Integrating systems and design thinking in transdisciplinary case studies

In the new Bachelor-level course Umweltproblemlösen (Tackling environmental problems), *a part of ETH Zurich's Environmental Sciences Bachelor's programme, we teach students to zoom in on elements of practice (design thinking) and to zoom out on the whole system (systems thinking). Participants take stakeholders' interests and needs into account and prepare possible measures, thus developing transformation knowledge and anticipating their future role as transdisciplinary sustainability scientists.*

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Abstract
Umweltproblemlösen (Tackling environmental problems) is a Bachelor-level course that carries on a long tradition of transdisciplinary (td) case studies in the Environmental Sciences curriculum at ETH Zurich. Td case studies introduce students to key features of transdisciplinarity. Two corresponding learning goals of the case studies are 1. to not only analyse problems, but to also suggest solutions, and 2. to take the complexity of the tackled socio-ecological system into account. In the new course we address both learning goals by integrating systems and design thinking. We present this approach in detail to show how features of transdisciplinarity are transferred to learning contexts. We compare it to the approaches of other td case studies by asking how each interprets and addresses the two learning goals. The comparison shows that the case study approaches implicitly impart different ideas about how a td environmental scientist should support societal problem solving. A key difference to previous approaches is that the new course asks students to enter deeply into the world of practice and the stakeholders' divergent needs.

Keywords
case study, design thinking, systems thinking, teaching, transdisciplinarity, transformation knowledge, Umweltproblemlösen

Teaching implicit and explicit knowledge

The course *Umweltproblemlösen (UPL, Tackling environmental problems)* carries on a long tradition of transdisciplinary (td) case studies in the curriculum of Environmental Sciences at ETH Zurich. The first BSc case study took place in 1987 and the first MSc case study in 1991 (Müller-Herold and Neuenschwander 1992, Oberle et al. 1997)[1]. Over the years, the key learning goals of the case studies persisted (cf. Müller-Herold and Neuenschwander 1992, p. 341):

1. to not only analyse problems, but to also suggest solutions;
2. to take the complexity of the tackled socio-ecological system into account,
3. to learn how to collaborate in teams.

What changed was the particular way in which the goals were interpreted and implemented in each case study approach.

By participating in a td case study, students get familiar with a specific approach to 1. and 2., that is, to help solve complex and wicked sustainability problems. Implicit in this approach, students furthermore internalize what a td environmental scientist can contribute to sustainable development, for instance, provide evidence to decision-makers or suggest innovative solutions to problems. Elkana (1979, 1986) called this implicit part of knowledge "image of knowledge" *(Wissensvorstellung)*, to distinguish it from the explicit "body of knowledge" *(Wissenskörper)*. The body of knowledge includes theories, methods or the state-of-the-art of a field. The

1 At that time, however, the first two years of the curriculum were called *Grundstudium* and the subsequent three years *Fachvertiefung*.

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image of knowledge are the assumptions underlying this body, for example, about the tasks of science or about legitimate sources of evidence. The following presentation of *UPL* and the comparison with other td case studies covers both, the explicit body of knowledge and the implicit image of knowledge.

Before presenting *UPL* in detail, we clarify our understanding of systems and design thinking. We then compare *UPL* to other case studies. First we analyse how former approaches addressed learning goals 1. and 2. and what images of knowledge about the role of a td environmental scientist this implies. We then briefly position *UPL*'s approach to integrate systems and design thinking among similar courses.

Systems thinking and design thinking

In *UPL* we rely on two different understandings of systems thinking. The first is Forrester's (1994) system dynamics. It entered the environmental debate through the world model and the limits to growth (Meadows et al. 1972). For Forrester the core of systems thinking is "the system dynamics paradigm that recognizes all systems as having the same fundamental structure of levels and rates (accumulations and flows) structured into feedback loops that cause all changes through time" (Forrester 1994, p. 251).

The second understanding is Checkland's (1985) soft systems thinking, as opposed to hard systems thinking represented, for example, by Forrester. For Checkland (2000, p. 17) in hard systems thinking "the word 'system' is used simply as a label for something taken to exist in the world outside ourselves". Once such a system is appropriately modelled, it can be "engineered" to meet specific objectives, for instance, targets set by politics. In soft systems thinking the "world is taken to be very complex, problematical, mysterious" and "the process of inquiry into it, it is assumed, can itself be organized as a learning system" (Checkland 2000, p. 17). Correspondingly, Checkland's *Soft Systems Methodology* to analyse a situation and to develop and implement ways to change it does not require a hard system model.

In *UPL* we practice systems thinking with the *"Sensitivitätsmodell"* of Vester (1999, p. 156–208). Vester's model combines elements of hard and soft systems thinking. It allows to analyse some aspects of a system's dynamic – loops, the role of variables – without requiring a precisely quantified "fundamental structure of levels and rates" (Forrester 1994, p. 251). In line with soft systems thinking, Vester explicitly delimits his model from Forrester's system dynamics, stressing that model simulations are only one way of how models can be used to learn about and intervene in complex socio-ecological systems (Vester 1999, p. 233). In *UPL* we work with the *"Sensitivitätsmodell"* as implemented in the software *SystemQ* (Tietje 2019) which was developed for former td case studies at ETH Zurich.

The idea of design as a particular way of thinking has its origins in the work of Simon (1969) and McKim (1980). Design refers to "the plan, project, or working hypothesis which constitutes the 'intention' in intentional operations" (Buchanan 1992, p. 10). Or as Rittel (1971, p. 19) formulates "a [wo]man designs whenever [s]he has a purpose in mind and devises a scheme to accomplish this purpose." Creativity and abductive reasoning are regarded as peculiarities of design thinking (Fischer 2015). Abduction "is an inference from a body of data to an explaining hypothesis" (Burks 1946, p. 301), or the act of wondering, as opposed to the act of observing (Pourdehnad et al. 2011, p. 5). Observing is key in inductive or deductive analytic reasoning. Although creativity and wondering are what distinguishes design thinking from analytic thinking "designing is not an incessant stream of creative events; it is highly patternized and organized labour, only occasionally interrupted by sudden insights and ideas" (Rittel 1971, p. 16). Design thinking is both, a tool for creative thinking and a structure to organize the process of design (Fischer 2015, p. 175).

The structure of design thinking followed in *UPL* – identify an insight, define problem statements, ideate possible solutions, prototype solutions, test solutions – has been codified by the Stanford University's d.school (Hasso Plattner Institute of Design at Stanford University 2020). This particular take on design thinking expanded upon McKim's (1980) work and was adapted by David Kelley for a product design context within IDEO, a design firm in California (Brown and Katz 2009). In 2001, the origin of the d.school was established when IDEO collaborated with the civil and environmental engineering department at Stanford University to re-adapt design thinking for an educational context. The first interdisciplinary course to apply design thinking for social innovation in developing countries[2] was launched at that time.

The course *Umweltproblemlösen (UPL)*

Students take *UPL* (figure 1, p. 260) in the first year of the BSc of Environmental Sciences. The first two semesters are mandatory (10 ECTS), the third is elective (3 ETCS). Every year around 150 students work in 24 groups of six to seven students on a sustainability topic. Besides a minimum of inputs from lecturers and experts from practice, students work self-organised or guided by twelve tutors. Tutors are second- and third-year BSc students. *UPL* is graded. In the exam students have to pass after the first year of the BSc, the three most important grades are math, chemistry and *UPL,* all having the same weight. In terms of the BSc qualification profile *UPL* trains the "basic skills in analysing real-life problems, developing ways of resolving them and evaluating those solutions"[3]. At ETH Zurich the first BSc year shall allow students to find out whether they are at the right place. *UPL* does so by providing insights into their professional reality and its challenges. >

2 One of the authors, BinBin Pearce, was a part of the original cohort in the first run of this course.
3 *https://usys.ethz.ch/en/studies/environmental-sciences/bachelor/qualification-profile.html*

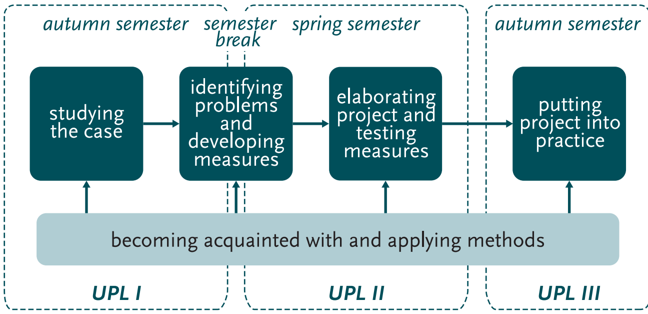

FIGURE 1: *Umweltproblemlösen (UPL)* is a mandatory course in the first year of the BSc of Environmental Sciences at ETH Zurich. In the first semester, students in groups of six to seven study one of six aspects of a given case. In a synthesis week during semester break, students are mixed in new groups, develop an overview of the case, and identify a problem to work on and measures to address it. In the second semester, students elaborate the measures until these are ready to be implemented. In the elective third semester they put the measures into practice.

Stage 1 (preparatory steps): identifying a topic and convening an advisory board

Around seven months before starting a case study, the lecturers identify a broad topic and search for a main partner. 2018/19 the topic was "Sustainable management of small rivers under climate change". Our main partner was the Office for Environment and Energy of the Canton Basel-Landschaft (Amt für Umweltschutz und Energie Basel-Landschaft).

In a first meeting with the main partner, we specified the topic to "Sustainable management of rivers in the catchment area of Birs and Birsig" (two small rivers in the Canton Basel-Landschaft) and discussed who to invite to the advisory board. The advisory board brings together not only local expertise, but also potentially conflicting interest, ideally with representatives from the public sector, the private sector, civil society (e.g., an NGO) and research. 2018/19 the board consisted of our main partner from Canton Basel-Landschaft, a CEO of an electricity company, a water researcher, and the head of a company for river restoration. To have all concerned stakes present, further members are the lecturers, two delegates of the students and two of the tutors. The first task of the advisory board is to select six aspects of the topic to be studied in detail during the first semester (see stage 2).

Underlying concepts

In stage 1 we walk the advisory board through a joint problem framing, the first step of a td project (Pohl and Hirsch Hadorn 2007, Jahn et al. 2012). The implicit idea to impart to students is that td work starts with a topic not yet framed as a problem. Problem framing requires exploring the topic from several stakeholders' and disciplines' perspectives. Joint problem framing is specific for td research (Pearce and Ejderyan 2019). In applied research, the framing is typically given by the mandating stakeholder. In basic research it is given by the researcher's discipline (Hirsch Hadorn et al. 2006). The actual joint problem framing in *UPL,* however, stays within the advisory board. Students only get to know that this process happened.

Stage 2: studying the case

The goal of the first semester is to familiarize students with the topic, with making enquiries and with scientific writing. Always four groups in parallel analyse one of the six aspects defined by the advisory board. In the river case, groups worked on 1. the runoff regime, 2. supply and disposal of water, 3. quality of water, 4. watercourse corridors, 5. river-related animals and plants, and 6. hydropower.

To start, we provide groups with a set of questions they have to answer in a report. All groups, for instance, have to identify the stakeholders and legal settings relevant for the investigated aspect. Groups get an introduction to their aspect by an expert from practice, three to five references, and an introduction in literature search. Furthermore, we introduce students to scientific writing and the typical structure of a scientific report. Every month, groups present a milestone (e.g., an outline) to lecturers or experts from practice and receive feedback. At the end of the semester groups hand in a twenty- to twenty-five-pages report. Students are now "experts" for one aspect of the overall topic.

Underlying concepts

The main message of the first semester is that tackling sustainability issues requires experts of (or expertise in) many different fields. We find this claim in td research as the different disciplines that have to be involved to develop a comprehensive understanding of a topic (Mittelstraß 1992, Hirsch Hadorn et al. 2006, Jahn et al. 2012). Students explore the disciplinary expertise through literature research. Working in local case areas, our students furthermore realize that relevant expertise stays not only with scientific databases, but also with experienced practitioners, local newspaper or governmental web pages (Tengo et al. 2014).

Stage 3: identifying problems and developing measures with a systems view

During semester break students attend an *UPL* week led by the student tutors. For this "synthesis week", new groups of six are built, teaming one student of each aspect analysed in the first semester. During the week, students familiarise with a process combining systems and design thinking. The process leads from the expertise gained in the first semester to specific problems and measures to address a problem. Figure 2 exemplifies the eight-step process by the students' project *Climate buffer beaver* (Wüthrich et al. 2019):

1. Getting an overview: Students, still in the groups of the first semester, identify the most important findings gained about the aspect. In the new groups, they draw a rich picture (Checkland

2000, pp. 22–23) to bring together important findings from all six aspects.

2. Identifying insights: Within the rich picture, groups identify insights. We introduce insights as aha moments, ideally connecting findings from different aspects and pointing to a contradiction in the current or in a future state of the system.

3. Identifying stakeholders and formulating problem statements: Groups identify the three to four most important stakeholders concerned by the insight. Stakeholders are concerned if they have an interest in keeping the system as it is or in changing it in a particular direction. Students express this interest in a problem statement for each stakeholder. A problem statement describes the insight from the stakeholder's perspective and clarifies which needs will be affected.

4. Brainstorming measures: Once the three or four problem statements are formulated, groups brainstorm measures. Groups rank the measures according to how many of the problem statements or stakeholder needs a measure takes into account.

5. Developing a system model: Groups develop a system model according to Vester (1999, pp. 156–208) using the software *SystemQ* (Tietje 2019). First, they define variables describing the needs of the three to four most important stakeholders as defined in the problem statement. With eight to ten further variables, they describe elements of the rich picture that influence the insight or the stakeholders or are relevant to capture the overall picture. Groups explore the model searching for leverage points, that is, where measures would impact the system.

6. Reviewing measures: Based on what groups learned about leverage points, they review the measures brainstormed in step 4 and change or add further measures. They select three to four promising measures.

7. Checking measures' effects in the system: Groups incorporate the three to four promising measures in the system model to check for intended and unintended effects. Ideally, they find two measures with synergies, that is, that jointly have a higher impact on the system than the sum of the impacts of both measures individually.

8. Prototyping measures: Finally, groups prepare prototypes – handcrafted models of the planned measures (cf. figure 4, p. 263) – and a presentation. The last day of the week, groups test the prototypes by presenting them to experts from practice (including those of the advisory board), other students and the lecturers in order to collect feedback.

Underlying concepts

During the synthesis week students familiarise with the main methodology of *UPL* (figure 2). They are guided through a step- >

FIGURE 2: The eight steps of *UPL*'s stage 3 exemplified by the student project *Climate buffer beaver*. The green and the orange arrows show two different pathways of how the steps build upon each other (cf. Wüthrich et al. 2019).

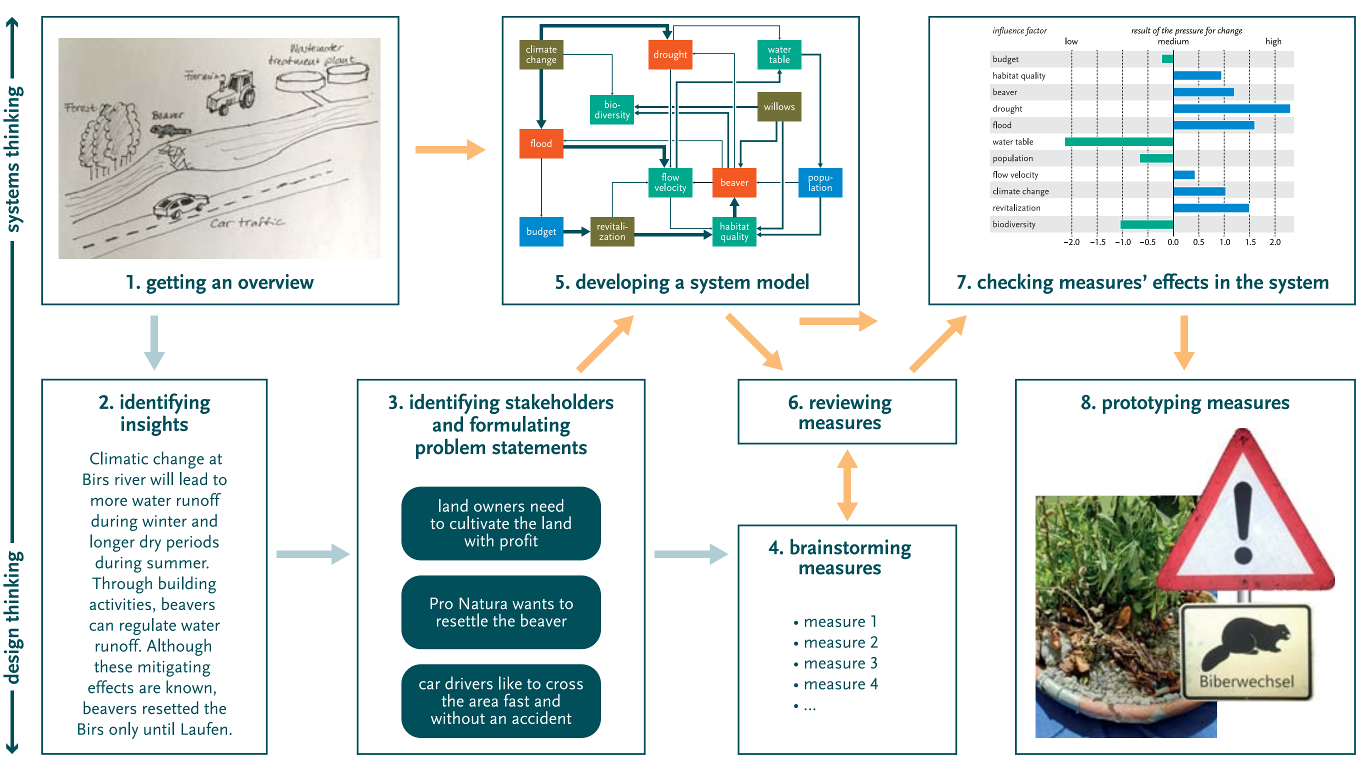

FIGURE 3: At the end of the second semester students present their projects at the market of measures to experts, stakeholders, their peers and the lecturers.

wise procedure of zooming out (systems thinking) and zooming in (design thinking). Zooming out to get an overview, to build a system model, to check what happens if two measures intervene in the same system. Zooming in on specific insights, on the stakeholders and their needs, on measures to address these needs and on prototypes that materialise the measures. The implicit message we impart is: for tackling environmental problems, stakeholders and their needs as well as the overall system both matter. As a td environmental scientist, one has to switch between both perspectives and to connect them.

Stage 4: elaborating a sustainability project

In the second semester, the groups built in stage 3 develop a sustainability project, that is, a project aimed to solve an environmental problem identified in stage 3. At the end of the semester they present the project at the market of measures to experts, stakeholders, their peers and the lecturers (figure 3). Same as at the end of stage 3, each group presents an insight, problem statements of the three to four most important stakeholders, two measures and an analysis of how both measures together impact the system. In addition, groups have to show in how far the measures promote sustainable development. Students now use the *UPL* methodology on their own. The only new methods we introduce are sustainability assessment and life cycle assessment.

A particular challenge students face in the second semester is how to involve stakeholders. We ask students to elaborate their measures up to a degree they could be put into practice. Thus, students have to be specific about where a measure is implemented, who owns that place, which stakeholders are providing financial and further support, what materials are used and what the costs are. As most of these points can only be clarified in exchange with stakeholders, students have to directly contact them. In this stage students contact the stakeholders on their own, always one student being the main contact point for one stakeholder. Students contact around 150 stakeholders over the semester. In addition, we ask students to test their prototypes with the three to four most important stakeholders, that is, to present them handcrafted models of the measures in face-to-face meetings to check whether the prototypes comply with their needs, and in case they don't, to collect feedback to further develop the measures.

Underlying concepts

The way stakeholders are approached is a mix of transdisciplinarity and design thinking. Same as in design thinking, we ask students to look at the insight through the stakeholder's eyes and to focus on his/her needs. Taking up the idea of wicked problems from td research (Rittel and Webber 1973), we ask students to do so for the three to four most important stakeholders. The underlying assumption we impart is that whether an issue is seen as problematic in the world of practice and whether a measure to address it is considered good or bad depends on the needs and interests of those who look at it, and that these needs and interests usually differ among stakeholders. Furthermore we impart a principle of td research, according to which td projects have to be embedded in the realm of science as well as in the realm of practice (Pohl and Hirsch Hadorn 2007, pp. 64–68). Students explore the realm of science by writing a report in stage 2. They explore the realm of practice by developing and testing measures in stage 4.

Stage 5: putting the sustainability project into practice

In the elective third semester students put their sustainability project into practice. One challenge are the intellectual property rights. Students own the intellectual property rights in their measures. In stage 5, they negotiate with the project partners (stakeholders) under what conditions they will hand over property rights and develop and sign a contract if needed. So far one to three groups per year enrol for stage 5. This year one group developed a steeplechase to make residents experience moving across the river from a fish's perspective (see figure 4). Münchenstein, a community on the Birs river, invited the group to implement the steeplechase in a community event.

Underlying concepts

When putting their project into practice, students experience that without expertise and support from practice nothing will be implemented. They also experience that their ideas are taken seriously and that some stakeholders are so excited about sustainability projects of first year BSc students that they help to put them into practice.

Comparing *UPL* to other case study courses

We structure the comparison of *UPL* to other courses in two parts. First, we compare *UPL* to former case studies of the Environmental Sciences curriculum to see whether the implicit idea of the td environmental scientist changed over time. Second, we briefly compare *UPL* to other courses combining systems and design thinking. Given this restricted focus, we stress that there are further courses we did not include in the discussion, for example, the td case study in the MSc of Environmental Sciences (Krütli et al. 2018) or comparable courses at ETH Zurich (Lippuner et al. 2015) and at other universities (e.g., Muhar et al. 2013, Vilsmaier and Lang 2015, Biberhofer and Rammel 2017, p. 71, Larsson and Holmberg 2018).

ETH Zurich's idea of the td environmental scientist over time

To uncover the implicit idea of the td environmental scientist, we compare how different case studiy approaches at ETH Zurich interpreted and implemented the learning goals 1. to not only analyse problems, but to also suggest solutions, and 2. to take the complexity of the tackled socio-ecological system into account. Figure 5 (p. 264) shows the former approaches used for the comparison.

Learning goal 1: to suggest solutions to problems

The link between science and problem solving has long bothered scholars of td research (Winch 1947, p. 72). The claim is that knowledge is produced and organised at universities according to disciplinary requirements, which are different from those of societal problem solving (Mittelstraß 1992). A td case study can be seen as a procedure of knowledge reorganisation to bridge this gap. The case study approaches vary in what they mean by suggesting solutions to problems.

In the early case study, Müller-Herold and Neuenschwander (1992, p. 348) restrict the role of environmental scientists to developing feasible solutions, without realizing them.[4] They elaborate what they mean by "develop feasible solutions" pointing to the progress made from the very first to the second case study. The results of the second case study were no longer scientific facts, like in the first case study, but justified suggestions for tackling the problem (Müller-Herold and Neuenschwander 1992, pp. 345–346).[5] Retrospectively this can be seen as a first step taken out of analytical environmental sciences into design thinking.

In the large case study, the environmental scientist's contribution to problem solving was to provide scenarios of alternative futures to support decision-makers. Students would gather knowledge on the case, build a system model of the current situation and develop and assess scenarios of possible future developments (Scholz et al. 2006). More recently, the former case study leader clarified how this approach relates to solutions: "We should note that, in contrast to a problem-solving approach (e.g., 'We have solved a problem and found a solution; consequently, we need to find an implementation strategy!'), an ideal transdisciplinary process does not call for implementation. The outcome for practice is the improved decision-making capacity as a form of empowerment" (Scholz and Steiner 2015, p. 539). In this view, the td environmental scientist does not develop solutions to problems, but supports societal decision-making by providing target knowledge,

FIGURE 4: One student group developed a steeplechase to make residents experience moving across the river from a fish's perspective. Münchenstein, a community on the Birs river, invited the group to implement the steeplechase in a community event.

that is, knowledge about where to go (ProClim 1997, Pohl and Hirsch Hadorn 2007). Target knowledge allows decision makers to learn about possible futures and their pros and cons and to base their decisions about the measures to be taken on that knowledge.

In *UPL* we ask students to develop solutions that are implementation-ready. The whole second semester is dedicated to this process that starts with having an idea for a solution and ends with a tested prototype of a politically, technically, legally and economically feasible measure in a particular place and time. By making abstract ideas specific, students thus provide transformation knowledge, that is, knowledge about how to come from where we are to where we should be (ProClim 1997, Pohl and Hirsch Hadorn 2007).

Letting students go all the way from first ideas to materialised measures opens a new area in td case study education. Design thinking provides points of reference to explore this area. From such a stakeholder- and need-centred perspective, for instance, the focus of the large case study on supporting decision-making by providing insights on possible futures implicitly assumed that this is what stakeholders need. In *UPL,* students would have to explore that assumption. The decision-makers would have to be specified, for example, as the politicians of a particular party in a national or cantonal parliament, or as the CEO of a particular company. Students would have to explicitly describe the need of decision support in a problem statement and to present prototypes – concrete examples of supportive information like tables, graphs, novellas or movies about possible futures – to the specified decision-makers. Besides decision-makers, further stakeholders and their needs, for instance, those concerned by the decision, would >

4 Original quote in German: "In den Umweltnaturwissenschaften bedeutet Umsetzung das Erarbeiten von realisierbaren Lösungen – nicht aber deren Verwirklichung."

5 Original quote in German: "Hauptergebnis der Fallstudie sind *begründete Vorschläge* und *nicht wissenschaftliche Tatsachen*" (emphasis in the original).

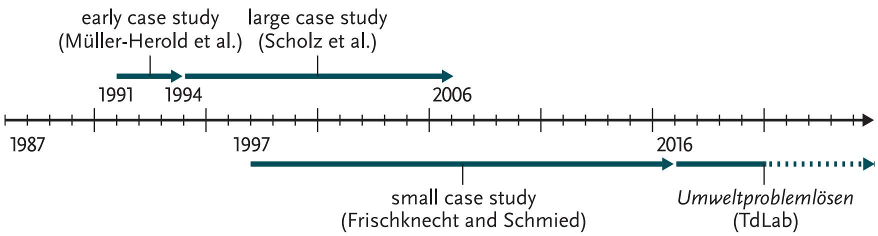

FIGURE 5: Transdisciplinary case studies are part of the Environmental Sciences curriculum since its beginning. The figure shows former approaches we compare to *UPL*, the period over which these approaches were taught at ETH Zurich and the case study leaders standing behind. "Large" and "small" referred to the weekly hours reserved in the curriculum and to the ECTS credits students received. The ongoing transdisciplinary case study in the MSc of Environmental Sciences (Krütli et al. 2018) is neither included in the figure nor in the comparison.

have to be specified and the same prototypes tested with them, to check whether the measures comply with their needs, too. This is how the focus on stakeholders and their needs asks students to enter deeply into the world of practice, interests and wicked problems. Students cannot provide transformation knowledge for a scientist's perceived need only (e. g., environmental information) but have to dig into the needs of the stakeholders and to materialise measures that respond to these needs. This also implies that students sometimes rethink and adapt their initially big ideas. It is a constant balancing of priorities – how far are the students willing to give up their ideal of a sustainable project to meet the stakeholders' needs and in return be able to implement the project in the end.

***Learning goal 2:* to take into account the complexity of the tackled socio-ecological system**

The issue of a system's complexity has bothered scholars of transdisciplinarity for a long time: "In our efforts to relate the parts and to see the problems 'whole,' we are recruiting teams of representatives from various disciplines" (Winch 1947, p. 72). Again, the case studies' approaches to tackling a system's complexity differ.

The leaders of the early case studies interpreted the complexity challenge as one of an overall synthesis: this synthesis should ensure that the diverse suggestions for improvement made by student groups would not contradict each other. Accordingly, the fact that two groups had suggested opposite strategies (either to take out, or to store heavy metals in waste incineration slag) was seen as a mistake (Müller-Herold and Neuenschwander 1992, p. 345). Synthesis or integration here meant the outputs of the case study – the solutions suggested by the students – should build a logically coherent whole.

In the small (Frischknecht and Schmied 2008) and the large case study (Scholz et al. 2006) a system model was used for tackling the complexity of socio-ecological systems. As in hard system thinking (Checkland 1985) it was the main "socio-cognitive framework" to integrate knowledge and to "establish findings" (Rossini and Porter 1979, p. 74). In the small case study, the system model was used to integrate systems knowledge (ProClim 1997, Pohl and Hirsch Hadorn 2007) in order to understand the system's complex behaviour. Students used the system model to identify leverage points for interventions, by analysing the different roles variables play in the system and by looking for feedback loops (Vester 1999). In the large case study, the system model was also used to integrate systems knowledge, but furthermore to provide target knowledge. Scenarios of possible future developments were built, the desirability of which was then discussed and evaluated in a multi-criteria assessment by experts and stakeholder groups (Walter et al. 2008). In the large case study, the system model hence moreover served to integrate knowledge about the system and assessments of the desirability of the system's future development.

In *UPL,* we build on the approach of the small case study (Frischknecht and Schmied 2008) and use the system model as socio-cognitive framework to integrate knowledge about the case. In comparison to the former case studies, there are two important differences in how we build and use system models (cf. stage 3, steps 5–7). The first is that we put the stakeholders in the centre, starting modelling with three or four variables that represent the most important stakeholders' needs. Accordingly, the model does not represent a general socio-ecological system, but the system of factors that influence the stakeholders' needs. The second difference is that students put promising measures into the model to check whether they effect the system as intended and whether two measures in parallel enforce or hinder each other. That is, we use the system model also to provide transformation knowledge. In *UPL,* we do not use the system model to provide target knowledge. Target knowledge comes in when students define the concerned stakeholders and their needs (stage 3, step 3) and when students perform a sustainability assessment of their project (stage 5).

How other curricula integrate systems and design thinking

UPL is not the only course that integrates systems and design thinking. Others can be found in curricula of engineering studies (Nagel et al. 2017) or in design studies (Pourdehnad et al. 2011, Crosby et al. 2018). In these courses systems thinking is included to make students aware of the complexity of the system they are intervening in as engineers or designers. "An integrated approach to problem resolution requires design thinkers to expand their understanding of good systems design principles with a purposeful consideration of the social systems they are working within" (Pourdehnad et al. 2011, pp. 7–8). The courses achieve this aim in different ways, for instance, by asking students to think about their own role in the system (Crosby et al. 2018, p. 120), by modelling the system's dynamic (Crosby et al. 2018, p. 125), by including many different stakeholders and their divergent needs (Pourdehnad et al. 2011, pp. 8–9), or by making students analyse how their decisions "affect the broader community and the global system" (Nagel et al. 2017, p. 1614), for example, by a sustainability assessment. Thus, *UPL* is one approach of how to integrate systems and design thinking in teaching among others. However, what makes *UPL* particular is its methodology, the clear procedure of how and when to switch between both ways of thinking and how to interconnect them (figure 2).

A challenge with the integration of systems and design thinking is how to engage with stakeholders and their divergent needs. In a design course in public and social innovation labs, the lecturers observed that "[u]pon entering the problem space, students found a milieu of complex organizational realities and political dynamics which for them remained somewhat opaque" (Penin et al. 2015, p. 446). Again, the *UPL* methodology helps students to clarify this opaqueness. They have to identify the three to four most important stakeholders for the insight identified, "important" meaning those interested in changing the current situation or in keeping it as it is. They have to describe the insight from the perspective of each stakeholder in a problem statement to make the different viewpoints and interests explicit. When brainstorming measures and testing prototypes, students have to deal with the tensions caused by these differences. The resulting measures do not represent a consensus, but rather what Checkland calls "accommodations". Accommodations occur when a proposed solution is "both desirable in terms of this analysis and feasible for these people with their particular history, relationships, culture and aspirations" (Checkland 2000, p. 15).

Conclusions

We started by asking what images of knowledge about a td environmental scientist's tasks in complex problem solving *UPL* imparts to students. In short it is: for tackling environmental problems, stakeholders and their needs as well as the overall system matter. As a td environmental scientist, one must be able to switch between both perspectives and to connect them. A td environmental scientist must be able to zoom out to get an overview, to build a system model, to check what happens if two measures intervene in the same system. And (s)he must be able to zoom in on specific insights, on the stakeholders and their needs, on measures to address these needs and on prototypes that materialise the measures. With the *UPL* methodology (figure 2) we provide methods, tools and a stepwise procedure to accomplish these tasks. However, *UPL* is no magic bullet and comes with new problems:

- There is no uniform system understanding in *UPL*. There are as many system models as student groups. Students may get confused, as in most other classes in the curriculum of Environmental Sciences at ETH Zurich models are used according to hard system thinking.
- Although we repeatedly stress the different needs and interest of stakeholders, some groups identify only stakeholders that support their measure. One reason is that students just ignore opposing stakeholders. Another is that students impute their own needs to stakeholders, for instance if a problem statement says that politicians need to know about climate change.
- A number of further problems come with the scale of the course. Besides the amount of teaching resources *UPL* requires, the scale also impacts the case area. Students contact around 150 stakeholders in the second semester. Some of them will feel disturbed or overwhelmed by the students' requests and questions, or complain that ETH Zurich is proposing outdated or unrealistic measures.

Finally, *UPL* imparts a different implicit idea about the td environmental scientist than former td case studies. This difference also points to a more fundamental discussion: about what adequate and fruitful roles of trained td environmental scientists are in supporting society to tackle complex and wicked sustainability problems, and where their responsibility ends.

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