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Education for Sustainable Development in German Science Education: Past – Present – Future

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In this paper, we trace selected strands of the German path to Education for Sustainable Development (ESD). We start by addressing pre-ESD research, and move to the concept of *Gestaltungskompetenz*, the core concept of German ESD. The concept had to be realigned as to become more compatible with international research on learning outcomes (competencies). Compared to its beginnings, the meaning of *Gestaltungskompetenz* has much advanced, e.g., influenced by German competence research in science education, to which the Göttingen Model for socioscientific reasoning and decision making contributes. The paper presents a new competence dimension on "*Evaluating and reflecting solutions quantitatively-economically*" for this model. The contribution highlights the integrative and interdisciplinary scope of the educational challenges posed by Sustainable Development.

Keywords: Education for Sustainable Development, Socioscientific Reasoning, Decision Making, Science Education, Economics Education

INTRODUCTION

Foremost, the prevalent patterns of human production and consumption influence whether the natural environment and its resources are used in a sustainable way or not. In turn, a careful management of these resources is of paramount importance for economic, social and cultural development. In this respect, the Millennium Ecosystem Assessment (MA, 2005), the international TEEB (The Economics of Ecosystems and Biodiversity) reviews (2008) as well as the IPCC reports on Climate change (2013) present comprehensive and socio-economically forceful evidence that the resources of the natural environment need to be protected and used in a manner compatible with the needs of future generations (TEEB, 2008; cf. also Costanza, d'Arge, De Groot, Farber, Grasso et al., 1997). However, there are substantial socio-economic conflicts of interests between low-income countries, emerging economies and high-income countries; between stakeholders interested in the utilisation and stakeholders interested in the protection of specific resources. Neither in the 1980ies nor today: "Sustainable Development" (SD) cannot be thought of as a "blueprint" for a better future (WCED, 1987). Rather, SD remains a regulative idea that has the capacity to guide the global discourse on development and the environment (Jörissen, Kopfmüller, Brandl & Paetau, 1999).

The scope and scale of the global challenges had already been realised, at least, by the Brundtland-Report (WCED, 1987). Consequently, the Rio Summit's Agenda 21 in 1992 placed SD firmly on the general political agenda and on the educational agenda (cf. UNCED, 1992). Chapter 36 of Agenda 21 as well as Chapter 13 of the Convention on Biological Diversity (CBD, 1992) formulate educational requirements for an Education for Sustainable Development (ESD). Some time later the General Assembly of the United Nations proclaimed the years from 2005 to 2014 as the "Decade

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State of the literature

- In Germany, environmental education is closely linked to science education. Mainstream environmental education was accompanied by *Ökopädagogik*, and a pedagogics of nature experience in the 1970ies and 1980ies. Environmental education evolved to Education for Sustainable Development (ESD) and its specific German embodiment of *Gestaltungskompetenz*.
- The concept of *Gestaltungskompetenz* became more articulated challenged by a missing focus on decision making, deficits in the reception of the international ESD and science education debate as well as a lacking formal competence definition.
- The Göttingen model of socioscientific reasoning and decision making provides a promising frame for operationalizing core aspects of *Gestaltungskompetenz*.

Contribution of this paper to the literature

- The paper links the German research approaches and practices in science education to the current state of the international discussion.
- An extension of the Göttingen Model is presented: a competence dimension on *evaluating and reflecting solutions quantitatively-economically*. Far beyond qualitative argumentation skills, the competence dimension focuses on the capacity of environmental and institutional economics concepts and procedures to inform systematic decision making. Results from a small pre-pilot study indicate that the test instrument may differentiate between competence levels, and may possess advantageous psychometric features.

of Education for Sustainable Development" (DESD; see UNESCO, 2005; de Haan, 2006). Towards the end of the decade, it makes sense to pause and take stock of the status of achievements in various branches of educational research including science education research with respect to ESD.

In this paper, we trace selected strands of the German path to ESD as reflected in science education research. Specifically, we start by addressing pre-ESD educational research, and move to the concept of *Gestaltungskompetenz* (de Haan & Harenberg, 1999), the core concept under which the German educational administrations organised their concerted ESD efforts. Compared to its problematic beginnings, the meaning of *Gestaltungskompetenz* has much advanced to include socioscientific reasoning and decision making. Also, the concept had to be realigned as to become more compatible with international definitions of learning outcomes (competencies) and requirements of student assessments. Based on this review of trends in German ESD research, we provide an overview of the current state of competence-based research in the field in Germany. With a recent review from the perspective of chemistry education already available (Burmeister, Rauch & Eilks, 2012), we take the liberty to focus on examples from biology education, physics education and geography education. We end with a brief outlook.

Trends in ESD in Science Education Research

We start with a look into the formative days of environmental education (Umwelterziehung) in the 1970ies and 1980ies when much research focused on the impacts of environmental knowledge and nature experience on environmental action (e.g., Rieß, 2010). These foundations are exemplarily reviewed below. With the results of the Brundtland report (WCED, 1987) and the Rio Summit in 1992, the need for a transformation of environmental education arose. Environmental issues as a cross-cutting, interdisciplinary topic in science education had to be embedded conceptually into the much broader demands of an ESD (e.g., de Haan, 1999; Bögeholz, Bittner & Knolle, 2006; Kohler, Bittner & Bögeholz, 2005; Seybold & Rieß, 2006). A well-funded programme devised by German *Bund-Länder-Kommission für Bildungsplanung und Forschungsförderung* (BLK), a governmental commission to co-ordinate national educational policies, had a substantial impact on mainstreaming German curricular ESD (see below). The past years are characterised by the demand for a more precise, quantitative definition of learning outcomes also in the ESD realm. Science education responds increasingly to these demands with studies that develop methods to define and measure cognitive learner competencies. Detailed examples on how that can be achieved are also presented.

Phase I: Environmental Education and Nature Experience

In the 1970ies and 1980ies, much research focused on the impacts of environmental knowledge on environmental action (cf. Gardner & Stern, 1996). A second line of research reflected the strong emphasis on nature experience in German environmental education (for a review see Bögeholz, 2006). The early steps of environmental education in Germany, and its transformation to ESD have recently been reviewed extensively by Rieß (2010, 99-101). In the following two paragraphs, we largely follow his account of main events.

As early as 1953, the German inter-state committee of the Länder ministers of education *(Kultusministerkonferenz)* demanded that nature and landscape conservation be "attributed special attention to" (cited after Rieß, 2010, 99). The first federal environmental policy programme from 1971 demanded that environmental knowledge and pro-environmental action be fostered; the Tiblisi World Conference on Environmental Education (UNESCO-UNEP, 1977) contained respective recommendations. For example, learners should be enabled to recognize environmental problems and participate in solving them in time. Several German educational researchers criticised the "individualistic" orientation of the Tiblisi recommendations. Instead, a more action- and problem-oriented approach to environmental education was proposed by authors such as Bolscho, Eulefeld and Seybold (1980) under the label *Umwelterziehung*. A focus on the capacity to solve problems in complex systems, and the preparation of learners for participation in real-world political discourses is central to this approach that closely intertwines environmental and citizenship education.

Two other approaches partly competed, partly complemented widely accepted *Umwelterziehung: Ökopädagogik* (ecological pedagogics) and the pedagogics of nature experience. *Ökopädagogik* largely followed anti-capitalistic and anti-imperialistic notions of the exploitation of humans and nature. As important proponents of *Ökopädagogik* in Germany, Rieß cites W. Beer and G. de Haan. Much more so than in *Umwelterziehung*, a fundamental transformation of society had to be achieved as a precondition to stop the "demise of nature" (cf. Beer & de Haan, 1984).

With roots in the romantic, anti-industrial, and idealistic cultural movements of the 19th and early 20th Century, an educational focus on nature experience has a strong traditional backing. One example is the influential *"Wandervogel"* youth movement that mingled elements of German romanticism and a general disenchantment with the state of post World War I politics in Germany with joint outdoor activities in the 1920ies. In the anglophone world, Joseph Cornell is well-known for his affective approach to environmental education by fostering individual, emotionally hued nature experiences (Cornell, 1998). The basic tenet of much of German educational interventions prominently featuring nature experiences was "Nur was man liebt, das schützt man" (only what you love, you protect). It was assumed that students were "estranged" from nature, and that nature experiences would positively influence pro-nature values, and ultimately pro-environmental action (for a review, see Bögeholz, 2006).

Empirically, nature experiences have shown to be motivating factors for environmental action (Kals, Schumacher & Montada, 1998; Leske & Bögeholz, 2008). The frequency and appreciation of nature experiences are more influential predictors of pro-environmental action than environmental knowledge (Bögeholz, 2006). Positive nature experiences foster the development of positive affective perspectives and nature-related values (Bögeholz, Bittner & Knolle, 2006) – further influencing the commitment to pro-environmental action (cf. Menzel & Bögeholz, 2010). Thus, educational interventions offering nature experience foster the normative development of learners – and ultimately their dispositions for responsible decision making beyond individual consumption patterns (Bögeholz, 2006; Bögeholz et al., 2006).

Phase II: From Environmental Education to ESD

The Rio Summit's Agenda 21 (cf. UNCED, 1992) as well as the Convention on Biological Diversity (CBD, 1992) firmly established ESD on the international political agenda. The educational Chapter 36 of the Agenda 21 demanded a "new orientation in Education for Sustainable Development". ESD was to aim at a comprehensive change in ecological and moral awareness including values, attitudes, skills and individual patterns of action. In line with the overall participative impetus of Agenda 21, ESD was also requested to foster an effective participation of the general public in political decision making. According to Rieß (2010, 102), these international demands met a situation in German environmental education at the beginning of the 1990ies that was characterised by a climate of increasing frustration. The economic and political turmoil after German re-unification had replaced environmental concerns from priority positions of societal concern. Consequently, the hope for a renewed interest in environmental issues via SD induced a swift acceptance of *Bildung für eine Nachhaltige Entwicklung* on part of many – but not all – environmental educators. Scientifically, this change was exemplified by renaming the committee on environmental education *(Kommission für Umweltbildung)* of the German Society for Educational Sciences (DGfE) that became *Kommission Bildung für nachhaltige Entwicklung*.

In the late 1990ies educational administrations in Germany started to move formally towards ESD. Administratively, the advent of ESD resulted in federally co-ordinated educational activities in Germany. In 1998 the German BLK issued an "orienting framework". The framework focused on a system- and problem-solving orientation: "Education for Sustainable Development should foster the understanding of complex situations and the development of creative problem solving competencies" (BLK, 1998, 27, 28; our translation). Furthermore, BLK stressed the importance of key qualifications/competencies, e.g., "*systems thinking* that attempts to account for the multitude of relations and interactions and to understand single phenomena within the comprehensive dynamics of the respective system" (BLK, 1998, 28; our translation). Schools were tasked with providing educational opportunities to foster competencies to assess projects, products and similar objects of decision making. This decision making competence has obtained substantial emphasis in order to deal constructively with conflicting interests and objectives (BLK, 1998, 24, 29).

This focus on facilitating decision making, judgment and action in the face of conflicting interests and objectives is, in our opinion, a highly important step towards a modern vision of ESD. The normative uncertainty underlying many – if not most – real-world SD challenges may not be ignored. The importance of this aspect can be related directly to a notion of Sustainable Development as a regulative idea. In this view, SD has some capacity to guide the global discourse on development and the environment (e.g., Jörissen et al., 1999). However, it is not a "blueprint" for a better world. Considering the omnipresence of conflicting interests and objectives, such a blueprint is unlikely to exist. Consequently, ESD needs to equip learners with the mental tools to analyse and deal with normative uncertainty.

In line with the action- and problem-oriented approach of *Umwelterziehung*, some federal state administrations developed curricula at that time that also stressed the importance of the assessment of alternative courses of action based on scientific knowledge and normative reflection. One example is the Lower Saxony framework for biology education in grade 11 to 13 (Niedersächsisches Kultusministerium, 1999, 10). In fact, the original definition of scientific literacy by OECD, on which the first PISA student assessment was based, can be read along these lines "Scientific Literacy is the capacity to use scientific knowledge, to identify questions and to draw evidence-based conclusions in order to understand and help make decisions about the natural world and the changes made to it through human activity" (OECD-PISA, 1999, 60).

The BLK framework was complemented by a professional opinion (de Haan & Harenberg, 1999) that culminates in the definition of *Gestaltungskompetenz* as "the specific capacity to act and solve problems. Those who possess this competence can help, through active participation, to modify and shape the future of society, and to guide its social, economic, technological and ecological changes along the lines of sustainable development" (de Haan, 2010, 320). The focus on active participation is stronger than in scientific literacy sensu OECD. On the need to systematically make decisions, the professional opinion remains silent, however. The orienting framework as well as the professional opinion guided a national research and development programme for ESD in German schools from 1999 to 2004. Nearly all federal states participated. This Programme "21" was succeeded by a transfer phase (2004-2008) aiming to reach 10% of German schools (de Haan, 2006, 30).

Phase III: Focus on Competencies and Decision Making

In addition to a lacking focus on decision making, the state of research on *Gestaltungskompetenz* at the late 1990ies had a second drawback: *Gestaltungskompetenz* remained a concept that – in spite of the term – was not based on a precise competence definition. Initially, this aspect drew little attention. The mediocre achievements of German pupils in the first international PISA study in 2000 (Deutsches PISA-Konsortium, 2001), however, resulted in a public outcry that severely shook the educational establishment. In consequence, educational authorities required competence-based definitions of learning outcomes. It became obvious that *Gestaltungskompetenz* had to turn into a truly competence-based research programme (cf. de Haan, 2010).

In this subsection, we focus on the incorporation of competence research into German ESD including the need to facilitate standardised outcome assessments. From such an international perspective, it also became more urgent to relate *Gestaltungskompetenz* conceptually to the international ESD discussion. Finally, the point from the previous section is taken up again: the postulate that ESD should equip learners with the intellectual abilities to cope successfully with decision making needs as typically showing up in real-world SD challenges. We first outline the main features of modern competence definitions, and then describe the ensuing transformation of *Gestaltungskompetenz*.

Modern Competence Definitions

The German discussion on the objectives of ESD is strongly linked with the understanding of the concept of "competence" (Kompetenz). Although a "unified definition" of the multitude of competence definitions is hard to give (Weinert, 2001a, 62), the competence concept is most usefully applied when a substantial degree of complexity is required to solve a problem. For more simple tasks, the term skill is proposed. The most frequently cited definition of competence within the German educational research stems from Weinert. He defines competence (Weinert, 2001b, 27, 28) as "cognitive abilities and skills to solve specific problems that individuals can either dispose of or can learn, as well as the related motivational, volitional and social dispositions and abilities to use promising solutions in variable contexts successfully and responsibly" (our translation). This definition strongly influenced educational policy documents – foremost the formulation of the German National Educational Standards (NES; e.g., KMK, 2005a, 2005b, 2005c). In

German science education, this definition was used, for example, for outlining approaches to competence-oriented teaching in biology education (Bayrhuber, Bögeholz, Elster, Hammann, Hössle et al., 2007).

German educational research on learner competencies was boosted by the implementation of a priority programme funded by German Science Foundation (DFG) focussing on educational competence modelling and competence measurement (2007-2014). In line with Weinert but focussing on the cognitive side, "competencies [are defined] as context-specific cognitive dispositions that are acquired by learning and needed to successfully cope with certain situations or tasks in specific domains" (Klieme, Hartig & Rauch, 2008, 9). This directly addresses the need for an empirical operationalization. This definition has proven to be useful for basic and applied studies in science education (e.g., Eggert & Bögeholz, 2010; Gresch, Hasselhorn & Bögeholz, 2013) as well as for evaluation research (e.g., for the assessment of NES; e.g., Hostenbach, Fischer, Kauertz, Mayer, Sumfleth et al., 2011). Also, it has strongly influenced our approach to competence research for ESD (see below).

The focus on cognitive dispositions tends to ignore the influence of motivational factors although these factors do influence performance in specific situations (Weinert, 2001a, 60). The current research focus on cognitive dispositions is also more restrictive than definitions often used internationally, that is, competence is defined as "any acquired skill or knowledge that constitutes an essential component for performance or achievement in a given domain" (Simonton, 2003, 230 cited after Klieme, Hartig & Rauch, 2008, 8).

The Transformation of Gestaltungskompetenz

The professional opinion and programme "21" gave *Gestaltungskompetenz* a specific spin. Most significantly, the professional opinion relied substantially on systems science and the "syndromes of global change" concept used by the German government's think tank on global environmental change (WBGU, 1997; de Haan, 1999). These syndromes describe exemplary, problematic trends in the development of the human-nature relation. Unfortunately, the link from identifying the syndromes to concrete action is missing: Learners and their educators were given little guidance on how to design and make informed decisions about suitable courses of action.

While we fully acknowledge the positive contribution of the professional opinion (de Haan & Harenberg, 1999), the educational potentials of socioscientific reasoning within a real-world decision making and action frame were not fully realized. For example, the programme document of "21" lists "local participation in the identification of sustainability indicators" as one main topic for implementation and related educational research activities. De Haan and Harenberg realize that sustainability indicators are a means to document system states and past developments (de Haan & Harenberg, 1999, 81, 82). However, they miss the point that sustainability indicators are normative indicators, i.e., indicators ultimately chosen to provide succinct information for decision making. Thus, a prime opportunity to foster skills for systematic, critical assessments on alternative courses of action was at risk. A substantial effort was needed to (re-) insert into programme "21" a focus on learner competencies that enable them to systematically confront real-world decision making challenges (Bögeholz, 2001; cf. Bögeholz & Barkmann, 2003, 2005). While *Umwelterziehung* had to change, *Gestaltungskompetenz* had to change as well.

In the international science education literature, complex environmental challenges are discussed as socioscientific issues. Drawing on the international debate, it became increasingly clear that the cognitive competencies required by *Gestaltungskompetenz* would have to rely on socioscientific reasoning and competencies for socioscientific decision making (cf. Sadler, Barab & Scott, 2007; Grace, 2009). Along these lines and referring to the PISA approach to scientific literacy, we pointed out the importance of learner abilities to combine scientific knowledge with normative reflection in face of factual and ethical complexity, and called for fostering competencies to systematically assess and judge alternative courses of action (assessment and judgment competencies: Bögeholz & Barkmann, 2003, 2005; Bögeholz, 2006). In 2005, socioscientific reasoning and decision making with respect to SD became a core facet of the German NES in science education (KMK, 2005a, 2005b, 2005c).

As a reaction to these developments, the definition of *Gestaltungskompetenz* was adjusted. The focus on the ability to identify problems of non-sustainable developments (cf. syndromes) was maintained. However, it was now complemented by the ability to make sound judgments in the face of ecological, economic and social developments to facilitate decision making on SD challenges (de Haan & Gerhold, 2008, 6).

Since 2005, German science education research had been improving the theoretical and empirical foundations of socioscientific reasoning and decision making with respect to ESD (Eggert & Bögeholz, 2006, 2010). One important improvement regards the incorporation of descriptive decision making theories into the approach. From a psychometric point of view, it became increasingly clear that the competencies to judge and assess SD challenges and respective courses of action do not fall along one single competence dimension. In fact, at least three dimensions were

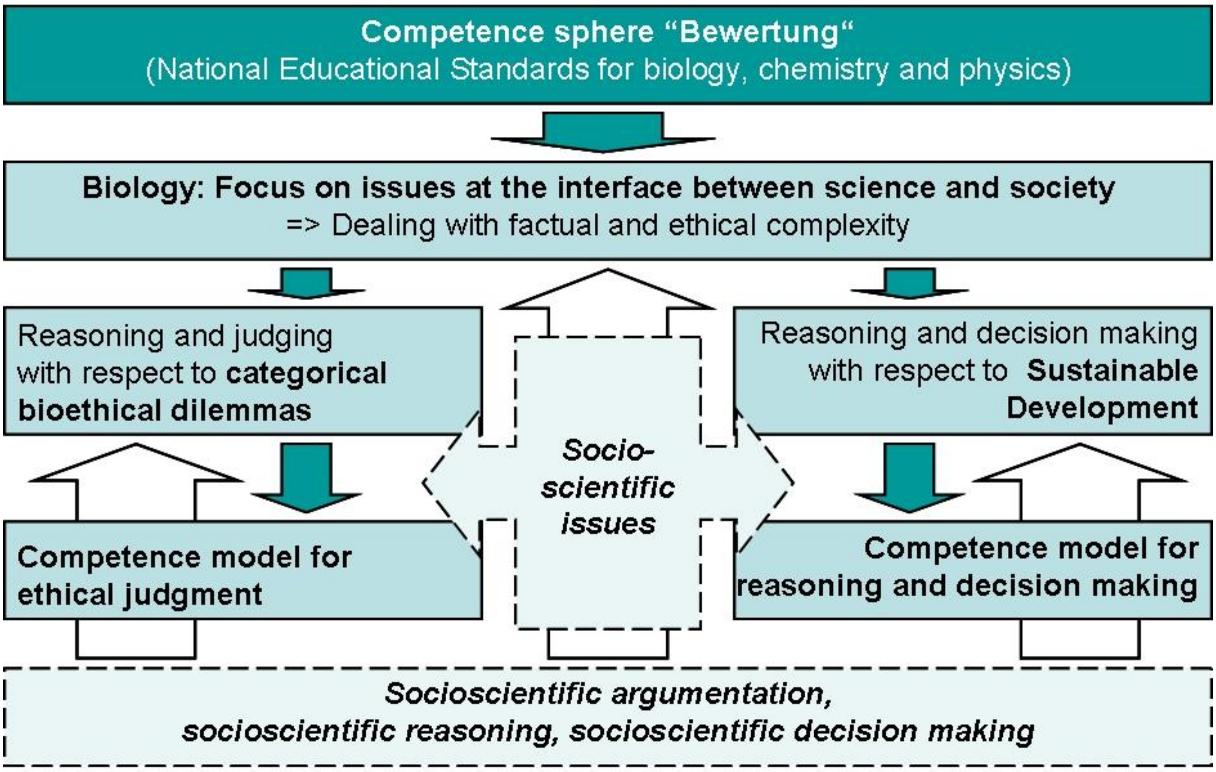

Figure 1. The German approach in science education with respect to the competence sphere *"Bewertung"* linked to the international discussion *(cf. Bögeholz, 2013, 74 Table 12-1)*

necessary even if a purely cognitive approach was followed (Bögeholz, 2013; Bernholt, Eggert & Kulgemeyer, 2012; for details see corresponding sections).

In effect, tracing these developments including the debate on modern competence definitions, also *Gestaltungskompetenz* was given a more elaborated and more specified description (de Haan, 2010). In its most current form, twelve sub-competencies are postulated and described in some detail (de Haan, 2010, 322-325). If these sub-competencies can be documented to have empirical substance, remains to be tested.

Specific German Approaches in Science Education

With respect to socioscientific issues, much of German biology education research follows two main lines. The first line focuses mainly on bio-ethical dilemmas, biotechnology and questions of medicine ethics (Reitschert, Langlet, Hößle, Mittelsten Scheid & Schlüter, 2007; Reitschert & Hößle, 2007). The other research branch emphasizes socioscientific reasoning and decision making with respect to SD (Eggert & Bögeholz, 2006, 2010; Bögeholz, 2011). For both branches, different theoretical backgrounds and methodological research approaches are used for competence assessment. While the first branch shows strong affinity to the study of verbal argumentation skills, the second was substantially developed with reference to decision making theories.

Both approaches have in common that pro-arguments and contra-arguments need to be developed and assessed. In the argumentation line of research, argumentative points have to be justified by using specific argumentation schemes, e.g., by using syllogisms (Reitschert & Hössle, 2010). In the other line, student competencies are graded according to the use of differently elaborated decision making strategies (e.g., Jungermann, Pfister & Fischer, 2005). Up to now, argumentation research in German biology education is often carried out using qualitative research methods. In contrast, the line investigating socioscientific reasoning and decision making has started to use quantitative methods. Specifically, competence models employing probabilistic Item-Response-Theory are used. As a result of this dualism, two different competence models were developed.

The two approaches are represented in the NES for biology education (KMK, 2005a). A closer look at the standards of the competence sphere "*Bewertung*" for the biology, chemistry and physics curriculum (KMK, 2005a, 2005b, 2005c) reveals the following: The interface between science and society as well as the explicit integration of SD issues are most intensively addressed in the NES for biology (e.g., KMK, 2005a; Hostenbach et al., 2011; Bögeholz, 2011). The NES with their competence sphere "*Bewertung*" – especially

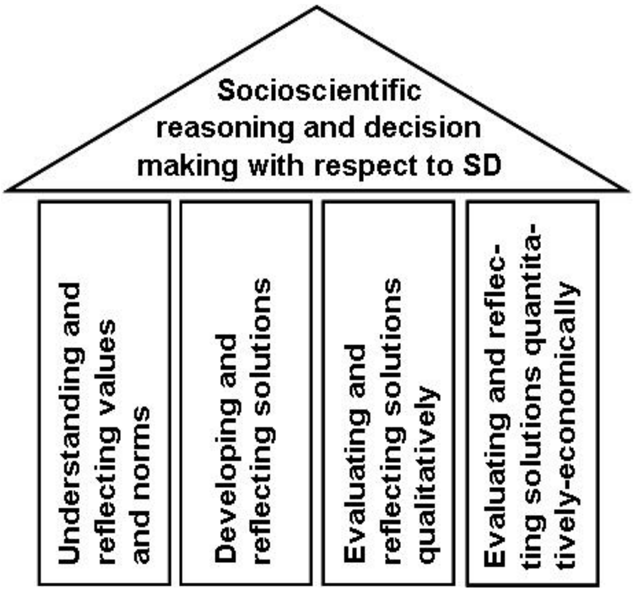

Figure 2. Göttingen competence model for socioscientific reasoning and decision making with respect to Sustainable Development (SD; cf. Bögeholz, 2013, 75 Table 12-2; Eggert & Bögeholz, 2006; Böhm, Barkmann, Eggert & Bögeholz, 2013)

the standards for biology – have become a template for the German "orienting framework" for the learning field of Global Development (KMK-BMZ, 2008).

Göttingen Model for Socioscientific Reasoning and Decision Making

Dealing with socioscientific issues in science classrooms is generally regarded as a promising strategy in the fields of science education, citizenship education, and ESD (e.g., Sadler et al., 2007). SD issues are one typical example for socioscientific issues as they are factually and ethically complex, lack a single "ideal" solution, and have to be solved by integrating multiple perspectives. In addition, they are often based on preliminary, fragile and conflicting evidence (e.g., Sadler et al., 2007). Likewise, conceptualising SD as a regulative idea suggests that ESD should promote the ability to analyse the viewpoints of different stakeholders, and to negotiate technically and economically viable, environmentally sound, and morally just solutions.

Previous research showed that the implementation of socioscientific issues in science classrooms can enhance interest in science topics (Ottander & Ekborg, 2012), foster learning outcomes with respect to conceptual scientific knowledge and enhances reasoning, argumentation and decision making skills (e.g., Eggert, Ostermeyer, Hasselhorn & Bögeholz, 2013; Eggert, Bögeholz, Watermann & Hasselhorn, 2010; Grace, 2009; Sadler et al., 2007; Seethaler & Linn, 2004; Siegel, 2006).

However, socioscientific issues are also challenging topics as they place high cognitive processing demands on students (e.g., Bernholt et al., 2012; Eggert et al., 2013). Students do not only have to rely on a profound scientific and interdisciplinary knowledge base, they also have to perform various information search and evaluation procedures. On top, they have to make use of argumentation, reasoning and decision making processes in order to reach informed decisions (e.g., Eggert & Bögeholz, 2010; Jimenez-Aleixandre & Pereiro-Muñoz, 2002; Ratcliffe & Grace, 2003; Zohar & Nemet, 2002). For a detailed overview of science education research into quality of reasoning, argumentation and decision making processes, see Erduran and Jimenez-Aleixandre (2008).

For respective research, several theoretical models are available. They include Toulmin's argumentation model (Toulmin, 1958), the developmental model of critical thinking (Kuhn, 1999), and descriptive or prescriptive models from decision theory (e.g., Betsch & Haberstroh, 2005). All models – and corresponding empirical research studies – highlight the notion of developing sound arguments, and to weigh these arguments in order to reach informed decisions (e.g., Osborne, Erduran & Simon, 2004; Jimenez-Aleixandre & Pereiro-Muñoz, 2002; Ratliffe & Grace, 2003; Grace, 2009; Papadouris & Constantinou, 2010; Sadler et al., 2007; Zohar & Nemet, 2002).

The Göttingen Model for socioscientific reasoning and decision making with respect to SD is based on a descriptive metamodel from decision theory (Betsch & Haberstroh, 2005; see Figure 2). The resulting model consists of several dimensions. With respect to the first dimension "Understanding and reflecting values and norms", students need to be able to comprehend and reflect on personal and societal values and norms that are inherent to socioscientific issues (e.g., Bögeholz, 2013; Bernholt et al., 2012; cf. Eggert & Bögeholz, 2006). The second dimension "Developing and reflecting solutions" addresses student abilities to describe and comprehend a socioscientific issue in its complexity, and to be able to develop sustainable solutions. With respect to SD, these solutions need to account for ecological, economical as well as social concerns. In addition, students need to reflect on these solutions and the evidence they are based on (e.g., Eggert & Bögeholz, 2006; Eggert et al., 2013; Gausmann, Eggert, Hasselhorn, Watermann & Bögeholz, 2010; Bögeholz, 2013). With respect to "Evaluating and reflecting solutions qualitatively", students need to be able to evaluate possible solutions with respect to their advantages and disadvantages, and to weigh respective arguments in order to reach informed decisions. Decision making can use different strategies (Eggert & Bögeholz, 2006, 2010). Using a "cut-off" strategy, students examine only one piece of

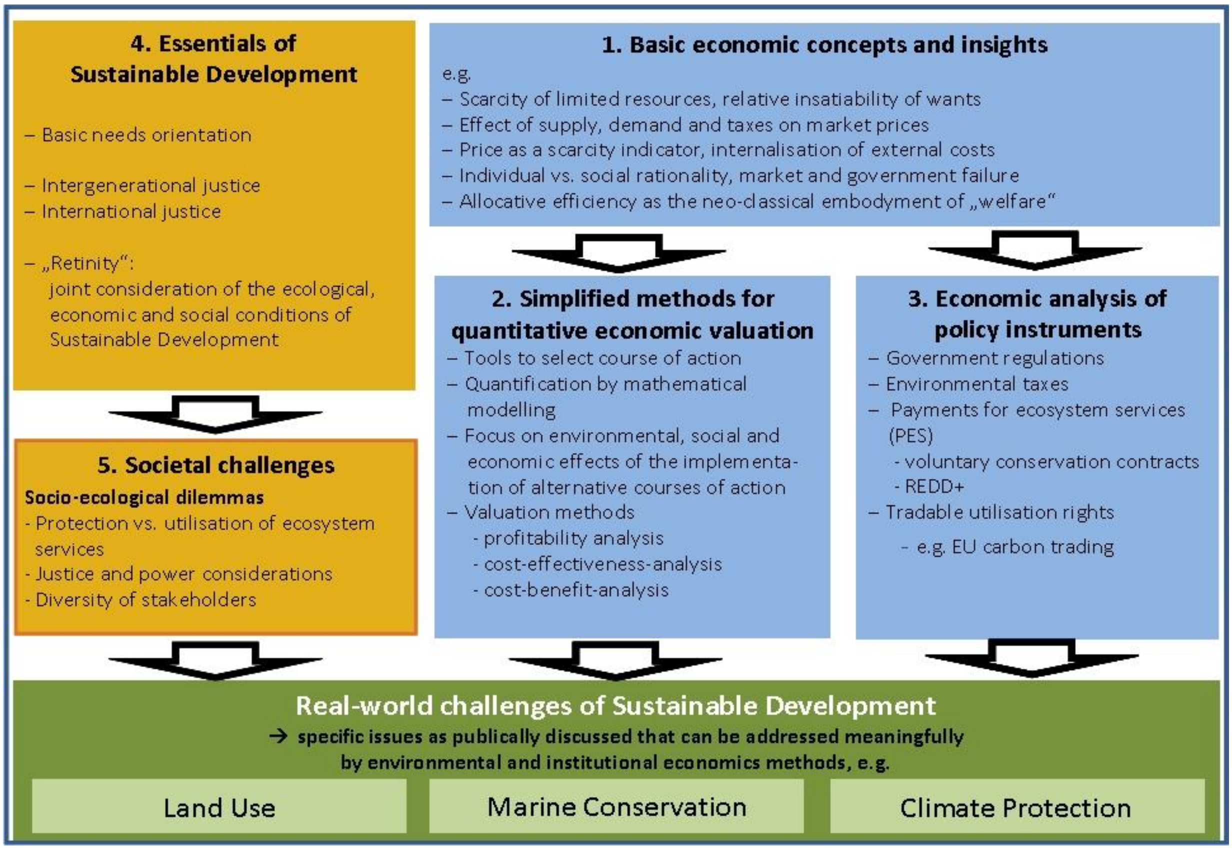

Figure 3. The framework for modelling and measuring "Evaluating and reflecting solutions quantitatively-economically"

evidence at a time, and eliminate solutions that do not reach a certain cut-off level. In contrast, students who use a "trade-off" strategy are able to compare different solutions simultaneously. We describe the fourth dimension in detail below.

Fostering Socioscientific Reasoning and Decision Making in Biology Education and other Fields

On the basis of the presented model for socioscientific reasoning and decision making, several test instruments were developed to measure and analyse student competencies. Training studies showed that socioscientific reasoning and decision making of students can actually be fostered, and that the developed measurement instruments can adequately describe student learning outcomes (Eggert et al., 2010; Eggert et al., 2013; Gresch et al., 2013; Gresch & Bögeholz, 2013).

On the national scale, socioscientific reasoning and decision making is also part of the national assessment for the NES in science education (Hostenbach et al., 2011). The described research influenced the assessment procedure to a great extent. Moreover, several empirical research studies exist that transferred the approach to other contexts and domains, such as genetically modified crops (Böttcher & Meisert, 2013) or artificial sweeteners as ingredients of nutrition in chemistry education (Heitmann, 2012). In addition, part of the model has been transferred to the area of physics education. Here, the focus is on the generation, storage and use of useful forms of energy (Sakschewski, accepted; Sakschewski, Bögeholz, Eggert & Schneider, 2013). Furthermore, other German working groups of physics education built upon our work on socioscientific reasoning and decision making (Knittel & Mikelskis-Seifert, 2012). In addition, the competence model for reasoning and decision making with respect to SD inspired other international science education researchers (e.g., with respect to physics education see Papadouris, 2012).

Last but not least, the research focussing on ESD challenges is – as ESD, and thus *Gestaltungskompetenz* itself – important beyond science education, e.g., for other subject matters such as geography education, politics education or economics education facing the same challenges. For example, the state standards for Lower Saxony for politics and economics education require that pupils evaluate potential policy instruments and other courses of action with a focus in reflective reasoning and decision making (Niedersächsisches Kultusministerium, 2007, 11). In the federal state standards for geography education, pupils are required to discuss options for economic and social development competently (Niedersächsisches Kultusministerium, 2010, 16). For these purposes, we enlarged our model by adding the fourth competence dimension (see next section).

Development of a new Competence Dimension: Evaluating and Reflecting Solutions quantitatively-economically

Qualitative Description of the Competence

In collaboration with environmental and resource economics as well as economics education, we enlarged our competence model by a fourth dimension "Evaluating and reflecting solutions quantitatively-economically" (Böhm et al., 2013). The German translation is abbreviated LUR. Why do we propose an additional competence dimension? Solutions to many real-world challenges of SD are often characterized in public discourse by their quantitative effects. For example, a new proposal to foster the generation of wind energy can be characterized by the tons of carbon avoided, by the square kilometres of landscape visually impacted by additional wind turbines, and by the additional costs to consumers and industry. Likewise, proposals for the conservation of marine fish stocks can be characterized by the expected development of the stocks in time, the expected fish harvest, and the impact on the national fishing industry in terms of profit and employment. These examples highlight the need for students to deal not only qualitatively but also quantitatively with the assessment of proposed courses of action. Specifically, there is a need to assess the expected impacts of the proposed solutions quantitatively, and to reflect on the effectiveness and ethical justification of proposed solutions. In sum, we define LUR as the competence of learners to understand, mathematically model, assess and reflect on alternative courses of action ("solutions") by getting insights into different stakeholder perspectives including environmental and institutional economics analysis, and the essentials of SD.

In a systematic manner, Figure 3 provides an overview of how this new dimension is conceptualised. At the most basic level, we find four essentials of SD (see 4. in Figure 3): basic needs orientation, international and intergenerational justice, and "retinity" – the norm demanding joint consideration of ecological, economic, and social conditions of SD (Bögeholz, 2000; WCED, 1987; SRU, 1994). With respect to the biological environment, the development challenges present themselves exemplarily in form of the aim to safeguard the long-term provisioning of ecosystem services (see, MA, 2005), and the need to utilise the environment for human needs. Societal challenges in the form of socio-ecological dilemmas are widespread (see 5. in Figure 3). At the most basic level, we also find basic economic insights into human decision making (see 1. in Figure 3). These insights include, e.g., the importance of resource scarcity or the effect of supply, demand and taxes on market prices. Basic insights also address individual versus social rationality and the possibility of market as well as of government failure. These basic economic insights should allow learners to advance in two relevant directions:

- *Understanding of key methods used in economics* (see 2. in Figure 3). Regularly, the methods are used to select the "best" course of action or to restrict the set of admissible options. Some simple mathematical modelling will be required to predict and assess the social, economic and/or ecological impacts of the implementation of an option. As valuation methods, we focus on simplified versions of profitability analysis, cost-effectiveness-analysis, and cost-benefit analysis. Thus, we include forms of multi-criteria analyses as well as of monetary analysis.
- *Analysing of key policy instruments from an environmental and institutional economics perspective* (see 3. in Figure 3) – no matter if the design of the policy instruments is economically informed or not. Again, we include a diverse set of often applied or discussed policy instruments such as legal government regulations, payments for ecosystem services (PES) schemes including voluntary conservation contracts and REDD/REDD+1, or tradable pollution rights[1].

We foresee that a substantial fraction of real-world challenges of SD can be successfully tacked based on the framework. The framework is not designed, however, to address strictly normative questions of right or wrong conduct. Power relations between individuals, groups and/or enterprises or countries are not explicitly mentioned in this subsection. However, a new institutional economics analysis of policy instruments, and the openness of the approach to market and government failures certainly would allow for the formulation of respective tasks and items. Also, the insistence on a critical reflection from a broader justice point of view should guard against an overly ideological usage of the framework.

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[1] According to the official United Nations definition, "Reducing Emissions from Deforestation and Forest Degradation (REDD) is an effort to create a financial value for the carbon stored in forests, offering incentives for developing countries to reduce emissions from forested lands and invest in low-carbon paths to sustainable development." (*http://www.un-redd.org/aboutredd/tabid/102614/default.aspx*; accessed March 6, 2014)

Development of the Competence Test

The development of a competence test for "Evaluating and reflecting solutions quantitatively-economically" follows Wilson's approach to design a measurement instrument (2005). Figure 3 provides a summary of how the theoretical construct is conceptualised ("construct map"). Based on the theoretical description of the construct, we identified suitable real-world SD challenges, and designed tasks to be included in a formal competence test ("item design", see Wilson, 2005). The three tasks used address exemplary issues of land use conflicts in low income countries in the tropics (task Land Use), alternative designs for a marine reserve in Great Britain (task Marine Conservation), and a Climate Protection task operationalised via considerations of a carbon trading scheme (see Figure 3). For each of the tasks, a written introduction including quantitative data and graphical elements was designed (see Appendix A). The introduction is followed by 5 to 7 single problems ("items") that students are asked to work on (for selected items from the Land Use task, see Table 1).

Figure 4 lists the main components of the theoretical construct. For each component, the three tasks include a varying number of items. For each of the items, we identified the characteristics of the ideal response and abstracted typical stages of understanding and elaboration of the response from empirical answers. The latter resulted in a scoring guide (e.g., Table 2) that assigns a numerical performance score to the given responses. Finally, a "measurement model" (see Wilson, 2005) needs to be defined. Psychometric analyses for the established dimensions show that the Rasch Partial Credit Model can be applied to the data (Eggert & Bögeholz, 2010; Bögeholz, 2011).

Currently, we have developed a set of suitable tasks and corresponding items, and are exploring the "outcome space" (see Wilson, 2005) via analysis of the first practical applications of our test booklets. Specifically, we have developed three tasks (Land Use, Marine Conservation and Climate Protection) to assess the theoretical construct "Evaluating and reflecting solutions quantitatively-economically". Because of time restrictions combined with the limited attention span of pupils, we placed the three tasks in two test booklets. Booklet 1 contains the Land Use task as well as the Climate Protection task. Booklet 2 contains the Marine Conservation task as well as the Climate Protection task.

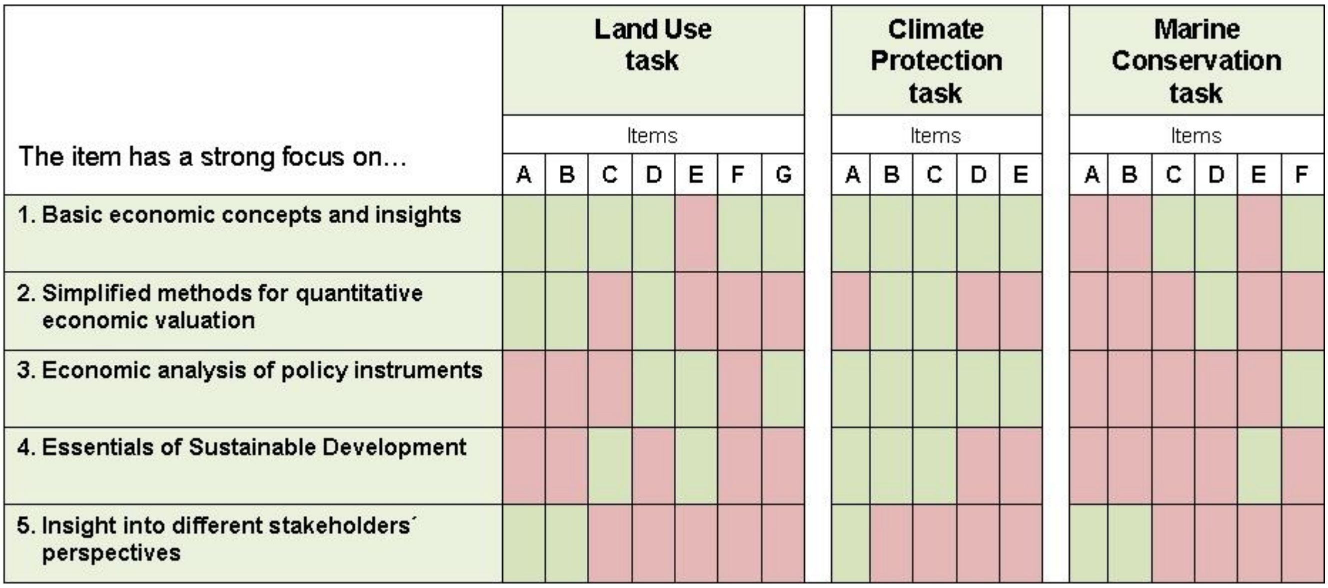

Figure 4. Tasks for measuring "Evaluating and reflecting solutions quantitatively-economically" and profiles of scored items (test booklet 1: Land Use task and Climate Protection task; test booklet 2: Marine Conservation task and Climate Protection task)

Table 1. Selected items from the Land Use task

	Items
A	Paco's family wants to maximise agricultural profit of their farm. How should they manage their land? Justify your decision also mathematically!
C	Suppose Paco's family wants to make a good living but also conserve the environment. Discuss possible conflicts in the light of social, ecological and economical consequences!
E	Should taxpayers from industrialised countries like Germany continue to pay for a REDD-programme in developing countries and emerging economies? Justify your decision!

In the Land Use task and the Marine Conservation task, the students have to apply basic economic concepts and insights as well as mathematical modelling to find potential solutions to pressing SD decision making issues. These tasks can be solved without complex arithmetic, and do not require formal knowledge of economic concepts. For the Climate Protection task, we chose a more challenging economic setting. The idea of tradable pollution rights itself is easy to grasp. It is more challenging, however, to understand that making pollution rights tradable has – in principle – a positive economic overall effect by increasing allocative efficiency. Pupils and university students without formal training in economics cannot be expected to come up with valid mathematical models of this efficiency effect. Still, we thought that it would be possible to address this level of complexity by designing the Climate Protection task as a reflection task. In reflection tasks, the text of the task does already include quantitative solutions attributed to peers of the respondents. Regularly, more than one solution is presented. For reflection tasks, learners are asked to comment on the provided solutions. For these comments, also the "outcome space" (see Wilson, 2005) is explored and a scoring guide developed.

Items A, C, and E from the Land Use task are presented in Table 1, the developed scoring guide in Table 2. The items address different components of the framework for modelling and measuring "Evaluating and reflecting solutions quantitatively-economically" (cf. Figures 3 and 4).

A first Pre-Piloting for Estimating the Quality of the Developed Tasks

We pre-piloted the test booklets with a sample consisting of 20 pupils during their mathematics class (aged 15-16; 15 females; grade 10 university-track high school). Additionally, the test was administered to 11 biology teacher students (aged 21-28; 9 females; 5th term Bachelor programme to 3rd term Master of Education). Test booklets were randomly assigned to the pupils and teacher students. 60 minutes were dedicated for the paper-and-pencil test. The participating pupils (teacher students) were 10 (6) for test booklet 1 and 10 (5) for test booklet 2.

Table 2. Scoring guide for selected items from the Land Use task

	Score 0	Score 1	Score 2	Score 3
A	Concept of profit maximisation not understood/applied	Concept of profit maximisation understood/applied	Score 1 & solution mathematically correctly modelled and argued	
C	Conflict was not, incorrectly or superficially described	Conflict was correctly described in all relevant details	Score 1 & social, ecological and economic consequences described	
E	No reasonable justification	Justification with one reasonable argument	Justification with two or more reasonable arguments	Score 2 & suggestion for improvement or constructive criticism

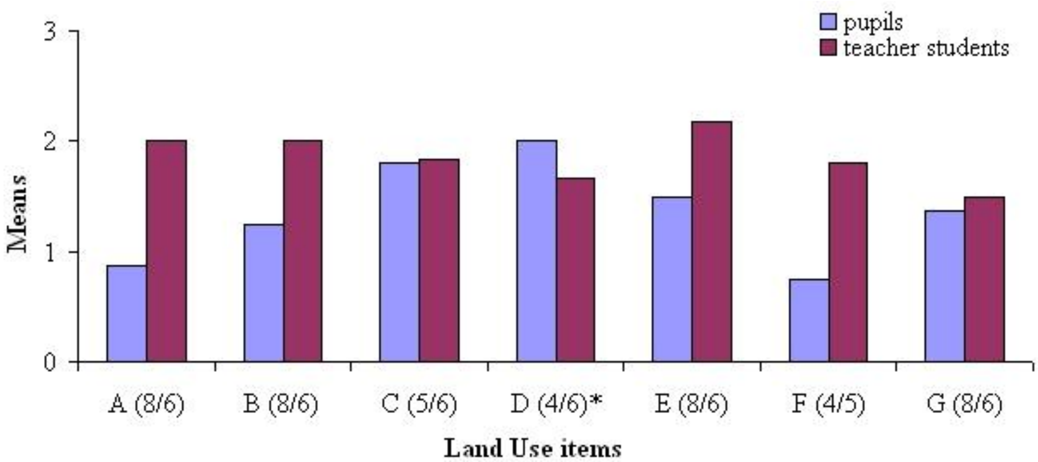

Figure 5. Pupil and teacher student performances for the Land Use task of the questionnaire for "Evaluating and reflecting solutions quantitatively-economically" (A-G = all 7 scored Land Use items; items A, C, F: maximal score = 2; items B, D, E, G: maximal score = 3; in brackets: n of pupils with valid response / n of teacher students with valid response).

At this step of development of the material, we seek to improve the content and wording of the items and tasks included in the test booklets. Specifically, we wanted to test if teacher students would outperform pupils. This would give a first hint that the competence may be learnable, and that the test instrument is actually able to differentiate different competence levels.

The answers of the students were scored according to the first draft of a scoring guide (see Table 2). All valid answers were scored according to their elaboration (Score 0 to 2 or 3). For a first quantitative analysis, data were entered into SPSS Version 21, analysed with non-parametric tests (Mann-Whitney U-test), and subjected to a very first reliability analysis. Missing answers or non-valid responses were coded "system missing". As missing answers often indicate a low level of competence and missing answers were overrepresented in the pupil subsample, our analysis tends to underestimate differences between pupils and teacher students.

The performance of pupils and biology teacher students with respect to the Land Use task is depicted in Figures 5. For this task as well as the Climate Protection and Marine Conservation task (data not shown), teacher students outperform pupils as expected ($p < .05$, one-way U-test). Investigating the reliability of the three tasks separately, Cronbach's Alpha for the seven Land Use items is .642. (.741 excluding item D). The five Climate Protection items display an Alpha value of .593 (.731 excluding one item). The six Marine Conservation items show an Alpha value of .277 (.633 excluding one item). The overall Cronbach´s Alpha for booklet 1 is .775 (12 items; .842 excluding two items). Regarding booklet 2 the Alpha value is only .192 (11 items; .543 excluding two items).

Outlook

In this contribution, we have outlined the development of selected strands of German science education that are relevant for an ESD. Even this outline revealed that the path to the current state of ESD as well as to the state of science education research on ESD has been anything but a straight line. Some achievements are likely to shape also future efforts. They include the introduction of formal references to empirically tractable competence definitions. They also include the transformation of *Gestaltungskompetenz* from a German peculiarity to an internationally reasonable interpretation that highlights the cognitive dispositions to solve complex reasoning and decision making tasks on socioscientific issues within the domain of real-world SD challenges.

Our research group has taken up the challenge to move single competencies and competence dimensions from conceptual hypotheses to psychometrically validated dimensions ("Göttingen Model"; Bögeholz, 2011, 2013; Eggert & Bögeholz, 2006, 2010). Considerable success was achieved in the application of competence modelling with Item-Response-Theory (e.g., Rasch Partial Credit Model; Eggert & Bögeholz, 2010) and the resulting ability not only to design successful educational interventions but also to document their impact (Eggert et al., 2010; Eggert et al., 2013; Gresch et al., 2013).

We summarized the current state of development of the Göttingen Model with special focus on the new, fourth dimension "Evaluating and reflecting solutions quantitatively-economically". The very first results – especially for the tasks and items included in test booklet 1 – are encouraging. Also the items promise to discriminate differing competence levels as indicated by the raw scores that were significantly higher in all three tasks for university students. The results also support the theoretical assumption that this dimension can, in fact, be modelled as a one-dimensional competence scale. Finally, the results indicate that the Marine Conservation task needs to be substantially improved.

Finally, we would like to stress that the instrument for the fourth dimension was developed in close contact to economics education and mathematics education. Some practitioners and researchers in ESD may regard these partners as unpleasant bedfellows. Still, their inclusion highlights once more the integrative and interdisciplinary scope of the educational challenges posed by SD.

The educational approach to SD – and to socioscientific issues in science education in general – needs to go further than ethical argumentation. The need to equip learners with quantitative competencies to systematically assess alternative courses of action to make decisions is itself a socioscientific necessity. The German discussion on *Gestaltungskompetenz* suggests that the need for a respective approach is increasingly understood; our empirical results suggest that this approach is quantitatively viable.

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Appendix A. Slightly modified and abridged version of the Land Use task

Land Use task – Part 1

About 36 % of the forests worldwide are primary forests. For about 57 % of the forests, there is evidence of substantial human influence, and about 6.5 % are forest plantations. Each year 13 million hectares (ha, 1 ha is equivalent to 10,000 m²) of forest get lost globally.

Huge amounts of carbon are stored not only in the wood itself but in the forest soil. Much of this carbon is emitted as carbon dioxide when natural forests are transformed to alternative land uses. Deforestation and degradation of forests impact the global climate and, thus, human well-being.

Table 1. The most important land use options and their average financial yields

Land use options	Average financial yields in \$/ha/yr	Carbon in t per hectare lost by transformation from natural forest in 1, 2 or 4.
1 Cropland: Production of maize	208.4 \$	220 t
2 Pasture: Production of milk	130.5 \$	220 t
3 Natural forest: a) Sustainable timber harvesting b) Under strict protection	31.8 \$ 0 \$	0 t 0 t
4 Reforestation of cropland or pasture	- 485.6 \$ *	- 195 t **
	* Reforestation costs money.	** Carbon is stored.

Imagine that the 37 year old Ecuadorian Paco, his wife Mayra and their two children inherit a farm with 25 ha land from Mayra's father. Mayra's father used 10 ha as cropland for the production of maize, 5 ha as pasture for the production of milk. 10 ha remained as a rain forest for sustainable timber harvesting.

Mayra used to spend a lot of time in the forest collecting fruits, fuel wood and medicinal plants during her childhood. Now she wants Paco to quit his job in the city. They want to live as farmers, and earn their living from the inherited farm land. In terms of official land use regulations, Mayra's family is free to decide how to manage the inherited land.

How much the family can earn per hectare and year is listed in Table 1. For the following items, consider that the cost of living for a four person family in rural Ecuador is about 285 $ per month.

Now, please work on the items A, B, C!

Land Use task – Part 2

If a forest is cut down, some animals and plants, and other forms of the diversity of life ("biodiversity") get lost. Also, climate gases are set free. People, who had used the forest for free before, may lose a source of income. This situation also applies to Ecuador. The Ecuadorian Ministry for the Environment and Nature estimates that 61,800 ha of forest get lost every year in the country.

One option to stop deforestation is *REDD*.

REDD - Reducing Emissions from Deforestation and Degradation
REDD is a programme by the United Nations. It means „*Reducing Emissions from Deforestation and Degradation*". REDD aims to slow down deforestation in forest-rich but low-income countries. High-income countries with high emissions of climate gases pay money to countries such as Ecuador if less forest is cut down or degraded. Ecuador is an official partner of the United Nations REDD programme. Germany paid about 350 millions € from 2010 to 2012 for REDD programmes worldwide. This money has been collected from German taxpayers.

Mayra has talked to another farmer who told her that a local REDD office paid him money for not converting his forest to farmland. The inherited natural forest on their farm means a lot to Mayra – but they also need money for food, clothing, schooling of the children, medical purposes, and for some savings for their old-age.

Now, please work on items D, E, F, G!