DEVELOPING SKILLS FOR SUSTAINABILITY CHANGE AGENTS WITH A PARTICIPATORY BACKCASTING TEACHING TOOLBOX

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Abstract: The paper describes and analyses a participatory backcasting teaching toolbox (PBTT) designed to develop a set of skills required for sustainability change agents, including critical and systems thinking, future orientation, ability to work in transdisciplinary frameworks, personal involvement, conflict resolution and consensus building, dealing with complexity and uncertainty, creativity, practical problem-solving and action skills. The PBTT has evolved through experience and insights gained from the implementation of participatory backcasting (PB) methodology within two research projects and from three years of PB teaching practices. The PBTT includes twelve modules based on different steps and procedures of the PB process. The paper describes effects of the PBTT on the development of students' skills that have been observed throughout ten teaching cases. Furthermore, the potentials and limitations of the PBTT for building up the sustainable development related skills are discussed.

1 INTRODUCTION

During the United Nations Decade of Education for Sustainable Development (DESD, 2004-2014), the integration of sustainability into engineering curricula has come a long way; sustainable development (SD) competencies have been defined by the academic community, a variety of SD modules and courses have been designed and new integration strategies and teaching methodologies have been developed to ensure achievement of generic competences in sustainability and social commitment.

While intended learning outcomes related to the awareness of sustainability challenges have been included in the majority of engineering curricula worldwide, achieving the DESD goals requires further interventions, namely empowerment of the agents of change for sustainability. Thus, there is a need to introduce teaching methods and tools that allow reaching a higher level of SD comprehension and advancing students' competences from an ability to recognise consequences of their own future professional activities to the ability to design and implement long-term engineering solutions taking into account social, economic and environmental factors.

There are a number of studies on the skills and competences that are important for sustainability change agents (Bath et al., 2007; Segalas, 2008; Svanstrom et al., 2008; Segalas et al., 2009; Missimer and Connell, 2012; Lambrechts et al., 2013; Hesselbarth and Schaaltegger, 2014; Mulder, 2014). Based on these studies and on the experience of the authors in the field of the Engineering Education for Sustainable Development (EESD), a list of transversal skills necessary for sustainability change agents has been developed: (1) *critical and (2) systems thinking, (3) future orientation, (4) ability to work in transdisciplinary frameworks, (5) personal involvement, (6) conflict resolution and consensus building, (7) dealing with complexity and uncertainty, (8) creativity, (9) practical problem-solving and (10) action skills*. The introduction of these skills into curricula calls for innovative pedagogic strategies.

Participatory Backcasting (PB) is a future studies method to design normative future scenarios with the broad participation of stakeholders, and its use in sustainability education has been suggested. The main application domain of the PB is multi-dimensional and multi-sectorial problems with long-term effects, which are characterised by great uncertainties and a large number of stakeholders with conflicting interests. (Holmberg, 1998; Quist and Vergragt, 2006; Robinson, 1990)

PB is particularly useful in dealing with sustainability issues due to the normative nature of both (Vergragt and Jansen, 1993; Robinson, 2003; Vergragt and Quist, 2011). PB has been discussed and tested as a tool for engineers to deal with the complex challenges of sustainability (Quist et al., 2006) and as a suitable framework to introduce sustainability-relevant competences for engineering students (Kordas et al., 2013; Mulder, 2014).

The authors have aimed at designing a teaching toolbox based on the PB methodology that would develop a set of skills for sustainability change agents and at the same time could be tuned for various pedagogic needs, time limits and target audiences.

The objectives of this paper are:

- To describe the designed participatory backcasting teaching toolbox (PBTT), which includes a set of teaching modules and pedagogic approaches reflecting the stages of the PB framework (Quist, 2007; Kordas et al., 2013).
- To discuss the observed skills of sustainability change agents, which students have acquired during ten courses and training sessions.

2 METHODOLOGY

2.1 Developing the Participatory Backcasting Teaching Toolbox (PBTT)

The PBTT has been developed in an iterative manner through the implementation of three types of activities:
(1) practicing PB as transdisciplinary research (TdR) method in two research projects; (2) implementing the PBTT in ten teaching cases; (3) advancing the PBTT based on outcomes of the EESD research. Figure 1 provides an overview of the input from each of these components into the development of the PBTT.

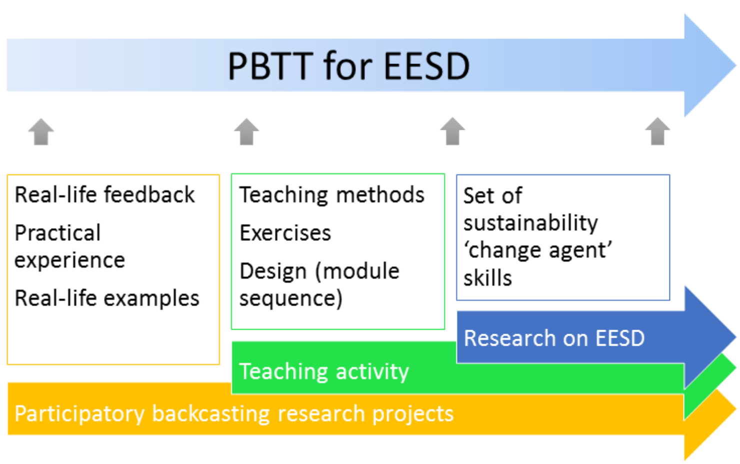

Figure 1: Scheme of the PBTT development

Two research projects have contributed to PBTT with real-life feedback on the approaches applied and with practical examples to be discussed during the teaching and training sessions. The first project was conducted during January 2012 – March 2013 in the Ukrainian city Bila Tserkva. It aimed at elaborating a long-term vision and an action plan for the provision of a comfortable indoor climate to its citizens. The second project was took place during November 2013 – April 2015 in the Serbian city Nis. This project had a similar topic and aims, but included additional steps and a more in-depth elaboration of the PB steps. Both projects were preceded by training courses on the PB methodology for involved researchers. The outcomes of those courses were used as a backbone for the PBTT design.

PBTT has been further advanced through its implementation in a number of teaching cases (Table 2), including regular courses, international summer schools and training workshops for various target groups. Due to the specific conditions of the teaching cases (e.g. goals, duration, topic, number and background of participants), the authors needed to adopt PBTT for each case. Therefore, the PBTT has been evolving from case to case. The multiple repetitions of the PBTT in different contexts allowed gradual enhancement of the teaching methods, testing various combinations of the PBBT modules as well as refining and diversifying the design of exercises and other learning activities.

This process led to the design of the PBTT, which includes a set of teaching modules and pedagogic approaches reflecting all stages of the PB framework (Quist, 2007; Kordas et al., 2013). It consists of the following modules: (A) problem orientation; (B) identification of needs; (C) definition of system boundaries; (D) stakeholder analysis; (E) current situation analysis; (F) driver analysis; (G) development of a future vision; (H) elaboration of a criteria for the vision; (I) creation of solutions; (J) testing solutions; (K) elaboration of combined solutions; (L) development of pathways for implementation of elaborated solutions; and (M) developing ideas for follow-ups.

In turn, various studies on EESD have provided insights on the transversal skills that are required to enable engineering students to become agents of change towards sustainability. Furthermore, deeper understanding of the active learning methods and creativity techniques are acquired from the EESD studies by Segalas, (2008); Missimer and Connell (2012). Table 1 depicts the expected learning outcomes in the form of skills to be acquired through various PBTT modules.

Table 1: Expected transversal skills to be acquired/advanced through various PBTT modules

Id	Module	System thinking	Critical thinking	Future orientation	Transdisciplinary framework	Personal involvement	Conflict resolution, consensus building	Complexity and uncertainty	Creativity	Problem-solving	Action skills
A	Problem orientation	S								PS	
B	Identification of needs	S	C						Cr	PS	
C	Definition of system boundaries	S						CU		PS	
D	Stakeholder analysis	S	C		TF		CB	CU		PS	
E	Current situation analysis	S	C					CU		PS	

Id	Module	System thinking	Critical thinking	Future orientation	Transdisciplinary framework	Personal involvement	Conflict resolution, consensus building	Complexity and uncertainty	Creativity	Problem-solving	Action skills
F	Driver analysis	S	C	F			CB	CU			
G	Development of a future vision			F			CB		Cr		
H	Elaboration of measurable criteria for the vision	S					CB				
I	Creation of solutions	S		F					Cr	PS	
J1	Testing solutions against criteria	S	C	F			CB	CU		PS	
J2	Robustness or sensitivity test	S	C	F			CB	CU		PS	
K	Elaboration of combined solution	S	C	F			CB	CU	Cr	PS	
L	Development of pathways	S	C	F		PI	CB		Cr	PS	A
M	Developing ideas for follow-ups	S	C	F		PI	CB		Cr	PS	A

2.2 Measuring achieved learning outcomes/skills

In order to measure the impact of the PBTT-based courses on the students' skills, the authors applied triangulation of the results from both direct measurements (test results, work products, observation of participants performing a task, etc.) and the indirect ones (surveys and interviews) as it is suggested by Breslow (2007) and Maki (2010). Particularly, the following tangible and intangible outputs of the PBTT-based courses have been used for measuring the acquired skills: 1) student work results, 2) observations of students performing exercises, 3) outcomes of pre- and post-questionnaires, and 4) conclusions from exit interviews. Table 2 presents the methods for measuring the acquired skills that have been used in each of the ten PBTT teaching cases.

Table 2: Methods for measuring achieved learning outcomes/acquired skills

#	Title of the learning activity (LA), date and place	Methods for measuring achieved learning outcomes/acquired skills
1	Training within the TEMPUS “SDTrain” and “REGENLAW” projects, Stockholm, December 2013 (23 participants; 20 h during 1 week)	1) Pre- and post-questionnaires. 2) Analysis/evaluation of the work results (final group presentations). 3) Observations of students performing exercises.
2	Training within the Tempus project “HETES”, Stockholm, March 2014 (8 participants; 6 hours during 1 day)	1) Post-evaluation of EA by participants (questionnaires); 2) Analysis/evaluation of the work results (final presentation) 3) Observations of participants performing exercises
3	Workshop within the Research Methodology and Theory of Science course at KTH, Stockholm, autumn 2012 (30 participants; 2 workshops, 2 h each)	1) Analysis/evaluation of the work results (final presentation). 2) Observations of students performing exercises. 3) Course evaluation on BILDA (KTH’s on-line platform).
4	Workshop within the Research Methodology and Theory of Science course at KTH, Stockholm, autumn term 2013 (25 participants; 2 workshops, 3 h each)	1) Analysis/evaluation of the work results (final presentation). 2) Observations of students performing exercises. 3) Course evaluation on BILDA (KTH’s on-line platform) 4) PB-workshop evaluation by participants (questionnaires)
5	Workshop within the Research Methodology and Theory of Science course at KTH, Stockholm, autumn 2014 (30 participants; 3 workshops, 2 h each)	1) Analysis/evaluation of the work results (final presentation). 2) Observations of students performing exercises. 3) Course evaluation on BILDA (KTH’s on-line platform) 4) PB-workshop evaluation by participants (questionnaires)
6	Sustainable Technology Development summer school, UPC Barcelona-Tech, June 2013 (30 participants; 2 weeks)	1) Analysis/evaluation of the work results (final group presentations and reports) 2) School evaluation by participants (questionnaires). 3) Observations of students performing exercises.

7	Sustainable Technology Development summer school, UPC Barcelona-Tech, June 2014 (20 participants; 2 weeks)	1) Analysis/evaluation of the work results (final group presentations and reports) 2) School evaluation by participants (questionnaires) 3) Observations of students performing exercises
8	Leo Jansen’s workshop on PB at NTUU KPI, Kyiv, May 2012 (20 participants; 1 day workshop)	1) Interview with participants. 2) Observation of students performing exercises.
9	Workshop within the MSc program on Sustainable Development and Governing, NTUU KPI, Kyiv, autumn term 2012 (25 participants; 2 workshops, 2 h each + 8 h of home work)	1) Analysis/evaluation of the work results (final group presentations) 2) Observations of students performing exercises
10	Student projects in the framework of Summer School “Chongming Island”, China, August 2013 (25 participants; 1 week)	1) Analysis/evaluation of the work results (final group presentations and reports). *2)* Observations of students performing exercises.

3 RESULTS

The current version of the designed PBTT consists of thirteen modules; each of them includes one or several exercises. This chapter describes the modules according to the following structure: the module *goal*; the list of included *exercises*; the suggested *pedagogical approaches*; and the list of *skills* which were observed/measured during implementation of the PBTT (using the methods presented in the Table 2).

3.1 Introductory lecture

An introductory lecture is an essential part of any PBTT-based learning activity. Depending on the background of the participants, it may cover a number of topics from sustainability science. future studies or transition theory to create a common basis among participants.

A. Problem orientation

Goal: to describe a given problem; to reach a common understanding of the problem among all participants; and to define a timeframe for problem solving and associated limitations.
Exercises: (1) identification of sustainability challenges within a given problem; (2) definition of the timeframe for problem solving; (3) description of the limitations: the scale and the parts of the problem to be considered.
Pedagogic approaches: group discussions.
The observed skills: critical thinking and problem-solving.

B. Identification of needs

Goal: to identify needs behind a given problem. This stage enables creativity and innovative thinking beyond the boundaries of the existing solutions.
Exercises: (1) identification of the needs behind a given problem, (2) generation of alternative solutions to fulfil each of the identified needs.
Pedagogic approaches: brainstorming and group discussion. Another technique that can help in identification of the root cause of a problem, or basic needs, is to repeatedly ask the question 'why?' to remove layers of the secondary causes or needs.

The observed skills: critical thinking, system thinking, and creativity.

C. Definition of system boundaries

Goal: to define the system boundaries of the problem under study and to specify the problem.
Exercises: (1) description of a socio-technical system related to a given problem; (2) identification of internal parts of such system and analysis of interrelations among the parts/subsystems; (3) description of the external environment.
Pedagogic approaches: brainstorming and group discussion.
The observed skills: system thinking, dealing with complexity, and problem solving.

D. Stakeholder analysis

Goal: to perform a comprehensive stakeholder analysis for a given problem.
Exercises: (1) stakeholder identification; (2) stakeholder mapping according to the level of stakeholder interest and power to influence a given problem using an interest-influence plane; (3) identification of potential conflicting and common interests among the stakeholders for further consensus-building exercises.
Pedagogic approaches: *brainstorming* to generate a list of relevant stakeholders; *group discussion* to analyse their power to influence and interest in a given problem; *interviews* with stakeholders and information search to identify stakeholders' points of view and concerns; *group discussion* to identify points of conflicts and common interest.
The observed skills: system thinking, critical thinking, ability to work in transdisciplinary framework, conflict-resolution and consensus building, dealing with complexity and uncertainties, and problem solving.

E. Current situation analysis

Goal: to analyse the current state of a given problem through a description of the main characteristics of the corresponding socio-technical system. This module is focused on the internal environment of the system.
Exercises: (1) defining the need for information about the system; (2) data collection and analysis; (3) identification of the current system's key problems, weaknesses and strengths.
Pedagogic approaches: *group work* on data collection and analysis, *group discussion* to identify the weaknesses and strengthen of the system.
The observed skills: system thinking, critical thinking, dealing with complexity, and problem-solving.

F. Driver analysis

Goal: to identify and classify external factors, which can influence a problem under study in the future. An important outcome of this module is the selection of two key uncertainties to be used for robustness testing within the module "J" of the PBTT and a list of trends to be considered during the following analysis.
Exercises: (1) identification of external forces for a given problem; (2) analysis of identified forces and placing them on the plane Impact – Uncertainty; (3) classification of the identified forces on *trends* (high impact, low uncertainty), *key uncertainties* (high impact, high uncertainty) and others (the forces with low impact); (4) selection of two key uncertainties to be used for robustness testing; (5) data collection for trend analysis.
Pedagogic approaches: *brainstorming* on driving forces; *group discussion* to analyse and classify the drivers; *role-play for consensus-building* while selecting two key uncertainties; *group work* on data collection and analysis.
The observed skills: system thinking, critical thinking, future orientation, dealing with complexity and uncertainty, and consensus-building.

G. Development of a future vision

Goal: to elaborate joint desirable future vision for a given problem/system to be achieved within the time frame defined within the module "A".
Exercises: (1) generation of the key words, which describe or are associated with desirable future; (2) clustering the key words and formulation of a vision.
Pedagogic approaches: brainstorming on key words, a role-play to cluster key worlds and to formulate a vision by consensus.

The observed skills: future orientation, consensus-building, conflict resolution, and creativity.

H. Elaboration of measurable criteria for the vision

Goal: to elaborate measurable criteria to specify the formulated desirable future vision. This module allows setting targets to be achieved within the defined time frame.
Exercises: (1) generation of ideas for criteria; (2) clustering and classification of the ideas aiming at a list of criteria and sub-criteria for each; (3) prioritization of the criteria and selection of those to be used at the further stages; (4) elaboration of measurement methods for each criterion.
Pedagogic approaches: *brainstorming* to generate ideas for criteria, *role-play* and other *consensus-building* activities to rank criteria and to select the most important of them.
The observed skills: system thinking and consensus-building.

I. Creation of solutions

Goal: to create several alternative solutions to fulfil the needs identified within module "B". The solutions should be proposed on a system-level and cover different aspect of the problem.
Exercises: (1) generation of ideas for solutions and elaboration of solutions using morphological analysis or different creativity techniques; (1a) shortening the list of the obtained solutions (if required); (2) description of the obtained solutions (using pictures, textual descriptions or in another way), (3) giving concise titles to each solution.
Pedagogic approaches: brainstorming, group discussion, group work on elaboration and analysis of solutions.
The observed skills: system thinking, future-orientation, creativity and problem solving.

J. Solutions testing and analysis

The module J includes two sub-modules: testing solutions against criteria and robustness testing.

J1. Testing solutions against criteria

Goal: to identify how each of the elaborated solutions suits the selected criteria, and the weaknesses and strengths of each solution
Exercises: (1) evaluation of each solution against all selected criteria; (2) selection of a solution or combination of several solutions that are meeting the criteria in the best way.
P*edagogic approaches: group work* to test solutions and to analyse results.
The observed skills: critical thinking, system thinking, future orientation, consensus-building, dealing with complexity and uncertainties, and problem solving.

J2. Testing solutions for robustness

Goal: to analyse robustness of the elaborated solutions in different external conditions that can occur in the future.
Exercises: (1) development of a "future plane", where two axes correspond to the key uncertainties identified within the module "F"; (2) attaching concise titles and descriptions to each of four created "futures"; (3) sensitivity analysis of the developed solutions.
Pedagogic approaches: group work, brainstorming, and consensus-building. The results of the sensitivity analysis can be visualised in the form of a drawing similar to a Venn diagram.
The observed skills: critical thinking, system thinking, future orientation, consensus-building, dealing with complexity and uncertainties, and problem solving.

K. Elaboration of a combined solution

Goal: to elaborate a solution (often a combined one) to be suggested for implementation.
Exercises: analysis of results obtained within the modules J1-J2 and designing an optimal solution.
Pedagogic approaches: group discussion and consensus-building.
The observed skills: critical thinking, system thinking, future orientation, creativity, consensus-building, dealing with complexity and uncertainties, and problem solving.

L. Development of pathways

Goal: to define pathway, e.g. necessary changes and related actions which can lead toward the vision.
Exercises: (1) developing a list of necessary technological, cultural, and institutional changes, (2) identifying stakeholders to be involved in initialisation/implementation/facilitation of the changes; (3)

placing the changes on the time line from the future to present, (4) identification of barriers and drivers for implementation of each change.
Pedagogical approaches: brainstorming to generate ideas for changes, group discussion to elaborate list of changes and to identify relevant stakeholders, barriers and drivers.
The observed skills: critical thinking, system thinking, future orientation, creativity, consensus-building, dealing with complexity and uncertainties, personal involvement, problem solving and action skills.

M. Identification of the potential spinoffs and follow-ups
Goal: to develop ideas for follow-ups and to elaborate a framework to monitor the action plan.
Exercises: (1) generation of ideas for short-term projects aligned with the PB project results; (2) development of a framework to measure progress.
Pedagogic approaches: brainstorming and group discussion.
The observed skills: critical thinking, system thinking, future orientation, creativity, consensus-building, dealing with complexity and uncertainties, personal involvement, problem solving and action skills.

4 DISCUSSION AND CONCLUSIONS

The developed PBTT has been implemented within ten teaching cases. The results have demonstrated a number of important features of the PBTT: a) it develops essential SD competences; b) it is flexible and can be tuned to various pedagogic needs, time limits and target audiences; and c) it provides high learning efficiency through utilising active learning methods, e.g. co-creation, peer-to-peer learning, learning by doing, group work, role-playing and analytical techniques. The PBTT may be used in its entirety or in parts: separate modules or their combination as well as individual exercises from the PBTT may be introduced in order to achieve certain learning outcomes within the EESD.

The current version of the PBTT ensures focus on sustainability transitions through the formulation of suitable problems and through moderation during the classes. In order to strengthen the emphasis on sustainability, the further advancements of the PBTT will include development of a sustainability test to be introduced as the third part of the module “J. Testing solutions”. The test might be developed using a framework such as that proposed by the Natural Steps (Robèrt at el., 2002). The goal of the test is to evaluate the developed solutions against a list of sustainability criteria.

Within the presented study, all ten teaching cases had different context and, therefore, it is hard to exclude the influence of the specific contexts on the achieved results. For measuring the effects of the PBTT on development of the transversal skills by engineering students, the more systematic research is required to enable generalisation of the conclusions.

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