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Learning while creating value for sustainability transitions: the case of Challenge Lab at Chalmers University of Technology

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Abstract

To achieve a sustainable future, a variety of societal systems need to be transformed and new ways of social collaboration created. Higher education institutions play an important role in guiding these changes, through education, research, and outreach. In this paper, we study a lab-based learning environment, the Challenge Lab, where master's degree students engage in, and create value in support of, the transition to a sustainable society. Three student cases are analyzed in-depth to understand how the Lab functions as an expansive learning process and provides space for transformative and integrative value creation. The Lab's guiding methodology is based on backcasting from principles, combined with clarifying the students' core values and drivers. The role of the teacher in such a learning environment is to provide the basis for the process by facilitating and guiding. Provided with the right conditions, these students have the ability to challenge underlying assumptions about how systems work and to build trust by facilitating dialogue among actors in society. The students perceived the opportunity to engage in real-world challenges as meaningful, drew valuable lessons for their future, and got to know themselves better. In this transitional period of achieving ambitious sustainability goals and targets, students' ability to be a source for change inside higher education institutions – maybe the most important source there – deserves much more attention.

Keywords: Education for Sustainable Development (ESD), Higher education, Sustainability, Transitions, Learning environment, Students

1 Introduction

In September 2015 all 193 United Nations (UN) Members States adopted the United Nations 2030 Agenda for Sustainable Development with its 17 Sustainable Development Goals. The UN stresses that the goals are integrated and indivisible and balance the three dimensions of sustainable development (United Nations, 2015). In December of the same year, 177 parties signed the Paris Agreement during COP21, agreeing to limit global warming to well below 2° C compared to pre-industrial levels (UNFCCC, 2015). These UN processes rely on two key concepts: *transformation* and *integration*.

Transformation – When unsustainable locked-in systems require fundamental change, business-as-usual is no longer an option to achieve sustainability (e.g., Raskin et al., 2010; Elzen et al., 2004; Rotmans et al., 2001).

Integration – No sector in society can handle the transformation alone. The complex nature of the sustainability challenges calls for an integration of actors, disciplines, and perspectives (Funtowicz & Ravetz, 1993; Geels, 2011; Klein, 2004) and for recognition of the importance of handling several issues in parallel. Such integration can reduce the risk of problem-shifting, redundancy, and the rise of externalities. Building trust becomes central to facilitating such social collaboration (Sandow & Allen, 2005).

Traditionally, universities engage with persistent societal problems. Since the Stockholm Conference (UNEP, 1972), education has been acknowledged as a key feature in achieving sustainable development (SD), referred to as Education for Sustainable Development (ESD) since the 1992 Earth Summit in Rio. The Aichi-Nagoya declaration, the final report of the United Nations Decade of Education for Sustainable Development (2005-2014) aiming at integrating the principles and practices of ESD, concludes that *"there is now an increased recognition at the international policy level that education is essential to the advancement of sustainable development"* (UNESCO, 2014, p. 9). In taking on the role of guiding the transition towards sustainability, many universities face the challenge of contributing society-relevant education, research, and outreach, as well as transforming their own operations to act as role models, including by providing appropriate learning environments for sustainable development (Cortese, 2003; Lozano, 2006; Ferrer-Balas et al., 2010).

However, the idea of SD has been criticized for being incremental (Bartlett, 1994) and often misconceived as promoting "sustainable growth" (e.g., Daly, 1990). Education for sustainable development has been criticized on similar grounds (Jickling, 1992). Environmentalist approaches tend to focus on imposing actions and values on others, whereas democratic approaches assume rational learners, which may be naïve given the exploitative mainstream practices in today's society (Bonnett, 2002). The proposed way forward is, first and foremost, to at least acknowledge that the term sustainable development has a role to play as an integrating concept across fields, sectors, and scales (Robinson, 2004). Educational approaches to SD are then understood as exploring perspectives and arguments, making room for critical thinking. Pluralist approaches are recommended (Öhman, 2006), including critical dialogue on not only what sustainable development should entail but also the very concepts of SD and ESD and the underlying assumptions (Kopnina, 2012; Kopnina & Meijers, 2014).

In the context of higher education, "whole-of-university approaches" (Mcmillin & Dyball, 2009) mainstream sustainability in all aspects of the learning environment and engage students in internal as well as external university practices. This is important as the students get hands-on[1] learning experiences that are beneficial in their future professions contributing to a sustainable development. This reflects an understanding of sustainable development as a process, not a goal. An understanding of complex systems and inter- and transdisciplinary approaches is central in this process (Jucker, 2002; Dale & Newman, 2005). What teaching and learning entail in this context can be understood from the ESD1/ESD2 approaches delineated by Vare and Scott (2007). ESD1 focuses on promoting behavior and ways of thinking to address short-term challenges, and ESD2 focuses on building capacity to think critically about what experts say, test SD ideas, and explore contradictions, in open-ended processes. Here, students can play an important role in the sustainability transition by challenging underlying assumptions and building trust among actors. Students are knowledgeable, often eager for change, and are, "when coming from the outside," either not aware of, or do not necessarily have to regard, internal structures and cultures in existing communities. Furthermore, students seldom represent established organizations with economic or power incentives, and most actors, who at some point have been students themselves, can identify with them. However, student engagement has been overlooked in ESD (Tilbury, 2016), although it is considered an important influence on learning and achievement (Kahu, 2013). When setting up learning environments for sustainability education, motivational factors are often mentioned as a central element (cf. Podger et al., 2010). Students engaging in deliberate and empowering processes tackling "real-world" challenges can build sustainability competencies (Barth et al., 2007; Wiek et al., 2011), learn from the experience, create new networks

[1] Learning experiences integrating "learning/knowing-that" and "learning/knowing-how" are central in teaching/learning activities in experiential, problem-based, and service learning.

when interacting across disciplines, and increase their motivation to learn as well as to engage further, in the future.

If provided with the right conditions, students can learn while contributing to sustainability transitions[2] by creating transformative and integrative value. Transformative value is here constituted by outcomes that challenge business-as-usual practices that reinforce the lock-in of systems understood as unsustainable. Integrative value is here constituted by the awareness raised and trust built when a diverse group of actors, disciplines, and perspectives are brought together in dialogue to explore a common issue. Value creation that is transformative and/or integrative here refers to the creation of influence on sustainability transitions in terms of direct outcomes as well as potential future societal impact.

This paper addresses the following research questions: How can a learning environment create transformative and integrative value inside as well as outside higher education institutions? What would such a learning environment mean for the students involved? These questions are addressed by studying the Challenge Lab at Chalmers University of Technology in Gothenburg, Sweden, where students are provided space to learn while engaging in sustainability transitions.

The outline of this paper is as follows: the background section presents key features for learning environments aiming at educating students while creating transformative and integrative value, followed by a presentation of the Challenge Lab. The methods section describes the case-study method used to understand the Challenge Lab as a learning environment and its related outcomes. The results section presents three cases and analyzes them in relation to theories on expansive learning and value creation. A focus group interview illustrates what the Challenge Lab experience meant for the students involved. Finally, the analysis is followed by a concluding discussion and a proposed path forward.

[2] Sustainability transitions are often said to be either guided, induced, or accelerated.

2 Background

Learning frameworks and processes in ESD underpin processes of collaboration and dialogue; processes that engage the "whole system"; processes that innovate curriculum as well as teaching and learning experiences; and processes of active and participatory learning (Tilbury, 2011). The aim of this section is to derive key features of a learning environment in which students during their education can learn by engaging in complex real-world sustainability challenges, while creating transformative and integrative value. A learning environment is here defined as the physical location, context, and culture in which the learning occurs, including teaching methods and structures (cf. Lizzio et al., 2002). The key features are summarized in Table 1.

Table 1 - Summary of key features for learning environments aiming at educating students while creating value for sustainability transitions (*input-process / outcome-impact* logic adapted from Penfield et al. (2014))

Dimension	**Input & Process** (Learning environment)	**Desired outcomes** (Direct effects/short-term value)	**Societal impact** (Indirect effects/long-term value)
Transformation	*Transformative process[3]: transition science (cf. Markard et al., 2012) and systems thinking*	*Understanding of lock-in of today's systems and requirements for a sustainable future* *Increased engagement aiming at bridging the gap between the present and future* *External/challenging influence on actors, organizations, and systems[4]*	*Fundamental change of systems/sustainability transition*
Integration	*Neutral arena for multi-stakeholder dialogue*	*… of actors, disciplines and perspectives*	*New types of collaboration/new actor constellations*
Student learning	*Competence, autonomy, and relatedness*	*Sustainability competencies* *Experience from real-world processes* *New networks*	*Guiding sustainability transitions in future profession*

The learning environment would benefit from incorporating a transformative approach, in order to unleash its transformative potential. By incorporating a transformative approach, the learning environment could provide guidance in uncertain environments, fostering exploration of new possibilities rather than exploitation of old certainties (cf. March, 1991),[5] including through elements of future state visioning (cf. (Stewart, 1993)), systems thinking (von Bertalanffy, 1968), and bridging the gap between present and future through processes of learning, leadership and creation (cf. Senge, 1994).

[3] Here "process" refers to the teaching methods and structures, i.e., to process methodology, not to be confused with the students' "learning process."

[4] Cf. Smith et al. (2005) section 3.4 on Purposive transitions (coordinated response, external adaptation).

[5] For March, "exploration" refers to searching, variation, risk taking, experimentation, flexibility, discovery, and innovation. "Exploitation" refers to refinement, choice, production, efficiency, selection, implementation, and execution.

For a learning environment to facilitate integration, it should strive toward neutrality so that stakeholders can meet as equals to the extent possible. The space should then acknowledge diversity and multi-stakeholder interactions in a safe space where dialogue (cf. Isaacs, 1993) is conducted to foster perspective awareness[6] (Jordan, 2011), broadening the scope of how challenges and problems are framed and defined.

By fostering motivational factors, the learning environment can achieve better student engagement, achievement, and learning. Ryan and Deci (2000) posit three motivational factors, the psychological needs for *competence*, *autonomy*, and *relatedness*. *Competence* is enhanced by providing optimal challenges[7], feedback, and freedom from demeaning evaluations. *Autonomy* is enhanced by choice, acknowledgement of feelings, and opportunities for self-direction. *Relatedness* is enhanced by belongingness and connectedness with others. In the context of sustainability education, *competence* could be fostered by equipping students with knowledge, methods, and tools to handle complex sustainability issues including abilities of leading one-self (Stewart et al., 2011) by clarifying one's own values, strengths, and visions. *Autonomy* would here, for instance, depend on the level of involvement among the students in analyzing the systems, identifying challenges, defining strategies, creating results, and applying solutions.[8] *Relatedness* is partly acknowledged by the integrative aspect of the learning environment; for the students it could be realized by integrating different educational backgrounds and cultures. Relatedness would also be facilitated by making the experience a collective one for the students with continuous guidance and support from staff and peers.

Initiatives corresponding to the features presented in Table 1 are manifold, such as: (a) "greening the campus" approaches, in which the university campus becomes a learning environment for the whole institution in promoting, and learning for, sustainable development (Koester et al., 2006); (b) community-based research, in which students engage in processes collaborating with researchers to facilitate bottom-up, micro-region sustainability planning and development (Bodorkós & Pataki, 2009); (c) service-learning to change universities from within by promoting sustainable consumption, in which students in groups conduct small transdisciplinary projects (Barth et al., 2014); (d) "transdisciplinary case studies" built upon interdisciplinarity, transdisciplinarity, and self-regulated learning, in which students interact with stakeholders to address "real-world" sustainability problems relevant to the local region (Steiner & Posch, 2006); and (e) project- and problem-based learning integrated in courses, projects, and theses, in which students develop solutions to "real-world" problems, often in collaboration with local communities (Wiek et al., 2014).

Initiatives in line with the thinking above exist outside the context of formal education as well. Prominent examples are lab approaches[9] aimed at creating value for sustainability transitions, such as "(urban) transition labs" (Loorbach, 2007; Nevens et al., 2013) and "social labs" (Hassan, 2014). *Transition labs* are built upon a transition management approach[10] (Loorbach, 2007), in which labs become arenas for change, with engaged visionary people with diverse backgrounds guided by a "transition team" that facilitates a process of system analysis, envisioning, 'backcasting' pathways, experimentation, and monitoring/evaluation. *Social labs* do not follow a specific process but share the

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[6] In a framework for meaning-making structures of societal change agents, Jordan describes five types of awareness: complexity, context, stakeholder, self, and perspective.

[7] In line with the work by Vygotsky (1896-1934) on the zone of proximal development.

[8] Cf. Talwar et al. (2011) on user-engagement in sustainability research.

[9] A setting not described in peer-reviewed literature is the MIT Media Lab applying design thinking and educating students in the same.

[10] Cf. Stephens & Graham (2010) on the potential of transition management for sustainability in higher education.

common characteristics of being: (i) *social* by bringing diverse participants together; (ii) *experimental* by being on-going, iterative, and sustained efforts rather than one-off experiences; and (iii) *systemic* by addressing root-causes rather than symptoms and by developing solutions taking the "whole system" into account (Hassan, 2014, p. 3).

The ESD initiatives identified above were not particularly articulate with respect to considering themselves as "labs" or "arenas," or explicit about aiming for sustainability transitions through transformative and integrative aspects. Often the challenges to be addressed are formulated based on previously established bi-lateral connections to communities, and students are invited to develop solutions but not to formulate the questions. There is also a lack of research contrasting the ambitions of student empowerment, participation, and change agency in higher education for sustainability (Tilbury, 2016).

Multi-stakeholder interactions (inherent in lab approaches) ease the challenge of re-orienting systems to incorporate sustainability-oriented learning (Wals, 2014); open-endedness endorses co-production of knowledge ranging from problem structuring to implementation, thus being deliberate as well as encouraging action. Lab approaches are guided processes built upon empowerment where space is created for the learners to explore, experiment, and test solutions in the real world.

The following sections evaluate a lab-based learning environment in the context of higher education, broadening the understanding of what higher education can do to develop sustainability into a golden thread throughout all levels of education. The lab, as a learning environment, is evaluated on its ability to create transformative and integrative value and what it means for the students involved.

3 Challenge Lab

Chalmers University of Technology in Gothenburg, Sweden, has by tradition engaged in societal challenges. In 2014, Chalmers initiated the Challenge Lab (Holmberg, 2014) as part of a whole-of-university approach. The purpose of Challenge Lab is to strengthen the educational dimension in the "education-research-outreach" triangle, become an important hub where actors from academia and the public and private sectors gather around the students, build trust among stakeholders, and give students the opportunity to develop unique capabilities in working across disciplines with a sustainability-driven approach.

The Challenge Lab offers a preparatory course "Leadership for Sustainability Transitions" for students enrolled in graduate degree programs at Chalmers; students can also do their thesis projects toward their master's degrees. The Challenge Lab is located at one of the Gothenburg science parks. In the Challenge Lab, students take on complex societal sustainability challenges in collaboration with others associated with the five regional knowledge clusters in West Sweden: Urban Future; Marine Environment and the Maritime Sector; Transport Solutions; Green Chemistry and Bio-based Products; and Life Science. The students can interact across disciplines within, as well as between, these clusters, backed up by Chalmers' challenge-driven "Areas of Advance": Building Futures, Energy, Information and Communication Technology, Life Science Engineering, Materials Science, Nanoscience and Nanotechnology, Production, and Transport.

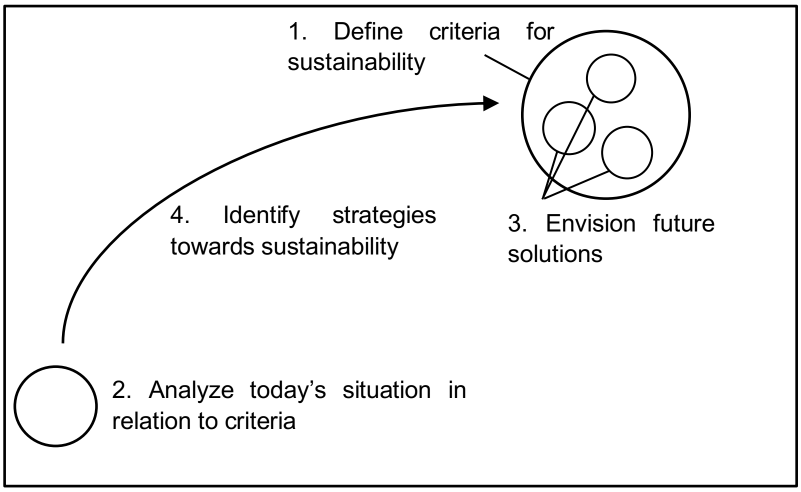

Figure 1 - The backcasting approach used at Challenge Lab, adapted from Holmberg (1998)

Challenge Lab follows a backcasting approach (Holmberg, 1998) (Figure 1) facilitated and guided by a team of teachers. The process starts with a first phase (4 weeks) during which the students follow the four steps in the backcasting approach from two perspectives: *outside-in* to understand what requirements global sustainability will put on various systems, and *inside-out* to understand how to cope with one's own values, strengths and visions and to manage dialogue between actors within the systems (Holmberg, 2014). The criteria for sustainability (step 1) are represented in the form of a framework of non-overlapping sustainability principles in the four dimensions of ecology, economy, society and well-being. In developing the framework, the students explore perspectives and arguments related to the idea of sustainable development, staying critical to its foundations and the meaning of its various dimensions. The framework is interpreted and used as a set of relevant questions to ask in the attempt to guide transitional processes towards sustainability. In parallel with the framework development, the students do individual value clarification exercises and work in groups to identify their own strengths and visions.

The students then research on-going regional processes and analyze the associated socio-technical systems by applying tools from systems thinking and transition science. Using the sustainability principles developed in step 1, the students analyze the current state (step 2) and identify gaps in the systems. The analyzed gaps become the starting point for dialogues in which stakeholders are invited to provide their perspectives on the gaps as sustainability challenges. Based on these dialogues, the students identify leverage points for system intervention (Meadows, 1997). From this, they formulate a research question, team up with a peer and connect with a supervisor. This becomes the start of the second phase (16 weeks), which applies steps 3 and 4 in the backcasting approach, but where design thinking (Lawson, 2006) becomes a central part. During this phase the students connect with relevant stakeholders to address the research questions formulated during the guided phase 1 process.

4 Method

To understand Challenge Lab as a learning environment creating value for sustainability transitions, as well as what it means to the students at the Lab, an evaluative case study method (Bassey, 1999) was chosen. This method was chosen because the boundary between the phenomenon and context is not clearly evident (Yin, 1994). Evaluative case studies should acknowledge the subtlety and complexity of the case and offer some support for alternative interpretations (Adelman et al., 1980). All data items gathered are presented in Table 2.

Since the establishment of the Challenge Lab its process has been continuously monitored, documented, and evaluated by its staff.[11] Throughout the thesis process, continuous dialogue is held with the students as a kind of reflexive monitoring. Data from the monitoring are collected in the form of documentation of the lab's processes, meeting minutes, and field notes.

Based on recommendations from the Challenge Lab staff, three published master's theses were selected from the 21 completed in 2014-2016. The staff considered each of these to represent the lab's purpose in its own way. [12]

To create space for the students' voices, evidence from their perspectives was gathered during a 1.5-hour group interview in which all 13 students from the 2016 cohort took part. It was held in an open dialogue format after their final theses had been submitted. They were asked to reflect upon what the Challenge Lab meant for them, what they learned during the process, and how they experienced the collaborative work.

The abovementioned data were complemented with interviews of the student teams from the selected theses combined with survey data from their closest connected stakeholder or supervisor.

Table 2 - Data gathered from the Challenge Lab

Data items	**Challenge Lab general**	**Case 1**	**Case 2**	**Case 3**
Documentation	Lab process documentation, meeting minutes	Published master's thesis (Ntemiris and Hoffman, 2016)	Published master's thesis (Cuaran and Lundberg, 2015)	Published master's thesis (Larsson[13] and Laumont, 2015)
Interviews	Group interview with 13 students	Interview with student team	Interview with one of the students	-
Surveys	-	Stakeholder questionnaire	Supervisor questionnaire	Stakeholder questionnaire
Observations	Field notes and direct observations by Challenge Lab staff during process and final presentation	Direct observations by Challenge Lab staff and interventions by students	Direct observations by Challenge Lab staff and interventions by students	Direct observations by Challenge Lab staff and interventions by students

[11] The Challenge Lab staff includes a lab director and lab assistant who manage the operations, along with three lecturers with expertise in sustainability, backcasting, and design thinking. External lecturers are brought in when needed. Both authors of this paper have been part of facilitating the Challenge Lab process, one as a teaching assistant and one as professor/project leader.

[12] This paper provides an in-depth study of three cases rather than a survey of all the published theses.

[13] Co-author of the current paper; as of 2016, part of the Challenge Lab staff, see footnote 11.

The data collected from the three theses were summarized as stories to represent how the Challenge Lab process unfolded for the students and how their respective stakeholders (or supervisor, in one case) perceived the process. The cases were then analyzed to identify general aspects of how the student intervention process unfolded and to what outcomes it led. The intervention process was analyzed as expansive learning (Engeström, 1987; 2001) and its outcomes as value creation (Bruyat & Julien, 2001).

The concept ‘expansive learning’ (Engeström, 1987; 2001) stems from cultural-historical activity theory, where the unit of analysis is a human activity system seen in its network relations to other human activity systems. Emphasis is put on horizontal or sideways inter-organizational learning and development, where contradictions become a driving force of change starting from the questioning, criticizing, or rejecting of some accepted practice or wisdom. Activity systems take shape and are transformed over lengthy periods of time, and changes in the system are understood as induced by contradiction. The adoption of a new element from the outside often collides with old elements, generating disturbance and conflict.

The effects of such disturbance/conflict may lead to a collective change effort, and expansive transformation is accomplished “when the object and motive of the activity are conceptualized to embrace radically wider horizons of possibilities than in the previous mode of the activity” (Engeström, 2001, p. 137). The learning environment analyzed in this paper can be considered an arena in which students, guided by a backcasting methodology, bring activity systems together in dialogue to illuminate contradictions, prompting emerging cycles of expansive learning. This approach to learning produces new forms of activity that were not there previously. The patterns created are learned as they are being created (ibid.).

Value creation is emphasized in entrepreneurial education (Lackéus, 2016). The frame of analysis used in this paper was inspired by Bruyat and Julien's (2001) work on the dialogic between individual and new value creation. This dialogic recognizes that new value is formed in processes of change, emergence, and creation. Further, the individual forming the value is also going through a process of change and creation. In terms of value creation specifically for sustainable development, the value created should be provided with direction (e.g., towards sustainability) and purpose (e.g., for the well-being of today’s and future generations).

In this paper, the value created as outcomes from the Challenge Lab process was divided into two categories: *transformative value* and *integrative value*. The outcomes that challenge business-as-usual practices that reinforce the lock-in of systems that are understood to be unsustainable constitute transformative value. The awareness raised and trust built when a diverse group of actors, disciplines, and perspectives are brought together in dialogue to explore a common issue constitute integrative value.

In relation to the students, the outcomes are understood in terms of what it meant for them to engage in the Challenge Lab environment with respect to their learning (change).

Together, these aspects form a three-dimensional space (Figure 2). The x- and y-axes form the transformative and integrative value creation, respectively, and the z-axis represents the students' learning. With an input-process/outcome-impact logic, the *input* can be understood as the space provided for the students (learning environment), bridging the opportunity to learn in the *process* of creating value, analyzed as *outcome* and potential *impact*.

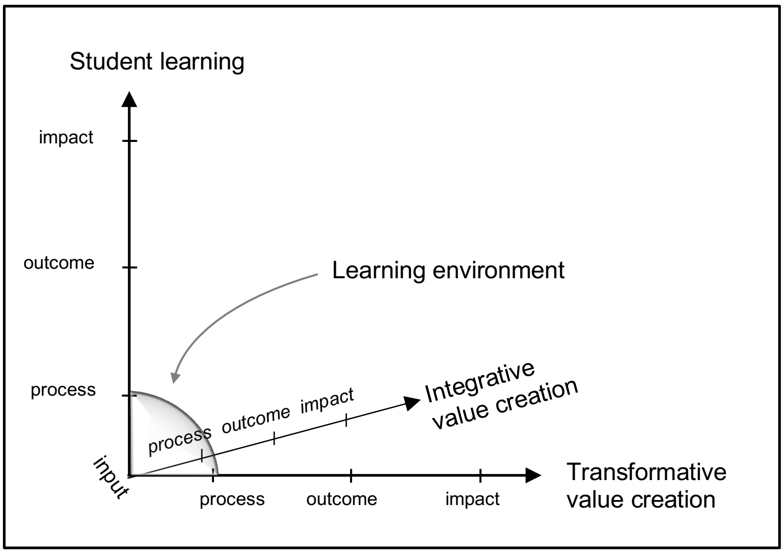

Figure 2 - Learning environment bridging student learning and transformative/integrative value creation

The separate descriptions and analyses of the cases are then complemented with results from the group interview reflecting the students' perspectives on the learning environment, process, and outcome.

5 Results: The process and outcomes of the Challenge Lab as a learning environment in three cases

5.1 Case 1: Electromobility and sustainable transportation in the city of Gothenburg, Sweden

Case 1 is the work of Ntemiris and Hoffman (2016) from Greece and Germany, respectively, who combined their disciplines, industrial ecology and sustainable energy systems. They decided to collaborate after a positive experience jointly facilitating a stakeholder dialogue during phase 1 of the Challenge Lab process. Their common interest in the tools and skills acquired during the Challenge Lab preparatory course on dialogue facilitation and backcasting became the starting point for their joint thesis.

The phase 1 stakeholder dialogue identified a gap, namely a lack of awareness of how the transportation system will be influenced by the diffusion of electromobility in Gothenburg. Ntemiris and Hoffman focused on this gap and came up with the research question of how to create strategies to scale up electromobility. They started by interviewing a total of 18 stakeholders from the public sector, private sector, and academia to better understand how electromobility questions are handled in the city. They then invited all stakeholders to a joint dialogue. The purpose of the dialogue was to create awareness around the issue by opening up space to explore possible future scenarios for a sustainable transportation system in Gothenburg and how to guide an eventual diffusion of electromobility into desirable pathways.

The stakeholders discussed criteria for a future transportation system in Gothenburg and how well these align with different scenarios. They further discussed what important steps are needed to get there, what individual stakeholders can do about it, and who can be relied on to make it happen. In an interview, the student facilitators reflected on the experience:

"...there comes a point during the dialogue [when] we realize, or maybe stakeholders realize, that we have two discussions going on. Two transitions going on. The first is how we achieve electromobility: how we go from [a] fossil fuel-based transport system to [an]electrified transport system. And how we achieve sustainable transportation at the same time."

The students had taken the initiative to bring the actors together. This meant that the ownership of the draft strategy was not clear following the dialogue. The Traffic Office in Gothenburg invited the students to do the same workshop for their board in order to use the results as a basis for creating the city's long-term strategy for electrified transportation modes. The main stakeholder from the Traffic office with whom the students had contact throughout the thesis work experienced the dialogue as "very transparent, trustful, and well-facilitated," stating that it meant a great deal that students arranged the dialogue since "the hard questions could be raised and we all could discuss based on the students' vision,[14] without the need to infuse our own."

Expansive learning and value created

The students took temporary ownership of the issue and brought together their own perspectives' and sustainability principles, private sector actors in the auto and associated services markets, public sector planners focused on the street-level landscape of a sustainable city, and researchers assessing future mobility options. The dialogue highlighted the need to address questions in parallel when considering

[14] Referring to the framework from sustainability principles that the students created during phase 1.

electromobility diffusion strategies in the broader context of how to achieve a sustainable transportation system.

This case exemplifies students creating integrative value in facilitating a dialogue among actors from different sectors who shared their perspectives on electromobility diffusion and sustainable development. The dialogue was situated outside the actors' regular context with a transformative approach, aiming at bridging the gap between today's situation and a sustainable future by guiding the transition of electromobility into desirable pathways.

5.2 Case 2: Addressing flooding and dispersal of pollutants due to storm water issues in Gothenburg

Case 2 is the work of Cuaran and Lundberg (2015) from Colombia and Sweden, respectively, who combined their disciplines, infrastructure/environmental engineering and industrial ecology. During the Challenge Lab phase 1 dialogues, they identified pressing issues related to the rising population in Gothenburg leading to a higher load on the sewage system. Gothenburg already suffers from wastewater issues due to storm-water flooding and dispersal of toxic contaminants. The flooding issues are likely to be more severe in the future due to climate change and rising sea levels (SMHI, 2005). Based on their shared interest in water issues, the students decided to team up to explore the challenges at a deeper level.

They connected with a research group looking into possibilities for opening up ponds in urban areas to treat storm water. Such ponds could also be used as recreation zones thus contributing to sustainability in a broader sense, in line with the sustainability framework developed in phase 1. After initiating contact with another research group engaging in water quality and filtering techniques, the students realized that the pond would be so contaminated that it would have to be fenced off. The two research groups had different perspectives on the issues, and the students initiated a new search process to identify alternative solutions.

During the search, they were inspired by the concept of raingardens/bioretention planters that could be part of the urban infrastructure, retaining the storm water and simultaneously treating the contaminants. They presented the concept to the researchers and to stakeholders from the municipal agencies of Circular Flows and Water Management, Park and Nature, and Traffic Planning to better understand their perspectives on such a solution, and what it would take for the concept to be implemented. Most interviewees showed an interest, but no one saw it clearly as their responsibility to pursue the idea further, despite bioretention being industry practice.

The students developed some concepts with design considerations, and shared their results with the two research groups as well as the stakeholders mentioned above. The concept was considered sufficiently novel and interesting for Chalmers campus development group to finance a pre-study for implementation on campus. Some bioretention planters were built in the city by the Circular Flows and Water Management agency as part of the Gothenburg Green World 2016 initiative.

The students' supervisor, who works in one of the research groups, stated the following when asked what the students' intervention meant for them:

"*Our main focus on storm water handling is through filters, but the students gave us new perspectives on the rain garden concept. I also think that the other research group opened their eyes for this concept. We should push more for this in future research applications.*"

Expansive learning and value created

The students took temporary ownership of bioretention as a way of handling storm water and widened the perspectives among some of the actors whom it might concern. Two research groups assessing different approaches to handling the same/similar issues were introduced to a third solution. The municipal agencies involved had different perspectives on the technology: Park and Nature saw it in terms of green areas; Traffic Planning saw it in terms of infrastructure; and Circular Flows and Water Management saw it in terms of water run-off. As the students demonstrated that bioretention currently is in "everyone's interest but nobody's responsibility" and cuts across at least three activity systems, it is likely that an eventual adoption would lead to contradictions challenging the current division of labor.

This case exemplifies integrative value created by the students in bringing together two research groups and several municipal agencies by introducing a novel solution complementing current mainstream approaches for managing storm water.

5.3 Case 3: Backcasting for a sustainable low-carbon West Sweden transition strategy

Case 3 is the work Larsson and Laumont (2015) from Sweden and France, respectively, who combined their disciplines of sustainable energy systems and sustainable urban development. During a stakeholder dialogue, they identified the momentum in Gothenburg's climate strategy and found that the Regional office of West Sweden had a similar ambition to intensify climate mitigation engagement, reflected by a political decision in 2014 to use the same backcasting approach that the Challenge Lab follows in forming their climate strategy, thus open for collaboration.

The students spent the spring participating in meetings and following the work performed by a transdisciplinary project group at the Regional office, planning workshops for a broader stakeholder engagement in crafting the climate strategy. By studying lessons learned from climate mitigation policy processes performed elsewhere and tenets of transition management (Loorbach, 2007), the students challenged the current focus of the regional policy, the 2030 and fossil-independency end-targets. They found the current thematic grouping to be oriented towards either a production or consumption, rather than a socio-technical, perspective. The students crafted recommendations for changing the end-goal to 2050 and climate neutrality, for the strategy to cover the full transition. They also recommended the inclusion of other sustainability dimensions in order to broaden the thematic grouping to socio-technical systems, and to involve stakeholders in the entire backcasting process to increase the level of participation.

The recommendations were presented during a dialogue at the Regional office. One project member described the experience:

"…it was agreed that it was better to free up space by aiming for the 2050 target of being fossil free [climate neutral]. The fossil independency goal of 2030 could be seen as an interim target to keep the urgency to act. With this new time frame the workshop themes could be broadened up and address wider socio-technical systems in need of transformation by integrating more sustainability aspects than fossil carbon emissions."

When the thesis project was completed, the students were invited to engage further in the design of the workshops, and during the fall of 2015 five parallel themes ran with a total of 100 stakeholders participating in backcasting workshops identifying ways forward in realizing a climate neutral region by 2050.

Expansive learning and value created

The dialogue included questioning the Region's current goal of, and motives for, realizing a low-carbon future. New elements were added in the "activity system" of the project group, broadening the agenda to include sustainability in more dimensions than climate mitigation. This shift opened up a wider horizon of possibilities in the search for a future action plan, with an openness towards co- and ancillary benefits for climate mitigation in combination with other sustainability goals.

The case thus exemplifies transformative value created by the students where they introduced a longer time frame in the strategic work. By lifting the view towards the end-goal of the low-carbon transition in the strategy formation process, activities and thinking could be encouraged to align with socio-technical transitions rather than towards incremental optimization and adjustments of the existing systems.

5.4 Learning – students' reflections on process and outcome

Students who have been involved in the Challenge Lab often describe the experience as different from experiences in their other learning environments. The students have been at the center, facilitated by teachers who provide the space but guided by their own values, motivation, and competencies, applying tools for sustainability transitions in real-world settings.

The students mention the values clarification exercise at the beginning of the thesis project as important and valuable; the staff also made this observation. The clarified values can become a basis for collaboration through shared intentions and for mutual respect. One student described the emphasis on a clarification of values as making him no longer feel that he was just considered "a number" in the educational system, but was seen as a human.

The open-ended backcasting process is accompanied by some uncertainty, especially in the beginning, as many parameters are open: the students join the Challenge Lab without having decided on a thesis partner, research question, supervisor, or stakeholder collaboration. Some students mention their concern that this is confusing and stressful due to the pressure of delivering a thesis result in time and satisfying the problem owners. One student added nuance to this perspective during the interview:

"For me the openness and uncertainty has been amazing. The process is guided but not steered. More open. You try to find the light. […] Without the openness and uncertainty maybe we wouldn't have been where we are now. […] in [the] traditional supervisor-student relation you take commands and you perform, but how much is then "you," in the thesis?"

The group then concluded in the interview that the most important thing in an open process is that it is guided and facilitated well, with its expectations made clear from the beginning.

Team work at the Challenge Lab was seen as a rewarding experience. Some students had never engaged in interdisciplinary approaches before and mention that knowledge and strengths are clarified when you are the only one in the team with a particular competence, as put forward by one student:

In job interviews [I describe] my knowledge and my strengths and also in letters you describe what you know. So much personal skills [have been developed] when I've been the only one with the competence I have... [On this project] I need[ed] to be the expert in my field. Before, I've only worked in fields with people having the same competence as I have. Self-leadership: I know what I know and don't know, when out there in "real life". I am confident in myself [that] this is what I know. "She knows what she can do, so she gets the job." Really valuable stuff.

6 Discussion and conclusions

Via an analysis of three cases from the Challenge Lab at Chalmers University of Technology in Gothenburg, Sweden, we have presented and evaluated value creation for sustainability transitions in a higher education learning environment. Expansive learning (Engeström, 1987; 2001) illuminates the process towards value creation and provides a frame of analysis to understand the interactions and tensions among activity systems brought together and challenged by the students.

The conclusions from the case method used to understand how such learning environments can create value and educate students would be strengthened if additional lab-based learning environments were evaluated. As far as the authors know, no other higher-education learning environments with characteristics similar to those of the Challenge Lab are described in the peer-reviewed literature, but there are probably many in the making. We look forward to learning from and comparing similar initiatives in the future. We aim to create a network of lab-based educational initiatives that engage with sustainability transitions. We also intend to collect further data for a longitudinal study in order to draw conclusions about potential societal impacts from the Challenge Lab.

The central aspect of the Challenge Lab learning environment – the backcasting approach based on sustainability principles (Holmberg & Robèrt, 2000) in combination with value clarification – is important. This provides a framework that guides actions and decisions towards sustainability when the students try to make sense of and navigate uncertainty and complex real-world systems. Designing the process based on the motivational factors of competence, autonomy, and relatedness (Ryan & Deci, 2000), with the teachers as facilitators, created space for the students to formulate research questions on their own and intervene in systems to address it, supporting deep learning and motivation.

The students of the Challenge Lab describe the experience of being part of a diverse team and having space to autonomously engage in real-world issues as meaningful. In the process the students have grown comfortable with the concept of sustainability, fostering what Dale and Newman (2005) conceptualize as 'sustainable development literacy.' To 'learn for change' (Vare & Scott, 2007), the students have put into practice tools from systems thinking and transition science in an inter- and transdisciplinary setting to address complex, real-world sustainability challenges. Furthermore, the students have created new networks and gotten to know themselves better in terms of visions, values and strengths, which they see as important for their future work.

In terms of value created through the Challenge Lab, the strived-for neutral approach, with stakeholders meeting as equals, and the students' ability to build trust among stakeholders have created integrative value. The backcasting process and the freedom to challenge and support on-going processes have created transformative value. Value creation can also be identified for the university, for its efforts to develop a sustainable campus, and in collaboration between researchers and staff, within the university as well as between the university and society.

Interactive and learner-driven pedagogies, where students are in charge by asking questions, analyzing, thinking critically, and making decisions in collaboration with others, are considered central in ESD (UNESCO, 2014). Challenge Lab puts these ESD components into practice, recognizing its students as change agents who, in the process of creating transformative and integrative value, experience meaningful learning that makes them ready to advance sustainable development in their future professions.

Most of the learning environments identified prior to this study were either *idea-driven* or externally provided with a challenge to be solved, i.e., *demand-driven*. The lab-based approach studied here complements such approaches with a *sustainability-driven* process in a neutral arena. In this sustainability-driven approach, considerable time is allocated to "staying in the question" by formulating a desirable future, represented by principles for all dimensions of sustainability, which then are used as a frame of analysis for today's systems, to identify gaps. These gaps can then in turn be used to formulate challenges, and, in connection with on-going local/regional processes, solutions can be developed that seek to address the challenges and consequently bridge the gaps.

Creating space in various dimensions, e.g., for self-determination, for new ways of thinking, for pluralism, diversity and minority perspectives, and for participation, can be considered central to critical thinking and meaningful learning in sustainability (cf. Wals & Jickling, 2002). Lab-based educational initiatives can provide room for a holistic approach to sustainability and foster collaboration within and between organizations. Students can engage with and learn from issues, comprehending complexity through real-world problems. However, this also requires support and commitment from teachers and staff (Lozano, 2006). In addition, as has been confirmed by studies of other kinds of "real-world" learning environments (Steiner & Posch, 2006; Bodorkós & Pataki, 2009; Wiek et al., 2014), commitment from stakeholders outside the university is critical, especially given the open-ended process.

Chalmers University of Technology has proactively engaged in change processes in order to be relevant to society (Holmberg et al., 2012). In this transitional period of achieving ambitious sustainability goals and targets, students' ability to be a source of change inside higher education institutions – maybe the most important source there – deserves much more attention.

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