The value of a conceptual model in Problem Based Learning to enhance students' reflexivity; framework and experimental design

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Abstract

A crucial skill for scientists involved in sustainability issues is the ability to reflect on knowledge and knowledge production in research projects with high levels of interaction between scientists and other stakeholders. Little is known about adequate teaching and learning strategies that allow for teaching reflexive skills. The research presented in this paper aims to contribute in this direction. In elaborating reflexive skills we distinguished three components: assessing the relative contributions of scientific disciplines and non-academic knowledge to environmental problem solving; assessing the role of norms and values in research; and critically assessing one's own position (in terms of knowledge and values) in research projects. We then developed a framework for teaching and learning reflexive skills which is based on the following interrelated core elements: theories on science-society interaction; concrete experiences in problem-oriented research; interactions with others engaged in learning reflexive skills, and explicit reflection tasks. In order to investigate whether and how this framework indeed can be applied for improving reflexive skills we applied an experimental design to an existing course. We aim to assess (i) whether students' interdisciplinary reflexive skills improved after successful completion of a course that adopted this framework, and (ii) whether the introduction of a special training influenced the improvement of these skills.

Three groups of 30 Master of Science students were involved in the study. Each group collaborated in a project usingd scientific knowledge and methods to address a real life issue. Two variables were applied: (i) lectures on theoretical aspects of science-society interactions in inter- and transdisciplinary research and (ii) teacher efforts to scaffold on the introduction of norms and values in problem-oriented research. The course enabled all students to interact with scientists as well as non-academic actors, to interact with students with various perspectives (based on different cultural or disciplinary background) and to reflect on the theory, experience and interaction. Students' reflexive skills were assessed through a questionnaire (pre-test and post-test) and a reflection assignment. The set-up of this experiment is presented.

1 Introduction

The design of sustainable solutions for environmental problems calls for university-level scientists with specific competencies. These competencies include the theory and understanding of a particular domain (e.g. disciplinary and interdisciplinary knowledge), as well cognitive abilities (e.g. critical thinking), technical and analytical abilities (e.g. lab skills) and general skills (e.g. written and oral communication, team work, project management). A crucial skill for scientists involved in sustainability issues is the ability to be reflexive on knowledge and knowledge production.

Active learning strategies in which students have to deal with diverse data, beliefs and values, such as scenario building and analysis, gaming and simulation, participatory modelling, focus groups and consensus can be very successful in creating integrated and interdisciplinary perspectives (Dieleman and Huisingh 2006, McLaughlan 2007). Other examples of active learning strategies that improve students' ability to integrate knowledge are case studies, practical field assignments and problem-based learning approaches (Scholz et al. 2006, Steiner and Posch 2006, Vedeld and Krogh 2005). Course and curriculum developers who prepare students to become professionals in the field of sustainability face the challenge of teaching students to become *reflexive*. Students experience difficulty in reflecting on the position of scientific knowledge within society, on the societal interests that guide scientific research, and on the differences between natural sciences, social sciences and lay or experiential knowledge (Fortuin et al. 2013). Little is known about adequate teaching and learning strategies that allow for teaching these skills.

Conceptual models might support students to reflect on their research activities and on the characteristics of environmental sciences research. Conceptual models that depict the process of environmental research and its relation with societal problems can offer students a framework to analyze and discuss the role of science in solving environmental problems and the contribution of various disciplines to tackle environmental issues (Fortuin et al. 2011). An example of a conceptual model illustrating the different phases in transdisciplinary research is developed by Jahn et al. (2008) (Jahn et al. 2012)(see Figure 1). Transdisciplinarity is an extension of interdisciplinarity. Both encompass the integration of problem-specific knowledge and methods. Interdisciplinarity is about the integration at the interface of various scientific disciplines. Transdisciplinarity addresses societal problems through collaboration between scientists from various disciplines as well as non-scientific actors (Jahn et al. 2012).

In this paper we present a theoretical framework and an experimental design for teaching and assessing reflexive skills in a problem-based, interdisciplinary course setting using the model by Jahn et al. We evaluate whether students' reflexive skills improved after successful completion of a course that is set up in line with this framework. We aim to investigate whether the course in general and the introduction of a special training session in particular, will improve students' interdisciplinary reflexive skills.

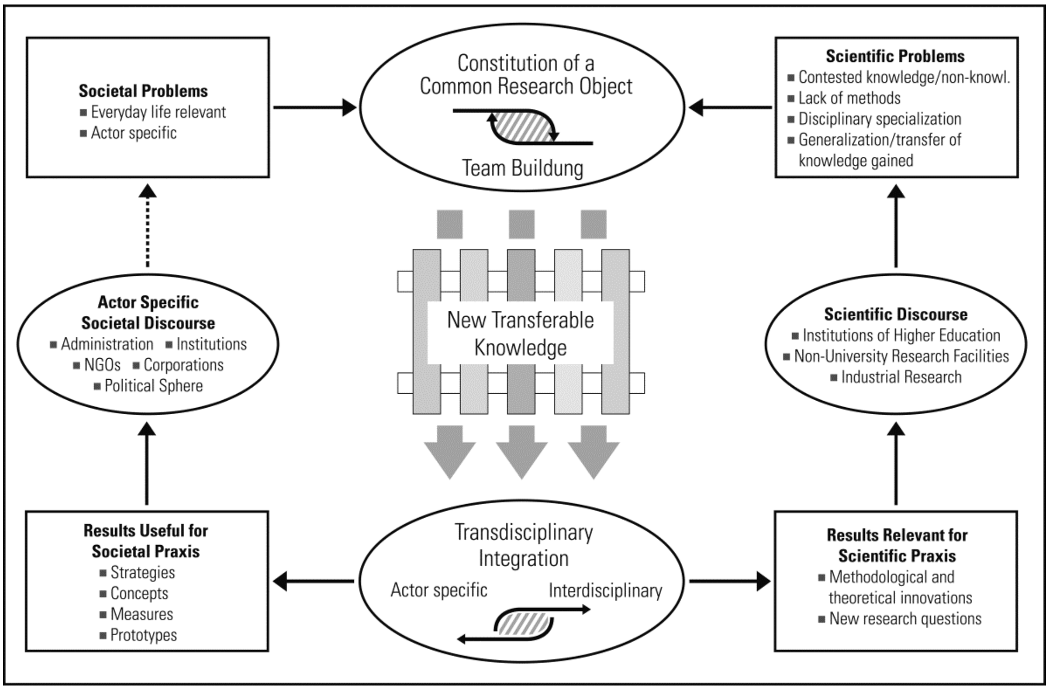

Figure 1: A general model of the transdisciplinary research process (Jahn 2008)

In the following sections, we first explain the importance of reflexivity in problem-oriented environmental science research and education and explicate reflexive skills in university level environmental science education. Secondly we present a framework for reflexive learning. Finally we introduce the empirical study.

2 Reflexivity in interdisciplinary environmental education

Reflection is a crucial academic skill. Scientists are used to reflect on data in order to analyse and interpret them. They are also used to reflect on the limitation of the methodology used in a study. What is less common is that scientists reflect on the theoretical framework from which they engage with their research questions and that forms the basis of their methodology (Ison 2008). Scientists from the same discipline share fundamental assumptions and values concerning the scientific process. They share a world view, language, disciplinary concepts and methods for acquiring and validating knowledge. A shared epistemological perspective is hardly discussed and in fact there is often no need to do so in a disciplinary context (Eigenbrode et al. 2007). In an interdisciplinary context, such as problem-oriented environmental science research, this is different. In such a context scientists with different epistemologies work together. Ignoring that different epistemologies exist and that various epistemologies are valuable for interdisciplinary research, might obstruct successful collaboration from the start (Jahn et al. 2012). By reflection on the differences between disciplines, scientists become aware of disciplinary characteristics which improves collaboration (Eigenbrode et al. 2007).

Moreover, because professionals in the environmental domain often deal with societal problems or ‘real-world problems’, i.e. environmental problems, they should be able to reflect on the difference between scientific knowledge and knowledge from non-scientific stakeholders. Environmental problems are characterized by uncertainties, diverging social interests and conflicting views on the nature of the problem and the best ways to solve it. Environmental scientists should realize that scientific knowledge alone is insufficient to address these problems. In order to develop sustainable solutions for environmental problems knowledge from non-scientific stakeholders is required as well. However, there is a difference between lay-knowledge or knowledge based on experience and scientific knowledge based on generalized theories and produced by applying strict methodologies. Experiential knowledge and scientific knowledge differ in their foundations, their epistemological status, and the role they play in addressing environmental problems (Scholz 2011: Chapter 15).

Professionals in the environmental domain should also be aware of the norms and values that enter scientific work when 'real-world problems' are addressed. A crucial difference between descriptive scientific research aimed to describe and explain what exists and prescriptive scientific research aimed to design sustainable solutions, is that in the latter norms and values are incorporated. Scientists should be aware of how and which (of the scientists him/herself, or stakeholders?) norms and values contribute to the transformation of the societal problem to a researchable problem, the formulation of the research questions, the production of new knowledge, and the integration of knowledge in order to contribute to societal needs (De Groot 1986, Jahn et al. 2012). In other words, these professionals should adopt a reflexive approach to knowledge and knowledge production. Such a reflexive approach is, however, often lacking among scientists (Miller et al. 2008). Teaching reflexive skills is therefore an essential part of an environmental science curriculum.

We distinguish between three components of reflexive skills characteristic for environmental science curricula:

1. the ability to identify, differentiate and evaluate the contribution of major relevant scientific disciplines as well as the contribution of non-academic knowledge to address a societal (i.e. environmental) problem;
2. the ability to identify, differentiate and evaluate the entering of norms, values and interests into a research process that addresses a societal problem as well as into the design of strategies, technologies or scenarios that address this problem;
3. the ability to critically assess one's own position and contribution (in terms of scientific and other knowledge, interests, norms, and values) in the context of addressing a problem.

These component skills can be manifested on a general level (e.g. science in general or an environmental problem in general) as well as on the level of a specific project.

3 A framework for reflexive learning

Dyke (2009) developed a framework that enables reflexive learning and distinguishes between four equally important elements: (1) theory, (2) experience, (3) reflection and (4) others. This framework can be very relevant for teaching interdisciplinary reflexive skills in environmental science. Below, we explain the framework adapted to the context of academic environmental science education.

The first element of the framework is *theory* or knowing. Theory plays a prominent role in university education. Theory established by years of experience and reflection of many scientists is passed on to students via papers, books and lectures. In the case of inter- or transdisciplinarity in environmental sciences curricula this theory consist for instance of knowledge about the differences in epistemology and ontology of disciplines, the differences in logic between scientific knowledge and lay or experiential knowledge and the importance of a reflexive attitude in environmental sciences and education. This theory also comprises knowledge about requirements for successful inter- or transdisciplinary research as well as methods or procedures to integrate scientific knowledge or to integrate scientific and lay knowledge. Conceptual models can be introduced to support reflection on environmental research (Fortuin et al. 2011). In particular the model of transdisciplinary research described by Jahn (2008) could be useful, because it distinguishes the societal practice and the scientific practice and illustrates clearly the various stages of the research process that starts from a real life issue, such as the problem framing and knowledge integration phase (see e.g.Godemann 2008, Bergmann et al. 2012).

For reflexive learning, theory alone is not sufficient. Students should learn to critically assess the theory and discuss it with others. Therefore theory should be accompanied by experience and reflection. As Dyke noted: “It is the relationship to such theory, not the theory itself, which is critical to providing reflexive education” (Dyke 2009: 299). Practical experience and application, therefore, is perhaps even more important than theoretical understanding. They should, for instance, apply a specific procedure for knowledge integration, and learn via this experience about the potentials and limitations of this procedure. Thus, the second element of the framework for reflexive learning is *experience*, or doing. As Dyke noted: “A key dimension of learning is that we learn by ‘doing’ ─it is our actions that produce experience and learning flows from the active transformations of these experiences” (2009: 304). In the context of environmental science education, this implies that students should practice addressing a real-world environmental problem, i.e. concrete societal problems experienced by common actors in society. It is not sufficient that students tackle academic assignments or case studies, students should engage with stakeholders outside academia. They should investigate an environmental problem and face differences in norms and values held by these stakeholders. They should apply disciplinary and interdisciplinary methodologies as well as techniques and procedures to integrate knowledge and experience the challenges.

For reflexive learning, theory and practice should be combined with *reflection.* Reflection on concrete experiences is needed to adapt one’s (theoretical) knowledge to new contexts. Reflection enables students to apply their learning in different situations and contexts. Without reflection the practice could become merely the application of instructions or procedures. To transform experience into learning and to acquire new knowledge, reflection is crucial. Therefore, the third element of the framework of reflexive learning is reflective thinking, or pensively looking at the world and at yourself. In an educational setting this reflection can be triggered by bringing students in a new situation, as Dyke states “It is when experience presents the new, the unusual, or the unexpected that we are forced to think and reflect" (Dyke 2009: 301). Reflection can be stimulated through scaffolding by supervisors and (guided) reflection assignments.

The last element of the framework for reflexive learning distinguished by Dyke is the *other, i.e. interaction and the social context* of learning. Dyke stresses that education is situated within and shaped by a broader social, cultural and historical context that should not be ignored. We fully agree, but in adopting Dyke's framework for our study we limited this part, 'other', to the interaction among those involved in a particular course or module, i.e. other students and scientists or supervisors. Reflexive learning requires interaction, requires sharing and discussing experiences with others because "[w]hat people say and how they interact with each other, their conversations, dialogue and shared practice, shapes perception and interpretation" (Dyke 2009: 300). Understanding is not created in social isolation, it requires communities of learning.

The core elements of reflexive learning are presented in Figure 1 that is based on Dyke (2009). The tetrahedron of Figure 2 illustrates that all four elements are interdependent and that there is no hierarchy in the sense that for instance theory is considered more important than experience or vice versa. The figure also illustrates that reflexive learning is not considered to follow a linear path or sequential phases. Instead, the learning activity should be flexible and learner centred. The learning is influenced by the interaction of all four core elements and a student should be enabled to move back and forth between any of these elements. In reflexive learning students should be encouraged to know, practice, interact and reflect in any particular order (Dyke 2009).

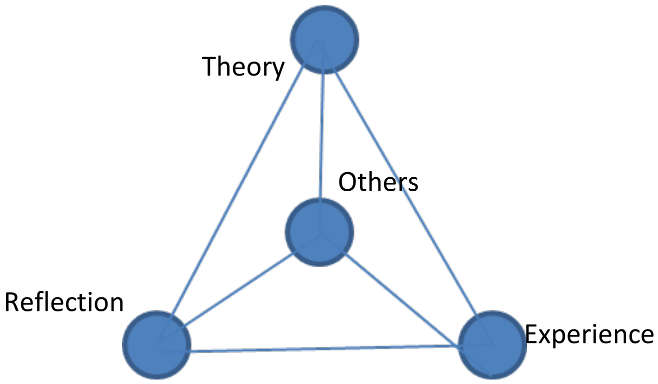

Figure 2: Core elements of reflexive learning (based on Dyke 2009)

Hypotheses and research questions

Based on this framework for reflexive learning we assume that a course that (i) includes theory on inter- and transdisciplinarity in environmental sciences, (ii) enables students to address a realistic environmental problem, and to interact with scientists as well as non-academic actors, (iii) enables them to interact with students with different perspectives (based on different cultural or disciplinary background) and (iv) enables them to reflect on the theory, experience and interaction, allows for the development of the students' interdisciplinary reflexive skills. In line with this assumption we formulated the following research questions:

(1) Do students' interdisciplinary reflexive skills improve after successful completion of a course that adopted the framework for reflexive learning?

(2) Does the introduction of (a) lectures on theoretical aspects of science-society interactions in inter- and transdisciplinary research and (b) teacher efforts to scaffold on the introduction of norms and values in problem-oriented research, have an effect on the improvement of students' interdisciplinary reflexive skills?

We assumed that the introduction and application of the Jahn-model (Jahn 2008) in the training session will enhance the development of reflexive skills. The Jahn-model illustrates the different phases of a research approach that addresses a societal problem through collaboration between researchers from various disciplines and extra-scientific actors. The model shows the different epistemic paths and allows for explaining the introduction of norms, values and interests in dealing with scientific problems and in dealing with societal problems.

4 The experimental design

4.1 Study context and participants

In order to investigated whether the framework indeed allowed for developing reflexive skills we applied it in an existing course for master of science (MSc) students in the field of environmental sciences and natural resource management, called *European Workshop in*

Environmental Sciences and Management (EUW). In the EUW a group of 30 MSc students work on a realistic consultancy project through a well-structured, collaborative interdisciplinary research project in an intercultural setting. Students are expected to use scientific knowledge and methods to address a real life issue for a non-academic commissioner. The following phases in the project can be distinguished: (1) problem orientation and problem framing, (2) developing the methodology and data collection methods, (3) data collection, (4) data analysis, (5) reporting and (6) reflection. Characteristic course components are the organizational “matrix structure” in which students work, a two week field-trip abroad, a customized SharePoint website, and the role of teachers as facilitators rather than experts providing information. The ‘matrix-approach’ enables students to deepen their disciplinary knowledge and skills, forces them to cross disciplinary boundaries, enables intensive group interaction and facilitates the involvement of every student. The didactic model of this workshop is elaborated elsewhere (see Fortuin and Bush 2010).

4.2 Procedure

In order to test our hypotheses we did a pseudo-experiment in the EUW. Three workshops, offered in the period 6 May – 5 July, 2013 were involved in the study. In every workshop 30 MSc students participated and three different staff members from various chair groups supervised a group of students (see Figure 3, Table 1).

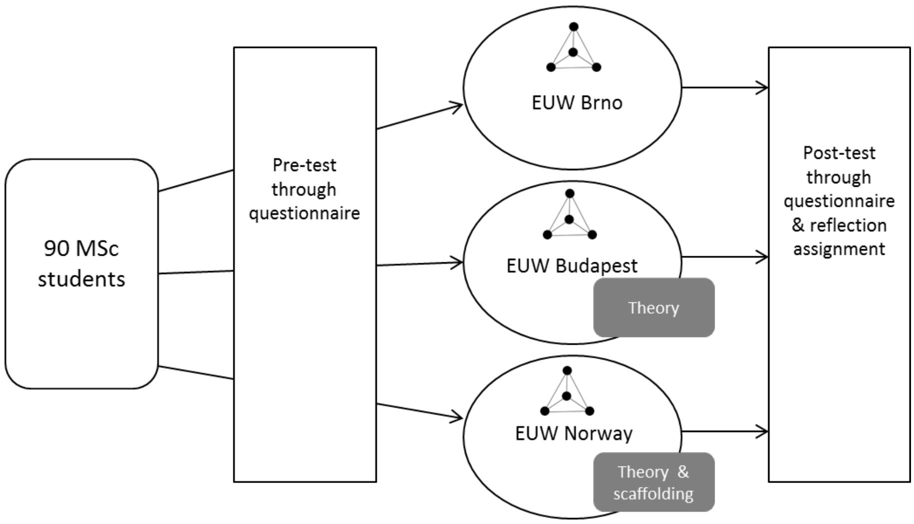

Figure 3: Design of the empirical study to test the framework to teach interdisciplinary reflexive skills

Two variables were introduced in the study: (1) the introduction of *theory* and (2) *scaffolding*. In the EUW-Budapest and the EUW-Norway a special training session (2 x 1,5 hour) was included to introduce students to differences in logic of societal and scientific practices and to the role of values in scientific research that aims to address an environmental problem. The conceptual model of transdisciplinarity developed by Jahn et al (2012) was introduced as well. In the EUW-Brno this training session was not included.

In the EUW-Norway scaffolding was used throughout the workshop on the role of norms and values in problem-oriented research. In the other workshops (EUW-Brno and Budapest) no scaffolding took place.

In all three EUW's students were encouraged to reflect on the use of scientific knowledge and working in an interdisciplinary and intercultural group, the process of the research project and the interaction with the commissioner and other stakeholders, and on project management.

Table 1: Characteristics of the three workshops involved in the study

	EUW-Brno	**EUW-Budapest**	**EUW-Norway**
Location of fieldwork	Brno	Budapest	Coastal area in mid-Norway
Commissioner	Nadace Partnerství, an environmental non-governmental organisation	Regional Environmental Center for Central and Eastern Europe	Kysten er klar, an umbrella organisation of several coastal municipalities near Trondheim
Topic of the consultancy	Developing travel plans to enhance sustainable mobility	Developing travel plans to enhance sustainable mobility	Reinvigoration of the coastal area through aquaculture, recreation & tourism, and wind energy
Expert analyses executed by students	Policy Stakeholders Mobility Infrastructure Environment & public health	Policy Stakeholders Mobility Infrastructure Environment & public health	Policy & stakeholder Commodity chain Natural resources Social well-being Scenario
Analyses were executed in	Five (groups of) companies	Five districts in Budapest	Four municipalities
Participants (30)	12 nationalities, 4 different MSc programs	12 nationalities, 4 different MSc programs	14 nationalities, 4 different MSc programs
Background supervisors	Environmental Technology Environmental systems analysis Methodology & skills	Environmental policy Environmental technology Methodology & skills	Environmental policy Environmental systems analysis Methodology & skills

4.3 Operationalizing and measuring interdisciplinary reflexive skills

In order to be able to measure students' reflexive skills, they were operationalized by formulating learning objectives (see Table 2). To assess whether students achieved these learning outcomes a questionnaire and reflection assignment were developed. The questionnaire was used to assess students' reflexive skills on a *general* level (see learning objectives 2-8) at the start (pre-test) and at the end of the EUW (post-test). The reflection assignment was used to assess students' reflexive skills in relation to the *EUW project* (see learning objectives 9-11, but also 1).

The core of the questionnaire consisted of 25 statements (for examples see Annex 1). Students were asked to indicate on a Likert scale (1-4) whether they agreed or disagreed with a statement or had no opinion. The pre-test also included a few general questions to determine the students' background and experience, because students with (working) experience in addressing real-life environmental problems or in working in (disciplinary and culturally) heterogeneous groups were expected to be more reflexive than students who lacked this experience. Experienced students were expected to have been confronted with "the unusual" and therefore forced to think and reflect in the past.

Table 2: Learning objectives for reflexive skills

1.	correctly apply the concepts of discipline, value, norm, empirical claim, normative claim, life-world knowledge, interdisciplinarity, transdisciplinarity, transdisciplinary research process.
2.	explain the difference between societal problem solving and doing scientific research
3.	explain the difference between natural and social sciences with regard to their distance to life-world knowledge
4.	explain how societal values play a role in scientific research
5.	explain potential problems with values in applied scientific research
6.	identify disciplinary knowledge aspects in a problem analysis description
7.	identify normative aspects in a problem analysis description
8.	explain why dealing with values is challenging in transdisciplinary research
9.	within an actual project, analyse your personal contribution in terms of disciplinary knowledge
10.	within an actual project, analyse your personal contribution in terms of normative beliefs
11.	for a given project, indicate how it could be organized in order to improve research outcomes, enhance collective learning, and avoid pitfalls

(The experiment is not finished and not all data are collected yet. Therefore data analysis and first results cannot be presented here. These will be presented at the conference in September).

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Annex 1: Examples of statements to assess reflexive skills*)

1. Biodiversity degradation can be halted, or at least slowed down, by doing more scientific research (2).
2. Non-academic stakeholders usually don't understand the core concepts in natural science (3).
3. Social values and political views play a role in every scientific research project (4).
4. In the nature area of the Veluwe, wild boars are hunted to reduce their number and to prevent that the animals go foraging and destroy the gardens in surrounding villages. There is, however, a heated debate between groups in favour of this hunting policy and groups that think the policy violates animal welfare. To analyse this problem, ecology is the key discipline (6).
5. In order to improve the sustainability of a city knowledge provided by scientists is more important than knowledge provided by non-academic stakeholders, such as civic associations or environmental non-governmental organisation (8).
6. When a team of scientists aims to address an environmental issue the disciplinary composition of the team influences the outcome of the study (6).
7. The main problem of transdisciplinary research is to get commitment from the stakeholder representatives (8).
8. The best way to do research that is useful to all stakeholder groups, is to remain objective and not include any values in research (5).
9. Wageningen Municipality aims to become a CO_2 neutral municipality. In this context scientific research can provide an answer to the question: 'How should Wageningen Municipality increase the use of solar panels?' (7)
10. As a scientist it is not my responsibility to solve an environmental problem. I have to provide evidence (2).

*) Between brackets is the corresponding learning objective from Table 2