

*sous la direction de*  
Claude Debru

# **La Transdisciplinarité**

## **Comment explorer les nouvelles interfaces**

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faire allusion à quelque chose qui est resté dans les annales : le philosophe Louis Althusser avait organisé au début des années soixante-dix un enseignement dit « Cours de philosophie pour scientifiques », sous la forme d'un cycle de conférences. On peut penser ce que l'on veut de cet intitulé, mais à l'époque il avait eu un réel succès. Il n'est peut-être pas souhaitable de reprendre un intitulé de ce type actuellement, mais l'idée générale de délivrer des enseignements portant sur des problèmes philosophiques, épistémologiques ou sociologiques à des étudiants scientifiques est une idée qui convient à l'établissement<sup>5</sup>. Tout autant que d'enseigner aux littéraires et philosophes des éléments de sciences et de leur transmettre l'esprit scientifique.

5. Depuis lors, un cours de ce type a été organisé.

## **Transdisciplinary elements in university education : the case of the environmental science programme at ETH Zurich**

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### **1. Concepts and elements of transdisciplinarity**

The term "transdisciplinarity" is typically used to characterize a certain way of knowledge production (Mittelstrass 1996 : 329, Kockelmans 1979 : 128f.), called "transdisciplinary research". The term also applies to the resulting knowledge as well as the respective competences of researchers, the respective structuring of university education and of institutions. The call for transdisciplinarity came up during the second half of the 20th century. It was driven by the growing awareness of the risks for the future of society that come along with applying knowledge from highly specialized academic disciplines in real-world contexts (Beck 1986). Today, there are manifold uses of the term, and there exists a bundle of somehow related terms to be either distinguished from "transdisciplinary research" or used more or less synonymously.

When "transdisciplinarity" is distinguished from "inter-", "cross-", "multi-" and "pluridisciplinarity", distinctions refer to the kind, to the degree, or to the elements of integration (Kockelmans 1979, Jantsch 1970). Within this perspective "transdisciplinarity" basically means a way of working beyond the boundaries of disciplines<sup>1</sup> which is different

1. Today, disciplines are the primary cognitive and social units of research and teaching in universities. They also give rise to occupational and professional

from or goes beyond interdisciplinarity. But scholars have considerably different things in mind when talking about integration across these boundaries. While some reserve "transdisciplinarity" for integrative work on an all-embracing conceptual level, others use this term for the participation of stakeholders and practitioners in research, which is integration of non-academic societal actors. When transdisciplinary research is distinguished from basic and applied research the term is used for research addressing wicked real-world problems.

Pioniers of transdisciplinarity in the 1970s conceived of "transdisciplinarity" as an intellectual endeavour striving for a unity of all of our knowledge on a theoretical, a methodological or an epistemological level. The motivation behind is a concern among intellectuals such as Piaget, Jantsch or Kockelmans about the progressive differentiation within the sciences including the social sciences and humanities since the 19th century. They see segmentation and specialization of knowledge as a major barrier in dealing with the complexity of real-world problems threatening the future of global civilisation. These scholars use the term "transdisciplinarity" for their work on blueprints for such an integrative framework as for instance systems theory, which then should give guidance for innovation and technology development. Jantsch for instance uses "transdisciplinarity" for the "co-ordination of all disciplines and interdisciplines in an education/innovation system on the basis of a generalized axiomatics" (Jantsch 1970 : 411). This kind of transdisciplinary research operates on a meta-level in striving for unity of knowledge.

A second and widespread use of the term "transdisciplinarity" today is for integrating perspectives of social groups outside of academia in research, and thus going beyond integrating knowledge from different disciplines. In this understanding of "transdisciplinarity", the core idea

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roles in society. Members of a discipline share basic assumptions about what they think are interesting problems, reliable methods, and important results - using abstraction and idealization. Disciplines are providing their specific education for the young generation and they have their own academic institutions such as institutes and faculties; scientific societies; conferences; scientific journals; etc. Boundaries between disciplines are vague and they move in the course of scientific development. (for details see Stichweh 1992, Kuhn 1962)

is "different academic disciplines working jointly with practitioners to solve a real-world problem" (Klein et al. 2001 : 4). Real-world problems are perceived as instrumental problems in a broad sense meaning how to realize best a given goal. These problems are typical for applied research. Real-world problems of this kind are solved by providing instrumental knowledge, which is knowledge about appropriate tools such as technologies, regulatory means, management tools or economic instruments to solve a problem. To come up with effective and efficient solutions for the administration or the private sector participation of experts and stakeholders from the context of application in knowledge production is a means to meet the challenge of fitting abstract academic knowledge with the contexts of application.

Many real-world problems society is facing are wicked problems. The term is used by Rittel & Webber (1973) to describe problems of social policy. Contrary to instrumental problems these problems cannot be definitively described, there is no undisputable value base, and there are neither optimal nor definitive solutions to them (Rittel & Webber 1973 : 155). In the same direction Funtowicz & Ravetz (1993), in their conception of post-normal science, point at high systems uncertainties and decision stakes involved in many of today's policy issues. For this reason, they argue for an "extended peer community" consisting of all those with a stake in the dialogue on the issue" (Funtowicz & Ravetz 1993 : 739). A third use of the term "transdisciplinary research" is for research addressing wicked real-world problems. In this understanding, transdisciplinary research is distinguished from basic and applied research (Hirsch Hadorn et al. 2008), which both address clearly determined problems of either fundamental understanding or of instrumental application of basic research, while the challenges of transdisciplinary research already start with problem framing. This kind of transdisciplinary research builds a family with other approaches (Pohl & Hirsch Hadorn 2007 : 88ff) including for instance post-normal science (Funtowicz & Ravetz 1993), policy sciences (Clark 2002) and sustainability science (Kates et al 2001).

As shown before, within the ambiguous use of the term "transdisciplinary research" basically three different concepts can be distinguished : unity of knowledge (transdisciplinarity<sub>1</sub>), participation of experts from the context of application (transdisciplinarity<sub>2</sub>), and addressing wicked

problems (transdisciplinarity<sub>3</sub>). These concepts are distinguished by their understanding of “integration” and by how they relate to solving real-world problems. Both points are also important in the definition of “interdisciplinary research” by the US National Academies:

“Interdisciplinary research (IDR) is a mode of research by teams of individuals that integrates information, data, techniques, tools, perspectives, concepts, and/or theories from two or more disciplines or bodies of specialized knowledge to advance fundamental understanding or to solve problems whose solutions are beyond of the scope of a single discipline or area of research practice.” (The National Academies 2005 : 188).

In this definition “to solve problems” as distinguished from “to advance fundamental understanding” is about solving real-world problems. To relate the three understandings of “transdisciplinary research” with this definition of “interdisciplinary research” we distinguish between two different purposes of interdisciplinary research for fundamental understanding, namely unity of knowledge vs. scientific innovation. Regarding problem solving we distinguish solving instrumental problems vs. dealing with wicked problems. The three concepts of “transdisciplinary research” fit with the US National Academies’ definition of “interdisciplinary research” as shown in figure 1.

Interdisciplinarity taking place in research for solving real-world problems is also called “Mode 2 Interdisciplinarity” (Bruce et al 2004 : 460) or “recherche interdisciplinaire finalisée” (Hubert et Bonnemaire 2000 : 7). To our knowledge, “transdisciplinary research” is not used in the context of scientific innovation. Interdisciplinarity in such contexts

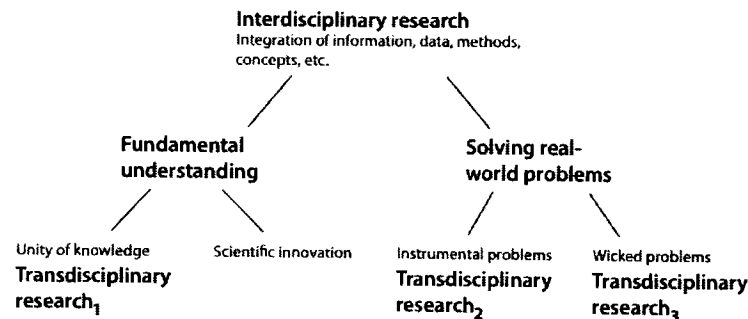


Figure 1. Interdisciplinary and transdisciplinary research.

often leads to a restructuring and progressive differentiation of disciplines. The roles that physics, chemistry or informatics have been and are playing in biology are an example of this. But interdisciplinary integration for fundamental understanding also takes place in research fields such as climate research, which conceives of climate as a complex system providing a framework for integrating subject-related knowledge from a broad range of disciplines. Such subject-oriented integration is important in research on solving real-world problems.

In what follows, we focus on transdisciplinary research addressing real-world problems. In the course of research a project on a clearly determined instrumental problem can develop towards dealing with a wicked problem, or vice versa. In general, research projects for solving real-world problems can account for the characteristics of wicked problems to varying degrees.

Transdisciplinary research addressing wicked real-world problems can be described in the following way, highlighting the core elements:

“Transdisciplinary research (TR) aims at better fitting academic knowledge production to societal needs for solving, mitigating or preventing problems such as violence, disease or environmental pollution. TR strives to grasp the relevant complexity of a problem, taking into account the diversity of both everyday world and academic perceptions of problems, linking abstract and case-specific knowledge, and developing descriptive, normative and practical knowledge for the common interest. Integration is a core feature and major challenge of TR. Practitioners of TR call for a recursive approach to problem solving, focusing on problem identification and structuring, investigation, and bringing results to fruition as the three phases of the TR process.” (Hirsch Hadorn et al. 2010 : 432).

Transdisciplinary research is providing descriptive, normative and practical knowledge for the common interest. The socio-political model of sustainable development is an elaboration of the old idea of the common good. In accordance with the precautionary principle this idea is extended to the global population and to possible harm in a long-term perspective by accounting for the complex interrelations between ecological, economic and social systems (WCED 1987). So transdisciplinary research is related to sustainable development as its guiding regulative idea (Hirsch Hadorn et al. 2006). Addressing wicked

real-world problems includes investigating (1) questions about the functioning, genesis and future perspectives of a real-world problem as well as its interpretations, (2) questions related to determining and explaining the need for change, desired goals and practices, as well as (3) questions about possible means to bring about desired change. The respective forms of knowledge have been named systems, target and transformation knowledge (ProClim 1997 : 15). Different terminology for similar distinctions have been proposed for instance by Grunwald (2004), Constanza et al (1997) or Jantsch (1970). Scholars agree that it is crucial to address these forms of knowledge in a way that accounts for mutual interdependencies to face related challenges (figure 2).

To grasp the relevant complexity of a wicked real-world problem in providing answers to these questions, it is important to account for the diversity of both everyday world and academic perceptions of problems and linking abstract and case-specific knowledge. Transdisciplinary research therefore integrates knowledge from various sources inside and outside academia, the latter encompassing the public and private sector as well as civil society. Participation is a means for integrating knowledge from different sources already in problem identification and structuring. In this first phase of the research process the needs for systems, target and transformation knowledge as well as the relevant sources of knowledge to account for complexity and diversity of perspectives are

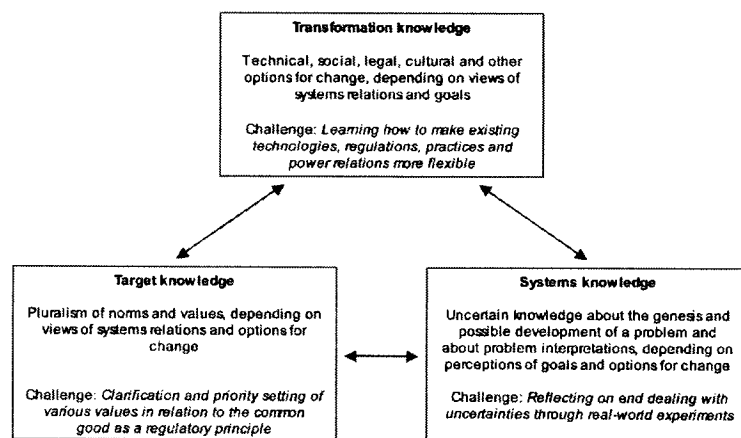


Figure 2. Interdependencies between systems, target and transformation knowledge and their particular challenges (Pohl & Hirsch Hadorn 2007 : 38), adapted.

to be determined. This means that already problem identification and structuring has to be designed as an integrative participatory endeavour. In addition, assumptions taken in problem identification and structuring might need revisions if indicated by the results of experimental implementation of knowledge in real-world case studies (Gross & Hoffmann-Riem 2005, van den Daele & Krohn 1998). Enabling reflectivity during the research process is the reason to call for dealing recursively with (1) problem identification and structuring, (2) problem investigation, and (3) bringing results to fruition as the three phases of the transdisciplinary research process (Pohl & Hirsch Hadorn 2007).

In the context of sustainable development solving wicked real-world problems through transdisciplinary research does not mean simply presenting alleged solutions from research to decision-makers. Researchers need to be concerned with bringing results to fruition in ongoing societal processes as stated by Funtowicz, Ravetz and O'Connor: "The objective of scientific endeavour in this new context may well be to enhance the process of the social resolution of the problem, including participation and mutual learning among stakeholders, rather than a definitive 'solution' or technological implementation. This is an important change in the relation between the problem identification and the prospects of science-based solutions." (Funtowicz et al. 1998 : 104)

## 2. Integrating transdisciplinarity into university education

Transdisciplinary research does not call for a universal genius, but for researchers, teachers, and professionals able to work on a project in a heterogeneous team and to relate their own perspective on a subject with other perspectives of relevance for understanding, assessing and transforming real-world problems. This requires special competences that need to complement disciplinary expertise. If transdisciplinary research is to be taken seriously, developing respective additional competences and skills has to start with university education.

Disciplines from natural sciences, engineering sciences, social sciences and humanities differ not only with respect to which aspects of a subject they are covering, but also in what is taken as sound knowledge, how this is acquired and how academics of a discipline interact with each other. Each discipline has its own paradigm or cognitive style, shared by the members of the community (Kuhn 1962, Fleck 1980).

Students trained only in a specialized field will hardly be able to overcome mutual incomprehension when they are later expected to work in a mixed team. Thus programmes in university education need to combine depth in one discipline or field with breadth by including modules that cover a broader range of relevant disciplines. This allows students to gain insight into other fields and what these fields can contribute to the understanding and dealing with environmental problems, which is necessary for fruitful joint work with colleagues and for realizing the potential inherent in the heterogeneity of perspectives (Loibl 2006).

Multidisciplinary breadth is required but not sufficient for transdisciplinary research, as integration of knowledge is needed which is a major challenge. "Integration of knowledge" in a broad sense means relating separate bodies of knowledge, such as concepts, theories, methods, data, etc. Integration calls for reflective skills to discover differences and similarities, but also requires conceptions and methods for integration (Boix Mansilla 2010). Qualitative and quantitative modelling for instance are formal tools that can be used for different subjects fields, and be part of a university education programme.

Transdisciplinary research is about solving wicked real-world problems. University education typically qualifies students to deal with clearly determined analytical or instrumental problems under standard conditions as research questions and methods are imbedded in the paradigm of the respective disciplines. Addressing wicked real-world problems requires switching from a discipline-oriented to a problem-oriented framework. It asks for an enlarged analytical focus by also including normative and instrumental questions and by accounting for the various perspectives on the problem in the public and private sector as well as the civil society. Finally, considerable engagement in a societal process to bring results to fruition is needed. Of course, given this complexity, the solving of real-world problems through transdisciplinary research is beyond the scope of university education programmes. But university education can provide crucial competences and motivation for such endeavours. From an educational perspective it is most important for students to understand that systematic treatment of problems, which is what science in its broadest sense is about (Hoyningen-Huene 2008), is not restricted to working within a disciplinary paradigm but is also

needed in addressing real-world problems with the help of methods and procedures accounting for their complexity.

Last but not least, transdisciplinary research is teamwork. Therefore, university education must not be restricted to subject-related skills. Instead, programmes have to include learning settings that also promote competence for project work in groups such as planning and managing tasks, communicative skills which are important for information and deliberation, and social competence in recognizing and dealing with conflicts (DeZure 2010).

Early birds in integrating transdisciplinarity in university education are found in environmental sciences, typically on a natural science base as the core expertise complemented by further perspectives. From the humanities and social sciences side, applied ethics, for instance medical ethics, is providing transdisciplinary elements on the graduate level (Balsamo & Mitcham 2010). Typically social sciences' and humanities' components are integrated into natural science based programmes, but not vice versa.

### **3. The case of the environmental science teaching programme at ETH Zurich**

#### ***3.1. A system approach for a natural science curriculum***

##### ***3.1.1. Concept***

In the late eighties, accidents like Chernobyl and Schweizerhalle demonstrated that intensive economic and technological anthropogenic activities create environmental problems of increasing complexity and that society fails in adequately dealing with them. The lack of and need for experts in analysing, understanding and handling these problems motivated the introduction of the environmental sciences curriculum at ETH Zurich in 1987 which was transformed in 2004 to the Bologna study system.

This teaching programme seeks to provide students with a multifaceted view of how the natural environment works and how humans interact with both the biotic and abiotic environment. Students should gain a deep system-oriented insight in a core area of the environmental sciences and are meant to acquire skills to understand and handle real-world problems and hence promote sustainable development (Müller-Herold 1990, Gigon et al 1993, Frischknecht 2000).

The curriculum was not explicitly developed as a comprehensive scientific education for transdisciplinarity. However – as the qualification profiles given in box 1 show – all core elements of transdisciplinarity are included:

(1) There is an exceptionally broad education encompassing mathematics, natural, social and technical sciences.

(2) With the focus on environmental systems the programme comprises a specific integrative concept with the topic of the environment. Students delve “into theoretical concepts and quantitative methods of an environmental system” and learn to “integrate information from a variety of sources to analyse complex issues” and “to synthesise knowledge”.

(3) There is an orientation towards problem solving. Students are trained “... to conceptualise real-world problems with realistic models and to analyse the results with appropriate methods; [and] ... to develop solutions”.

(4) General skills are of importance in all parts of the curriculum. With respect to collaboration students learn “to work in a team”, “[to] work in an international environment” and “to develop solutions in collaboration with stakeholders”.

There are special courses with a new didactic approach (e.g. case studies) where the interplay of the different element of transdisciplinarity is taught and practised. The example of a compulsory first year course is presented in paragraph 3.2. (see also Frischknecht et al. 2000). On graduate level students may choose a case study which was developed further to a “transdisciplinary case study” (Stauffacher & Scholz 2004, Stauffacher et al. 2006).

### 3.1.2. Teaching programme

Teaching in environmental sciences is organised according to the Bologna system, with a bachelor programme designed to be completed within three years (180 credit points ECTS) and a master programme of two years (120 credit points ECTS). The qualification profiles of both the bachelor and master programmes are given in box 1.

In the first three semesters of the bachelor, the largest part of the curriculum is devoted to the fundamentals of mathematics and the natural sciences (figure 3). In the 3<sup>rd</sup> and 4<sup>th</sup> semesters there are introductory courses to the various environmental systems, designed to provide

BACHELOR	MASTER
General skills and competences	General skills and competences (building on the bachelor level)
Graduates will be able to learn independently; have the numerical skills to analyse data using quantitative methods; effectively use electronic, as well as traditional, information technologies; integrate information from a variety of sources to analyse complex issues; communicate effectively in oral presentations and in written reports for both specialist and non-specialist audiences; work effectively in a team.	Graduates will be analytical in their work; have a broad and in-depth scientific knowledge; have experience in acquiring knowledge independently in new areas; be able to synthesise knowledge and to investigate complex issues; have the ability to engage in interdisciplinary work; effectively communicate and discuss research topics and results of research; qualify for employment that requires sound judgement, personal responsibility, initiative and innovation power; successfully work in an international environment.
Subject-specific skills and competences	Subject-specific skills and competences (building on the bachelor level)
Graduates will have basic knowledge in mathematics, chemistry, physics, biology, informatics and aspects of the social sciences; have an overview of atmosphere, biosphere, pedosphere, hydrosphere and anthroposphere; apply their disciplinary knowledge in system-oriented and interdisciplinary contexts; profit from exemplary insights into theoretical concepts and quantitative methods of an environmental system (see figure 3); have basic knowledge in selected areas of environmental technology; know how to incorporate aspects of the social sciences and humanities into their work; have basic knowledge to analyse real-life problems, to develop solutions and assess their merit.	The Master phase involves specialisation in a major. The selection of subjects forms a coherent package combining general methods and tools. Thus graduates will have an in-depth knowledge and be at the forefront of the research in the field of the chosen major; be able to adapt and extend scientific methods and techniques to new applications; have carried out scientific research as demonstrated by a master thesis; know how to conceptualise real-life problems with realistic models and to analyse the results with appropriate methods; be able to develop solutions in collaboration with stakeholders.
Box 1. Qualification profiles of the environmental science teaching programmes at ETH Zurich.	

Bachelor semester 1-2 (60 CP)	Basics in mathematics and natural sciences (43 CP)		Environmental systems (12 CP)	Social sciences (5 CP)	
Basic exam					
Bachelor semester 3-6 (120 CP)	Basics in mathematics and natural sciences (30 CP)	Elective courses in natural and technical sciences (28 CP)	Environmental systems (22 CP)	Specialisation in an environmental system (21 CP)	Social sciences and humanities module (19 CP)
Master semester 1-4 (120 CP)	In-depth subjects (6 majors) (40 CP)		Elective courses (20 CP)	Work experience (30 CP)	Master thesis (30 CP)

Figure 3. Structure, subjects and credit points (CP) in the bachelor and master study programme environmental sciences of ETH Zurich.

students with their first insights into system-oriented, interdisciplinary approaches. In the third year of the bachelor, the students can then set their own area of focus by selecting a *specialisation in an environmental system*, electives in natural and social sciences as well as in environmental technology and in two term papers.

The core element of the master curriculum is the *major* (figure 3). The major courses are intended to provide students with in-depth knowledge of their chosen field, both conceptually and methodologically. A wide range of optional courses is available, which allow students to deepen their scientific knowledge in specific fields and/or broaden their knowledge in complementary or interdisciplinary subjects. *Minors* represent particular combinations of optional courses designed to enable the students to explore a chosen topic in greater depth.

The *work experience* provides students with practical experience in a professional, non-academic environment outside ETH. This internship exposes students to understand the institutional framework within which solutions to environmental problems are developed and implemented (Steiner & Frischknecht 2001).

The last part of the master programme is the *master thesis*, lasting six months, in which students are required to design, perform and write up an independent scientific study on a topic related to the chosen major programme.

### 3.1.3. Assessment of the curriculum

As the curriculum differs distinctly from traditional science teaching programmes a comprehensive quality control and evaluation of the success was considered essential from the very beginning. A continual evaluation system was implemented and further supplemented through various specific evaluation projects running in parallel. Brunner et al. (2010) summarise the work and give an overview of the available literature which in many cases is downloadable from the website of the department of environmental sciences<sup>2</sup>.

A good and fast external feedback is obtained from the supervisors of the practical work experience, who were regularly asked to assess students on the basis of ten subject-related and nine general qualifications (figure 4) after their six months internship. Additionally, they had to state the required qualification for the tasks.

On a scale of 1 to 5 with 1 = poor and 5 = excellent, the qualifications of the students were rated between 3.8 and 4.5 and were generally judged to be superior than required for the tasks. In particular, the students were considered to have excellent abilities for *natural science analysis*, for *finding the relevant aspects of a problem*, for *being able to cooperate with non-specialists* and as well for *cooperating in teams*. All of these qualifications are important for transdisciplinarity. The supervisors of the practical work experience observed a substantial surplus in the qualifications *modelling environmental systems* and *social science analysis* compared to what they assumed as needed. These two qualifications are needed as well for transdisciplinarity (see section 2). Though, environmental professionals do not (yet) acknowledge the value of these qualifications accordingly.

### 3.2. The study course "Introduction to the handling of environmental systems"

#### 3.2.1. Introduction

The practice-oriented study course "Introduction to the handling of environmental systems" focuses specifically on problem-solving competences. It aims at imparting the knowledge of (1) selected analyses methods from different disciplines for working out different aspects of

2. [www.env.ethz.ch/docs/survey](http://www.env.ethz.ch/docs/survey)



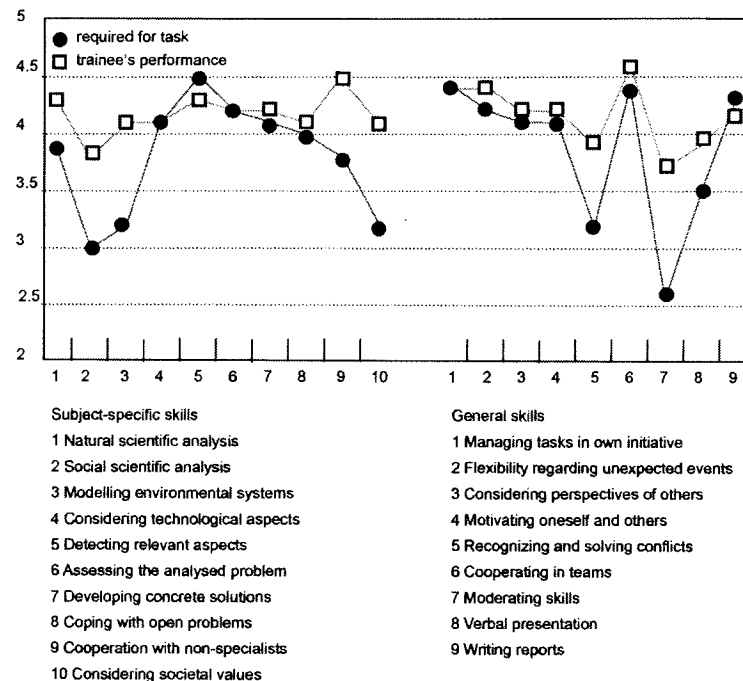


Figure 4. Assessment of master students by supervisors or the work experience ( $N = 75$ , scale: 1 = poor... 5 = excellent).

environmentally relevant problems; (2) how to integrate knowledge from various disciplinary approaches into a qualitative system model; (3) a systematically problem-solving and target-oriented process by the practical application of the theoretical knowledge of a real-world case study; as well as the practice of (4) communication skills, in particular teamwork and writing scientific reports.

The study course is offered already in the first semester of the bachelor programme as a completion to the basic study courses in the general disciplines such as chemistry, physics, biology, or mathematics. Every year about 120 freshmen attend the course and work on a case study dealing with subjects such as "Use of solar thermal energy in Davos", "Invasive neophytes in the commune of Thalwil", "Widening of the river Inn at Bever", or "Waste concept for the Ski World Cup St.

Moritz". These "cases" were developed in close cooperation with external partners from local governments, administration or NGOs. This allows contextualizing the case study subject within the real-world, and allows students to work on prevailing questions. The time allotted to the course sums up to 120 hours, which corresponds to 4 ECTS (credit points of the European Credit Transfer System). The relevance of the course topics within the curriculum is mirrored by their participation in the selection process within the first year assessment examination.

The design of the study course is subjected to the four principles of designing transdisciplinary research processes (Pohl & Hirsch Hadorn 2007): The *reduction of complexity*, i.e., specifying the need for knowledge and identifying the involved actors, is – with the exception of the additional analysis of the actors (see below) – mainly observed during the preparations by the lecturers. *Effectiveness through contextualization* is given with the "case" being anchored through the partnership with practitioners and the location within a specific region. The *integration* of different perspectives is followed through the problem-solving cycle (see below), whereas the open encounters can be only partially maintained. However, the principle *reflexivity through recursiveness* of the process is limited, since there are only few possibilities to repeat project steps within the course.

### 3.2.2. A problem-solving cycle of nine steps

Problem-solving in general encompasses the three phases (1) problem identification and structuring, (2) problem analysis and (3) bringing results to fruition (Pohl & Hirsch Hadorn 2007). In the learning context a problem solving cycle of nine steps has proven suitable to integrate these phases and the main aspects to be considered (figure 5). Each step is associated with specific questions and analysing methods. The single analyses are not independent and possibly interact with others (thin arrows). Frequently they entail new aspects that add to an altered problem perception and a new problem structure. Also, pooling the findings into a system model and analysing the systems' interrelations often require previous analyses to be redone to clarify new questions and aspects. To reduce complexity only four perspectives (step 2-5) are included that are – in our viewpoint – inevitable to understand environmental systems. However, the problem-solving cycle may be complemented with further analysis if needed.

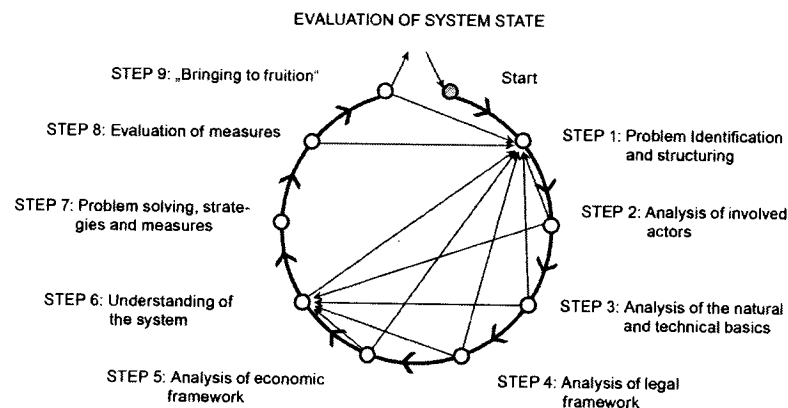


Figure 5. Problem solving cycle of 9 steps developed for the study course "Introduction to the handling of environmental systems" (Frischknecht & Schmied 2009, modified).

Problem identification and structuring (step 1) is the first and most important step where the problem must be defined and represented well enough to understand how to solve it. Since this phase is the starting point of problem-solving it is crucial to come to terms with the complexity of problems and to consider only those relations which are relevant to the problem-solving, e.g., to identify the particular need for knowledge and the people involved (first principle of the Swiss Academies of Art and Sciences towards transdisciplinary research processes, cf. Pohl & Hirsch Hadorn 2007). This implicates a thorough consideration of the problems' economical, historical, spatial and social background. A reflection from different points of views – including the perspective of various stakeholders – allows describing the actual system, target and transformation knowledge (see figure 2) related to the case. Subsequently, the respective knowledge gaps can be defined and the desired end state or objective verbalized. The result is a questionnaire to be answered within the problem analysis. In this phase collaboration with external partners (such as NGOs, communal administration, and scientific or field experts) is indispensable.

In the study course "Introduction to the handling of environmental systems" this first phase is carried out in advance by the lecturers and without the student's contribution. As an example, the case study subject "use of solar thermal energy in Davos" was defined and shaped in cooperation with the environmental officer of Davos and the head of "Science City Davos". The resulting questions focused on thermal energy production in Davos, and the main options and restrictions to further this renewable energy source with regard to various groups of residents and the high number of second-home owners. The overall goal of the case study was taken from the mission statement of Davos City stating a possibly energy self-sustaining region until 2036 (Thallmann 2009) and the subgoal to increase energy efficiency and implementing new technologies in buildings such as solar energy conversion. Subsequently the lecturers prepared a background dossier in a recursive discussion including the questionnaires for the analyses of step 2 to 5 (examples see box 2 and 3) and the selected "raw data" (publications, web links, articles of print media, design and calculation criteria as well as various data sets, maps, etc.) needed to answer the various questions.

The students' contributions start with the problem analysis phase (step 2-8). In working groups of four they elaborate one of the questionnaires related to the perspectives of the actors involved and their relation to the overall goal (step 2); the natural scientific and technical aspects (step 3); the legal or the economic framework (step 4 and 5). For the case study of Davos this meant:

The questionnaire regarding the actor analysis (Frischknecht & Schmied 2009) focused on the stakeholders involved in the issue of thermal solar energy of single-family houses and secondary residences, as well as hotels and other accommodation facilities. The second-home problem of Davos, typical for Swiss alpine regions, had also to be taken into account.

The natural scientific and technical analysis looked into the potential of using solar energy to meet the hot water demand in Davos and the related reduction of fossil energy; and into the possible reduction of hot water use by installing water tap devices to reduce water flow. A specific challenge was the use of appropriate estimates to extrapolate the hot water and energy need of the various user categories.

Determine the microeconomic costs and benefits of the installation and the use of solar heaters in Davos for

a) an average single family house (SFH)

b) an average apartment building (AB)  
Calculate the cost-benefit analysis for both building types for the following four cases:

- The building is used as primary residence, and is occupied for 340 day per year.
- The building is used as secondary residence, and is occupied for 90 days per year.
- No water savers are installed within the building.
- Water savers are installed in all apartments.

**Answer the following questions:**

1. *Microeconomic cost-benefit analysis:*

- a. For which type of building (SFH/AB), and under which conditions (primary/secondary residence, with/without water savers) do solar thermal installations pay off on a microeconomic level.
- b. How will the cost-effectiveness vary with changing energy prices? Make reasonable assumptions about energy prices for the next 25-30 years. Account for the maximal subsidies of the canton Graubünden, the maximal cantonal and state tax allowances, and make reasonable assumptions for the effects of using solar thermal energy on the buildings value.

*Box 2. Questionnaire for the analysis of the economic framework for the case study in Davos (autumn 2010), i.e., a cost-benefit analysis of the use of solar thermal energy on the microeconomic and the macroeconomic level, respectively.*

Determine the macroeconomic costs and benefits of the installation and use of solar heaters in Davos. Besides the private costs (see microeconomic analysis), the external costs and benefits have to be taken into account. This includes the avoided external costs of the fossil energy substituted by the potential solar energy use. For your calculation, average energy mix and the ration of SFH and AB from the communal building statistics. Take only those buildings into consideration in which the installation of solar panels is shown to be cost-effective. Assume that only a percentage of existing houses are furnished with solar modules.

**Answer the following questions:**

2. *Macroeconomic cost-benefit analysis:*

- a. Is the installation of solar thermal modules in Davos profitable on a macroeconomic level?
- b. Which aspects in your macroeconomic cost-benefit analysis remain unaccounted for (for practical reasons) that also effect the macroeconomic cost-effectiveness?

Read the documents, focussing on the technical aspects of solar thermal energy use. Then, calculate the energy required for hot water processing and the potential coverage of solar energy for one year on a monthly basis for the following user groups: (i) inhabitants of Davos, (ii) guests in hotels and group accommodation facilities, (iii) patients at a health resort, (iv) guests in holiday flats (commercial letting) and (v) holidays of owners of secondary homes.

For each group, assess the amount of fossil energy that could be substituted by the installation of solar panels. Document the methods and assumptions used and show the results in table form or graphically.

**Answer the following questions:**

1. *Potential of solar thermal energy in Davos*

- a. What is the hot water demand of the various user groups mentioned above on a monthly basis? What is the energy demand to provide the hot water required for each group?
- b. What is the area of solar panels needed to cover this energy demand?
- c. Determine the optimal panel area for each user group and justify you choice. Compare this area with the accessible roof area.
- d. Determine the energy output for the chosen panel area and the corresponding solar coverage when heat losses in the solar panel and in the hot water supply system are taken into account.
- e. Compare and discuss the monthly energy demand for hot water in [a] with the monthly energy yield in [d].
- f. Compare the potential of solar thermal energy for providing hot water with the energy balance of Davos? How many litres of fuel could be substituted?
- g. Discuss your results with respect to tourism and its seasonal demand for hot water.
- h. Which difficulties may arise with respect to the alpine climate (snow load) of Davos?

*Box 3. Questionnaire of the analysis of the natural and technical basics for the case study in Davos (autumn 2010), i.e. the assessment of the potential of solarthermics.*

The analysis of the legal framework dealt with the possibilities of the City of Davos of furthering energy efficiency on the three legal levels existing in Switzerland (federal state, canton, municipality). In particular, students identified the legal de-facto means of the authorities to further solar energy in Davos. Additionally the question was investigated whether there is a legal basis to oblige owner-occupants to use renewable energy sources or water saving devices or with special focus on secondary residences.

Economic aspects were worked out in a micro- and a macroeconomic cost-benefit analysis. In the latter the private costs and benefits were supplemented with externalities such as avoided emissions etc. (external benefit) and energy expenditure and emissions during the production of solar panels (external costs).

The analyses' results are written down in an internal expert report with a consideration for the main principles for scientific writing. Students have to follow standards for "scientific integrity" (e.g., to quote literature references correctly, to be transparent about the theoretical and/or methodical background they refer to, and to draw only conclusions which are reasoned and justified by the findings).

Step 6 aims to pool the findings of the various analyses and to understand the dynamics of the system under examination. To this end a system model is drafted including factors representing the most important features of the problem considered in a sufficient way (cf. Scholz & Tietje 2002) and allowing for a qualitative analysis of their interrelations. The conception of the respective system models were implemented with the help of the software SystAim<sup>3</sup>. For reasons of time, the model is restricted to about 12 factors allowing the analysis of the interrelations of a specific aspect (subsystem). The interrelations are interpreted by the role of the different factors within the system model and the feedback loops existing through their interconnections.

Finally, considering the previous findings, possible strategies and measures for problem solving are developed (step 7) and evaluated (step 8) with regard to their contribution to the overall goal and to sustainability.

Step 7 includes the development of a strategic plan of how to achieve the desired systems state. A strategy map for environmental systems (Tietje 2009) a further development of the balanced scorecard methodology (Kaplan & Norton 2004) helps to develop, evaluate and communicate strategies to the project or, here, the case study partners. With help of the software SStrategy<sup>3</sup> connections between activities, actors and processes were made visible and an overview of planned activities and their consequences are given with respect to the desired goals.

3. Tietje Olaf, Systaim GmbH, Pfingstweidstr. 31a, CH 8005 Zürich, [www.systaim.ch/](http://www.systaim.ch/)

Steps 6 to 8 are carried out during a workshop of four days. With the presentation of the measures and possible strategies to the external partners the case study is closed and the students' contributions completed.

Bring to fruition (step 9) concentrates on the implementation of selected problem solutions or measures and has to be left entirely to the external partners. In the past, students were involved in implementation of measures in a few cases, which happens only occasionally. For Davos bringing to fruition means that the environmental officers introduce the findings and conclusions of the case study into his daily work and into the political process of Davos towards the increasing use of solar energy.

### 3.2.3. *Insights - after 10 years of experience*

The study course "Introduction to the handling of environmental systems" successfully integrates different elements of transdisciplinarity. It enables freshmen to become acquainted with a systematically problem-solving and target-oriented approach to environmentally relevant problems. Additionally, they learn to distinguish different forms of knowledge, especially the systems and transformation knowledge. And finally, most of the general skills shown in figure 4, such as the self-initiated managing of tasks, motivating oneself and others, or writing reports, are practiced.

The case studies of the past years show that one of the most important difficulties students encounter is the passage from the system's analysis (step 6) to the problem-solving phase (step 7). Often, students start again by brainstorming problem solutions without taking into account the results of the previous analyses. Therefore, the introduction of the target-oriented strategy map strongly supported the transition from the systems to the transformation knowledge.

With respect to transdisciplinarity, students may not be actively aware of the case study's design according to the four principles mentioned above. Also, because of time constraints these aspects, particularly recursivity, are only marginally treated and are subject of further elements of the curriculum. However, the problem-solving cycle of nine steps, according to which the course of activities is organised, points to the dependencies between the different steps (figure 5, thin arrows), and thus the recursivity of the process.

Although the phase "bringing results to fruition" is left out within the case study course, this implementation phase is accessible to students. On occasion, they were briefed with the latest news about further activities of the external partners. As an example, the widening of the river Inn at Bever turned out to be a running project of the municipality of Bever (Jur 2009). And as a result of the case study 2002/03, some of the students had the opportunity to act as voluntary "waste collectors" in order to implement the waste concept at the Ski WM in St. Moritz.

### ***3.3 The success of graduates on the job market and in promoting sustainable development***

#### ***3.3.1 Introduction***

Projects of basic research end with presentations of the outcome at scientific conferences and written reports in scientific journals. In projects of applied research the outcome usually contains recommendations with respect to questions and problems of partners outside of academia. Transdisciplinary research on the other hand is not complete before results were brought successfully to fruition. Regarding research and teaching at a university it is impossible to meet this demand in most cases. The graduates of a university teaching programme however may have a leverage effect in bringing results to fruition during their professional life.

In the case of the environmental sciences there is the pivotal question of whether graduates are able to handle complex environmental systems in a way that supports societal change towards sustainability. In 2009 a comprehensive study has been carried out on this question (Brunner et al. 2010, Hansmann et al., in preparation, Mieg et al., in preparation). One part of the study comprised the analyses of career development. 808 graduates from 1992 to 2005 were invited via email to complete an extensive web-based questionnaire. 70 % responded at least to the first question, and 55 % completed the entire questionnaire. Information was elicited on the following:

Professional activities since graduation (e.g., income, position, size of company/organisation, field of activities) and advantages of their environmental sciences education for these activities.

Engagement in sustainable development through these professional activities in general and by means of two examples of best practice.

The assessment of the best practice example with regard to (1) the integration of the ecological, economic and social dimensions of sustainability; (2) conflicts between these three dimensions; and (3) evaluation or monitoring of the achieved effects. The concept of sustainable development was not introduced by definition, but rather was explored on the basis of the 15 goals stated in the Swiss Strategy for Sustainable Development as defined by the Swiss Federal Council (Schweizerischer Bundesrat 2002).

#### ***3.3.2. Employment***

Overall, our findings showed very good employment rates: on average six years after graduation, 96 % of the survey participants were professionally active. A survey of the Swiss Federal Office of Statistics shows that this employment rate is considerably higher than in comparable age groups of the Swiss general population (87 %, Bundesamt für Statistik 2009) and similar to the rate of other Swiss university students five years after graduation (95 %, Bundesamt für Statistik 2008).

The environmental sciences graduates work in all four societal sectors: the private sector (50 %), public administration and education (25 %), the scientific sector (20 %) and civil society (NGOs, 5 %). Table 1 shows that the most prominent fields of professional activity are environmental planning and consulting, public administration and universities. A high percentage of graduates also work in banks and insurance companies, in positions with attractive income prospects and special possibilities for contributing to sustainable development. Further activities are dispersed over a broad range of professional fields and reveal a variety of career opportunities for environmental scientists.

#### ***3.3.3. Perceived contributions to sustainable development***

The graduates reflected and assessed their influence on sustainability based on their best practice examples of contributions to sustainable development. These again reflect the broad range of professional activities engaged in by environmental scientists.

Based on the graduates' evaluation of their careers and best practice examples, the societal role of environmental sciences graduates on sustainability could be assessed (Mieg et al., in preparation).

**Leaders:** The perceived overall achievements of graduates in upper-level managerial positions were significantly higher than those in lower level positions, and they also perceived more substantial increases

Environmental planning & consulting	15	3.7
Public administration	15	3.4
Universities	13	2.7
Banks, Insurances*	10	2.2
Education	8	2.6
Research outside universities	7	3.3
Environmental NGOs	5	4.0
Financial and management consulting	4	2.8
Health sector*	3	2.4
Energy/water supply	3	4.2
Other industry	2	3.3
Transport	2	3.2
Media	2	2.8
Chemical Industry	2	3.3
Commerce	1	3.7
Farming/forest/garden	1	3.8
Construction industry	1	3.2
Other public services*	4	2.0
Other	2	2.7
* Branches weakly related to sustainable development		
Table 1. Professional activities with median incomes and their relation to sustainability. Scale: 1 = no relation, 2 rather no, 3 = rather yes, 4 = yes, 5 = yes, very strong relation. (N between 501 and 524).		

in their influence on sustainable development during their career. Accordingly, graduates demonstrate continuous engagement in sustainability over time and do not forget their "roots" during the advancement of their careers.

*Specialists:* In most professional fields, graduates perceived their activity as fairly to strongly related to sustainability (values > 2.5, Table 1). Jobs in energy and water supply, NGOs and environmental planning and consulting in particular, were strongly oriented towards sustainability, as well as activities in farming and forestry and commerce. Fields

such as universities, education and the media are in an intermediate range (values > 2.5 and < 3.0).

*Pioneers:* In banks, insurance companies, in the health sector and in other public services, which are classified as having a weak relation to sustainability (Table 1), there are some graduates whose work is closely related to sustainability. Their perceived personal influence as having increased significantly in the course of their careers.

In conclusion, the graduates of environmental sciences have been successful in introducing the sustainability issue to problem solving in their professional life.

#### 4. Conclusions

In the 1970s awareness of the risks for the future of society of applying knowledge from highly specialized academic disciplines to real-world contexts has given rise for a call for transdisciplinarity. The core idea with this is that the complexity of real-world problems requires integration of separate bodies of knowledge, transgressing not only disciplinary boundaries but also those of academia. The term "transdisciplinarity" is used for such avenues of knowledge production and for the resulting knowledge as well as competences of researchers, structuring of university education, and of institutions. The request for transdisciplinary research was renewed and emphasized in the 1990s driven by the need to cope with the challenges of sustainable development. Due to the complexity and variability of problems, the diversity of perspectives, and the value uncertainties, among other characteristics, the path towards sustainable development often involves wicked real-world problems. Problems of this kind do not allow for definitive solutions, but ask for ongoing reflective problem solving processes.

The introduction of the environmental science programme at ETH Zurich in the 1980s was motivated by the need for experts in analysing, understanding and handling environmental problems of increasing complexity. The building of transdisciplinary elements into the curriculum is motivated by the department's mission to strive for an understanding of how the environment works, and it is focussing on the environment. Thus a systems approach to the environment is providing the basis for integration of knowledge from various subject-related disciplines. The emphasis on dealing with real-world problems is due to the need

for qualifying experts also for handling environmental problems. This close connection of transdisciplinary elements with the subject of the curriculum has shaped how these elements have been elaborated and warrants their value for education. Consequences of this close connection with the subject need to be considered if one thinks of transferring ideas to education programmes on other subjects.

The environmental science programme at ETH Zurich comprises elements for developing transdisciplinary competences. These competences are complementary to the core competences of an environmental scientist with an expertise in one of the various environmental systems. Thus there is a broad range of carrier opportunities open to graduates, from basic research on specific processes in environmental systems to practitioners in a field requiring the handling of complex issues. A commitment to contribute to sustainable development, that is solving real-world problems, is found by graduates in all professional branches. It is this combination of competences, and the spectrum of professional opportunities, that attracts students to enrol in the curriculum.

The functioning of transdisciplinary elements in the environmental science programme at ETH Zurich rests on three pillars: firstly, conceptions of transdisciplinarity in research and education need to be clear, secondly, their place within the curriculum has to be determined, and thirdly, adequate didactic approaches are required. Work on these pillars is always ongoing, engaging researchers, lecturers and students, in practising, evaluating and further developing transdisciplinary elements<sup>4</sup>.

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## One world or many?

Sir ALAN COOK (F.R.S.)

### Transdisciplinarity is quite recent

Science as we know it today emerged in the 17<sup>th</sup> century with the foundation of the Accademia dei Lincei by Prince Federico Cesi in Rome, 400 years ago in August 1603. Throughout that century and beyond there was no sense that natural sciences knowledge could be divided into compartments. Our questions about transdisciplinarity would have been meaningless. Cesi himself was quite clear. His aims as he stated them explicitly were to forego the magic, the mysticism, the subjection to authority, which so determined the Renaissance view of the natural world, and instead to apply empirical observation and rational argument, irrespective of the field of study. Our view of Lincei is coloured today by Galileo's controversy with the Holy Office over the two great world systems of Aristotle and Copernicus. This was far from all. Galileo's own interests were much wider, while Cesi himself was a most accomplished botanist and the first to use a microscope to study plants.

Half a century later, the early Fellows of the Royal Society in London would not have recognised any boundaries in the studies of the natural world. Nowadays we remember Robert Boyle by his law, Robert Hooke by his law, Newton by mathematical physics, Edmond Halley by comets, but those discoveries took up rather small proportions of their lives. Boyle had medical interests and pursued alchemy, as did Newton, Halley spent many years on what we now call earth sciences, and Hooke