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The Value of Conceptual Models in Coping with Complexity and Interdisciplinarity in Environmental Sciences Education

KAREN P. J. FORTUIN, C. S. A. (KRIS) VAN KOPPEN, AND RIK LEEMANS

Conceptual models are useful for facing the challenges of environmental sciences curriculum and course developers and students. These challenges are inherent to the interdisciplinary and problem-oriented character of environmental sciences curricula. In this article, we review the merits of conceptual models in facing these challenges. These models are valuable because they can be used to (a) improve the coherence and focus of an environmental sciences curriculum, (b) analyze environmental issues and integrate knowledge, (c) examine and guide the process of environmental research and problem solving, and (d) examine and guide the integration of knowledge in the environmental-research and problem-solving processes. We advocate the use of various conceptual models in environmental sciences education. By applying and reflecting on these models, students start to recognize the complexity of human–environment systems, to appreciate the various approaches to framing environmental problems, and to comprehend the role of science in dealing with these problems.

Keywords: conceptual models, interdisciplinarity, curriculum development, problem-oriented education, environmental science

Since its emergence in the 1970s as a new interdisciplinary research and education field, the environmental sciences have acquired an established place in academia worldwide. In virtually all countries of the world, universities offer environmental sciences education at the bachelor's, master's, or PhD level. This does not mean, however, that all challenges involved in implementing environmental sciences as an academic curriculum have successfully been solved. The wide range of relevant topics and the interdisciplinary character of environmental sciences pose potential problems to curriculum and course developers, as well as to students. A real danger is that environmental sciences programs may lack curricular depth and coherence and that their students could be exposed to a superficial hodgepodge of competing disciplinary perspectives on environmental issues (Soulé and Press 1998).

These problems have been addressed and strategies for coping with them have been presented in several studies (see, e.g., Soulé and Press 1998, Maniates and Whissel 2000, Vedeld and Krogh 2005, Chapman 2007). Among these studies, however, there are few in which the use of conceptual models for structuring academic environmental sciences education was elaborated on. This is remarkable because models play a crucial role in structuring environmental sciences research. In the past, such models have repeatedly been proposed as major instruments for obtaining insight into environmental problems and solutions and as a unifying framework in environmental sciences education (Macinko 1978, Petak 1981, Janssen et al. 1990, Udo de Haes 1991, De Groot 1992, Udo de Haes and Heijungs 1996). As we will demonstrate, such models are also more frequently applied in environmental education than the lack of coverage in the literature might suggest.

In this article, we review the merits of conceptual models as tools for integrating knowledge of environmental issues and for clarifying the process of environmental sciences research. Therefore, the following guiding questions are addressed in the present article: What major conceptual models may have been used implicitly or explicitly as unifying frameworks in environmental sciences research and education? What can be learned from comparing and analyzing these models about their potential roles in structuring environmental sciences education?

Our analysis is based on literature research and on our personal experiences and communications. For more than three decades, we have been intensively involved in the

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development of the environmental sciences curriculum at Wageningen University and have remained in close contact with the developers of many similar curricula worldwide.

In the following sections, we first address the characteristics of environmental sciences education, in order to delineate the focus of our study within the rich and variegated landscape of higher education about environmental issues. Second, we discuss conceptual models and their role in environmental sciences and education. Then, we describe the major types of conceptual models used in environmental sciences over the last forty years that are relevant for the educational context. To illustrate the use of these models in education, we present a few explicit examples in separate boxes. When discussing how to apply the models to environmental problems, we will use examples of fisheries, fish stocks, and the conservation of marine resources. In the last part of the article, we compare and discuss the models and identify consequences for contemporary environmental sciences education.

Characteristics and challenges of environmental sciences programs

Fueled by an increasing scientific and societal attention to environmental issues, a widely diverging set of higher education environmental programs has been developed over the last four decades (e.g., for the Netherlands, Copius Peereboom and Bouwer 1993, Ginjaar and Zijderveld 1996, Schoot Uiterkamp and Leroy 2008; for the United States, Maniates and Whissel 2000, Vincent and Focht 2009). Many of these programs are labeled *environmental sciences* or *environmental studies*, but similar programs are also offered under labels such as *ecology*, *resource management*, *environmental management*, *land-use planning*, or *human geography* (see, e.g., Vedeld and Krogh 2005, Kainer et al. 2006, QAA 2007). Before we embark on analyzing conceptual models, it is important that we characterize the different types of programs and specify the scope of the present article.

An approach frequently used to distinguish environmental programs is to look at the disciplines involved. An environmental degree program can be situated in a triangle covered by the natural sciences, the social sciences, and the humanities (Maniates and Whissel 2000). In the Anglo-Saxon tradition, *environmental science* (or *sciences*) often signals an emphasis on natural sciences (including ecology, toxicology, geology, hydrology, and meteorology), whereas *environmental studies* indicates an emphasis on social and policy studies and humanities (Vincent and Focht 2009). A similar distinction is used by an expert group that defined subject benchmarks of environmental sciences programs for the UK Quality Assurance Agency for Higher Education (QAA). They identified the study of the relationship between human systems and Earth systems as a key feature of environmental sciences programs and located environmental sciences programs between Earth sciences, which are focused on the study of the Earth systems (or the biophysical environment), and environmental studies, which are focused on the human systems (QAA 2007). As was demonstrated by the positioning of environmental sciences between biophysical systems and human systems, the emphasis on natural sciences in environmental sciences programs is relative, not exclusive. Studying the interactions between Earth systems and human systems is generally highlighted as a central characteristic of environmental sciences programs (Vincent and Focht 2009). Environmental sciences programs—notwithstanding the differences in emphases—will therefore typically contain a broad range of disciplines from different corners of the triangle.

In their review, Vincent and Focht (2009) presented another interesting principle for distinguishing programs. This principle is based on the perspective that guides curriculum design. They identified three distinct but not opposing perspectives: (1) *the environmental scientist*, which refers to a curriculum that is anchored within a single discipline, such as chemistry or biology; (2) *the environmental citizen*, in which a broad curriculum that includes the natural sciences, social sciences, and the humanities is favored; and (3) *the environmental problem solver*, a curriculum in which the aim is to educate environmental professionals, who are able to use systems approaches and to draw on insights and tools from various disciplines in order to address complex environmental issues.

These three perspectives help to further specify the scope of the present article. We will investigate the use and meaning of conceptual models in curricula in which natural and social sciences are combined with an *environmental problem solver* perspective. Analyzing and designing solutions to environmental problems by integrating knowledge from different disciplines is a key component of such programs. We have further limited our scope to programs at the university level (undergraduate and graduate). When we discuss disciplinary and interdisciplinary knowledge, our focus is on both the natural and the social sciences (including economics) and less on the humanities, although some of the issues discussed will be relevant to the latter, too.

The characteristics of such an environmental sciences program induce two interrelated challenges for curriculum and course developers. The first challenge concerns the structure of the program: How to does one design a curriculum that is coherent while including various disciplines? Environmental sciences programs often encompass courses or course tracks from particular disciplinary angles, together with integrating courses, seminars, and workgroups (Maniates and Whissel 2000). But which disciplines should be central in the curriculum, and how far should students be educated within each of them? What is the proper place for integrating elements, and how can these elements be organized? And last but not least, how can students gain an overview of this structure, so that they can understand how specific course contents fit within the bigger picture? This challenge of program structuring has been illustrated in many studies (e.g., Soulé and Press 1998, De Groot and De Wit 1999, Maniates and Whissel 2000, Chapman 2007, Vincent and Focht 2009).

The second challenge is teaching integrated problem solving. How can students be stimulated to develop the capacity to analyze and solve complex problems? This second challenge follows from the previous one. It is not sufficient that students acquire relevant combinations of disciplinary knowledge and skills and participate in integrating courses or workshops. In doing so, they also need to learn how to integrate knowledge and skills in dealing with complex environmental problems (i.e., problems characterized by uncertainties, diverging social interests, and conflicting views on the nature of the problem and the best ways to solve it). This challenge has also been addressed in many studies (see e.g., Scholz and Tietje 2002, Vedeld and Krogh 2005, Fortuin and Bush 2010).

In exploring the prospects of interdisciplinarity and transdisciplinarity, Pohl and Hirsch Hadorn (2008) and Klein (2008) pointed at several aspects of learning: Students need to be able to grasp the complexity of human and Earth systems; students need to acknowledge the political and ethical aspects of dealing with such problems; students need to be aware of various scientific and nonscientific perspectives, methods, and approaches; students need to be able to communicate over the boundaries of disciplines and to see the importance of mutual learning; and students need to learn how to interrelate broad ranges of factors to come up with an integrated understanding. In this article, we explore the potential of conceptual models to help in these crucial learning processes.

Searching for models in environmental sciences education

Conceptual models, as we use the term here, are abstract representations of reality. They are usually depicted as two-dimensional diagrams consisting of circles or boxes showing the main elements or variables of a system and lines or arrows explaining the relationships among these elements. The elements can be qualitative or quantitative. Their relationships may be mathematically defined but may also consist of other, more loosely defined sorts of influences. Quantitative mathematical models are almost always used in computerized forms to facilitate the calculation and graphical presentation of results. Because of the increasing availability of information and communication technology facilities, such models are increasingly used in education. Qualitative modeling, with or without computer support, can also be used successfully in education. Examples are the so-called “mind maps” and “concept maps.” Novak and Canas (2008), for instance, described the use of concept maps in education and argued that these concept maps can help students structure, retrieve, and construct knowledge, which thereby substantially improves the learning process.

In the literature on interdisciplinary environmental research, conceptual models are frequently put forward as vital tools. They can provide a common framework to analyze and describe complex systems, such as social–ecological systems, and to integrate knowledge from different disciplines (Ostrom 2009). They can be important for bringing together different disciplinary perspectives and terminology (Leemans 2008). They can also help to define a common structure for an interdisciplinary research project that consists of different subprojects. Such a model can help identify the main components of the problem area addressed and can also facilitate the distribution of work among the researchers involved (Olsson and Sjöstedt 2005). Using similar arguments, several other authors have advocated the use of conceptual models as a heuristic tool in a collaborative research project, to assist in the integration of knowledge and the framing of the problem, as well as to improve the communication among scientists with different backgrounds (e.g., Heemskerk et al. 2003). Given these arguments, it is plausible that conceptual models could also be useful in overcoming the challenges of interdisciplinary environmental education, as it was described in the previous section. Several authors have, indeed, advocated the use of “unifying” models to help clarify the domain of environmental sciences and to help integrate different types of knowledge in researching environmental problems (Petak 1981, Janssen et al. 1990, Udo de Haes 1991, De Groot 1998, Scholz and Binder 2003, Tapio and Willamo 2008).

In order to identify conceptual models that could serve these purposes, we reviewed the literature in a general science database (Scopus) and in an educational database (ERIC). We searched for models that met the following criteria: (a) The model must be sufficiently generic to cover the key components of environmental sciences, (b) the physical and social aspects of the environmental sciences must be included in the model, (c) the integration of scientific disciplines in environmental research must be addressed, and (d) the model must be operationally applied in an environmental sciences curriculum or course.

The results surprised us. Only a few models met these criteria. Clearly, there is an abundance of literature on multi- and interdisciplinarity in environmental sciences. However, we did not search for models that were used in a particular environmental sciences *research project* and that were tailored for that project. These models are likely not generic enough to provide an overarching view of complex environmental problems and interdisciplinary environmental research. There are also many publications on frameworks used to explain the teaching and learning processes in an interdisciplinary context in a curriculum or specific course (e.g., Kainer et al. 2006, Ivens et al. 2007). Although these frameworks can definitely be helpful for students, we did not include them because they were not focused on environmental sciences and research. We found remarkably few publications on the types of models we were interested in—that is, generic models that could help curriculum and course developers and students structure environmental sciences or interdisciplinary environmental research and that could be used in the development of environmental sciences curricula.

The models we retrieved can broadly be divided into two categories: domain models and process models. *Domain models* are conceptual models that structure the domain of environmental problems. In other words, these models provide an overview of the subject areas that the environmental sciences deal with. Process models are models that structure the process of environmental research; that is, they depict the different steps in an environmental-research process and clarify how these steps are related to the societal processes important to the research (i.e., how they relate to environmental problem solving). In the next section, we will further examine these two categories. Given the scarcity of publications on these models, we cannot provide a comprehensive overview of generic models used in environmental sciences education. Rather, we will focus on four examples of models—two from each category—that are applied in education and that we consider to be well developed and fairly representative for the scope of our investigation.

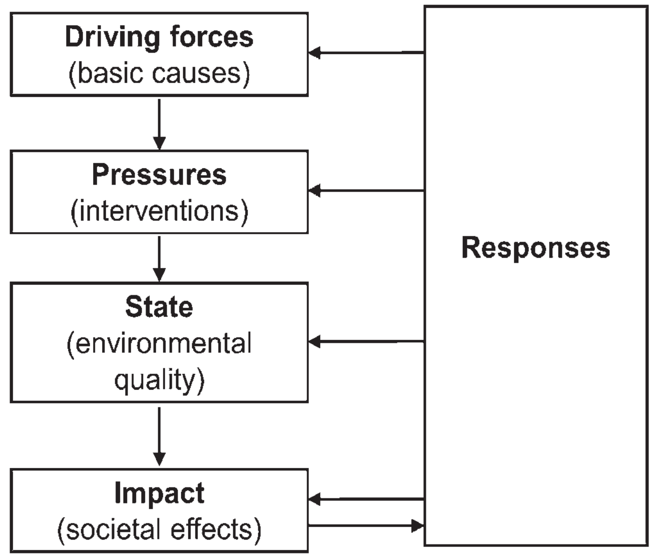

Figure 1. The DPSIR (driving forces–pressure–state–impact–response) framework. Source: Adapted from Smeets and Weterings 1999.

Domain models

Domain models are conceptual models that structure the domain of environmental sciences. They describe components or processes involved in environmental problems. These models thus structure the objects of environmental research. The most basic domain models describe the different compartments of the physical environment (e.g., hydrosphere, lithosphere, atmosphere, biosphere) and their links with sociocultural systems. A different, somewhat affiliated type of domain model is the *level model*, which distinguishes different levels in the physical environment—for example, from atoms and molecules to organisms and ecosystems. Humans and societies can also be added to such hierarchies, which are often inspired by Von Bertalanffy's general systems theory (Von Bertalanffy 1968). Such models are frequently taught in environmental courses but are generally not used as overarching models for environmental sciences curricula. An obvious reason for this is that they ignore processes of causation of or action against environmental problems.

DPSIR and other causal-chain models. A major group of domain models is influenced by the PSR (pressure–state–response) model developed by the Organisation for Economic Co-operation and Development (OECD 1993). This model distinguishes *pressures* from human activities that affect the system's *state* (i.e., the quality and quantity of natural resources) and societal *responses* (i.e., environmental and other policies and changes in awareness and behavior) to mitigate the environmental impacts. After its publication in the early 1990s, it soon became a well-known and widely used framework.

The European Environment Agency expanded the PSR model into the DPSIR (driving forces–pressure–state–impact–response) model to structure the use of environmental indicators and to harmonize environmental policy reporting. The DPSIR model added the social and economic developments denoted as *driving forces* and makes a distinction between changes in the system's *state* of the environment and the *impacts* on ecosystems, resources, materials, and human health. A societal response may provide feedback on the driving forces but also on the pressures, state, or impacts directly, through adaptation or curative action (figure 1; Smeets and Weterings 1999).

The DPSIR model can be used to analyze an environmental issue, as we illustrate here with the example of depleted fish stocks. Examples of driving forces that deplete fish stocks are the rising demand for seafood and the recent increase in fishing fleet size and efficiency, which has resulted in an enormous growth of the exploitation of marine fishes (pressure). Fish stocks have seriously declined or even been depleted in many parts of the world (state). Fish stock depletion has an impact on people who depend on seafood as their main source of protein and on people who depend on fishing for their income. To cope with these problems, several kinds of solutions (responses) have been proposed, such as catch restrictions, gear modification, and the protection of marine areas.

In the Dutch debate on the domain of environmental sciences in the 1980s and 1990s, cause–effect frameworks similar to the DPSIR model were proposed, such as the *environmental problem chain* (EPC), which was quite generally used in characterizing the domain of environmental sciences (see, e.g., Janssen et al. 1990, Udo de Haes 1991). The EPC is a framework that describes environmental problems as a chain of the following elements: Basic causes lead through societal activities or situations and interventions to environmental effects and finally to societal effects (i.e., effects that are considered problematic by society).

Both the PSR and the DPSIR frameworks have strong natural-science bases. From a social-sciences perspective, these frameworks have shortcomings, because they do not account for all the complexity of and interactions within society. In reality, responses do not automatically follow an impact, and what happens within society is much more complicated than what can be illustrated by a single *driving force*. That is why there have been several attempts to expand the EPC and DPSIR models to include societal aspects.

Janssen and colleagues (1990) expanded the EPC model with an *environmental policy chain*, which mirrors the problem chain. The environmental policy chain explains where and how environmental problems are influenced by society and indicates where interventions are possible. It was developed to identify ways to regulate or mitigate environmental problems and provides an analytical tool to evaluate and design environmental policy. Although this model is useful, it lacks some of the simplicity and transparency of the DPSIR model.

Tapio and Willamo (2008) introduced the environmental protection process (EPP) framework as a more detailed version of the DPSIR model to counteract its shortcomings. Just like Janssen and colleagues (1990), they included the policymaking process. Moreover, instead of treating society as a generalized abstraction and lumping all factors that affect human action together as *drivers*, they distinguished in their model three categories that affect human actions on different levels: (1) individual factors (e.g., knowledge, values, emotions, experiences, resources), (2) societal factors (e.g., politics, administration, legislation, economy, science, education, religion, mass media, social activism), and (3) ecological factors (e.g., landscape topography).

A common feature of all of the frameworks described so far (DPSIR, EPC, and EPP) is their perspective: They all take environmental *problems* as their starting point. These problems originate in the interaction between human systems and Earth systems. The EPC and EPP models are designed to investigate the root causes more thoroughly than the DPSIR model, but in the end, all three frameworks are designed to answer three main questions (following Tapio and Willamo 2008): (1) Why are there environmental problems? (2) What are these problems' characteristics? And (3) in what ways can these problems be mitigated?

Obviously, the real world is far more complex than what can be expressed in these simple linear conceptual models. The strengths of the DPSIR-like models are, however, that they are easy to understand and that they can be used to clearly visualize the interactions between changes in the biophysical environment and human systems. They are generic and therefore suitable analytical tools for the examination of many environmental issues. DPSIR-like models are frequently used in environmental assessments and research projects and have great merits for education as well.

The DPSIR, EPC, and EPP models have all been used in education to structure environmental issues and to navigate and focus in the broad range of relevant disciplines (Bouwer and Leroy 1995, Tapio and Willamo 2008, Boersema and Reijnders 2009). At Wageningen University, the DPSIR model was central in the environmental sciences curriculum developed in 2000 (see box 1). In Finnish environmental sciences education, the EPP model is used to structure a university-level basic course textbook (Tapio and Willamo 2008; see box 2). These models are thus used as a framework to assist students in seeing connections between different elements of a curriculum or course and as conceptual tools that assist those students in analyzing an environmental problem and in identifying ways to mitigate it.

The ecosystem-based model of the Millennium Ecosystem Assessment. Since the turn of the twenty-first century, sustainability has become more and more important as a guiding principle in environmental sciences education (see, e.g., the textbooks by Botkin and Keller 2000, Nebel and Wright 2000, Wright 2005, Cunningham and Cunningham 2006, Miller and Spoolman 2008). A framework that fits well within this sustainability approach is that of the Millennium Ecosystem Assessment (MA 2003). Crucial to this framework is the use of the concept of *ecosystem services* as

Box 1. The DPSIR model and the Wageningen environmental sciences curriculum.

Until the late 1980s, the environmental sciences curriculum of Wageningen University was focused on pollution problems, and the source–distribution–effect model was dominant in the study. Courses mainly addressed the emission of environmental pollution into the environment; the distribution and transformation of this pollution in water, air and, soil; and the effects of pollution on public health and ecosystems. Students could specialize in water, air, and soil quality; environmental technology; environmental toxicology; and environment health. Within the environmental technology specialization, the focus was mainly on wastewater treatment. Since the 1980s, courses in environmental policy and company environmental management have gained importance, and in addition to cleaning and sanitation, prevention became a key element of environmental technology. Furthermore, the integration of compartments and the integration of environmental issues with spatial-planning issues became more prominent. In 2000, environmental systems analysis, environmental policy (studying driving forces of environmental problems), and environmental management (addressing the response of society to the impacts of environmental problems) were added as new specializations to the curriculum. As an overarching model of this curriculum, the source–distribution–effect model was replaced by the DPSIR (driving forces–pressure–state–impact–response) model.

Box 2. The EPP model in Finnish environmental sciences education.

The environmental protection process (EPP) model is used in Finland to structure environmental sciences education. The model is broad in scope, but it helps its users to navigate and focus within the many disciplines relevant for environmental sciences. The EPP model takes a problem-oriented approach, just like the DPSIR model. Starting with an environmental problem, such as air pollution in a particular city, the EPP model helps determine which knowledge from, for instance, cognitive psychology, environmental economy, environmental sociology, environmental chemistry, environmental health, or environmental technology is relevant enough to be taken into account—namely, the knowledge that is useful for understanding why there is air pollution in the city (e.g., increased traffic caused by urban sprawl), what the characteristics are of this air pollution (e.g., mainly carbon monoxide, oxides of nitrogen, volatile organic compounds and particulates caused by car traffic), and how it can be mitigated (e.g., improved public transportation). The model is not meant to provide an overall theory. Instead, it is used as a broad, flexible framework, open to different kinds of theories and interpretations (Tapio and Willamo 2008).

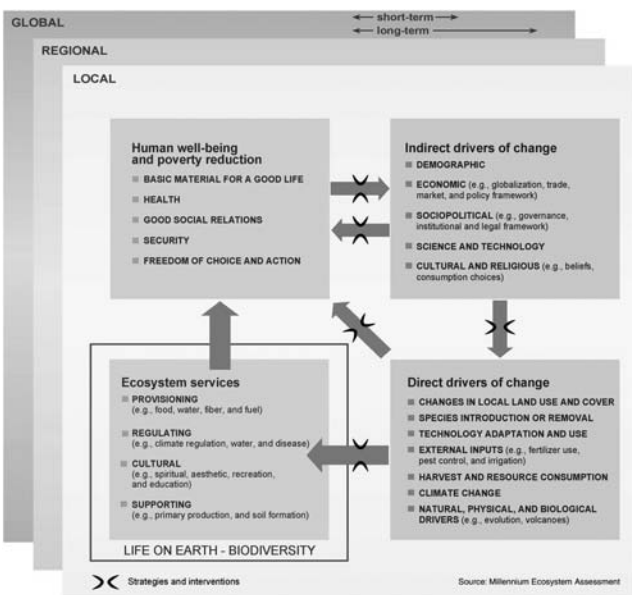

Figure 2. Millennium Ecosystem Assessment framework. Credit: Reprinted with permission from MA 2003.

a way of explaining the shorter- and longer-term linkages between people and the environment at local, regional, and global levels. Humans depend on the benefits they obtain from ecosystems (i.e., the ecosystem services) for their well-being. In the MA framework, a distinction is made between provisioning services, regulating services, cultural services, and supporting services (see figure 2). Marine ecosystems, for instance, provide vital food resources for millions of people but also provide regulating services, such as carbon sequestration and waste detoxification. For many fishing societies, in which fishing is an inextricably part of the livelihood, fish resources not only provide food and income but also have important cultural meaning and therefore provide cultural services. Changes in these provisioning, regulating, and cultural services affect human well-being through impacts on the basic material needed for a good life, health, good social and cultural relations, and security. These constituents of well-being are in turn influenced by and have an influence on the freedoms and choices available to people (MA 2003). Therefore, instead of investigating the impacts of human actions on the environment (e.g., the exploitation of fish stocks) and instead of treating ecosystems and the environment as externalities to the human system, as is often done in environmental sciences models (see, e.g., DPSIR and related models), humans are considered an integral part of ecosystems in the MA framework.

Whereas we found that the DPSIR model is focused on the problematic aspects of the relationship between human and environment systems (e.g., the depletion of fish stocks), the MA framework highlights the opportunities that nature (biodiversity) provides for improved quality of human life (e.g., the various marine ecosystem services). It takes biodiversity as its basic starting point. By focusing on ecosystem services and human well-being, the MA framework takes a more positive and future-oriented perspective than the problem-oriented DPSIR approach. Moreover, by identifying various categories of services, the MA framework assumes that nature provides a broad range of positive services. Because it includes the category of cultural services and because it takes a broad view of human well-being, it also integrates nonmaterial services. In this way, the role of culture in dealing with nature is highlighted. This is completely lacking in DPSIR-like models.

Just a few years after the release of the MA, it is used in university education all over the world. Reid (2006) did a survey among individuals that were involved in the MA process to investigate the impacts of the assessment. He found that the MA material and the MA conceptual framework are being used extensively in university courses and curricula. The material is not only used in environmental sciences (see, e.g., box 3) but also in courses on conservation biology or ecology and in courses addressing sustainability and globalization. The MA framework appears to be suitable for teaching global issues, but it can also be used to teach resource use in a specific region, to analyze drivers of change, and to identify opportunities for intervention. Reid (2006) did not address whether the conceptual framework had an impact on whole curricula, but it is clear that the framework was rapidly adopted and integrated into university courses. This is also illustrated by environmental textbooks that have

Box 3. The MA framework in Wright's environmental sciences textbook.

In the ninth edition of his textbook *Environmental Science*, Wright (2005) introduced the Millennium Ecosystem Assessment (MA 2003) framework for the first time. The MA and its conceptual framework are explained in the first chapter, and new integrative themes that are influenced by this framework are introduced: (a) ecosystem capital, (b) policy and politics, and (c) globalization (Wright 2005, p. xviii). These integrative themes provide important threads for the textbook and link the different subjects and chapters, together with three strategic themes that were retained from the eighth edition: sustainability, science, and stewardship.

In the 10th edition (Wright 2008), the MA is fully integrated into Wright's textbook. Again, the MA and its framework are introduced in the first chapter, and the integrative and strategic themes are kept, but in this edition the findings from the MA are used throughout the textbook to illustrate or underpin the author's message and to interconnect different subjects and issues.

The 11th edition (Wright and Boorse 2011) starts with the introduction of a framework for a sustainable future. A chapter on economics, politics, and public policy that used to be one of the last chapters has become part of this framework. The authors have chosen to go back to the three themes for environmental sciences that they used in earlier editions of the book: "*sound science*, the basis for our understanding of how the world works and how human systems interact with it; *sustainability*, the practical goal that our interaction with the world should be working toward; and *stewardship*, the actions and programs that manage natural resources and human-well-being for the common good" (Wright and Boorse 2011, p. xvi).

Overall, the MA framework helped to further articulate and illustrate old ideas. It did not represent a revolutionary new way of thinking but did help to label earlier perceptions. The MA framework was apparently less appropriate for the organization of the full content of the environmental sciences textbook. The structuring value of the MA framework was mainly its role as a recurring theme: as a typical example (paradigm) of sound science for sustainability.

recently been published (e.g., De Kraker 2007, Miller and Spoolman 2008, Wright 2008).

Process models

In this section, we describe *process models*, which structure the process of environmental research (in particular, research that addresses societal problems). The models of this category do not describe the components or processes that are the object of environmental research; they depict the steps in an environmental-research process and its relation with societal processes. As we explained above, a characteristic of environmental sciences research is its link to societal problems. Integration of knowledge and moral and ethical aspects related to societal problems are important for environmental research. The process models may be applicable to other (problem-oriented or interdisciplinary) research as well. In this section, however, we focus on those models that are sufficiently generic to cover the key components of the environmental-research process.

Models for problem-oriented research. In the 1980s, several models for problem-oriented research were developed, usually by combining models in which the different steps in research were described with models in which problem solving was described. A model that is used in environmental sciences education and that is characteristic of this period is the model for problem-oriented research developed by van Koppen and Blom (1986; also see figure 3). This model highlights the point that, in problem-oriented research, science becomes involved in a societal process of problem solving. Scientists take part in this process, but the logic of problem solving and the logic of scientific research are not the same. Societal actors determine whether there is a problem (e.g., fish stocks are declining) and are responsible for solving the societal problem by performing a successful intervention (e.g., the implementation of catch restrictions or protected areas), whereas scientists are responsible for generating reliable knowledge to support these problem definitions and interventions. Scientists can, for instance, investigate the effects of the exploitation of marine resources on species composition, size structure, biomass, and other ecosystem properties or those of the impacts or minimum size of protected areas. Scientists, when they are doing research, follow the logic of the empirical cycle of scientific research (the right side of figure 3). To translate societal questions on analysis and strategy into scientific research questions, scientists use specific frames and models (e.g., ecosystem models, "Scientific model" in figure 3) that are usually simplified representations of the problem domain.

The van Koppen and Blom (1986) model helps students to understand the differences between problem solving as a societal process and scientific research and to distinguish different steps that are relevant to problem-oriented research. For instance, it helps them to see that defining a problem is a normative process determined by stakeholders, that their scientific models provide only a partial view on the problem domain, and that a good scientific outcome, as such, does not solve the societal problem. The results of the ecosystem models do not solve the problems of resource depletion or the difficulties related to the implementation of catch restrictions or protected areas.

The van Koppen and Blom (1986) model does not explicitly address interdisciplinarity. Although students who do problem-oriented research might realize that knowledge from various scientific disciplines and other sorts of knowledge play a role in tackling the societal problem, the research they conduct can be based on a purely disciplinary model.

Several other authors have made efforts to further detail and elaborate models of the environmental-research process. An elaborate example is the problem-in-context (PiC) model developed by De Groot (1998). The PiC model encompasses the whole domain of environmental sciences, including the natural sciences, the social sciences, and the humanities, as well as normative elements related to societal problems. At the same time, the PiC model provides a methodological framework (a) to analyze perceived environmental problems; (b) to explain their societal root causes; (c) to identify any involved actors, their options, and motivations; and (d) to design and evaluate solutions for these problems. De Groot (1998) tried, in fact, to combine the domain of environmental sciences and environmental research and problem solving into one comprehensive model. The PiC model is used in education, but its comprehensiveness and complexity make it difficult to implement.

Both the van Koppen and Blom (1986) model and the PiC model have been used in environmental sciences education in the Netherlands. They are introduced to students in courses in which the students have to practice environmental research and to reflect both on the societal and ethical implications of that research and on their role as scientists in solving a societal problem. A methodological framework turned out to be necessary to help the students structure their work and their reflection (see box 4; van Koppen and Blom 1986).

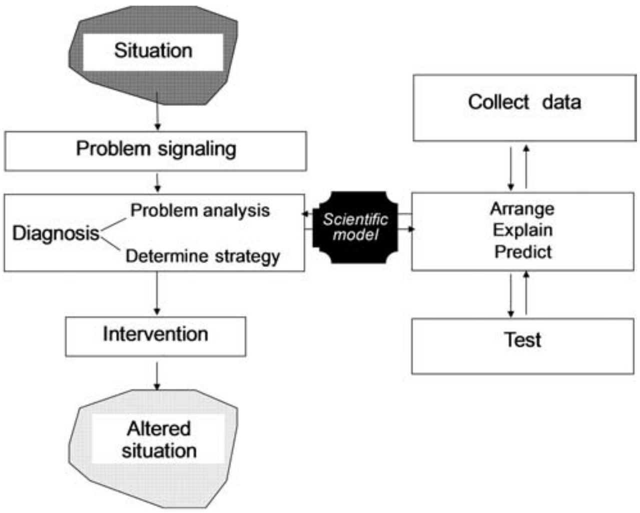

Figure 3. The van Koppen and Blom (1986) model for problem-oriented research. Source: Adapted from van Koppen and Blom 1986.

Models for transdisciplinary research. In current publications on environmental sciences education and research, transdisciplinary approaches have become prominent (see, e.g., Pohl 2005, Scholz et al. 2006, Regeer and Bunders 2009). Transdisciplinary research aims to contribute to solving or mitigating complex social problems by including stakeholders. Characteristic of transdisciplinary research is that it

Box 4. The van Koppen and Blom (1986) model for problem-oriented research in a bachelor's-level course.

The van Koppen and Blom (1986) model (figure 3) is used in the bachelor's-level course Environmental Project Studies at Wageningen University. The aim of this course is to acquaint students with solving an environmental problem, with carrying out scientific research, and with the relationship between science and society.

In this course, a team of four students analyzes a real-life environmental problem proposed by a nonacademic professional (e.g., from a local government or nongovernmental organization). This professional—the commissioner of the project—proposes the problem and is responsible for the interventions to solve the problem (see the left side of figure 3). The students discuss the problem with the professional, design a research plan, and execute this research plan (see the right side of figure 3). Usually, they review literature, interview people, or conduct practical research to collect data and analyze them. The team arranges its results and formulates conclusions. Finally, the team presents the professional with a written report on the results of their research. The professional, who is responsible for dealing with the societal problem, decides what to do with the students' results and communicates this to the students.

One student project was related to the problem of global warming caused by the high consumption of fossil fuels. To mitigate this problem, the European Union has proposed gradually increasing the percentage of biodiesel in diesel fuel to 10% by the year 2020. A Dutch firm with commercial interests in sustainable energy wanted to understand the possible contribution of sustainable palm oil in this strategy. The main research question that the students formulated was "How much can the production of sustainable palm oil contribute to the European diesel-fuel market by the year 2020?" Their subresearch questions were related to the developments of the diesel-fuel market in Europe and the palm oil market in the world, as well as to the possibilities of a sustainable palm oil production. The students did a literature review, investigated databases, and interviewed experts. One of their conclusions was that palm oil production practice has many shortcomings. They pointed out the necessity of designing solutions to overcome the unsustainability of current production.

After conducting the research, the students reflected on their work. They discussed the societal and ethical implications of their research and their role as scientists in solving a societal problem. One of the issues that they discussed was the trade-off between the solutions proposed by the European Union to mitigate global warming and the loss of biodiversity caused by palm oil cultivation in other parts of the world. The framework illustrated in figure 3 proved to be helpful for this reflection. The students realized that the design and execution of their problem-oriented research and their recommendations were partly determined by the interests and needs of the professional who had proposed the problem (Fortuin and Van Es 1999).

tries to "(a) grasp the complexity of problems, (b) take into account the diversity of life–world and scientific perceptions of problems, (c) link abstract and case-specific knowledge, and (d) develop knowledge and practices that promote what is perceived to be the common good" (Pohl and Hirsch Hadorn 2007, p. 20). The *Lebenswelt* perceptions of laypeople are explicitly included in transdisciplinary research, and an intensive interaction between scientists from different disciplines and actors from society is required in all stages of the research.

Jahn (2008) developed a conceptual model for transdisciplinary research (see figure 4). We introduce it here because it provides a characteristic and clear representation of transdisciplinary approaches. In this model for transdisciplinary research, there is still a distinction between dealing with a societal problem (see the left column in figure 4) and doing scientific research (see the right column in figure 4), but during the transdisciplinary research process, the interaction between scientists and societal actors is very intensive (see the middle column of figure 4). The example of the overexploitation of marine ecosystems and the depletion of fish stocks can again illustrate this interaction. Several management tools have been proposed and implemented to mitigate these problems. These management tools are based on scientific research in disciplines such as fisheries and conservation biology. Indeed, catch restrictions, gear modification, and protected areas have helped to reduce the exploitation rates of fish stocks. The results are, however, very different in different ecosystems (Worm et al. 2009). Apparently, the interaction among fish, fisherman, and management system is very complex, and context-dependent solutions are needed. Such solutions must involve the local characteristics of the fisheries, ecosystem, and governance system. The development of these context-dependent solutions can be the starting point of a transdisciplinary research process.

This process starts with a problem-framing phase, in which a team of scientists and societal actors jointly formulate a common research object (e.g., sustainable fisheries) and (disciplinary or interdisciplinary) research questions. Consequently, different subprojects are executed for which knowledge from several disciplines (e.g., ecology and economics) and knowledge from practice (e.g., local fisheries practices) is needed. This is also the phase at which new knowledge is produced or existing knowledge is combined or integrated. The compatibility among the different subprojects and the possibility of integrating these projects are of special concern ("New transferable knowledge" in figure 4).

Finally, at the last phase of the research process, transdisciplinary integration, strategies, innovations, and transformations should be developed to address both societal and scientific problems (Jahn 2008). Although the Jahn (2008) model for transdisciplinary research is quite recent, it is already used in education (see box 5).

Potential functions of the selected models

The DPSIR model, the MA framework, the van Koppen and Blom (1986) model, and the Jahn (2008) model described in this article are valuable heuristic tools that can be used to structure environmental sciences education. They are helpful because they are generic, simple, and straightforward and can be easily understood by students. The function that these models might serve in structuring environmental sciences education varies. Table 1 lists the potential functions as we have encountered them in the literature and in our analysis. We have also indicated our assessment of the relative strengths of the models in fulfilling these functions. We will discuss these functions and our assessment of them below.

Of the two domain models, the DPSIR model provides a better framework to structure an environmental sciences curriculum—in particular, a curriculum with an *environmental problem solver* perspective—than the MA framework does. Disciplinary scientific knowledge can be more easily located within the DPSIR model than within the MA framework. Practitioners of the natural sciences (e.g., biology, physics, chemistry) study the environmental pressures, states, and impacts through the investigation of, for instance, the emission of pollutants and their effects on organisms and

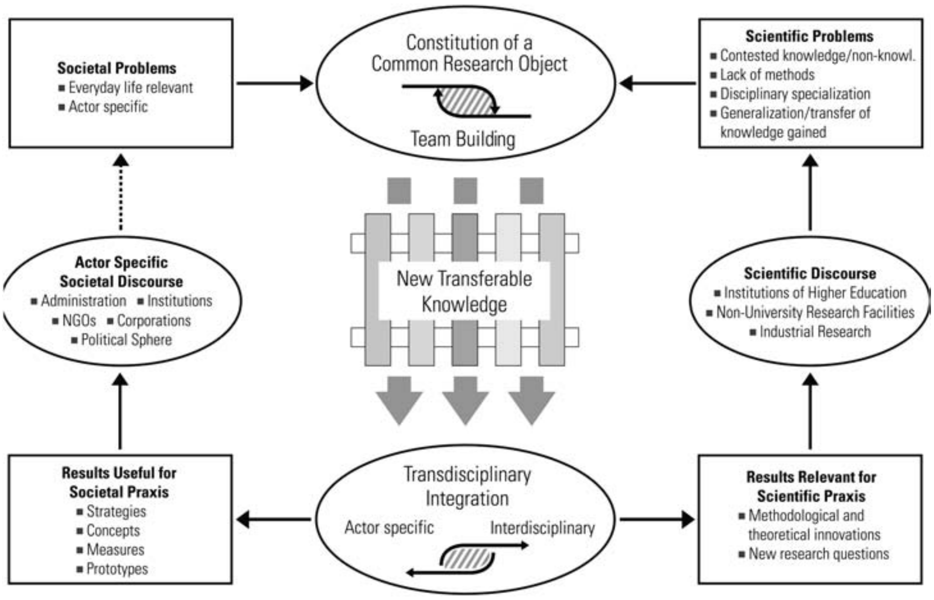

Figure 4. The Jahn (2008) model for transdisciplinary research. Source: Reprinted with permission from Jahn 2008.

Box 5. The Jahn (2008) model for transdisciplinary research in an interdisciplinary course at the Technische Universität Darmstadt.

The Jahn (2008) model for transdisciplinary research is used by Stieß and Field in their course, Social Ecology—Theory, Methodology, and Praxis of Transdisciplinary Research, at the Technische Universität Darmstadt. The course is part of an interdisciplinary study focus in environmental sciences and was attended by students from engineering and the social and educational sciences. Stieß explained that, on a general level, the model was used to introduce and explain characteristic stages of the transdisciplinary research process and to discuss basic methodological implications, such as problem–actor orientation and knowledge integration. It was also used as a tool for analyzing empirical research processes in order to exemplify those characteristic stages, with two research projects of the Institute for Social–Ecological Research (ISOE) as examples. Stieß said, "We found it very helpful to use the model as a device to link the discussion on a conceptual level to the analysis of more tangible empirical examples. This helped the students to better understand the specific features of inter- and transdisciplinary research" (Immanuel Stieß, ISOE, Frankfurt am Main, personal communication, 4 April 2010).

Table 1. Potential functions of four conceptual models in structuring environmental sciences education.

	Model			
Function of the model	DPSIR	MA	Van Koppen and Blom (1986) model for problem-oriented research	Jahn (2008) model for transdisciplinary research
To improve the coherence and focus of an environmental sciences curriculum	+	+–	–	–
To analyze environmental problems and solutions and to integrate divergent knowledge	++	++	–	–
To examine and guide an environmental problem-solving and research process	–	–	++	+
To examine and guide the integration of divergent knowledge in the environmental problem-solving and research process	+–	+–	+	++

Note: The pluses and minuses indicate the relative strengths of the models in fulfilling a specific function.
DPSIR, driving forces–pressure–state–impact–response; MA, Millennium Ecosystem Assessment.

ecosystems. Practitioners of societal disciplines, such as sociology and economics, investigate *drivers*, the societal causes of environmental problems, and pressures. Those in environmental technology and environmental policy and management investigate societal responses in order to find ways to mitigate the problem. This discipline-oriented character of the DPSIR model makes it suited to provide a framework that connects various disciplinary elements within an environmental sciences curriculum. Its problem-oriented character helps to focus and to select among the abundance of disciplinary knowledge. Using the DPSIR model as the framework of an environmental sciences program can improve the coherence of such a program.

In the MA model, however, it is possible to identify and integrate fields of study that are linked to specific services. Ecology and geology are, for instance, related to regulating and supporting services, social and cultural studies to cultural services, and agricultural sciences and mining to provisioning services. The MA framework is also one that might connect various elements or courses within a curriculum. We found, however, that it seems less suitable to structure a complete environmental sciences curriculum. Yet the MA framework offers opportunities to make connections to other areas, such as development studies, as is illustrated by the use of the MA framework in courses addressing sustainability and globalization. The DPSIR model is poorly suited for analyzing development issues (Carr et al. 2007).

Both domain models provide a very good framework for analyzing the interactions in the human–environment systems and for integrating knowledge from various disciplines. The DPSIR model is better suited for analyzing environmental problems—in particular, pollution problems. Because the MA framework takes biodiversity as its basic starting point, it is less appropriate for analyzing pollution problems that do not involve biological systems (e.g., the effects of acid rain on buildings). Crucial in the MA framework is the concept of *ecosystem service*, which is an integrative concept itself and which allows ecologists, economists, sociologists, and specialists in other disciplines to have a common language on the importance of ecosystems for human well-being.

Another difference between the MA and the DPSIR models is that the latter is a rather linear model. The DPSIR model includes feedback in the form of deliberate actions—responses—but does not address the systemic feedback that changes in ecosystems, driven directly or indirectly by changes in human condition, might have on human-well-being. The MA framework is designed to allow the examination of how changes in ecosystems influence human well-being and vice versa. In doing so, this framework takes a more dynamic perspective on the interaction between people and ecosystems than the DPSIR model does.

In both the van Koppen and Blom (1986) model for problem-oriented research and the Jahn (2008) model for transdisciplinary research, the process of environmental problem solving and research are examined and the relationship between scientific research and societal problems is clearly addressed. There are three crucial and interrelated differences in how this is illustrated in the models. First, in the Jahn (2008) model, the complexity and different perceptions of the problem and the research process are highlighted. Several research questions, which will require their own scientific methodologies, need to be formulated to tackle the full complexity of the problem. By contrast, the van Koppen and Blom (1986) model would also apply to rather simple problems that could be solved by, for example, one rather technical research project addressing an important issue in the diagnosis process (e.g., establishing whether the concentrations of specific pollutants are below or above existing standards).

At some point, the diverse perspectives in the Jahn (2008) model have to come together. The integration of divergent concepts, scientific knowledge, and practical knowledge and needs is explicitly addressed in this model (Godemann 2008). This is the second crucial difference between it and the van Koppen and Blom (1986) model. The latter stresses that scientific research has to fit in a sequence of problem solving but does not highlight the need for integrating different knowledge.

Finally, the role of science in solving societal problems is illustrated differently. In the van Koppen and Blom (1986) model, the domains of science (the empirical cycle) and that of society (the process of problem solving) are interrelated, but their relation is rather linear and they remain in distinct domains. The outcome of scientific research feeds into the problem-solving process, in which societal actors decide what to do with the results—which interventions to undertake in order to change a situation that is considered problematic. The Jahn (2008) model illustrates a continuous dialogue and interaction between the scientific world and society.

These three aspects (i.e., complexity, knowledge integration, and the role of science) are key issues in the contemporary debate on environmental sciences and illustrate the major challenges for current environmental sciences education.

Although not all models used in academic courses are documented in the literature, we believe that the models that we have discussed cover the major model types used in structuring environmental sciences education. The two more recent models present a broader approach to environmental sciences than the older models do, which have a more linear character. The MA framework does so by taking a broad range of positive environmental services (including cultural services) and a broad view on human well-being as its core, instead of focusing on the problematic relationship between humans and the environment. The transdisciplinarity model does so by highlighting the complexity of environmental issues and by representing a continuous process of interaction between scientific research and societal problem solving. These recent shifts reflect developments in society: (a) the shift from environmental problem solving toward a more systemic view of the human–environment relationship and its complexity, (b) the increased interest in sustainability or sustainable development, and (c) the changing views on the role of science in dealing with societal issues. Instead of adding specific insights to the analysis of societal problems or providing technological implementations, the role of science is seen as enhancing "the process of the social resolution of the problem, including participation and mutual learning among stakeholders" (Funtowicz et al. 1998, p. 104). If students must become aware of the various approaches to frame environmental issues and to illustrate and explain the developments in this field, these models are very suited for their education.

The conceptual models that students are exposed to during their education will affect the way they learn to look at human–environment systems and the role of science. Svarstad and colleagues (2008) clearly illustrated that the DPSIR framework is not a value-free tool but favors specific types of discourses. Therefore, the models that students use during their education will influence the ways in which they will frame environmental issues in the future. For environmental scientists, being aware of one's own framework is crucial, because it is a prerequisite for being able to reflect on it and to discuss frameworks with scientists from other disciplines (Fortuin and Bush 2010). Therefore, the models underlying a curriculum should be made explicit to students, and the students should critically reflect on these models.

Conclusions

Simple, generic conceptual models are valuable for environmental sciences education. They provide an easy to understand framework that improves the coherence and structure of an environmental sciences curriculum. Seeing the connections between different elements within a curriculum is important for curriculum and course developers and for students. Moreover, conceptual models can provide a common framework to analyze environmental problems and to integrate knowledge, and they can be used to communicate across disciplines.

It is possible to distinguish between domain models and process models. Domain models describe the components or processes involved in environmental problems. They indicate the subject area of environmental sciences. Process models depict the process of environmental research and its relation with societal problems. Both types of models are meaningful for environmental sciences education, but they have different strengths. Domain models can be used to improve the coherence and focus of an entire curriculum. In an individual course, these models can be used as an illustrative and typical example of how conceptual models can be used as frameworks for dealing with complexity and for integrating divergent knowledge. As such, their structuring value goes beyond the individual course. Process models can be introduced along with a research project on a realistic societal problem. The models discussed in this article can help students reflect on their research activities and on the characteristics of environmental sciences research. They also offer students a framework to analyze and discuss the role of science in solving environmental problems and the contribution of various disciplines to tackle environmental issues.

Although all four models presented in this article are valuable for structuring environmental sciences education, none of them is sufficient to become the only unifying framework. Rather, specific models should be used at specific points in a curriculum, with the more complex models (e.g., the MA framework, the Jahn (2008) model) situated at later stages. In the beginning of a study program (e.g., bachelor of science level), the older, more linear models (e.g., the DPSIR model and the van Koppen and Blom (1986) model) can guide students in their first stages of mastering environmental sciences. These simple models are still adequate for many environmental issues. Later, in the master's and PhD phases, more-encompassing and complex integrative conceptual models that include feedback systems and interactions between phenomena on different temporal, geographical, and organizational scales should be used. Models in which the full complexity of human–environment systems is addressed and in which the need of integrating divergent perspectives to fully comprehend this interaction is indicated should be part of graduate and postgraduate environmental sciences education.

It is essential that students be exposed to a range of conceptual models during their education, because such a variety is instrumental in making the students aware of the various approaches to framing environmental issues and in illustrating and explaining how this framing has changed over time. By applying and reflecting on these conceptual models, students become aware of the complexity of the human–environment systems and the role of science in dealing with environmental problems that affect society. That is why we strenuously advocate the use of different conceptual models for students at different stages of their education.

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