you know what, we are spot on in terms of where we want to go in our research and our thinking'. And that was quite heartening for me because biosafety-related research has not been really well funded in South Africa…so at least from a scientific [standpoint], our thinking is on track."

DISCUSSION

Our participatory ERA process generated successful moments of social learning, despite the relatively short period of engagement, the complex nature of the topic and history of contentious interaction between some stakeholder groups. Overall, the components and attributes necessary for social learning were present, and evaluations from the survey and open-ended questions were consistent. Short term social learning outcomes were achieved, though longer term ones on shared understanding were not. It is important to note that several participants expressed negative opinions throughout the ERA process, during workshop evaluations and in post-workshop interviews. Several other participants commented on these few unfavorable attitudes during the workshop and that they influenced their overall evaluation of the process. Below we discuss how our results are similar to those of other social learning studies and several factors influencing such learning.

Our findings are similar to those from Schusler et al (2003) and Krasny and Lee (2002) in that we identified comparable social learning outcomes, including acquisition of new factual information and knowledge about new perspectives. Our process was also evaluated as generating open communication and time for extended engagement with diverse participants during the workshop. Our project was more limited in scope than those of other social learning scholars (Pahl-Wostl et al. 2007; Steyaert and Jiggins 2007; Maarleveld and Dangbegnon 1999), and its short timeframe limited the ability to achieve longer-term, geographically broad social learning outcomes such as new biodiversity management plans and changes in institutional power arrangements. Our study topic, genetically modified crops, was similar to that of other social learning studies, in that was characterized by socio-ecological complexity, generated interest among a wide variety of stakeholders, and was politically charged.

The presence of hardened positional stances by some participating stakeholders toward genetically modified crops hindered social learning. Marris (2001) found that such stances often stem from underlying beliefs about how food scarcity problems should be solved (some say GM crops are the answer), who bears risks and reaps rewards of GM crops, and whether the technology's safety has been satisfactorily proven. As a result, some stakeholder groups have extensive histories of opposition. While venues of social learning can provide a constructive environment for improving relations, a single 3.5 day workshop such as ours can only be considered the beginning step towards long-term sustained engagement necessary for transforming relationships. Evidence from the workshop that half of the participants learned about others' perspectives and began to accommodate each others' viewpoints suggests that more significant progress may be possible with additional extended engagement.

Social learning is more difficult when participants lack sufficient knowledge to make informed and meaningful contributions. Genetically modified organisms are complicated technologies, created using molecular biology and biochemical techniques, scientific processes difficult for many people to quickly understand. While most participants reported learning a great deal of new knowledge, some of those new to the topic were particularly frustrated by their inability to participate fully in the exercise, which in turn influenced their satisfaction with the process. We support Mostert et al's (2007) conclusion that social learning in participatory processes investigating complex environmental issues benefits from adequate education and access to information before and during the process. Future participatory ERAs are advised to include specific, dedicated educational activities such as working groups or seminars for those whose participation could be enhanced by learning about the scope and type of information and perspectives about the topic under consideration. Such learning activities should be carefully developed to avoid bias that can be introduced by appearing to privilege certain types of knowledge, perspectives or stakeholder groups.

We echo Muro and Jeffrey's (2008) words of caution when advocating for a participatory, social learning-focused approach to addressing environmental problems. Good participatory processes are often time consuming and expensive, and it is important to evaluate each situation and whether a social learning process will add value or even be possible. We learned that planning, designing and facilitating effective social learning processes requires care and commitment on the part of organizers and participants, and we expect this will often be true for complex risk-related situations. Mostert et al (2007) point out that social learning is not normal in such situations, and fostering it will require dedicated time, money and a professional facilitator. We were fortunate that SANBI provided adequate resources to help identify stakeholders, engage one-on-one with each to build rapport before the workshop and hire an experienced facilitator.

A limitation to using social learning as a lens to evaluate participatory processes is that there is not a one-size fits all metric for whether a process achieved such learning (Muro and Jeffrey 2008). We suggest scholars and practitioners remain flexible when defining and evaluating social learning outcomes and calibrate expectations according to the complexity and history of the issue. As in our case, even shared "awareness" may be valuable progress. It is also possible that stakeholder engagement can lead to further divisions between groups as they learn about each others' perspectives and worldviews and how much they disagree (Preus 2005). Even in such situations, participants may still benefit from a *better* understanding (or awareness) of how various stakeholders define the natural resource management problem and possible solutions, even if a collective plan of action cannot be found. Other objectives for social learning processes can be equally important to foster, such as building adaptive learning communities equipped to work together to investigate and solve complex problems (Bawden 2007; Finger and Verlaan 1995) or empowering stakeholders to solve problems that affect them (Pahl-Wostl et al. 2007). These longer-term outcomes would help build better-informed, engaged and committed communities valuable for addressing thorny socio-ecological dilemmas constantly appearing on the horizon.

Outcomes like trust and empowerment require time and multiple, sustained interactions, so short, participatory ERA workshops are best focused on short term outcomes like systemic thinking and developing new knowledge. Such participatory endeavors would be well-advised to pay careful attention to systemic thinking, as many of today's risks reside in complex, messy socio-ecological systems that are difficult to understand from the perspective of one worldview or perspective. Future processes could be enhanced for this purpose by devoting more attention to the first step of conceptual modeling, and having participants explicitly think through how certain changes or inputs into the system would change relationships and feedbacks. Providing dedicated time after this step for reflection on what they learned and how it could be applied to other situations they face in their lives could also reinforce systemic thinking skills (Ardnt 2006).

Deeply embedded *societal* factors, such as race, power, and historical and institutional relationships, have been identified as influencing other South African collaborative endeavors, including natural resource management (El Ansari and Phillips, 2001; Fabricius et al 2001). We did not attempt to investigate such factors, but we suspect they played a role in the degree to which social learning occurred about GM crops and biodiversity. Dillenborg et al. (1996) provided a valuable review of factors influencing group learning (e.g., heterogeneity of the group; how individual cognitive abilities change when working in groups), and in the future we could incorporate such scholarship into evaluations of social learning in collaborative natural resource management decision-making processes.

Collaborative endeavors for managing complex and controversial biotechnologies like GM crops are difficult, and any progress in understanding different perspectives and gaining new knowledge should be viewed as valuable. Social learning is often cited as an essential element of participatory natural resource management processes, and our case study suggests that elements of social learning are possible in a participatory ERA. However, this was the first attempt at a participatory ERA of GM crops in South Africa. Should such participatory approaches for investigating environmental impacts be continued, additional, long-term social learning outcomes may emerge. Evaluating the ability to create social learning environments around biotechnology risk assessment and governance will require additional investigation beyond our participatory workshop. However, evidence from this study offers hope that it is possible to achieve social learning during environmental risk analysis provided there is attention to process design, strong facilitation, and open-minded participants.

Table 2-1. Participant survey responses rating the degree to which the workshop exhibited components and attributes necessary for social learning. (*n*=22)

	Mean	SD	Range		Mean	SD	Range
Process Component				**Process Attribute**			
Facilitation	4.8	0.5	3 - 5	Diverse knowledge types	4.3	0.5	4 - 5
Diverse Participation	4.1	0.8	2 - 5	Open communication	4.3	0.7	3 - 5
Democratic Structure	4.0	0.8	3 - 5	Extended engagement	4.1	0.7	3 - 5
				Unrestrained thinking	3.9	0.6	3 - 5
				Constructive conflict	3.5	0.7	2 - 5

Note. Measured on a five-point scale from 1-5, with 1= None and 5=Exception

Table 2-2. Participant open-ended responses regarding components and attributes important for social learning in the ERA process (with 4+ mentions). (*n* = number of participants responding in a specific category; total workshop N = 22)

Process components	**What participants said** (# = number of mentions)
Facilitation *n=17*	Positive responses (10) Kept the process democratic (5) Kept process focused (4)
Diverse participation *n=4*	Workshop had diverse participants (4)
Democratic *n=19*	Everyone's contributions were well received (11) There was time and opportunity for everyone to contribute (10) They identified their own contributions (10) Upset about observers (9) Identified important contributions from others (6) They limited their contributions (6) People were receptive to contributions (4)
Process attributes	
Diverse knowledge *n=18*	Diverse knowledge was present (12) On-the-ground knowledge was present (7) Identified specific group of participants as particularly knowledgeable (5) Diverse perspectives were present (4) Expertise or knowledge missing: other random scientific knowledge (9); farmers (7); regulatory authorities (5); no one (4)
Unrestrained thinking *n=10*	Process restrained thinking (6) Process encouraged creative thinking (4)
Extended engagement *n=14*	Much discussion during tea and lunch breaks; sought out others with knowledge; confirmed what they had heard or learned (13)

Open communication *n=20*	Reported open communication (13) Experienced negative communicative experience (6)
Constructive conflict *n=19*	Divergence in opinions was accommodated, debated until cleared (10) Not as much conflict as expected (4)

Table 2-3. Participant open-ended responses regarding social learning outcomes from the ERA process (with 4+mentions). (*n* = number of participants responding in a specific category; total workshop N = 22)

Social learning outcomes	**What participants said** *(# = number of mentions)*
New information learned *n=22*	New information about maize genetic engineering, farming practices, and the diversity of environmental components maize interacts with (21)
Knowledge about other perspectives *n=11*	Learning, understanding, accommodating, realizing, appreciating divergent or different perspectives (11)
New or transformed relationships *n=11*	Altered impressions about participants based their behavior at the workshop (7) New relationships (4)
Systemic thinking *n=14*	Realized the complexity of the environment/agricultural system/biodiversity (8) Realized the interconnectedness of the system (6) Gained a bigger picture understanding of the issue and agricultural production (4)
Changing perspectives on risk *n=22*	No change (8); Increased concern (7); Decreased concern (4); Issue became more complicated (3)
Other *n=6*	Legitimacy of the process, new research projects, capacity building in ERA, validation of priority research directions (6)

Figure 2-1. Affiliations of participatory ERA workshop participants, hosted by the South African National Biodiversity Institute, November 2008.

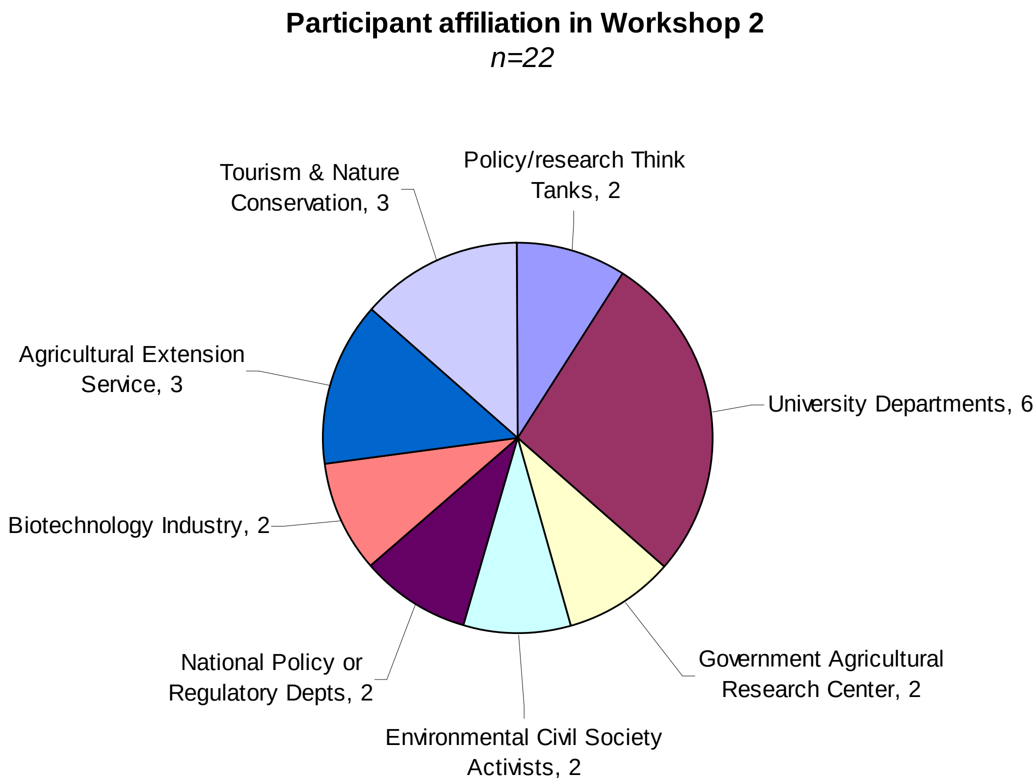


Figure 1-2. Analysis framework for social learning process components, resulting attributes and potential outcomes

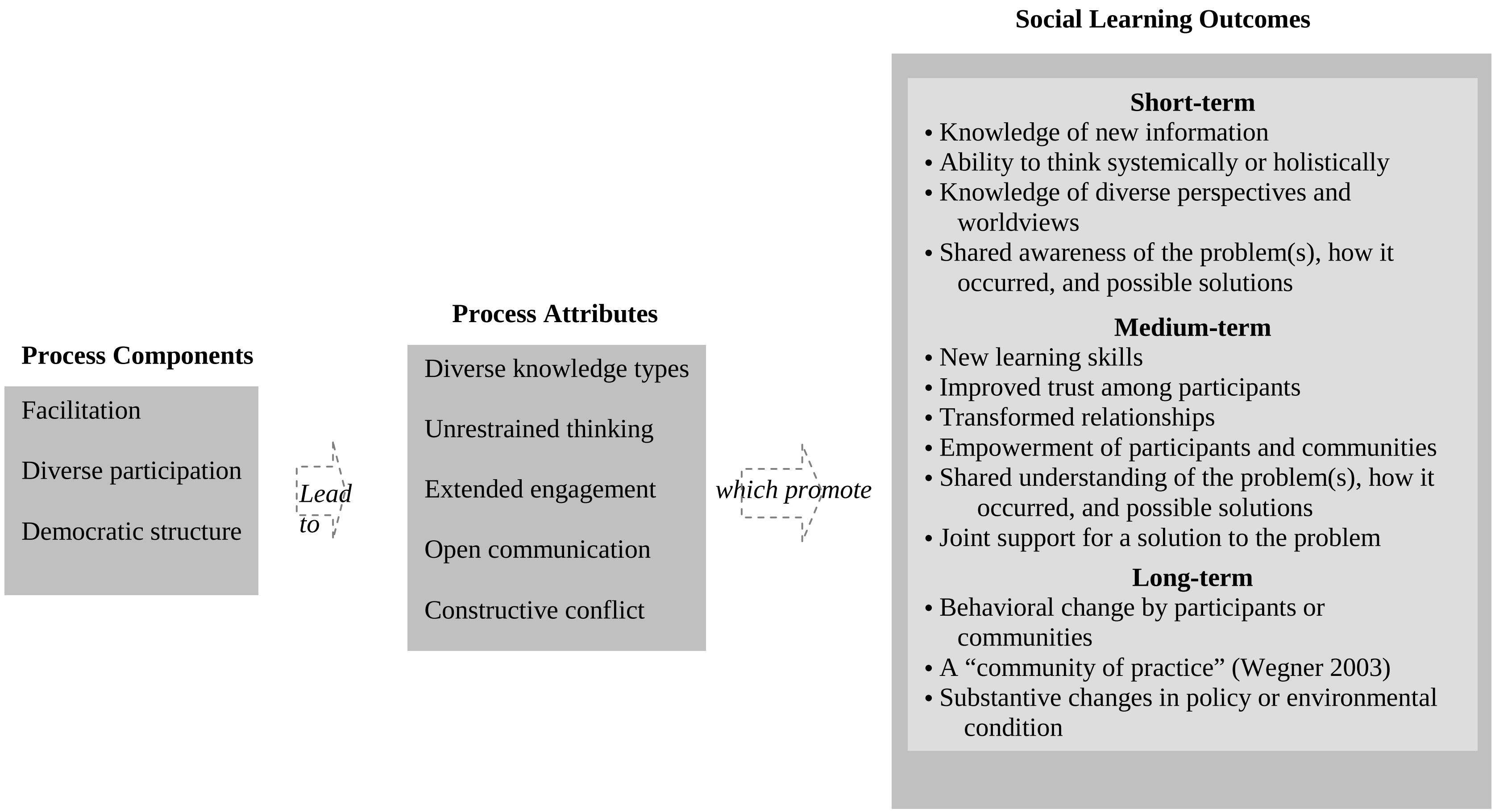
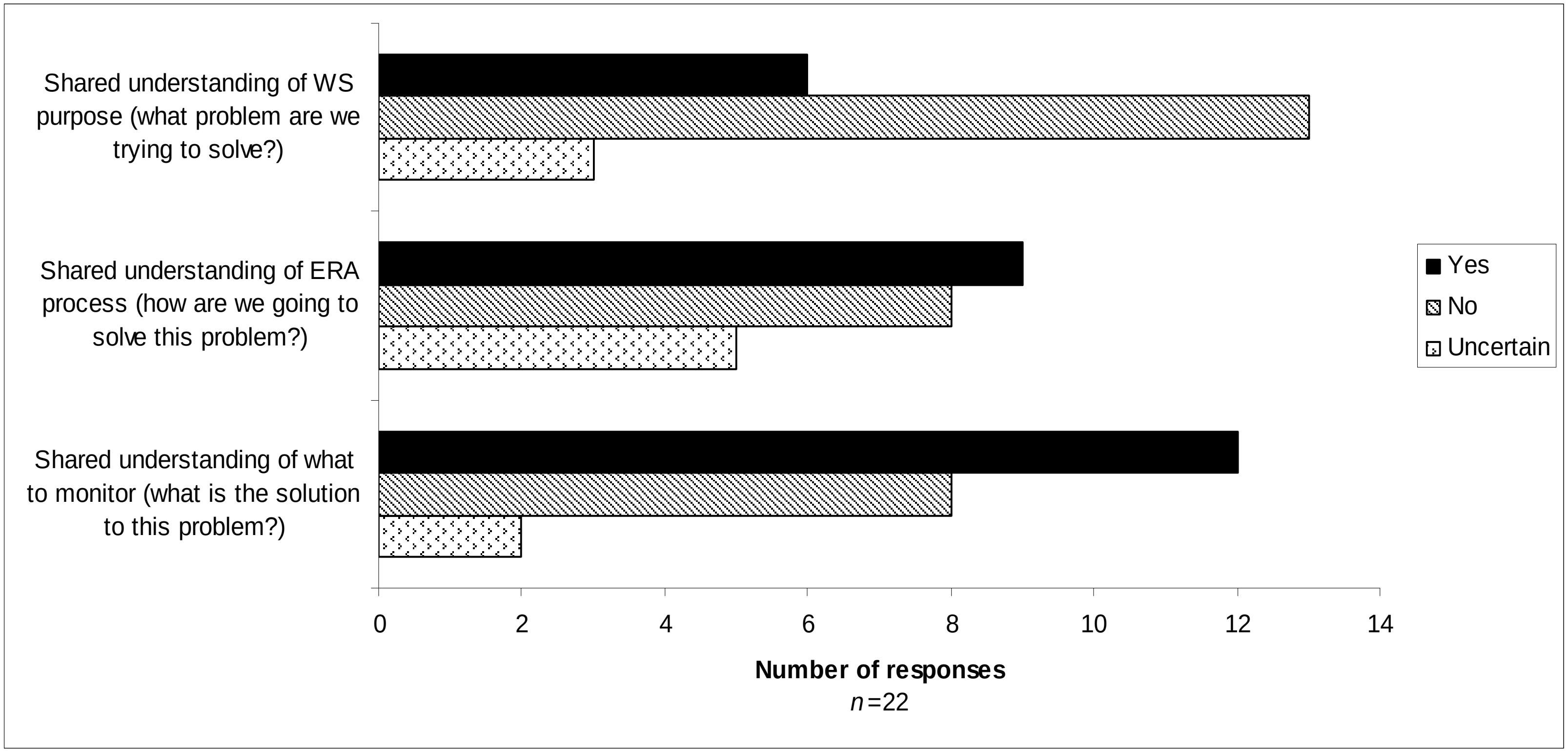


Figure 1-3. Participant responses to whether the group developed a shared understanding of the problem, how to solve it and the solution.



CHAPTER 3: Reflexive Risk Governance and the Role of Social Learning

Human activity and technological innovation inherently generate effects that are difficult to anticipate, because such events happen within complex socio-ecological systems and impacts often materialize much later. Societal distrust of prevailing risk analyses stems not only from the public's realization that expert-generated risk assessments (the probability of adverse effects from some event) are of decreasing utility in complex socio-ecological systems, but also because they cannot incorporate stakeholder deliberation or societal concerns. A *reflexive* approach to risk governance aims not only to widen the scope of impacts considered during risk analysis, but also to consider how societal values and norms, technological innovation, and governance processes themselves, influence the conception and handling of risk. A reflexive approach is at its core a learning exercise by diverse members of society: learning of different knowledge types and perspectives, how to think systemically and how design and adapt risk governance strategies across institutions and actor-networks. Social learning, whereby diverse members of society share, re-frame, and integrate knowledge with their personal experiences, and then work to jointly create a foundation for collection action, is the mechanism by which to achieve reflexive in risk governance. Reflexive endeavors must recognize and design for such learning by including participants with different epistemologies and worldviews, providing space and time for each participant to contribute, and enlisting a strong facilitator. Social learning outcomes, including ability to think systemically, new learning skills, and communities of practice, are essential elements in the move towards reflexivity, and require sustained societal deliberation, refinement and testing of collaborative tools and risk analysis frameworks, and support for incremental change in prevailing risk governance methods and institutions.

INTRODUCTION

Human activity and technological innovation inherently generate effects that are difficult to anticipate, because such events happen within complex socio-ecological systems and impacts often materialize long after the initiating event. Nonetheless, many institutions tasked with protecting human and environmental health attempt to predict the probability of harmful events and characterize their possible consequences using risk analyses. Such analyses are traditionally expert-driven and use scientific data as their primary input, though there are some calls to include more diverse participation and different knowledge types in the process (NRC 1996). Many of these analyses have not been particularly successful at anticipating adverse affects (Hobbs et al. 2006; Law 2006; Hennessy et al. 2003; Wynne 1992a). Additionally, even if the analysis is fairly robust, the public may not be convinced that the activity or technological application poses no threat (Slovic 1999). This is because many members of the public evaluate risks not through technical analyses and estimates, but instead by asking questions such as whether their exposure to the risk is voluntarily, if it is familiar to something they previously observed or experienced, if it is reversible, and who controls it (Slovic 1997). Thus, the term “risk” refers not only to an event with consequences that on can estimate, but also a more nebulous, socially constructed, multi-dimensional concept.

Societal distrust of risk analyses stems not only from the public’s realization that prevailing methods are ineffective for predicting risks in complex socio-ecological systems, but also because they are not designed to incorporate societal concerns (Wynne 1992a). Scholars also criticize traditional risk analyses because they do not include consideration of how institutional practices and governance activities influence human activity and technology development and their attendant risks (Stirling 2006). An increasingly pluralistic conception of risk transforms risk analysis from a calculation of probability to a conflict over power and morality, and choosing between different risks can be conceived of as a choice between different world views: who is important and who is not in terms of bearing the consequences and benefits, whose vision of modernity and progress is privileged and whose institutional rules are superior (Fischer 2000). Cultural norms and values, power structures, institutional histories and processes of technological innovation also shape the process of risk analysis and governance (Beck et al. 2003; Fischer 1993; Renn 1992). Because prevailing risk analyses cannot accommodate societal engagement required to grapple with these issues, or the outcomes from such deliberations (e.g., a rejection of the technology), a more sophisticated approach is needed.

A *reflexive* approach to risk governance aims not only to widen the scope of impacts considered during risk analysis, but also to consider how societal values and norms, processes of technological innovation, and governance processes themselves, influence the conception and handling of risk. A reflexive approach requires re-thinking what constitutes risk-relevant questions, increasing the level of citizen engagement, and recognizing that risks are socially constructed and reshaped as societal values and norms evolve. Such an approach involves integrating different knowledge types and epistemologies, creating opportunities for diverse participants to articulate how their worldviews influence their risk perceptions, and recognizing the interconnectedness of social and natural environments.

A reflexive approach is at its core an exercise in learning by diverse members of society—learning of different knowledge types and perspectives, learning to think in terms of systems, and learning how to coordinate actions across institutions and networks of actors. Social learning, a concept that describes the process whereby people share, re-frame, and integrate knowledge with their personal experiences, and then work to create a joint foundation for collection action (Schusler et al. 2003), is fundamental to achieving reflexivity in risk governance. Any effort intended to promote reflexivity must therefore recognize and design for such learning by, for example, explicitly identifying and including participants with different epistemologies and worldviews, providing space and time for each participant to make a contribution, and enlisting a strong facilitator (Dana and Nelson in prep; Mostert et al. 2007; Webler and Tuler 2000). The concept of social learning can help discussions about operationalizing reflexivity move beyond general recognition of the importance of fostering learning in social environments (or "social" learning—Genus 2006; Wynne 1992b; Voß et al. 2006) by providing specific guidance on how to design participatory, learning-focused processes and illustrating how specific social learning outcomes underpin reflexive risk governance.

In this paper, we contrast the prevailing conception of risk with a pluralistic one and describe why traditional risk analysis methods are inadequate for understanding or coping with complex risk situations. We consider the pluralistic version to be better suited to the attributes of many of today's complex risk situations and outline the main elements of a reflexive risk governance approach designed to grapple with multi-faceted risk-related concerns. We anticipate scholarly advances in risk analysis, science and technology studies, public engagement and collaborative processes will move risk governance toward reflexivity, and that successful endeavors will require recognition of and design for social learning. We offer insights on how to explicitly design and investigate social learning in processes intending to promote reflexivity and explore challenges to achieving genuine reflexive risk governance.

PREVAILING CONCEPTION OF RISK

Many institutions formally tasked with protecting human, economic or environmental health conceptualize risk as estimable actions or events, albeit with some uncertainty, that have undesired consequences that humans can try to mitigate (Graham 2005; Saner 2005; Power and McCarty 2004). Prevailing risk analysis frameworks proceed in a linear fashion through problem formulation, risk assessment, management and communication. In the problem formulation stage, managers and risk analysts (and in some cases stakeholders—interested or affected parties) define the investigation's scope and objectives, gather existing information, and develop risk hypotheses (EPA 1998). During the actual risk assessment, scientific and technical experts generate estimates of the likelihood that various environmental and social entities will be exposed to stressors, which can be objects or events such as chemical pollutants or natural disasters, and what the effects might be (e.g, changes in water quality or damage to beachfront property) (EPA 1998; Suter 1993; NRC 1983). Risk assessment is a process for determining the frequency and consequences of harmful events, informed by the best available scientific information and with all biases or opinions clearly stated (Campbell 2001; Latin 1988; Russell and Gruber 1987).

Decision-makers and managers then integrate risk assessment results—the likelihood and effects estimates—with other considerations such as existing management strategies, risk perceptions, and public opinion to develop risk management solutions, which might include new laws, policies, measures to reduce risk or educational efforts. Risk assessment and management are often thought of as separate steps; results of both are typically communicated to stakeholders and the public during a final "risk communication" step (Suter 1993). Recently, the U.S. National Research Council suggested a major shift in the steps in the risk analysis process, i.e., that risk management questions should be posed first, and then risk assessment should proceed once all parties are confident that the analysis is focused on the most pressing or relevant overarching problem (NRC 2009).

There are growing calls for prevailing risk analyses to become more participatory by involving stakeholders at various points or throughout the process (NRC 2009; Renn 2008; Kapuscinski et al. 2007; EPA 1998; USPCC 1997; NRC

1996). These calls stem from normative, substantive, and instrumental rationales. Respectively, these rationales suggest that citizens have a right to participate in decision-making about things that interest or affect them, they have important knowledge and insights that can improve the risk analysis, and broad participation may decrease conflict and ease implementation of resulting decisions (NRC 1996; Fiorino 1990). It is hoped that opening risk analysis to broader participation will encourage societal values and perspectives to be formally considered during the process (NRC 1996). The shift towards greater stakeholder engagement and transparency in formal risk-related decision-making bodies, at least in the US, is a slow process. However, a recent call for recommendations on how to revise US Federal regulatory processes to include greater public participation, transparency, and input from the behavioral sciences could provide impetus for such a shift (OMB 2009).

Risk analysis scholars and practitioners continue to advance new methodologies and tools, in part motivated by the realization that prevailing risk analysis approaches are difficult to apply to many of the more complex stressors entering socio-ecological systems. Such stressors include non-native species that have the potential to establish and become invasive, or nanoparticles with radically new properties when reduced the atomic level (Nel et al. 2006; Kolar and Lodge 2002). Scholars and practitioners are grappling with how to modify current frameworks and methods for characterizing such multi-faceted and mobile stressors and to better represent and treat the uncertainties introduced into assessments from variability (natural variation that can be better represented but not reduced) and incertitude (lack of knowledge that can reduced by gathering more information). New risk analysis frameworks are appearing (Walshe and Burgman 2010; Renn 2008, Morgan 2005; Kolar and Lodge 2002; Groves et al. 2001) and sophisticated mathematical techniques for characterizing and propagating different types of uncertainty—sometimes simultaneously—are being tested (Hayes et al. 2007 and references therein). Advances in scholarship also include testing methods for engaging stakeholders at various stages or throughout formal risk analyses (Dana et al. in review; Carey et al. 2007). These advances are not yet well integrated into the mainstream risk analysis practices of bodies with the authority and responsibility to govern risk.

ALTERNATIVE, PLURALISTIC CONCEPTION OF RISK

Several prominent social scientists criticize the prevailing conceptualization of risk, claiming that it is inappropriate for today's age of sophisticated technological innovation and social complexity (Stirling 2006; Beck 2003, 1992; Fischer 2000; Giddens 1999). Risk is instead *pluralistic*: i.e., a multi-faceted, multi-dimensional, socially-constructed concept whose investigation must also include questions of cultural norms and values, power structures, institutional histories and processes of technological innovation. These scholars outline a number of reasons why predominate risk analysis approaches are difficult or inappropriate to apply to pluralistic risk. Some of these reasons are summarized below:

- *The global-scale* of human activities and technological applications, exhibited by dumping of ballast water by ships from foreign ports, or the addition of nanoparticles to globally distributed electronics, increases the scope of uncertainty involved when trying to predict "unknown unknowns" or understand risk situations whose existence is just being encountered or imagined (Giddens 1999).

- *Long latency periods* for some impacts make it difficult to attribute a "cause" to the activity creating the risk, hampering predictions or assignation of responsibility for risk management. Additionally, these long-term risks often arise through the confluence of many actors' actions.
- *Boundaries of science are collapsing* and science takes place increasingly outside of controlled laboratory conditions and in the real world. Technologies (e.g., genetically modified organisms, nanomaterials) often have to be released into the environment or large infrastructure (e.g., dams, nuclear power plants) built before their long term, large scale risks can be studied (Levidow and Carr, 2007; Beck, cited in Fischer 2000).
- *Increasing multi-dimensionality* of impacts from global scale applications means that risk can materialize across cultural, political, economic and ecological domains.
- *Global interdependence of institutions and blurring of nation-state boundaries* leads to conflicting, divergent political and cultural values in situations involving risk, which in turn increases its pluralism and decreases the availability of univocal solutions (Jasanoff 2005).

EXAMPLES OF PLURALISTIC RISK: EMERGING TECHNOLOGIES

Beck (1992) mentions a number of challenges facing the globe that serve as examples of pluralistic risks: nuclear radiation, emerging technologies, diseases, global warming, and invasive species. These examples exemplify pluralistic risk, as their presence and impacts can range from local to global scales, generate considerable tension and debate by diverse members of society about the level and distribution of risks, and are influenced, enabled, and constrained by a confluence of actors. We describe three emerging (or emergent) technologies that are the topic of our own risk analysis and governance research to illustrate the pluralistic risk: Genetically modified organisms (GMOs), nanotechnology, and synthetic biology (Dana et al in review; Kuzma and Tanji 2010; Kuzma and Beasley 2008; Kapuscinski et al. 2007). These three technologies have recently or are just poised to enter global socio-ecological systems in novel ways with uncertain effects, and they present major challenges in oversight and risk governance. Indeed, Torgersen (2009) suggested that all three exhibit analogous risks, and they have already or will require paradigm shifts in risk governance approaches (Garfinkel et al. 2007; Roco and Bainbridge 2005).

GMOs are created by inserting or deleting genes, either from other organisms or their own genome (NRC 2002). The most widespread GMOs are agricultural crops genetically modified to include genes that either produce toxins detrimental to certain pests or confer resistance to herbicides. Some crops now have “stacked” genes enabling the plant to do both (Castle et al. 2006). Since their introduction in the United States in the early 1990s, GM crops have been adopted by over a dozen countries, and James (2009) estimated that in 2009, 14.0 million farmers were growing GM crops globally. The first generation of GM crops developed traits useful to farmers, and now research is focused on enhancing a second generation of consumer-targeted food qualities, like taste and nutritional value (Marshall 2010). Another area of significant food-related research is GM fish, for increased growth rates and other production traits such as disease resistance (Kapuscinski 2005). Many people anticipate that GMOs will play a significant role in meeting increasing food demand as the world's population continues to rise, and that their development and dissemination will continue to expand globally, particularly in Africa and Asia (James 2009).

Nanotechnology refers to the development and application of materials, devices and systems with fundamentally new properties endowed by the extremely small size of component structures (1-100 nanometers; one nanometer is one-billionth of a meter). Nanomaterials are designed at the molecular level to have novel properties, such as enhanced heat conductivity or strength, which are very different from the bulk forms of the same material (Nel et al. 2006). Thus, they have many promising applications, permeating nearly all sectors and spheres of life: communication, health, labor, mobility, energy, and food (Bhushan 2006). Indeed, nanomaterials are already found in thousands of consumer products around the world (Woodrow Wilson Center 2010).

Synthetic biology is an emerging field of research that combines principles of engineering and information technology to create biological components and systems that do not exist in nature or to re-engineer existing ones from scratch

(Heinemann and Panke 2006; Endy 2005). Whereas previous GMOs were created by starting with an organism's genome and modifying it in various ways, synthetic biology allows the construction of any specific genetic sequence, enabling the synthesis of genes or entire genomes (Garfinkel et al 2007). Synthetic biology allows researchers to build living machines from off-the shelf ingredients, using the same approach that engineers use to make computer chips (Cohen 2008). Potential applications of synthetic, bioengineered organisms include production of pharmaceutical products, breakdown of environmental pollutants, creation of alternative energy sources, and vectors for cancer-fighting drugs (Keasling and Cho 2008; Lee et al. 2008; Ro et al. 2006). Most of these applications are theoretical or in the beginning stages of development, as synthetic biology is a nascent field less than a decade old.

These three technologies exhibit similar multi-dimensional risks in ecological, economic and social domains. Potential threats to ecological systems are difficult to anticipate for all three. The physical and chemical properties of many nanoparticles are not well characterized and few studies exist on their movement in and effects on natural systems (Nowack and Bucheli 2007). Predicting the survival and behavior of GMOs and synthetically created organisms in the environment is complicated by their ability to self replicate and scientists' uncertainty about how gene expression can be altered by environmental factors (Bossdorf et al 2008). Lack of data and associated high levels of uncertainty about the magnitude, duration and consequences of environmental exposure from these technologies and their products decreases the utility of prevailing risk analysis approaches.

From an economic perspective, both technologies require increasingly specialized work forces and may further marginalize already disaffected classes of workers (Foladori and Invernizzi 2008; Thompson 2007). All technologies are touted as a global economic drivers (James 2009; Kay and Shapira 2009; DeFrancesco 2003; Heinemann and Panke 2006), and as such have already (in the case of GMOs) or could potentially change international trade patterns, research and development allocations, and induce creation of new laws, regulations, and financial incentives (Newcomb et al. 2007; Roco and Bainbridge 2005; NRC 2002). The diversity of proposed and current applications of all three technologies, and the difficulty of assigning them to a specific regulatory body, creates confusion over who to task with ensuring their safety (Kuzma 2006; Kuzma et al. 2009; Kuzma & Tanji 2010; Garfinkel et al. 2007). Furthermore, it seems clear that current regulatory practices are not well equipped to consider nebulous and variable social and ethical concerns that flow from their potential socio-ecological effects (Schmidt 2009; Kuzma and Besley 2008; Thompson 2007).

REFLEXIVE RISK GOVERANCE

We agree with the usefulness of a pluralistic conception of risk and draw upon the concept of reflexivity articulated by European scholars (Voß et al. 2006a; Wynne 1993) to inform a new reflexive approach to risk governance. *Reflexive risk* *governance* is based on the recognition that institutional constraints, relationships between actors, the type of epistemologies applied, and public perceptions all recursively shape how the risks of a particular activity or technology are conceptualized and governed. Such an approach recognizes systemic relationships and interdependencies inherent in complex risk situations, that traditional disciplinary knowledge alone is insufficient to solve such problems, uncertainty precludes the use of linear cause and effect models, and unforeseen changes in societal norms and institutions influence what is considered risky. It attempts to incorporate uncertainty, heterogeneity, unintended consequences, error and lack of control in the evaluation and handling of risk. Reflexivity requires attention not only to how the activity or technology being investigated appears or is represented to the actors undertaking the investigation, but also to how the actors' attributes help condition the activity or technology's representation, and then how those representations can then recondition actors (Voß et al. 2006a). Such attributes might include worldviews, preferred ways of knowing, institutional processes, or cultural norms. This is a recursive loop. A reflexive approach would include recognition of the possibility that governance approaches undermine themselves, by causing changes in the world that then affect their own working (Voß et al. 2006a). Interestingly, such a reflexive approach is also consistent with a systems thinking and resilience thinking approach to addressing complex society-environment problems (Meadows 2008; Walker and Salt 2006).

A reflexive approach to risk governance is not only different from the prevailing, unreflective approach to risk, but it also goes beyond a more reflective approach that some of the newer risk analysis models espouse (e.g., NRC 2009) (Figure 3-1). An *unreflective* approach generally identifies and evaluates the most obvious attributes of the technology and its direct impacts, with human, economic and environmental health the most common foci. A *reflective* approach takes a step forward by broadening the scope of analyses to examine the full range of attributes of and all possible consequences (or so-called "externalities") from the stressor or technology. However, it still falls short of our conception of a reflexive approach because it does not promote consideration of how societal forces recursively shape the concept of risk nor does it promote challenges to normative assumptions (e.g., questioning the fundamental premises of technological innovation as societal progress).

Reflexive risk governance is fundamentally a *participatory endeavor* and is grounded in deliberative democratic ideals (Benhabib 2006), meaning that citizens have the right to freely and equally participate in challenging of normative presuppositions underpinning risk analysis, technological progress, calculations of risk and uncertainty, and the role of science and scientists in society. Diverse participation and deliberation is necessary to expose and consider uncertainty, interconnectedness of socio-ecological systems, and diverse values and worldviews. A reflexive approach requires a level of societal deliberation and broadening of scope (or an "opening-up"—Stirling 2008) that is fundamentally different from the focus on the need for risk analysis processes to include stakeholders. In the latter, policy-makers and the risk analysis community typically view increased participation as occurring inside structured, linear (but iterative) analysis frameworks (NRC 2009; NRC 1996), instead of viewing participation as necessary for challenging dominant paradigms, building adaptive communities (Walker and Salt 2006; Norgaard 1994), and increasing capacities for agency by a broader spectrum of society.

FROM UNREFLECTIVE TO REFLEXIVE RISK GOVERANCE: GMO MONITORING IN SOUTH AFRICA

We encountered examples of both unreflective and reflective risk governance during our work on environmental risk analysis (ERA) of genetically modified organisms (GMOs) in South Africa in 2008. Our description below of the South African situation illustrates and contrasts the two approaches to risk governance, and the lessons we learned inform suggestions on what a reflexive approach might look like in real life (Figure 3-1).

South Africa's GMO regulatory system was developed in the 1990s with heavy involvement of scientists in response to requests for importation of GM seeds and field trials of transgenic crops developed by South African scientists (Dana, unpublished data[9]). The National GMO Act of 1997 mandates the development of safety measures for humans, animals and the environment, and the establishment of acceptable standards for biotechnology risk assessment, all coordinated by the national Department of Agriculture (NDA) (Republic of South Africa 1997). A scientific advisory panel evaluates risk assessment information provided by biotechnology companies (which is often confidential or incomplete because of proprietary business information) as part of their application for

[9] Interviews with Participants T and V.

glasshouse experiments, field trials, or commercial release of GMOs (primarily GM crops). Interviews with scientists involved in evaluating such information suggest that a small set of environmental and human health impacts is considered, and information is often based on desktop studies or experiments outside South Africa (Dana, unpublished data). The GMO Act does not set standards for ecological or socio-economic risk assessments, and it appears that the lack of such standards leaves assessment contents at the discretion of the applicant (Jaffe 2008).

Applicants are required to publish a notice of their application and the public is given 30 days to submit comments. However, any commenter who wants to see non-confidential portions of the application before making comments must formally request that information under the public information law. The Executive Council (comprised of eight representatives from government agencies and research units, the chair of the scientific advisory panel, and the GMO registrar who administers the Act) considers the scientific advisory panel's recommendations, along with other relevant political and social issues, and makes a consensual decision about the GMO application (USDA FAS 2006). A notice of this decision is posted on the Council's website, but little other information regarding the reasoning behind the decision is available to the public (Jaffe 2008). In cases where the Executive Council rejects the application, as in the case of nutrient-enhanced GM sorghum for glasshouse trials, the applicant has the opportunity to appeal the decision (Venter 2008).

This risk governance system is unreflective primarily because of decision-makers' reliance on scientific information about a small subset of risks of GMOs, and the fact that this information is generated without the input of non-industry scientists or other interested and affected parties (i.e., stakeholders). Public participation and opportunities for critical questioning of the purpose and compatibility of GM crops with South African values has been minimal. Technology promoters justify this non-participatory approach by pointing out that South Africans in general have limited interest in or capacity to evaluate technological innovations such as GMOs, and that the need to increase agricultural production (with GM crops) in a food-strapped continent is obviously of paramount importance (Bafana 2009). Alternative opinions about the utility and appropriateness of GM crops are typically expressed by non-governmental organizations (NGOs), and over time an adversarial, rather than constructive, relationship has developed between such groups, the biotechnology industry and government departments (Humby 2010).

An opportunity for moving towards a reflective approach emerged after the passage of the National Biodiversity Act in 2004, which mandated that the South African National Biodiversity Institute (SANBI) develop a monitoring program for impacts of GMOs on the nation's biodiversity (Republic of South Africa, 2004). Monitoring helps GMO risk governance be more reflective by identifying how the system changes in response to the technology, which in turn allows adaptation by users, developers, scholars and policy makers (Kapuscinski 2002; NRC 2001; CBD 2000). SANBI and the lead author implemented a participatory ERA process to determine the most likely and consequential interactions between GM maize and biodiversity, thereby generating information useful for informing the focus of the biodiversity monitoring program. Twenty-two diverse stakeholders, including environmental NGOs, biotechnology developers, policy makers, nature conservationists and agricultural extension officers, engaged in analysis and deliberation about diverse types of knowledge (experiential and scientific) and perspectives (pro- and anti-GMO) while evaluating interactions in a complex agro-ecological system.

This participatory process moved risk governance to a reflective level by broadening participation, incorporating different types of knowledge and worldviews, and evaluating potential risks on a much broader scale than in previous risk assessments. One participant noted after the workshop that: "The info from the [NDA risk assessment] dossiers in terms of the general interactions, on a scale of 1 to 10, would be zero, compared to the level of interaction that we were discussing [at the workshop]" (Dana, unpublished data). The mandate's focus on impacts to biodiversity from GMOs prevented participants from identifying and comparing non-GM alternatives to increasing agricultural production and pest reduction, or evaluating the technology's socio-economic impacts. However, workshop participants evaluated impacts of the technology at multiple ecological levels and as it moves through agro-ecosystem food webs. This level of analysis represents a substantial move towards a reflective approach and away from the current unreflective one, in which biological scientists spanning a narrow range of knowledge systems look at immediately obvious interactions.

Moving towards a *reflexive* risk governance approach would require the development of venues and opportunities for genuine learning about and challenging of the normative assumptions underlying the introduction of GMOs and GM crops (e.g., that biotechnology is essential for increasing food production) by potentially affected and interested people from diverse sectors of society. Such activities would not constitute risk assessments per se, but a larger societal deliberation about the value of the technology and the role it could (or should) play in people's lives. The legitimacy of these deliberations would be enhanced if results are incorporated into the deliberations of current governance authorities (typically government agencies), the biotechnology industry, and the scientific community. This shift would be a major challenge given the prevailing institutional reliance on scientific inputs and isolated review and decision-making processes.

A reflexive approach would draw on results from the biodiversity monitoring program, and include diverse stakeholders (ideally those involved in the participatory ERA process) in the evaluation of observed changes and the design of adaptive or corrective measures. Agricultural systems change in response to economic conditions, climate variation, technological innovation and regulatory requirements, and the use of GM crops and their impacts on biodiversity need to be evaluated in the current socio-ecological context. Such evaluations would require sustained stewardship of diverse learning communities and repeated, long-term engagement opportunities. We believe that South Africa has great potential indeed for moving towards a reflexive approach to risk governance, as their citizens have undertaken other brave and groundbreaking national deliberations about social, political, economic and international governance during the country's transition from apartheid (Kahane 2004).

ELEMENTS OF A REFLEXIVE RISK GOVERANCE APPROACH

A reflexive approach to risk governance is a specific way of framing the problem of risk that emphasizes the interconnectedness of socio-ecological systems across spatial and temporal scales, as well as the longer term and unintended effects of risk governance actions. Reflexive risk governance endeavors should be implemented around five fundamental elements described below (adapted from Voß et al. 2006a) (Table 3-1).

- *Element 1: A systemic evaluation process*—a diversity of knowledge types is necessary to create a holistic picture of complex and interconnected socio-ecological systems in which risks propagate, and for understanding how seemingly minor decisions (including governance choices) can trigger indirect effects in the long-term.

  Example: One way to begin systemic evaluation is through conceptual mapping, which we used as the beginning exercise in our participatory ERA workshop in South Africa. Participants created conceptual maps of the agro-ecological system, depicting interconnections and relationships between social, economic, biological and cultural components. The group then used their understanding of the system to identify hundreds of interactions between the GM maize and the different components of biodiversity, and to evaluate how those interactions could have consequences at multiple ecological levels (Dana et al in review).

- *Element 2: Integrated, transdisciplinary knowledge production*—the involvement of different disciplines and members of society is necessary for investigating the heterogeneity and interconnectedness of system elements. Experiential knowledge gained through on-the-ground practice complements that produced via scientific methods of analysis and helps move knowledge production beyond disciplinary silos, to take a more holistic approach and ground it in real-world situations (Wickson et al. 2006; Berkes et al. 2000). *Example*: We made a small step in the direction of transdisciplinarity in the ERA workshop by having a mixture of participants from different disciplinary backgrounds (e.g., molecular biologists, ecologists, zoologists, economists) and professional affiliations (agricultural extension, biotechnology industry, policy, nature conservation) construct and evaluate the agro-ecological system. They also each brought worldviews and perspectives about GM crops, ranging from strong opposition to them because of their desire to preserve the genetic integrity of natural systems to vehement support for their potential lifesaving food production increases. The exchange of different types of knowledge, epistemologies, and worldviews definitely created an interdisciplinary knowledge base, and took steps toward situating that knowledge within larger societal concerns as required for transdisciplinarity.

- *Element 3: Iterative, participatory problem formulation*—diverse participants should help define the societal and ecological context in which risk is manifested, how such risks relate to other pressing problems, and how their values and worldviews inform their perceptions of and choices between risks. Such a deliberation can help define what risk-related problem is most important to investigate and how this investigation should proceed (Nelson et al. 2009). Human activities and attendant risks change over time and impact groups of society differently, with some problems or risks becoming less important over time (particularly if they are being managed successfully). *Example*: The ERA workshop fell short on participatory problem formulation, as SANBI's mandate defined the problem as identifying impacts on biodiversity and there were no opportunities for deliberation about whether GM crops would solve a pressing societal problem. Furthermore, SANBI did not engage with stakeholders when deciding that an ERA approach was the best way to structure the analysis of the myriad interactions between GM maize and biodiversity. Their lack of involvement at the outset may have contributed to several participants' displeasure with the process, as they felt that an ERA process was not useful for helping develop a monitoring program. They thought that SANBI should instead choose a relevant set of indicator species with the scientific community's help, monitor those for impacts from GM maize, and then extrapolate results to the broader ecological system. Incorporating more participation during the problem formulation process might have helped SANBI determine if an ERA was the most acceptable approach and allowed divergent opinions to be voiced and incorporated during this decision. Perhaps a diverse group of stakeholders could have convened to deliberate about the most appropriate indicator species (in lieu of an ERA), or to identify indicator species representative of the biodiversity components that the ERA process identified as at most risk from GM maize.

- *Element 4: Adaptive strategies and institutions*—because of the inherent uncertainty in socio-ecological system interactions, it is important to be able to make errors and learn from unexpected effects. Cognitive, institutional, methodological and technological structures should be designed with the flexibility to incorporate the results of experiments, monitoring and evaluation, as well as altered risk perceptions and changing societal conditions.

  Example: Workshop participants could help contextualize emerging findings from the monitoring program with their academic, institutional, and experiential knowledge and help determine whether the results were of concern, at which domain and to which groups of society. Governance approaches could be modified in light of new information and stakeholders could help their respective institutions evaluate their own activities in light of these changes. Indeed, two participants indicated in post-workshop interviews that they planned to introduce some methods from the ERA workshop into their GM crop risk assessment processes, indicating some adaptation in institutional processes was already being considered as a direct result of their participation.

- *Element 5: Interactive processes of strategy development*—risk governance situations contain many different actors with various desires, levels of control and institutional arrangements. Even within agencies formally tasked with oversight of risks, tasks are often distributed between committees, advisory panels and scientific teams, each with different mandates, power, interests and resources. A reflexive approach to risk governance requires coordination between different actors as they develop strategies, as well as attention to periodic review and adaption of such strategies in response to changing risk situations.

  Example: The final exercise in the ERA workshop asked participants to depict their ideal biodiversity monitoring program, and several emphasized connections between different policy and regulatory agencies and scientific research organizations (Figure 3-2). These graphics began to elucidate the interconnectedness of diverse actors whose support and resources may need to align in order to implement a monitoring program at different temporal, geographic and ecological scales. Additionally, many participants were themselves part of institutions or communities that could provide useful information or help carry out research and monitoring of GMOs or conduct future ERAs. They also belonged to communities that may need to adapt their regulatory guidelines, scientific research agendas or farming practices in light of monitoring program results. Convening stakeholders and beginning to build a diverse community familiar GMOs was an important step in identifying key actors, building relationships, understanding legislative responsibilities and determining resource levels that will impact monitoring and risk governance strategies.

SOCIAL LEARNING FOR REFLEXIVITY

Social learning is the means by which to operationalize the elements of reflexivity, which at their core require diverse participants to learn new information, perspectives, worldviews and pedagogical approaches. The concept of social learning describes a process whereby actors engage democratically in constructive, extended communication, learn about each others' perspectives and knowledge, think systemically and build a foundation for joint action (Schusler et al. 2003). This concept is increasingly being studied in collaborative approaches for natural resource management (Dana and Nelson in prep; Brummel et al. in press; Steyaert and Jiggins 2007; Mostert et al. 2007; Rist et al. 2006), where the main challenge to managing socio-ecological systems is less about finding an optimal solution and more about ongoing learning and adaptation by communities (Tompkins and Adger 2004; Campbell et al. 2001). Developing flexible and adaptive communities capable of undertaking the challenge of reflexive risk governance requires that diverse actors be able to effectively deliberate, negotiate and make decisions together. Social learning processes facilitate such communicative actions (Bouwen and Taillieu 2004).

Social learning processes and outcomes

Social learning has to be carefully fostered. Muro and Jeffrey (2008) point out that it is not normal in complex, contentious situations where risks manifest, and engendering it requires attention to the *components* and *attributes* of the participatory process (Rowe and Frewer 2000; Renn et al. 1995). In our ERA process, we paid explicit attention to the following three *components*: 1) quality of facilitation, 2) diversity of participants, and 3) democratic nature of the process (Figure 3-3). First, we hired a scientifically literate, neutral facilitator with over 20 years of experience in natural resource management and conflict resolution. Second, we identified a mixture of participants who were either interested in or potentially affected by the GMO monitoring program or represented the range of expertise necessary to evaluate a complex agro-ecological system. This also contributed to the workshop's democratic nature by ensuring representation of different societal groups. We also tried to increase democratic structure by including exercises (e.g., conceptual mapping of the agro-ecosystem) able to capture everyone's knowledge and by carefully facilitating space for everyone to make a contribution and for it to be included in the ERA process.

Attention to these three components contributed to ERA process *attributes* important for social learning, including open communication between participants, constructive conflict when challenging information and perspectives, and extended engagement outside of formal workshop activities (Dana and Nelson in prep). Participants noted in post-workshop interviews that they felt free to question information being presented, that others listened respectfully, and that they valued the many opportunities to approach other participants during tea and meal times to follow up on or learn additional insights (Dana and Nelson in prep). Such attributes are important for building the group's knowledge, setting the tone of ongoing communication, and helping foster relationships, trust and respect between participants (Mostert et al. 2007).

Attention to process components and attributes helps foster social learning *outcomes*, which fundamentally underpin reflexive risk governance (Figure 3-4). These outcomes occur over different time horizons, with change first occurring at the individual stakeholder level, then at the actor-network level, and finally within governance structures (Pahl-Wostl et al. 2007). We examine below five social learning outcomes that span the different time horizons to better understand how they underpin elements of reflexivity.

1. *Knowledge of diverse perspectives and worldviews*—is essential when amalgamating disciplines and for grounding investigations in real world risk problems (i.e., achieving transdisciplinarity) (*Element 2*). Participatory problem formulation (*Element 3*) requires knowledge of diverse perspectives and worldviews, as does the evaluation of systemic interactions and feedback loops in socio-ecological systems (*Element 1*).
2. *Ability to think systemically*—is necessary before one can recognize long-term system effects (*Element 1*). Understanding the world as comprised of systems that constantly co-occur and co-evolve with one another (Norgaard 1994) is fundamental to evaluating how stressors travel and cause undesired effects at multiple domains. Changes in system components may not be obviously

linked to a particular stressor, and the ability to envision the world as interconnected systems can help one trace back and identify the initiating event. Systemic thinking skills are also important for evaluating how adaptive actions by strategies and institutions (*Element 4*) influence other social and ecological components.

3. *New learning skills*—are required in order to recognize and evaluate underlying norms and worldviews that drive institutional actions and shape conceptions and governance of risk. These evaluative skills are useful in systemic evaluations (which are uncommon in risk analyses) (*Element 1*), transdisciplinary knowledge production (the scientific method may not be the only or best way to study the world) (*Element 2*), and problem formulation (technological innovation may not mean societal progress) (*Element 3*). What is needed is a move from single-loop learning, which is the most common, to double- and triple-loop learning. Single-loop learning takes place when outcomes of decision-making and collaborative actions are evaluated terms of how well they contributed to realizing normative goals and expectations (Pahl-Wostl et al. 2007). Double-loop learning happens when actors begin to change their assumptions on which such actions and goals are based. This kind of learning will require non-traditional pedagogical training, the depth of which can be enhanced by further recognizing the dominant assumptions underlying prevailing analytic and decision-making processes. Such recognition occurs through triple-loop learning (which is very difficult to achieve), where learners start to reflect and act upon conditions that structure

interaction patterns in single- and double-loop learning (Maarleveld and Dangbegnon 1999).

4. *Shared understanding of a problem or goal*—helps generate cohesion around and ownership of the final product, whether it be a risk management plan, the definition of the problem (*Element 3*) or a risk governance strategy (*Element 4*). A sense of shared purpose can also assist in building a community with shared norms and practices, which can operate more effectively than multiple individuals on their own (Wenger 2003). Such communities generate social capital--networks, norms, and social trust--that facilitates coordination and cooperation for mutual benefit (Pahl-Wostl et al. 2007). Such networks and trust may aid the process of interactive strategy development (*Element 5*).
5. *Community of practice*—is where groups of people who share a concern or a passion for something learn how to do it better as they interact regularly (Wenger 2003). Groups develop shared repertoires of resources, practices and norms over time and through sustained interaction, and an entity develops that is separate from the individuals who comprise it. Such communities can be the actual adaptive institution listed in *Element 4,* and can serve as a social forum for transdisciplinary knowledge generation (*Element 2*), iterative problem formulation processes (*Element 3*) and interactive risk governance strategy development (*Elements 5*).

Structuring adult learning activities

Adult education (i.e., andragogy) and collaborative learning scholars note that the structure of learning activities influences the quality of learning (Ardnt 2006; Daniels and Walker 2001; Kolb 1984). For example, repeated, action-oriented learning activities, followed by opportunities for reflection, help participants integrate new information and concepts into existing mental models and "ground-truth" them against their conceptions of the world (Kolb 1984). Social learning processes aim to be experiential, i.e., grounding learning in participants' real-world experiences while affecting change in their beliefs and understanding of how the world works (Daniels and Walker 2001). To facilitate experiential learning, we designed our ERA process to include individual and group activities, hands-on written and graphic exercises, with periodic pauses for participants to reflect with the group on recent insights. Additionally, participants completed a learning evaluation worksheet at the end of each day, a task designed to prompt further reflection on newly learned concepts or perspectives (Dana and Nelson in prep).

Convening groups of participants who have different learning styles can improve the group's learning by bringing different skill sets, interaction styles, and mental models into contact with each other. Scholars identify four distinct learning styles: some learners are creative and grounded in feelings and values, while others take charge by making goals and setting criteria, others classify and order information, and finally others want to identify and implement solutions (summarized in Daniels and Walker 2001; see Garner 2000 for a critique). A mixture of the four kinds can contribute to more efficacious solutions, as different problem-solving stages can benefit from different approaches to information gathering, analysis and decision-making. We evaluated each participant's learning style before the ERA workshop using the Kolb Learning Style Inventory online questionnaire (Hay Group 2010) and found that participants were split almost evenly between two learning types: assimilating or converging. This information made us aware that participants' strengths lay mainly in organizing and understanding wide-ranging information and finding practical uses for ideas and theories, not in generating ideas with other people or hands-on experimentation with different ideas (Dana, unpublished data)[10]. We did not, however, further evaluate how group composition influenced the group's overall learning experience or the quality of ERA products.

CONCLUSION

The concept of reflexive risk governance is based on an understanding of risk as a pluralistic concept recursively shaped by institutional structures, societal values, and risk governance measures. Prevailing science-based analyses are no longer sufficient for informing risk governance strategies for many of today's complex risks. Identifying, evaluating, and managing risks of, for example, emerging technologies, requires crossing boundaries, engaging with diverse perspectives and types of knowledge, embracing uncertainty, and fashioning flexible, adaptive institutional arrangements. These actions require participatory and

[10] Appendices VI and VII contain the learning style questionnaire and description of Kolb's four learning styles.

transdisciplinary processes designed specifically to foster social learning by diverse actors, where participants have the space and guidance to articulate their values, challenge normative assumptions, and begin working towards integrative, adaptive risk governance strategies.

Operationalizing a concept as complex and lofty as reflexive risk governance will most likely be achieved through incremental changes in worldviews, institutional arrangements, policies and methodologies. Affecting movement of the scientific and policy community away from prevailing conceptions of risk toward a more socially-negotiated concept will require continued modification, integration and testing of risk governance frameworks, processes and tools. Efforts by scholars such as Renn and Walker (2008), who are testing a new, comprehensive, participatory risk governance framework for systemic risks, are just as important as those testing specific tools such as scenario planning for nanotechnology applications (Weik et al. 2009). Reflexive governance itself is an emerging concept that will be shaped by many actors, and we do not want to be prescriptive about what exactly it encompasses or how to achieve it. Instead, we outline some central elements we think genuine reflexive processes should aim to incorporate, and propose that sustained attention to fostering learning by diverse groups of actors is a key mechanism by which incremental changes can build and meld into a genuine reflexive approach.

We acknowledge that there are a variety of different participatory tools and strategies that either already do foster social learning or can be adapted for this explicit task. Such methods include Problem Formulation and Options

Assessment (PFOA) (Nelson et al. 2009), comprehensive environmental assessment (CEA) (Davis 2007), and real-time technology assessment (Guston and Sarewitz 2002). We believe that these methods can provide venues important for moving towards an explicitly reflexive approach to risk governance, but recommend that any method's utility should be evaluated based on the context of the risk situation. Each human activity or technological development has a different set of risks, which materialize differently in societies at specific points in their history. For example, levels of support for diverse participation in risk-related policy discourses may differ between Europe, the United States and developing nations. Successful facilitation methods may differ depending on the nature of the participants, technical complexity of the topic being discussed, cultural norms and the history of interaction between participants. Political situations, cultural differences, the stage of a country's development, and corresponding critical societal problems require adapting social learning processes (and evaluations of reflexivity) to local situations.

We want to emphasize that reflexive risk governance approaches do not have to exclude quantitative, predictive risk analysis methods. Such traditional approaches are embedded in important institutions, have shaped technology development and governance for decades, and have historical significance and stature in important communities of actors. These approaches have legitimacy in the eyes of many, and a reflexive risk governance approach would be unwise to ignore or discard them. Such analyses produce useful information, particularly when a technology has reached a more advanced stage where its properties, pathways of movement, and possible consequences are better understood. However, even in situations characterized by relatively good information, societal debate about the meaning of the results and how to contextualize them with other considerations is critical. The challenge is then to examine the degree to which traditional risk analysis results are sensitive to different framing conditions and assumptions, and not to privilege scientific modes of inquiry during such an examination (Stirling 2008).

Although recognizing and designing for social learning offers a way to take tangible steps toward reflexivity, one must be careful not to assume that achieving social learning outcomes automatically means that one has also achieved reflexivity. For example, we achieved a variety of social learning outcomes in the participatory ERA process (e.g., participants learned new information, diverse knowledge and perspectives, began thinking systemically, and altered their impressions of other participants) (Dana and Nelson in prep), but fell far short of true reflexivity. Reflexive risk governance will require long term, sustained engagement and reorientation of risk-related discourses to include fundamental questioning of normative assumptions of the objectivity of scientific methods and what constitutes societal progress. Even achieving more challenging, long-term social learning outcomes, such as changes in environmental policies or condition, or formation of adaptive communities, does not necessarily mean that a pluralistic vision of risk has been adopted and that institutional structures and procedures have changed.

Table 3-1. Reflexive risk governance elements that reflexively oriented risk governance endeavors should be implemented around. Adapted from (Voß et al. 2006).

Reflexive Risk Governance Element	**Definition**	**Description**
1	Systemic approach to evaluation	Use a diversity of knowledge types to create a holistic picture of complex, interconnected socio-ecological systems pervasive in risk situations.
2	Integrated, transdisciplinary knowledge production	Involve different disciplines and members of society to investigate the heterogeneity of system elements, combining a variety of knowledge types and grounding emerging concepts in real world context.
3	Iterative, participatory problem formulation	Involve diverse participants in defining and periodically re-visiting the socio-ecological risk context, how the risk relates to other problems, which ones are most pressing to investigate and how such an investigation should proceed.
4	Adaptive strategies and institutions	Cognitive, institutional, methodological and technological structures should be designed to be able to adapt to new insights from experiments, evaluations and monitoring.
5	Interactive process of strategy development	Diverse actors with different desires, interests, authority and control over resources should coordinate to develop strategies and respond to new insights from risk governance activities.

Figure 3-1a. An *unreflective* approach to risk governance: One main actor (e.g., the competent regulatory agency) focuses only on the most obvious attributes of the object (e.g., insecticidal properties of genetically modified maize). Adapted from (Stirling 2006).

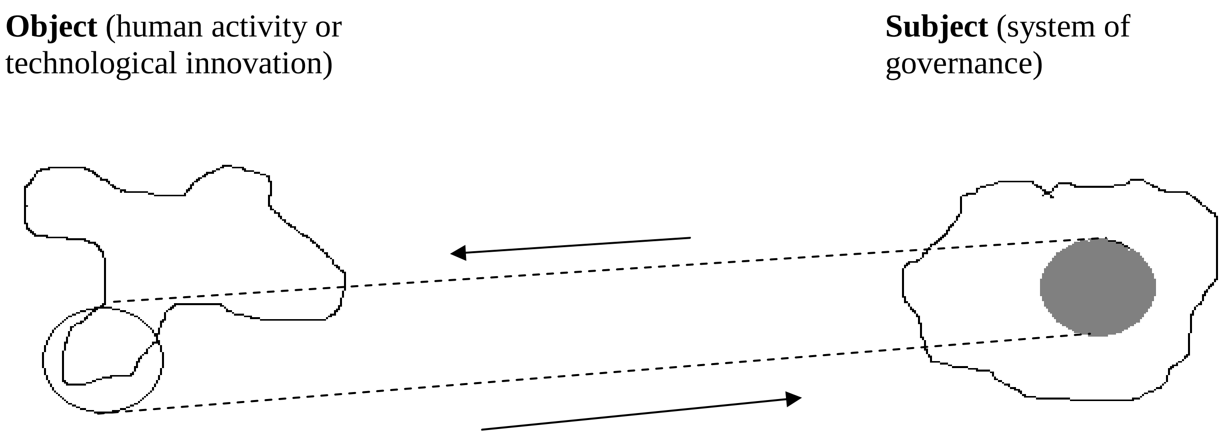


Figure 3-1b. A *reflective* approach to risk governance: Multiple actors (e.g., diverse stakeholders) evaluate the full range of attributes and all possible consequences of the object (e.g., socio-economic impacts, ecological impacts at multiple scales of genetically modified maize). A reflective evaluation could also include identification of the most pressing societal problem and a range of alternative objects that could also address the problem (Nelson et al. 2009). Adapted from Stirling (2006).

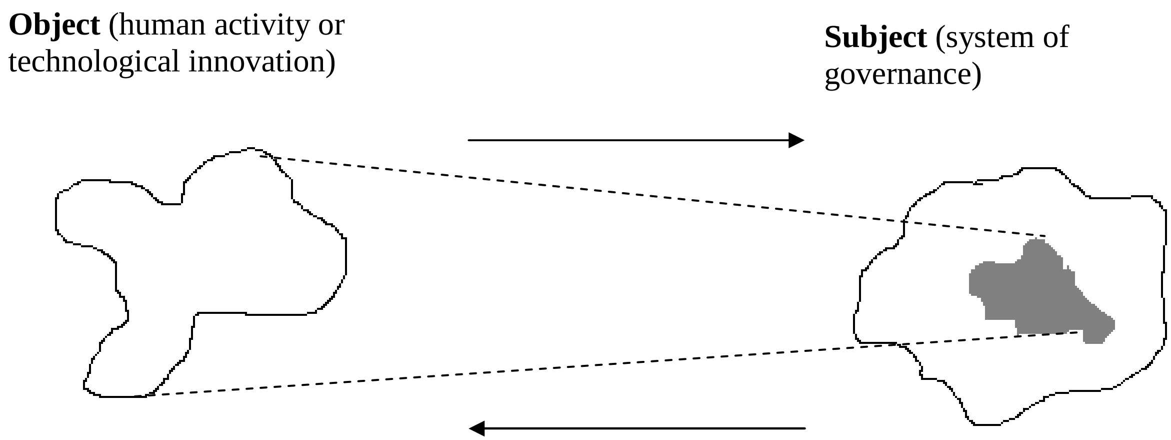


Figure 3-1c. A *reflexive* approach to risk governance. Attention is shifted to also include the attributes of the actors conducting the evaluation (e.g., the regulatory authority's prevailing approach to risk assessment; the worldviews of environmental groups). The subject itself forms a large part of the object (e.g., a regulatory body's tradition of cursorily evaluating ecological risk means that genetically modified maize did not undergo field trials in a range of geographic or temporal situations). A reflexive approach would appreciate the way in which representations of the purposes, conditions, or consequences associated with the use of GM crops are socially contingent, meaning the manner in which they are developed and deployed is influenced by a variety of actors with different power, resources, institutional procedures, cultural norms, and worldviews. Adapted from Stirling (2006).

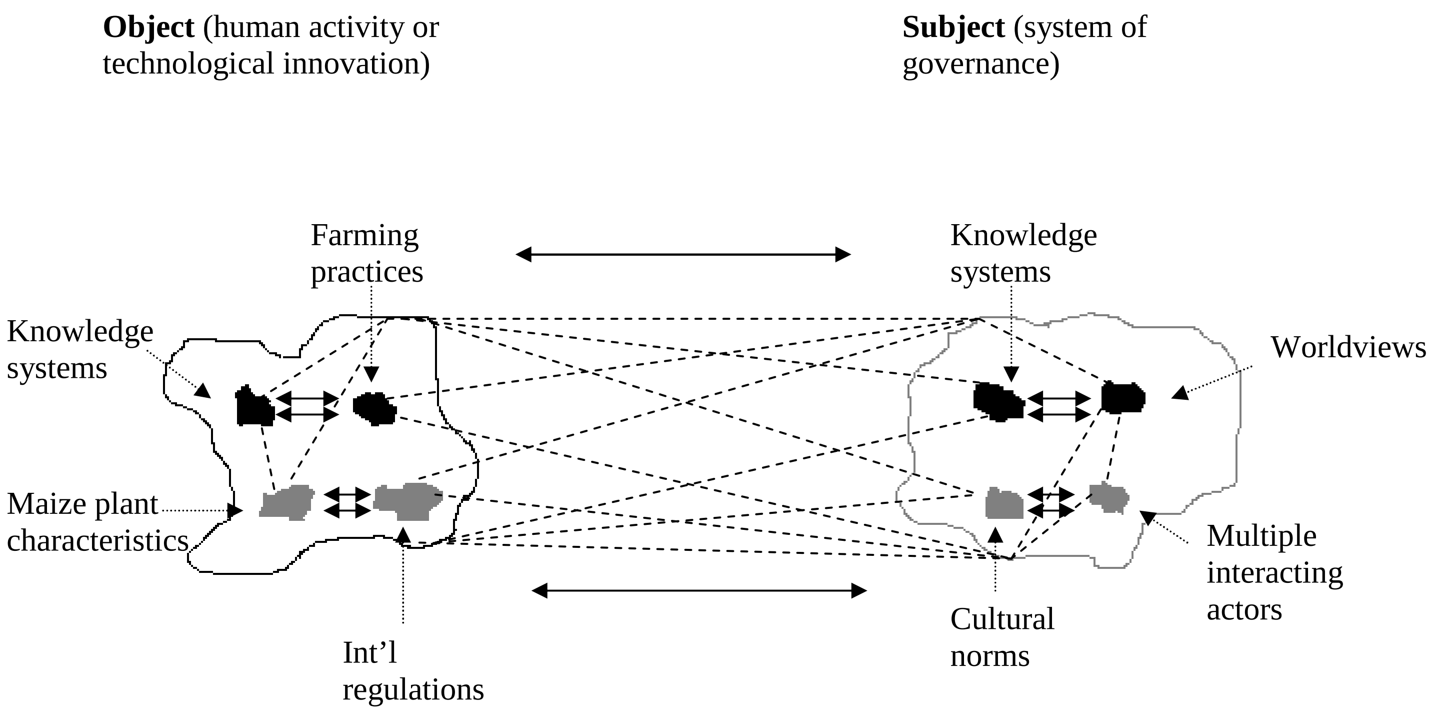


Figure 3-2. Example mind map for systemic thinking about institutional relationships necessary for a reflexive GM crop and biodiversity monitoring program. Such conceptual maps are tangible evidence of the social learning outcome “systemic thinking”. This outcome is fundamental to many reflexive risk governance activities, with this example showing the beginnings of interactive strategy development for monitoring program design**.**

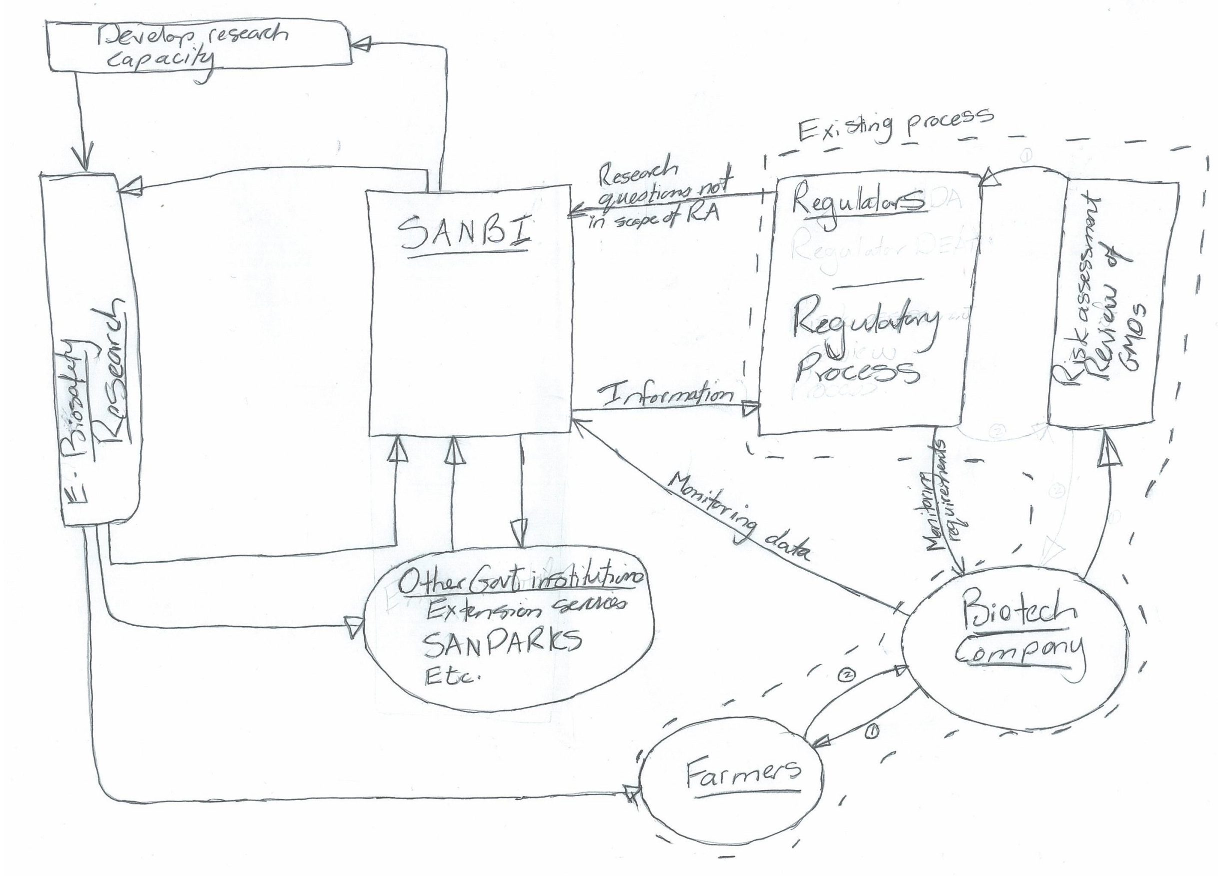


Figure 3-3. Social learning process components, resulting attributes and potential outcomes (Dana and Nelson in prep).

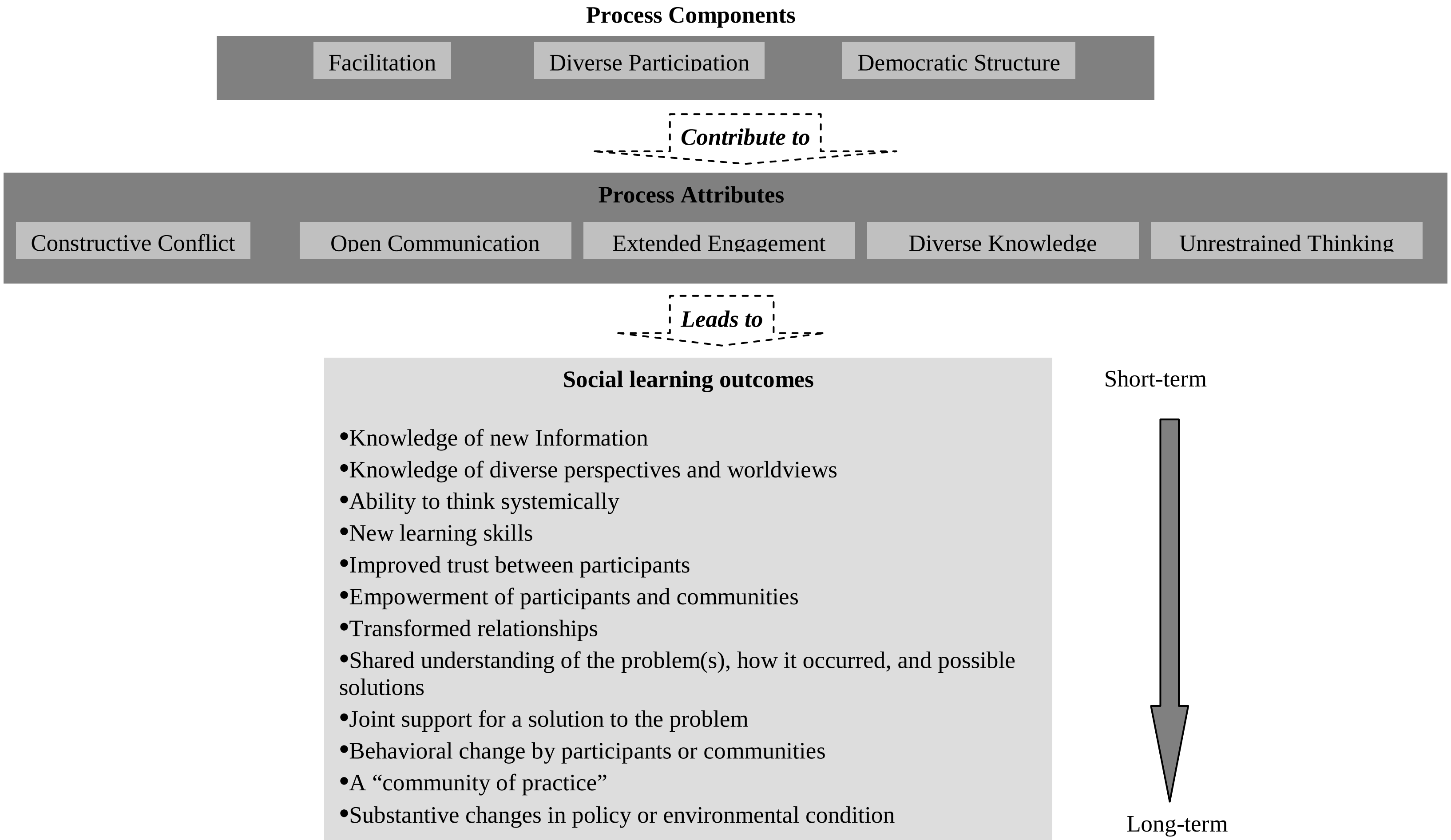
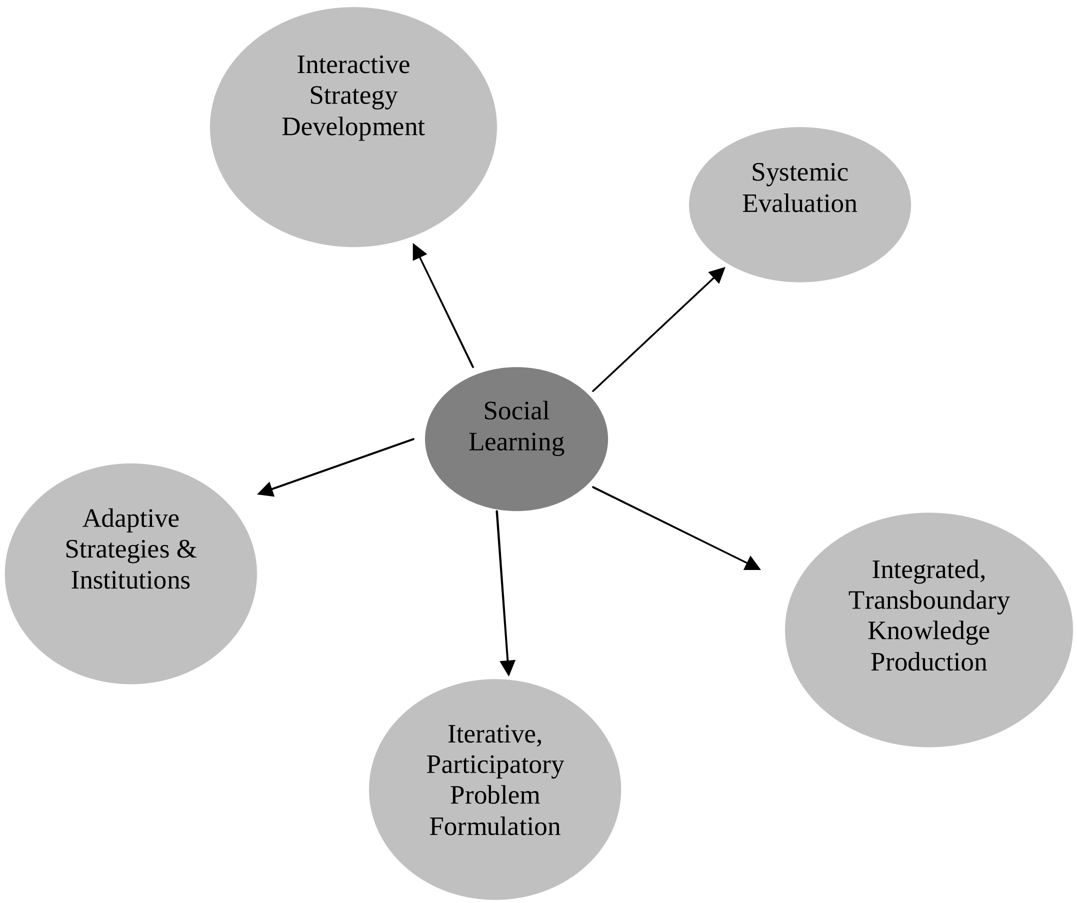


Figure 3-4. Social learning and reflexive risk governance elements.



Conclusion to the dissertation

My dissertation research provides evidence that it is possible to involve diverse stakeholders in an ecological risk assessment and that their involvement can produce more valuable risk-related information than a small group of experts. Future participatory ERAs may benefit from an iterative process between hazard identification and prioritization and a more expert-driven quantitative evaluation of the likelihood and consequence of priority hazards (Chapter 1; Figure 1-1). My results also suggest that it is possible to design participatory ERAs with important components and attributes for social learning, and short-term social learning outcomes are possible, but that longer-term outcomes important for developing jointly supported risk management solutions require more sustained engagement (Chapter 2). I conclude with a call to recognize the fundamental role of social learning in attempts to move risk analysis and governance toward a more participatory and reflexive bent (Chapter 3; Figure 3-1).

There are several cautionary areas to be aware of when interpreting the results of the dissertation, starting with Chapter 1. In this chapter, a much more diverse group of stakeholders participated than is normally included in an ERA of biotechnology. However, all participants were well-educated, many with scientific and technical training, and other stakeholder groups with less formal scientific training or English language skills were not included. This deficiency was part of the motivation for recommending that knowledge and perspectives of some stakeholder groups be gathered in a more culturally appropriate manner and then incorporated into the ERA via trusted representatives (Chapter 1). We also were constrained from evaluating humans as part of biodiversity by SANBI's mandate, which some might view as an important exclusion in a biodiversity ERA. An evaluative framework of components, attributes and outcomes was used to structure the analysis of surveys, daily evaluation worksheets and interviews. During coding, I made choices about how to interpret and categorize participants' responses, which might not always exactly align with the exact meaning given by the participant. This realization motivated me to have another social learning scholar external to the project check intent of my coding, but a complete side-by-side comparison for each piece of data was not done, nor did I have the opportunity to confirm the assignation of codes with participants.

Most risk analyses currently conducted by competent authorities to inform decisions about human and environmental health are generally unreflective, in that a small set of experts typically evaluate the most obvious attributes of a stressor. The research I conducted in South Africa examined how to take early steps in a more reflective approach to ERA, in that diverse stakeholders were involved in evaluating a range of effects from GM maize across ecological levels. My findings add to the growing sophistication of ERA; other advances in the field include new or improved methods for handling complex evaluations of system dynamics and different types of uncertainty. This breadth of scholarship provides tools and guidance to help competent authorities take a more reflective approach as well. I proposed, in my final chapter, that moving toward a reflective approach is not sufficient for handling today's complex risks. Indeed, the governance of risk must become more reflexive, allowing the consideration of fundamental questions about normative assumptions underpinning technological innovation and human development, how values and norms shape the development of stressors, and how the wide variety of actors (including risk analysts) recursively shape the understanding and treatment of risk. This ambitious proposal requires additional scholarship and the space to fundamentally rethink the presuppositions on which human development is based (Norgaard 1994).

My research findings represent another tool in Conservation Biology's toolbox of methods for addressing pressing problems of conserving biological diversity. Participatory endeavors have gained in popularity and utility in conservation efforts, as practitioners aim to improve the social and biological relevancy of their measures. Ecological risk analysis is another method to support such conservation efforts, and the finding that it too can be done successfully, and with better results, in a participatory manner may increase its relevancy and efficacy for addressing today's conservation problems. My research represents an in-depth case study of a participatory ERA, and the process and results need to be repeated in other contexts and with other technologies or stressors. However, the finding that 22 diverse participants were able to navigate a structured analysis and learn about a controversial technology in a complex, data-poor system offers hope that ERA can work in other controversial, complex situations.

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Appendix I: Pre-workshop interview questions

GENERAL KNOWLEDGE, FAMILIARITY AND PERCEPTIONS

We will start generally with a discussion about the nature of each participant's involvement in the GMO debate.

1. Please tell me about your involvement thus far in the GMO debate. For example, have you been an interested observer, served in a regulatory capacity, conducted scientific research or field trials, or not involved at all.

For those who ***are or have been*** *involved, ask the duration of their involvement.*

2. How long have you been involved in these activities?

For those ***not involved*** *in the GMO debate, explore what they may have gathered during their daily activities.*

3. Can you tell me a little about what you know or have heard about genetically engineered organisms?

For everyone

4. Can you tell me what you think about GM crops generally?

Preface Q5 by mentioning the controversy and differing opinions about GM crops (reference their comments from Q4 as one of many viewpoints).

5. Can you tell me what you personally think is underlying the debate around GM crops?

6. Why do you think this is? Why is the debate evolving in this way?

RISK AND RISKS OF GM CROPS

I'd like to discuss the concept of risk and GM crops, as the workshop is designed to explore potential risks of GM crops to biodiversity.

7. When you hear the term "risk", what comes to mind?

8. In your opinion, what might be some risks of GM crops?

9. Risks of Bt maize specifically?

10. Do you think others involved in the GMO debate share your opinion about the risks *(or lack of risk)*? And why would that be?

DECISIONMAKING AND INFORMATION

I'd like to talk more about how you think society should approach situations characterized by debates about risk. GMOs are one example of this type of situation.

11. How do you think one should make decisions about technology issues which generate societal debate about issues of risk?

12. Who do you think should make these types of decisions?

You've told me your opinions about GMOs (in Q4 and Q5) already, and I want to ask you a bit more about how you came to those conclusions. You likely had to evaluate different sources of information to form your opinion.

13. Can you tell me how you determined whether information being presented in the GMO debate was valid?

14. Do you think that others involved in the debate follow this same process, or would they approach it differently?

POWER/INFLUENCE

I'd like talk now about how different members of society can and do contribute to the debate about GMOs. I'll first discuss your role *(or potential role)* and then ask how you see it relating to others.

15. What do you feel that you contribute *(or can contribute)* to the GMO debate?

16. How much power or influence do you feel you have in the GMO debate?

If they indicate that they don't feel much power, ask Q16.

17. Who do you think holds the power in the GMO debate, and why?

If they do feel like they have a lot of power ask, Q17.

18. Does anyone else share this power with you?

LEARNING STYLES

Thank you for your thoughts. I want to ask you some questions about your learning style, information important for understanding how to best facilitate the group's learning during the workshop.

19. Can you tell me a little about your educational and professional background?

20. Generally, how do you feel most comfortable learning (group, solo, mixture)?

ADMINISTER KOLB LEARNING STYLE INVENTORY (designed and analyzed by Hay Group www.haygroup.com)

Appendix II: Post workshop interview (for WS2)

SOCIAL LEARNING

Start the interview discussing their workshop experience generally, and then ask about social learning (whether there was a shared understanding or not by the group).

1. First, can you tell me your general impressions on the workshop?

2. Do you think that the group came to a shared understanding of the purpose of the workshop? How would you describe that understanding? *(The problem)*

If they say no, ask:

3. What was your understanding of the purpose of the workshop?

4. Do you think the group came to a shared understanding about the process being used during the workshop? *(How to solve it)*

5. Do you think the group came to a shared understanding of what interactions are concerning enough to do monitoring and research? *(The solution)*

If no to any of the questions:

6. Why do you think the group was unable to develop this shared understanding? *(may have already covered it in previous questions)*

7. Would you say that your understanding of any of these things differed from that of the group's?

8. Talk to me about each of the steps in the framework and what you thought of the tools. *(Show them their products at each step and the overall framework)*

9. At which steps did you learn the most? Why?

KNOWLEDGE, POWER, FRAMING

Let's talk about the information that emerged from participants during the workshop and how it was used.

10. What are some important concepts or realizations that you took away from the workshop?

11. What do you feel you contributed to the workshop? Or did you learn more than you contributed?

12. How do you feel these contributions were received by the group? *(may not be applicable if they did not contribute)*

13. Why do you think these contributions were received this way? *(may not be applicable if they did not contribute)*

14. What type of information did you find most helpful in gaining a better understanding the topic of Bt maize and its interaction with biodiversity?

15. What information do you think was missing from the process?

16. Who did you find most informative during the workshop? Why?

17. Did anyone's behavior surprise you at the workshop, ie did anyone act differently than you anticipated? *(Added after the first three interviewees really wanted to talk about other participant's behavior at the workshop.)*

18. Where the insights from the four scientists who had participated in the earlier workshop useful? *(Asked to 18 participants who were new to the ERA process.)*

19. Do you think important groups or individuals were missing from the workshop?

SOCIAL LEARNING: CHANGES IN POWER & BELIEFS

The next part of the interview will follow up on some of your responses from the pre-workshop interview. For instance, you made statement X about GM crops, and I'd like to see if your opinion has changed at all. If their statements change, ask if it is a result of their participation in the workshop or some other event.

20. What do you think generally about GM crops?

21. Can you tell me what you think is "at stake" in the debate around genetically engineered crops?

22. Did your participation in the workshop change your perceptions about potential interactions of concern between Bt maize and biodiversity?

23. Who do you think is particularly influential/powerful in the GMO debate?

24. How much influence/power do you think you hold in the overall debate over GMOs?

WORKSHOP PROCESS

25. Is there anything further you'd like to add in terms of improvements to the framework and tools used? *(Outline some suggested improvements if they seem stuck)*

26. How would you like to engage in similar processes? *(This could be at particular steps, or in a particular way)*

Ask Q27 if time remains, to collect a sample of answers regarding the definition of risk acceptance criteria (a step we did not implement in the workshop).

27. Drawing upon the risk estimation process, can you tell me what levels of change in the agro-ecosystem would you be willing to accept? Anything below a 2?

Appendix III: Daily evaluation worksheet

Day ____ P # ____

1. What are three things you learned today during the Workshop? Why might these be important to you in the future?

2. What were two ideas you tried to communicate today? How was your information or insights received by others in the workshop?

3. What worked well for you today at the Workshop?

4. What did not work well for you today, and how would you improve it?

5. Other comments you'd like to share?

Appendix IV: Workshop Survey

Participant #_____

Thank you for your participation in SANBI's environmental risk analysis (ERA) workshop. I'd like to ask you to respond to the following questions, which will take about 10 minutes. Your answers will help evaluate the workshop process for its ability to engender learning between participants, how well it worked to evaluate the potential risks of Bt maize to biodiversity, and to gather suggestions on how to improve the workshop design and implementation.

Questions 1-8:

Please rate how well the workshop exhibited the attributes listed in the table below.

Scale	1	2	3	4	5
	None	A little	Moderate	A lot	Exceptional

Indicate Rating 1 to 5	Attribute
	Open communication
	Diverse participation
	Unrestrained thinking
	Constructive conflict
	Democratic structure
	Diverse types of knowledge
	Extended engagement with other participants
	Facilitation

9. Please rate amount of new factual information you learned at the workshop.

1	2	3	4	5
None	A little	Moderate	A lot	Exceptional

10. Please rate amount you learned about other participants' perspectives or concerns.

1 2 3 4 5

None A little Moderate A lot Exceptional

11. Please rate the usefulness of deliberation between participants for identifying and examining information important to the workshop.

1	2	3	4	5
None	A little	Moderate	A lot	Exceptional

12. Please rate the degree to which the diversity of participants improved the BREADTH of information considered during the workshop.

1	2	3	4	5
None	A little	Moderate	A lot	Exceptional

13. Please rate the degree to which the diversity of participants improved the QUALITY of information considered during the workshop.

1	2	3	4	5
None	A little	Moderate	A lot	Exceptional

14. How much did your opinion about the potential risks change after participating in the workshop?

1	2	3	4	5
None	A little	Moderate	A lot	Exceptional

15. How much did participating in the workshop change your relationships with other participants?

1	2	3	4	5
None	A little	Moderate	A lot	Exceptional

16. Please rate the degree to which the group came to a shared understanding about the relationships between Bt maize and biodiversity.

1	2	3	4	5
None	A little	Moderate	A lot	Exceptional

Briefly identify your reasons for this rating.

17. The communication between participants was conducive to the development of the above level of understanding.

1	2	3	4	5
None	A little	Moderate	A lot	Exceptional

Briefly identify your reasons for this rating.

18. Please list up to three things that you learned during the workshop that will be useful in future environmental risk analysis processes.

1.

2.

3.

19. Please list up to three things you think worked well with the workshop process or specific tools we used.

1.

2.

3.

20. Please list three improvements you would suggest for the process or the tools.

1.

2.

3.

21. Do you have any final thoughts or suggestions for the workshop organizers?

Appendix V. Coding Scheme for Social Learning

NVIVO Coding Nodes as of 6-11-09

1. Collaborative process **attributes**
    a. Open communication (yes or no)
        i. Participants are allowed voice, and felt free to speak up at any time
    b. Unrestrained thinking (yes or no)
        i. Opportunity to think creatively about the topic and the system; process encouraged holistic thinking
    c. Constructive conflict (yes or no)
        i. Differing opinions can be voiced and challenged in a productive manner
    d. Extended engagement with other participants (yes or no)
        i. Possibility for longer conversations outside of workshop
    e. Diverse participation (yes or no)
        i. A range of disciplines, industries, interest groups, and practitioners attended
    f. Other

2. Collaborative process **components**
    a. Democratic structure (yes or no)
        i. Participants have voice because everyone can easily speak (though not everyone CHOSE to speak) (adding things or criticizing too)
        ii. Participants have influence because their contributions are incorporated in the ERA process, and they see themselves moving the process forward
    b. Diverse types of knowledge (yes or no)
        i. Experiential (on-the-ground) vs scientific (Google) knowledge
    c. Facilitation
        i. Provided guidance for participants to get through the workshop
            1. legitimizes the process, keeps it on track, synthesizes, provides space for voice, provides training, sets boundaries, and provides a reality check
    d. Other

3. Steps of the ERA process at which the components and attributes are manifested
    a. Conceptual mapping
    b. Farmer practice
    c. Hazard matrix
    d. Prioritization
    e. Risk estimation

4. Participant attributes as articulated by other participants

a. Open-mindedness to the process, non-scientific or Google knowledge
b. Goal/outcome oriented vs go with the flow
c. Curious
d. passive vs active engagement
e. type of learner?
f. Other

5. The process of getting to social learning
    a. Participants teaching each other (relational)
    b. Participants seeking out knowledge from others (relational)
    c. Participants defining the purpose, process or outcomes of the workshop with each other (process oriented to know what their job is)
    d. Other

6. Outcomes of social learning
    a. Knowledge of "other"
        i. Creation of new relationships (did not know person X before WS)
        ii. Transformation of relationships (had a different opinion of X before WS)
        iii. Knowing of diverse perspectives (never thought of X in X way before)
    b. Knowing of "substance"
        i. Shifts from individual preferences to group preferences
            1. We statements about tools, group functioning in the process
        ii. Shared repertoire (concepts, products, language)
            1. (negotiation of definitions farmers, biodiversity components, methods of action of Bt toxin
    c. Systemic understanding
        i. The complexity of the system and its parts
        ii. Requires being exposed to and integrating diverse knowledge to expand original conception of the world or system
    d. Other

These outcomes ultimately should coalesce to produce a:

e. Shared understanding of problem/task/objective, the process of how to solve it/achieve it, and its solution/outcome
    i. The group came to a shared an understanding of the purpose of the workshop (the problem trying to be solved)
        1. What is that shared understanding?
            a. x,y,z
    ii. The group did not come to a shared understanding of the purpose of the workshop
        1. Why not?
            a. x, yz

iii. The group came to a shared understanding of the purpose of the workshop at some points
    1. Which points
        a. x,y,z
iv. The group came to a shared understanding of the workshop process (how to solve the problem)
v. The group did not come to a shared understanding of the workshop process
    1. Why not
        a. x,y,z
vi. The group came to a shared understanding of the workshop process at some points
    1. Which points?
        a. x,y,z
vii. The group came to a shared understanding of the highest priority interactions for monitoring (the solution)
viii. The group did not come a shared understanding of the highest priority interactions for monitoring
ix. The group got something else from the process

Appendix VI. Kolb Learning Cycle Questionnaire

Participant #___

Directions: Please think about some situations that you have been in recently, for example at work or school or at home. Think of how you would act those situations where learning and group interaction is necessary.

Please rate the following statements in descending order, with 4 being most like you and 1 being least like you. Please do not leave any statements blank, as the software used to analyze the answers does not accept null values.

4= the most like you
3= like you
2= somewhat like you
1= the least like you

1. When I learn:
   _____ I like to watch and listen
   _____ I like to think about ideas
   _____ I like to deal with my feelings
   _____ I like to be doing things

2. I learn best when:
   _____ I work hard to get things done
   _____ I rely on logical thinking
   _____ I listen and watch carefully
   _____ I trust my hunches and feelings

3. When I am learning:
   _____ I have strong feelings and reactions
   _____ I am quiet and reserved
   _____ I tend to reason things out
   _____ I am responsible about things

4. I learn by
   _____ thinking
   _____ doing
   _____ watching
   _____ feeling

5. When I learn:
   _____ I am open to new experiences

_____ I look at all sides of issues
_____ I like to try things out
_____ I like to analyze things, break them down into their parts

6. When I am learning:
_____ I am an intuitive person
_____ I am a logical person
_____ I am an active person
_____ I am an observing person

7. I learn best from:
_____ personal relationships
_____ observation
_____ a chance to try out and practice
_____ rational theories

8. When I learn:
_____ I feel personally involved in things
_____ I like to see results from my work
_____ I like ideas and theories
_____ I take my time before acting

9. I learn best when:
_____ I rely on my ideas
_____ I rely on my feelings
_____ I rely on my observations
_____ I can try things out for myself

10. When I am learning:
_____ I am a reserved person
_____ I am a responsible person
_____ I am an accepting person
_____ I am a rational person

11. When I learn
_____ I evaluate things
_____ I like to observe
_____ I like to be active
_____ I get involved

12. I learn best when:
_____ I am practical
_____ I analyze ideas

_____ I am careful
_____ I am receptive and open-minded

13. When I start something new:
_____ I imagine different possibilities
_____ I rely on my feelings to guide me
_____ I analyze the situation
_____ I try to be practical and realistic

14. When I decide between two alternatives:
_____ I establish criteria to evaluate them
_____ I rely on what feels right to me
_____ I collect information about them
_____ I try them out

15. When I plan something:
_____ I am open to making changes
_____ I am organized and logical
_____ I consider all possibilities
_____ I am goal and action oriented

16. When I learn in a group setting:
_____ I jump in and contribute
_____ I sit back and listen
_____ I get to know everyone
_____ I look for experts

17. When I try to influence someone:
_____ I take initiative to talk with them
_____ I try to understand their point of view
_____ I explain my ideas logically
_____ I share my feelings with them

18. When I evaluate an opportunity:
_____ I trust my sense of what is best
_____ I consider different opinions about it
_____ I weigh the costs against the benefits
_____ I act quickly

19. When I analyze something:
_____ Intuition is often my best guide
_____ I think about how the basic principles relate to each other
_____ I look at it from different perspectives

_____ I search for its practical applications

20. When I want to know someone better:
_____ I do things with them
_____ I analyze why they act the way they do
_____ I pay attention to their feelings
_____ I talk with them

Questions are exactly the same as on the on-line version found at www.haygroup.com. I entered and analyzed each participant's hard copy answers using the online program, after purchasing 25 single-use subscriptions (1 for each participant and 3 for research staff).

Appendix VII. Kolb Learning Style Information Sheet *(given to ERA workshop participants)*

Information on Learning Assessment Theory and Results
SANBI ERA and Biodiversity Workshop 4-7 November

I determined your preferred learning style using the Kolb Learning Styles Inventory. David Kolb, a professor of Organizational Development at Case Western Reserve University in Ohio, published his learning styles model in 1984. This learning model is acknowledged world-wide by academics, teachers, managers, and trainers as a seminal work towards understanding human learning.

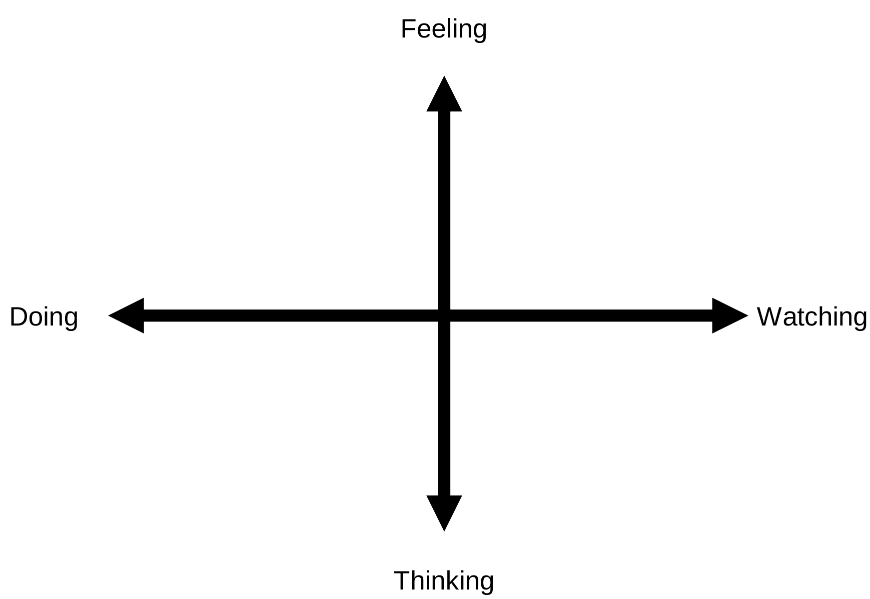
Kolb's learning theory identifies four distinct learning styles, which are based on a four stage learning cycle (a picture of this cycle is on the first page of your learning assessment results).

People prefer a certain single learning style. The learning style is a product of two pairs of choices that we each make when learning:

1. **Doing** (Active Experimentation) versus **Watching** (Reflective Observation)

2. **Feeling** (Concrete Experience) versus **Thinking** (Abstract Conceptualization)

We must internally decide whether we want to **do** or to **watch**, and at the same time, whether we want to **think** or **feel**.



In other words, we can choose to approach the learning task by:

1a. Watching others involved in the experience and reflecting on what happens (**Reflective Observation--watching**), OR

1b. Jumping straight into the task and just doing it (**Active Experimentation--doing**).

At the same time, we must choose how to emotionally transform the experience into something meaningful and useful:

2a. By thinking or analyzing new information (**Abstract Conceptualization--thinking**), OR

2b. By experiencing the concrete, tangible qualities of the world (**Concrete Experience---feeling**).

Please refer to your printout to determine your preferred learning style.

Information on each of the four “learning styles”:

1. **Diverging** (feeling and watching-- Concrete Experience and Reflective Observation)

   Diverging learners look at things from different perspectives. They are sensitive. They prefer to watch rather than do, tending to gather information and use imagination to solve problems. They are best at viewing concrete situations several different viewpoints. These learners perform better in situations that require generation of ideas (e.g., brainstorming). These learners have broad cultural interests and like to gather information. They are interested in people, tend to be imaginative and emotional, and tend to be strong in the arts. Diverging learners prefer to work in groups, to listen with an open mind and to receive personal feedback.

2. **Assimilating** (watching and thinking-- Abstract Conceptualization and Reflective Observation)

   Assimilating learners prefer a concise, logical approach. These learners require good, clear explanations rather than practical opportunities. They excel at understanding wide-ranging information and organizing it a clear logical format. Assimilating learners are less focused on people and more interested in ideas and abstract concepts. These learners are more attracted to logically sound theories than to approaches based on practical value, and tend to be effective in information and science careers. Assimilating learners prefer readings, lectures, exploring analytical models, and having time to think things through.

3. **Converging** (doing and thinking-- Abstract Conceptualization and Active Experimentation)

   Converging learners can solve problems and will use their learning to find solutions to practical issues. They prefer technical tasks, and are less concerned with people and interpersonal aspects. Converging learners are best at finding practical uses for ideas and theories. They can solve problems and make decisions by finding solutions to questions and problems. These learners are more attracted to technical tasks and problems than social or interpersonal issues, and tend to have specialist and technology abilities. Converging learners like to experiment with new ideas, to simulate, and to work with practical applications.

4. **Accommodating** (doing and feeling-- Concrete Experience and Active Experimentation)

Accommodating learners are 'hands-on', and rely on intuition rather than logic. These learners use other people's analysis, and prefer to take a practical, experiential approach. They are attracted to new challenges and experiences, and to carrying out plans. They commonly act on 'gut' instinct rather than logical analysis. These learners tend to rely on others for information, rather than carrying out their own analysis. This learning style is prevalent and useful in roles requiring action and initiative. Accommodating learners prefer to work in teams to complete tasks, and they set targets and actively work in the field trying different ways to achieve an objective.

These learning styles are a guide, not strict rules. Although people can utilize a combination of learning styles, most people exhibit a strong preference for a specific style.

Information is from www.businessballs.com website and is copyrighted: David Kolb original concept, and Alan Chapman 2003-08 review.

See the following references for more information:

Kolb Learning Styles: http://www.businessballs.com/kolblearningstyles.htm

D.A. Kolb, 1984. Experiential Learning: Experience as the Source of Learning and Development. New Jersey, Prentice Hall.