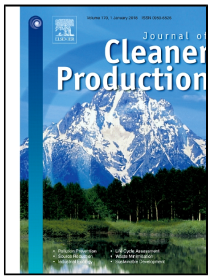

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Transdisciplinarity in higher education for sustainability: how discourses are approached in engineering education

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Abstract

Sustainability issues, as unwanted results of not fully respecting natural cycles, are widely recognized as wicked problems, which should not be thought of as problems to be solved, but rather as "conditions" to be managed, as if they were a chronic disease (Seager et al., 2011). There exists a general agreement on the need to reform scientific expertise by developing new ways of knowledge production and decision-making able to cope with the challenges sustainability poses. In this sense, transdisciplinary aspects of sustainability are acknowledged as a transformational stream of sustainability science.

Transdisciplinarity is considered a competence for sustainability in technological curriculums. Nevertheless, engineering education professionals tread on unfamiliar ground when entering transdisciplinarity approach, as it includes social sciences and humanities perspectives. Advancing sustainable engineering science requires creating new long-term, participatory, solution-oriented programs as platforms to recognize and engage with the macro-ethical, adaptive and cross-disciplinary challenges embedded in professional issues.

Meanwhile, individual university professors and researchers take a step forward to try out innovative experiences in their classrooms to deal with complexity and reach holism in fostering knowledge in different ways. This paper analyses first what is being done and how is it being focused, and second, What are the strategies for and purposes of implementing transdisciplinary experiences in engineering higher education.

Assuming that distinct patterns of definition of transdisciplinary exists, the authors collated transdisciplinary initiatives in engineering education for sustainability from Thompson Klein (2014) *discourses on transdisciplinarity*: transcendence, problem solving and transgression. They also explored how practical constraints imposed by a classroom context, highlighted the limits of transdisciplinarity, and offered suggestions on improvements, which could be implemented. Balsiger (2014) proposes four *varieties of transdisciplinarity* (soft, hard, inclusive and reflexive) to identify ways for moving from one type to another as circumstances change, in terms of stakeholder's collaboration and knowledge integration possibilities.

The methodology consisted in literature review of articles published in relevant journals in the field of sustainability, which focussed on transdisciplinarity approaches in engineering education. We have analysed how the different initiatives fit in Klein's *discourses on* *transdisciplinarity*. Moreover, an affinity analysis has been performed to cluster transdisciplinarity initiatives in engineering education for sustainability in homogeneous groups. Finally, in the *varieties of transdisciplinarity* framework, the experiences identified when reviewing the literature have been spread over the range among Balsiger's taxonomy.

The investigation indicates that most transdisciplinary initiatives in technological education for sustainability fit in the *problem solving discourse*, where co-production of knowledge and method-driven aspects are relevant. Additionally, they fit in the scheme of broad collaboration and deep integration understood as *hard transdisciplinarity*. Within such discourse, experiences related to "innovation" fit in the *reflexive transdisciplinarity* area, which depends more on the efforts of education entities. It is relevant that none of the experiences analysed seems to fit under the *transgression discourse* paradigm, linked to human rights and emotional intelligence.

We conclude that, if engineering programs are to challenge transdisciplinarity, in order to assure the acquisition of competences and worldviews needed to cope with complexity, a new brand of engineer should be trained, one that thinks critically about the co-construction of public welfare and the technological systems in which he or she works.

This analysis is a starting point to analyse transdisciplinarity in engineering education for sustainability and to construct the education framework (curriculum structure, faculty competences, pedagogical approaches, etc.) that best facilitates the practice of transdisciplinarity in engineering education.

Key words: Transdisciplinarity, Engineering Education, Sustainability Education, Sustainability

1. Introduction

In our world characterised by rapid change, uncertainty and increasing interconnectedness (Morin & Kern, 1999), science is increasingly called to contribute to the solution of urgent, persistent, complex sustainability challenges, not only environmental issues such as climate change and biodiversity loss, but also related issues such as poverty, epidemics, security and governance, ranging from global to local. However, academia is currently poorly positioned to address sustainability problems (Brundiers & Wiek, 2010; Leeuw et al. , 2012; Yarime et al., 2012), and in despite of the increase in availability of scientific knowledge, much must be learned in sustainability for Higher Education Institutions (HEIs) (Mulder et al., 2012) to become true leaders with growing interactions at the disciplinary level (Waas et al., 2010) and to play a bridging role for societal collaboration in sustainability (Sedlacek, 2013).

Nevertheless, as sustainability challenges can no longer be ignored, there is a general agreement on the need to reform scientific expertise at university level, by developing new ways of knowledge production and decision-making (Lang et al., 2012). Many efforts have been made in this process: increasing the number of engaged HEIs in incorporating and institutionalising sustainable development (SD); adopting new communication patterns in science and education (Adomssent, 2013; Barth et al., 2014); opening up a reframing process of curriculum (Lozano, 2006), learning goals, interactive strategies (Segalàs et al., 2010; Dloula & Burandt, 2014), competences for sustainability (Cortés et al., 2010; Lambrechts et al., 2012; Wiek et al., 2011); and creating new societal dialogue opportunities (Kates et al., 2001; Steiner and Posch, 2006; Lehmann et al., 2009; Correia et al., 2010; Ferrer-Balas et al., 2010).

A critical element of sustainability science is the engagement of different actors from outside academia in the research processes. Related to the specialized mono-disciplinary thinking, interdisciplinarity, like multidisciplinarity, are approaching fragmented aspects of reality, to search spaces of consensus. Interdisciplinarity can construct common model or transfers tools between involved disciplines (e.g. biotechnology, nuclear medicine, etc.).

Transdisciplinarity (Td), however, goes one step further in the science/society interface (Muhar et al., 2013; Posch & Steiner, 2006; Scholz et al., 2006; Vilsmaier, 2008). The objective is no longer the search for consensus but the search for articulations, preserving the different realities and confronting them in a controlled way. It implies identifying the transitions of relevant societal problems through knowledge integration in mutual learning processes, with socially robust and transferable results (Lang et al., 2012). Transdisciplinary approaches can thus not only be associated with a type of reasoning that is more fluid and ad hoc than problem solving in most sciences (Huutonieni et al. 2010) but can also be used to help faculty overcome academic fragmentation and mono-disciplinarity (Gaziulusoy & Boyle, 2012).

When entering Td, which includes the fields of social sciences and humanities, engineering researchers, enter unfamiliar grounds (Mulder, 2016). Advancing sustainable engineering science requires creating new long-term, participatory, solution-oriented programs as platforms to recognize and engage with the macro-ethical, adaptive and cross-disciplinary challenges embedded in professional issues (Seager et al. 2011).

However, education often seems to go after the events. It is argued that the transience terms of most engineering academic projects do not match the long-term relationship and capacity building required for meaningful participatory engagement and transformational change (Benessia et al., 2012) Furthermore, engineering education (EE) is usually structured around the search for specific technological solutions. Engineers have traditionally separated themselves from their work, as this was considered appropriate when the types of problems engineers were dealing with were well-structured, technological problems (Walther et al. 2012). Moreover, some studies point to a perverse effect of training, suggesting a culture of disengagement. The engineer and sociologist Erin A. Cech found that students' public welfare concerns decline significantly over the course of their EE. On both environmental and humanistic level, the disengagement of engineering students from considerations of public welfare is problematic. If engineers cannot adequately reflect upon the social impact of their work, there are few individuals in the lay public with the specialized competencies to do so (Cech, 2014) and even more to attain an eco-efficient human activity to be able to celebrate the relationship between man and nature as mutually beneficial (Braungart et al., 2007).

Education is an important condition but does not guarantee change to sustainability (Segalàs et al., 2012). An analysis of the SD competences in the cognitive domain showed that engineering students should have both competences of systemic thinking and transdisciplinarity upon graduating (Segalàs et al., 2009). This should be achieved by providing a deep understanding of the basics and also building competence in engineering students' capacity in relation to their future professional practice, through meaningful learning processes which are generally not comprehensively integrated in higher education systems (Segalàs et al., 2012).

This research wonders on what is being done and how is it being focused, with the aim to have a map image of engineering higher education initiatives in transdisciplinarity. They have been clustered according to the caractherisation proposed by Thompson Klein (2014) after analysing one decade of contributions in transdisciplinarity (2004-2014), in which she identifies three recurrent *discourses on transdisciplinarity*: transcendence, problem solving and transgression.

The authors also explored how practical constraints imposed by a classroom context, highlight limitations to transdisciplinarity, based on the four *varieties of transdisciplinarity* (soft, hard, inclusive and reflexive) proposed by Balsiger (2014), in an attempt to identify ways for moving from one type to another as circumstances change, in terms of stakeholder's collaboration and knowledge integration possibilities. Next sections briefly present the *discourses on* and the *varieties of transdisciplinarity*.

1.1. Discourses on Transdisciplinarity

To frame Td historically, we can go back to the First International Conference on Interdisciplinarity, held in France in 1970. At this time, higher education was being pressed worldwide by calls for reform. There was defined Td as ''a common system of axioms for a set of disciplines'' that goes beyond the limited view of a single discipline, toward a synthesis that embraces the globality of visions. As example, anthropology is explained as "a broad science of humans". Two participants developed the concept further, progressing from interdisciplinarity to transdisciplinarity, as the final integration or unification of knowledge among disciplines. Jean Piaget (1972) focused on internal dynamics of science, considering Td as a "kind of mature interdisciplinarity stage", with the capability of producing a "general" science. On his part, Jantsch (1972) introduced an education model focused on solving societal with coordinated activities at all levels, towards a common social purpose.

In general Td has been stated differently, whether focusing on philosophical reflection, critique, or the role of science in society where interdisciplinary research occurs when there is collaboration between academics, whereas transdisciplinarity involves cooperation with non-academics (Balsiger, 2004; Lang et al., 2012; Scholz et al., 2006; Stauffacher et al., 2006). Meanwhile, Thomson Klein (2004; 2014) noting the increasing of Td approaches, proposed three aroused major *discourses on Td*: transcendence, problem solving, and transgression.

1.1.1. The discourse of transcendence

The core epistemological issue in the discourse of *transcendence* is the idea of unity of knowledge, long sought since the times of ancient Greece. In the Middle Ages, universities were divided into "faculties", which all answered to the School of Theology, responding to the ideological wish to reach unity by mean of synthesis of branches of knowledge. The search for unity continues in the Enlightenment, when the *Encyclopédie*[1] fit together knowledge in the age of reason, and later as the unification concept of holism in fields like biology, physics, philosophy, social and systems theories. In our time of increasing cultural and scientific fragmentation Td, although not fully identified with this idea of unity, appear to point to the need of a synthetic connotation which appears in interdisciplinary fields (cultural, religious, areal studies) and new criticism paradigms (feminism, sustainability) (Thompson Klein, 2014). The quality of interrelatedness of knowledge also moves to the individual sphere, arising the

[1] Diderot, D. D'Alembert, J.R. (1751). *Encyclopédie, ou Dictionnaire raisonné des sciences, des arts et des métiers*. (Briasson, David, Le Breton, Durand, Eds.). Paris

proposal of the need for a new kind of specialist, or type of professional though with a "transdisciplinary attitude"(Nicolescu, 1996; Kockelmans, 1979; Augsburg, 2014; CIRET[2]), who mediates to the result of "making sense together" (Thompson Klein, 2014).

1.1.2. The discourse of problem solving

Relevance is placed in this discourse on the sense of social purpose of science. A study of the Organisation for Economic Co-operation and Development, OECD (CERI, 1982) declares the need for universities to address societal problems, meeting their commitment requirements. By his side, the Academy of Transdisciplinary Learning and Advanced Study (ATLAS, 2000) takes the Jantsch's model proposal (see section 1.1), suggesting that is not necessary to completely change universities structure to introduce Td, but integrating knowledge and skills from all disciplines, in complex systems and engineering towards sustainability.

Three currents of alignment (hereinafter, named arguments) with *problem solving* discourse could be drawn, posing Td as a kind of research methodology: Real world, Innovation and Transcendent interdisciplinary research.

Real world argument

The argument emphasizes the co-production of knowledge concerning real-life problems in society. Mittelstraß uses the term in defining "*Td as a form of research that transcends disciplinary boundaries to address and solve problems related to the life-world*" and "*science becomes Td if it reflects on real life problems"* (Mittelstraß, 1992 cited in: Hadorn et al., 2008: 20). At the International Transdisciplinarity Conference in Zurich in 2000, the Swiss-German School of Td emerged, featuring an approach on "real-world" problem solving. The Swiss-based Network for Transdisciplinary Research, known as <td-net>[3], born also there, highlights that the solution of problems coming from society, do not emanate from within science, but are achieved during periods of co-production of knowledge with stakeholders. Also in his discourse at Leuphana Summit (2012), Scholz aligned Td with the Real world argument in technical development fields and in those areas of human interaction with natural systems and cultural values.

Innovation argument

Other references align the concept of Td with "innovation". The National Academies of Science in the US (NAS), reports[4] a roadmap for innovation through "convergence of sciences" that promises new inventions, treatment protocols, and approaches to education and training (Committee on Convergence. National Research Council of the National Academies, 2014) which integrates life and physical sciences, medicine, and engineering into not linear combinations models of application, towards generating transformative spin-offs close to engineering and manufacturing (Thompson Klein, 2014). The NAS promotes STEM (science, technology, engineering, and mathematics) education framework, considering these disciplines as essential for technologically advanced societies.

[2] Centre International de Recherches et Études Transdisciplinaires. Available from http://ciret-transdisciplinarity.org/index.php. Accessed 30.05.16.

[3] Td-net at http://www.transdisciplinarity.ch/en/td-net/Aktuell.html

[4] It is the report of a task force sponsored in 2013–14 by the National Academies of Science in the US, entitled Convergence: Facilitating Transdisciplinary Integration of Life Sciences, Physical Sciences, Engineering, and Beyond

"Transcendent" interdisciplinary research argument

At the end of last century, the "transdisciplinary science" connotation appeared in the United States in the field of cancer and well-being studies (Hadorn et al., 2010), bringing many initiatives together. The ''transcendence" connotation is placed in the attempt to generate new methodological and conceptual frameworks in order to influence human health and wellness, by analysing all affecting factors (social, economic, political, environmental and institutional). The initiative was led by National Cancer Institute (NCI) in The United States (since 2008) and centred on the emerging field of the Science of Team Science (SciTS)[5]. A range of stakeholders is involved, but their participation is not so relevant as considered in the Real-world argument, exemplified by <td-net>.

1.1.3 The discourse of transgressionThis discourse promotes challenging existing disciplinary structures and methods considered not apt to deal with complex real world problems, with the connotation of being "sceptical"[6] (Sardar, 2010), that is going further integration of knowledge to the idea of reformulating the current state of things by means of criticizing and reimagining the status quo. Silvio Funtowicz and Jerome Ravetz (1993) deal with the concept of post-normal science, where science just becomes one voice and vote in a decision making of high uncertainty. Science has to establish a dialogue with those engaged in any complex contextualized process, in which truth can no longer be addressed only from science. In these decades, social and environmental critique aligned Td and the discourse of transgression in humanities and environmental interdisciplinary fields (gender, native cultural communications, urban and regional studies) (Vickers, 1997). Also, in the field of human rights, Upendra Baxi highlighted gaps between colonial and indigenous approaches and traditions, or between esoteric and organic knowledge. In the discourse of transgression is imperative to recognize different ways of knowing and seeing (indigenous, traditional, esoteric, organic, etc.), as well as the willing to manage "irreducible uncertainties in knowledge and in ethics" (Thompson Klein, 2014).

1.2. The limits of transdisciplinarity

In his work, Jörg Balsiger (2014) mentions that Td has focused much more on research than on teaching, where could be better incorporated by mean of recognizing its varieties and limits, highlighted by the practical constraints imposed by a classroom context, what however, leaves room to possible improvements.

Balsiger proposes two conceptualisations, namely *collaboration* and *integration* to argue how Td can be subjected to limits. He proposes four *varieties of Td*, understood as just analytical categories. Any one feature of Td could be combined into a matrix to develop the varieties of Td, as shown in Table 1. In the matrix, collaboration is referred to ''procedural questions,'' such as coordinating institutional complex tasks. Meanwhile, integration is referred to crossing boundaries limitations between fields. He proposes using the matrix as a tool to identify ways for moving from one type to another as circumstances for change: intensifying its collaborative dimension to "inclusive" by increasing the number of stakeholders, or moving towards

[5] National Cancer Institute. Science of Team Science Toolkit. Available from https://www.teamsciencetoolkit.cancer.gov/public/home.aspx?js=1 Accessed 30.03.16.
[6] Sardar's four laws of futures studies being: wicked (deal with complex, inter-connected problems), MAD (emphasise Mutually Assured Diversity), sceptical (question dominant axioms and assumptions) and futureless (bear fruit in the present).

"reflexive", strengthens integration from different areas, by achieving cognitive synthesis rather than simple cross-disciplinary borrowing. Balanced intense collaboration and integration goes to "hard", the ideal-typical transdisciplinary research process (Lang et al., 2012). In addition, any "hard" can regress along dimensions to simplified "soft Td". The framework of *varieties of Td* has been used in this work to approach the educational initiatives in Td identified in the literature review (see Table 3).

Table 1. Matrix of varieties of transdisciplinarity (adapted from Balsiger, 2014)

		Collaboration	
		Narrower	*Broader*
Integration	*Shallower*	Soft transdisciplinarity	Inclusive transdisciplinarity
	Deeper	Reflexive transdisciplinarity	Hard transdisciplinarity

2. Methodology

The methodology process started with a literature review of peer-reviewed journals. Table 2 shows the search strategy (keywords) and the taxonomy used to group some identified articles related to Td and education for sustainability according to their focus. The first group contains papers related to higher education in general. Articles regarding Td initiatives within the EE context were grouped in group 2 and group 3, was dedicated to the Transdisciplinary Case Study Approach (TCS) (G. Steiner & Posch, 2006). Group 4 was destined to identifying general perspectives on Td for sustainability. The following steps in the process consisted in identifying information from the whole text corpus of 22 selected papers (corresponding to groups 2 and 3), on different ways to apply or bring Td approaches to engineering and technology fields.

Table 2: Data search strategy

Databases	Keywords used for search	Td group (num. of articles)
Web of Science / Scopus / Emerald Insights / IEEE-Explore /Science Direct / Springer / Compendex	(transdisciplinar*) AND (sustainability) AND (higher education)	1- Td experiences (12) 2- Td and EE experiences (14) 3- TCS approach (8) 4- General perspective (20)
	(transdisciplinar*) AND (sustainability) AND (higher education). Refined by: (engineer*)	

The authors expanded on the argumentation of the three *discourses on Td* provided by Klein (2014) (see section 1.1), taking this argumentation to approach Td initiatives in engineering education for sustainability.

A first *qualitative analysis* of the whole text corpus was performed, by taking key concepts and fundamental components about transdisciplinarity and engineering education into consideration. This was done in order to assign the different identified educative initiatives to the three discourses on Td (see Table 3).

To validate this first qualitative analysis, the authors conducted an *affinity analysis* to cluster Transdisciplinarity initiatives in engineering education for sustainability in homogeneous groups. The affinity analysis procedure has been performed using VOSwiever 1.6.2. (http://www.vosviewer.com) and NodeXL (http://nodexl.codeplex.com/). VOSviewer is a free computer program for creating maps based on bibliographic or network data and for visualizing and exploring these maps. NodeXL is a free, open-source Microsoft® Excel® template that allows the user to explore network graphs. With VOSwiever, maps can be created based directly on the adjacency matrix of a network, but it is also possible to create maps of scientific publications, authors, or journals based on bibliographic coupling relations (i.e., multiple items citing the same publication), co-citation relations (i.e., multiple items cited by the same publication), or co-authorship relations (i.e., multiple items co-authoring the same publication) extracted from Web of Science or Scopus data. Also, term maps can be created directly based on a text corpus.

Maps were created of the 22 selected articles, based on bibliographic coupling (*BC*) relations (Martyn, 1964) and weighted degree analysis (Barrat et al., 2004). The coupling *BCij* of two articles *i* and *j* is determined by the number of references they share. CSV files were extracted from Scopus articles publications[7] and introduced in VOSviewer, which established the links between the different articles based on BC. The normalized coupling *BC(ij_norm)* of two articles *i* and *j* is written as

$$BC\left(ij_{norm}\right) = \frac{BCij}{\sqrt{Ri \times Rj}} \quad (1)$$

where *Ri* and *Rj* are the references used by articles *i* and *j* respectively. In order to obtain the overall structure of the network and the importance of every article in relation with the group, *BC(ij_norm)* is used to calculate the weighted degree WD_i of each article. This is simply determined as the sum of each article's $BC(ij_{norm})$ values:

$$WD_i = \sum_j BC(ij_{norm}) \quad (2)$$

Afterwards, NodeXL was used to (a) calculate the modularity of the network (i.e., groups of nodes connected with higher probability than if edges were distributed at random) and (b) to make the strength of relations visible. Thus, by means of NodeXL mapping options, the group of articles was clustered, the relationships established and its strength evidenced. The use of the combination option allowed the combination of all the edges that connects each cluster or module to not interfere with the general vision (see section 3, fig 1).

Finally, a second qualitative analysis of the whole text corpus was performed, according to the varieties of Td framework (see section 1.2). The educational initiatives identified in the literature review were distributed between hard Td, inclusive Td, reflexive Td and soft Td, considering the integration and collaboration levels of each analysed experience (see figure 2).

3. Results

Transdisciplinary education appears in many contexts, widening its conceptualization. The investigation shows that beyond the implemented experiential learning environments at the university, transdisciplinary education also occurs in situ, in the workplace and in projects with community stakeholders. It has been introduced as compulsory courses in undergraduate programs and master and doctoral programs, minors, winter or summer courses, workshops

[7] The article num. 1 wasn't published at Scopus so that it's no present in the VOSwiever analysis.

related or not to formal programmes, training courses or activities for professionals and other academic modalities. A central role that project work and mutual learning play in transdisciplinary education is viewed in master and doctoral programmes.

Qualitative analysis of the literature review

The *qualitative analysis* of the whole text corpus has been synthetized in Table 3, where the EESD experiences are clustered under the Td discourses and arguments, showing their format and main characteristics.

The search in the EESD area indicates that most of the initiatives in Td are related to the discourse of *problem solving*. In this group of educational experiences, the underlying argument that brings Td to the EESD is the Real-world argument, by means of the co-production of knowledge with stakeholders to provide solutions to problems originating in society. Emerging from the Swiss-German School, one of the most widely performed approaches (for research and teaching) is the Transdisciplinary Case Study (TCS), developed and elaborated at the Swiss Federal Institute of Technology (ETH), as a means of transition support, used in many university programmes in Germany, Austria, Switzerland, United States, Canada, South-Africa, etc. (Lang et al., 2012, Scholz et al., 2006, Oswald et al., 2000, Posch & Steiner, 2006, Stauffacher et al., 2006, Steiner & Laws, 2006 (Germany) Brundiers & Wiek, 2010 (Arizona), Holden et al., 2008 (Vancouver). The method-driven aspect of this approach is relevant.

The second argument included in the *problem solving* discourse, brings together a substantial amount of initiatives in Td for EESD,. This is the Innovation argument, related to the US National Academies of Science proposal on "convergence" or integration of life, human and physical sciences and engineering, which brings new approaches to education and training in EE that are considered essential in technologically advanced societies. As a consequence, engineering has to develop approaches that allow for stakeholder perspectives in the design process. This approach has led to the creation of the following innovative experiences: engineering and social work instructional modules to address and self-report empathy within engineering education (Walther et al., 2012); special communication modes project-course, Robotics for Theater, for engineering students, a course which designs and builds a robot from scratch, to take on the role of an actor in theatrical productions (del Cerro Santamaría, 2014); collaborative Engineering Sculpture (CES), capstone engineering project which incorporates collaborative work between engineering and fine art students, for whom the practice of "design" is different. (Dartt et al., 2009); transdisciplinary master of engineering program, developed jointly by industry and the Institute for Design and Advanced Technology at Texas Tech University (Ertas et al., 2003; Tate et al., 2010).

The third argument under the *problem solving* discourse, Transcendent interdisciplinary research, focuses on service learning, which means learning with a social purpose. We can find many experiences of global service learning communities at Purdue University which respond to community needs at home and abroad as engaged citizens (Jesiek & Lafayette, 2013). Similarly, another kind of transdisciplinary collaboration related to this argument promote the academic development of blended learning (Allen et al., 2010), in the field of health (Committee on Convergence. NAS, 2014), bringing together students and entities in a team-based process.

Finally, under the discourse of *transcendence*, three initiatives can be included. A model based on negotiated Learning Development Agreements (LDA) facilitates learning professional development agreements in the off-campus environment, concluding that the model provides a new paradigm approach to global engineering professional development (Chisholm et al., 2005). A transdisciplinary problem-based three module (a competitive game, a role-play, and an IT integration project) learning course, addresses business and IT. In both, the process-related/technical and emotional learning experience (Wegmann, 2004) is emphasized. The third initiative proposes *Td niches*, fostering lifelong learning in different stages of education and research to solve real problems in Romania (Canter & Brumar, 2011).

Table 3. EESD initiatives according to discourses (and its arguments) on transdisciplinarity (see References)

Discourse on Td/ Argument	**Id.**	**Referenced initiative in Td** (see section References)	**Format**	**Characteristics**
Transcendence	1	Chisholm et al., 2005 (Glasgow)	LDA: Negotiated Learning Development Agreements	- Transdisciplinary individual - Process-related/**emotional** balanced learning
	2	Wegmann, 2004 (Lausanne)	Problem-based learning course on technical and emotional learning	
	3	Canter & Brumar, 2011 (Romania)	Lifelong learning transdisciplinary niches	- Lifelong learning
Problem Solving/ Jantsch' model	4, 5	Tate et al., 2010, Ertas et al., 2003 (Texas)	Sustainable design master course, with research activities (laboratories) in industry	- **Common social purpose** - Coordinated activities in structure industry/university
Problem Solving/ Real world	6 7, 8 9,10 11 12 13	Lang et al., 2012 (Lunebürg) Scholz et al., 2006, Oswald et al., 2000, Posch & Steiner, 2006, Stauffacher et al., 2006 Steiner & Laws, 2006 (Zurich) Brundiers & Wiek, 2010 (Arizona) Holden et al., 2008 (Vancouver)	TCS: Transdisciplinary case study approach. "Swiss-German school"	- **Method-driven process** - Case study based - Co-creation of knowledge - Social accountability
	14 15	Boyd et al., 2014) (Geneva); Balsiger, 2014 (Vancouver)	Atelier: Intensive teamwork performance courses SDIE: teaching classroom simulation	-"Transdisciplinarity in the class-room" - Single exercise from TCS
Problem Solving/ Innovation	16	Walther et al., 2012 (Athens, USA)	Instructional modules to address and self-report empathy	- "Convergence", the 3rd revolution[8]: sciences for well-being
	17	del Cerro Santamaría, 2014 (NY)	Robotics-for-Theatre project: Team-based 3 consecutive weekly courses	
	18	Dartt et al., 2009 (NY)	CES capstone project: collaboration students/ staff, fine-arts/ engineering	
Problem Solving/ Transcendent interdisciplinary research	19	Allen et al., 2010 (Sidney)	Team-based approach: blended learning course. Innovation	- Team-based process - Blended learning
	20	Mick & Ackerman, 2005 (NY)	Team-based capstone design course in medical centres	
	21	Barth et al., 2014 (Lüneburg)	Project-based BINK1: seminars in service and incidental learning	- Service learning
	22	Jesiek & Lafayette, 2013 (Purdue)	Service-learning and global engineering programs	
Transgression	-			- "Socially robust knowledge"

[8] The Third Revolution (2011). The convergence of the life sciences, physical sciences and engineering. Washington, DC: Massachusetts Institute of Technology web.mit.edu/dc/Policy/MIT%20White%20Paper%20on%20Convergence.pdf

Affinity Analysis

Bibliographic coupling, which is a typical networking tool, has been used to identify clusters that share references and this enables a classification of the articles on some of the Discourses on Td. The affinity analysis shows four different clusters (see Figure 1). Cluster 1 includes authors who have had mentors related or pertaining to the ETH (Wiek, in Brundier's article; Lang; Boyd) and who have spread Td "beyond borders", to Arizona in the United States Luneburg in Germany and Murdoch in Australia. Cluster 2 includes these primary authors (Scholz, Stauffacher, Steiner and Posch) directly linked to the "Swiss-German School" and the beginnings of Td methodology in ETH. Cluster 3 shows authors belonging to the *Jantsch' education model* argumentation, located at Texas University. Cluster 4 group authors (Barth, Allen) belonging to the "convergence of disciplines for human well-being" argumentation (*Transcendent Id research* argument) and Wegmann, assigned to the *transcendence* discourse. Scholz is also present in cluster 4, showing a high *betweenness centrality degree* (see below).

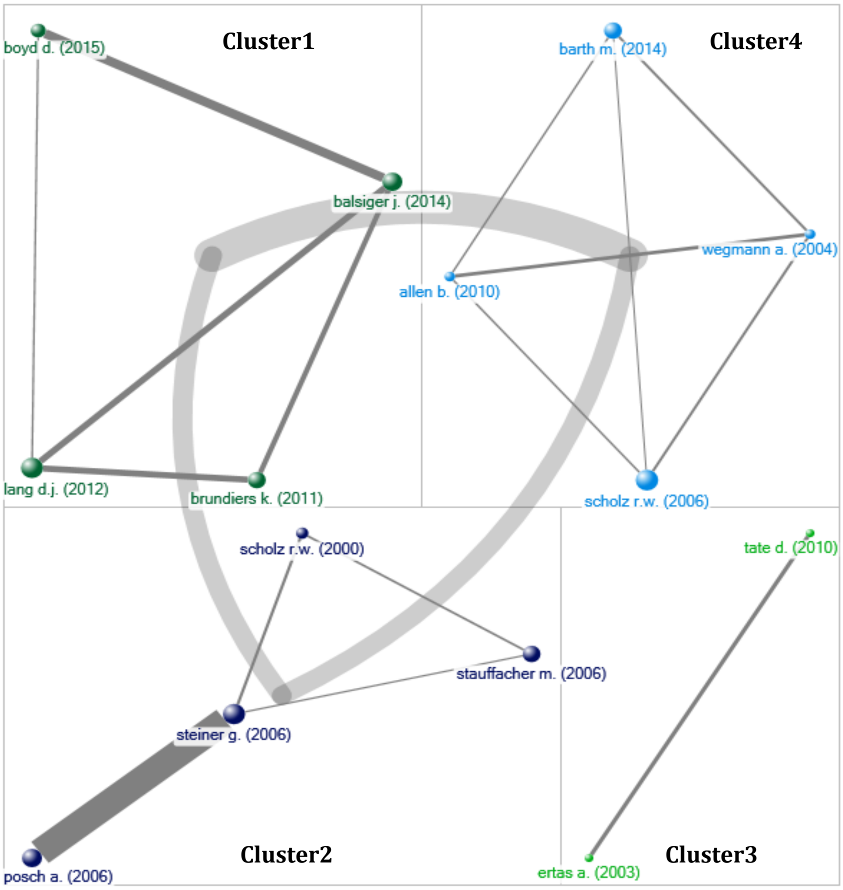

Fig. 1. Affinity and clustering analysis by means of NodeXL mapping options

Clusters (1 and 4) appear to be strongly linked. This should be expected if we take into account that most of the articles are based on IT systems educational experiences (Barth, Allen and Wegmann). Both clusters belong to the *Transcendent Id research* argument. Pondering the classification of the last component of cluster 4, Wegmann (2004), from *Trascendence* discourse to *problem solving- Transcendent Id research* discourse should be taken into consideration.

The other clusters with the exception of Cluster 3 also maintain high interrelation levels (see fig. 2).

The *betweenness centrality degree* refers to the ability of an item to act as a point of connection between the different clusters of a map. The *betweenness centrality degree* of the authors who are related to the articles analysed, is shown below:

Table 4. *Betweenness centrality degree*

Author/Article	Betweenness centrality degree
Scholz (2006)	24,3
Stauffacher (2006)	19,0
Lang (2012)	6,3
Barth (2014)	3,3
Steiner (2006)	2,0

The interpretation of Scholz (2006) (specially) and Stauffacher (2006) high degree, suggest that the authors should act as an "informer" for other clusters or authors. Lang (2012) and Barth (2014) come from the same institutional environment the Leuphana University of Luneburg, as do the rest of the authors of Barth (2014) and Lang (2012) This should suggest a kind of "informer institution" quality.

The affinity analysis methodology validates the classification realized showing, through experimental demonstration, what rationality informs; namely that if some authors are part of the same system, they should share similar thoughts. In this sense, it can be considered that the affinity analysis agrees with reality, since we have some clusters that identify the same scientific basis. Affinity analysis provides a good starting point to identify the Discourses on Td.

Qualitative Analysis of the varieties of Td framework

We used the framework of *varieties of Td* to approach the experiences identified in the literature review (see Table 3). The qualitative analysis of the article's whole text corpus, plots the distribution of the 22 experiences around the two axes Integration and Collaboration, as is shown in Figure 2, whether their location is in the range between *hard Td*, *inclusive Td*, *reflexive Td* and *soft Td.*

Figure 2 shows the integration of the analysed experiences, which are identified by different colours in the Balsiger matrix, where the limits of Td are present.

The investigation indicates that most of the initiatives in Td for EESD fit in the scheme of broad collaboration and deep integration understood as Hard Td (see Figure 2) and under the problem solving discourse (see Table 3).

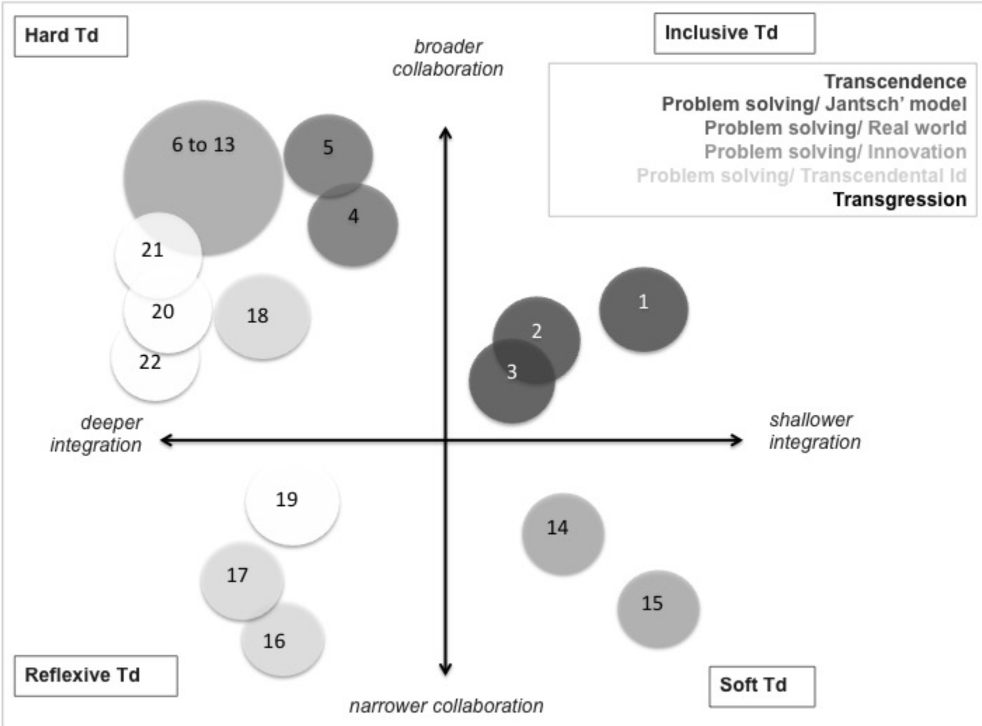

Figure 2: Location of EESD Td experiences in the collaboration/integration Balsiger matrix

From the analysis, it appears that problem solving under the Jantsch paradigm does not cross boundaries between disciplines in depth, but does however intensify the stakeholder's participation.

Real world paradigm approaches usually involve Hard Td by means of the co-production of knowledge with stakeholders to manage problems and integrate field and areas of research. The method-driven aspect is relevant here. Experiences related to "innovation" fit in the Reflexive Td area, which tend to depend on the education entities efforts more. It is relevant that none of the experiences analysed seems to fit under the Transgression paradigm, although num. 22 (global service learning) might belong to it, because it deals with human rights and emotional intelligence.

4. Conclusions

Much personal and social interest and efforts have been invested to achieve Td in different ways, presenting an enlarged range of separate approaches, of which it has been speculated need to be unified. As Klein (2014) concludes, Td work moves between boundaries, which emphasize the different ways Td can be applied, especially with regards to education. So that, emphasis in Td approaches in EESD will continue to vary across discourses, and across deepening connotations.

In this manner, different contexts and relationship will contribute to express any initiative differently. From an epistemological or ideological perspective, Td will be aligned more closely with the discourse of transcendence; as a method of knowledge production, it will be linked with problem solving targets, in fields such as health, land use or sustainability; as a form of critique (related to the discourse of transgression), it will continue questioning the university's role in society or worldview new paradigms (Klein, 2014). Affinity analysis is a good starting point to identify the *discourses on Td*.

On the other hand, as suggested by Balsiger (2014) with the *varieties of Td* matrix, some forms of Td are appropriate in some contexts but not others. In the same way, each higher engineering institution has to find its own way to achieve the goals it is pursuing.

The analysis of Td educational initiatives regarding discourses on Td, has allowed us to visualize how the Td in EESD is being approached. We conclude, on the one hand, that engineers can feel comfortable in initiatives related to the *discourse of problem solving*. On the other hand, we think that the analized initiatives are using the transdisciplinarity approach to overcome classical training in technological problem solving, consisting in looking at problems locally, or from one dimension (Scholz et al., 2006), what takes engineers away from the source of the needs posed to them.

Related to the *real world argument*, the educational initiatives show a strong method-driven aspect to facilitate co-production of knowledge with stakeholders, in the attempt to provide solutions to problems originated in society and nature.

Related to the *innovation argument,* in attempting to "engage the public" in the design process, the assigned initiatives emphasize communication and empathy skills as core learning outcomes. In this sense, introducing into engineering programs collaborative strategies as Campus Lab (Vezzoli et al. 2016) or Living Labs (Evans et al., 2015; Voytenko et al. 2016) could be relevant.

In the case of the *transcendental Id research argument*, the focus lies in learning with a social purpose, by means of team-based work processes, working closely with entities or societal bodies. The academic development of blended learning processes as for example the achievements of Learning Service practice with the focus on social justice, wich enhance the development of more complex thinking than a traditional Service Learning (Aramburuzabala, 2013) can be key in this kind of educational initiatives.

In the discourse of transcendence, in addition to the process-related/technical learning, the emphasis is on the emotional learning experience. The idea is to promote a kind of "transdisciplinary attitude" (Nicolescu, 1996) at the individual sphere of professionals, allowing them to be competent in "making sense together" (Thompson Klein, 2014) and adequately reflect upon the impact of their work.

Where engineers "get a hold", is in the discourse of transgression, with its idea of being "sceptical" and reformulating things (Sardar, 2010) which goes further integration of knowledge. For that is necessary to take up alternative knowledge and lay perspectives arising from different ways of knowing. When recognized, a shift occurs from solely ''reliable scientific knowledge'' to inclusion of ''socially robust knowledge'' (Nowotny et al., 2001).

The real-world need for universities to prioritize their social and environmental protection missions towards a common purpose (Jantsch, 1972) should be the key to guiding the "transgression path" towards ''socially robust knowledge''

Professional engineers are assumed to ''hold paramount'' the well-being of the public more broadly, even while working on specific tasks (Cech 2014). If engineering programs are able to challenge transdisciplinarity, then they may be able to train a different kind of critically thinking engineer, who reflects on and rewrite the co-construction of public welfare, the understanding and respect for the rules of natural cycles and the management of the technological systems that he or she knows.

In the different analysed Td approaches to engineering education, the underlying theme is the need of a cognitive flexibility manifested in a willingness to see beyond one's own discipline, and to the integration of knowledge. Competences and skills to teach and to learn under this scheme should be analysed in depth in further research. Of course, authors warn that nobody will be an expert in all areas and perhaps other members and teams will be needed. This awareness is essential to fill skill gaps.

Although this analysis is a starting point to assess Td in EESD, much research is still needed before an education framework can be designed (curriculum structure, faculty competences, pedagogical approaches, etc.) that best facilitates the practice of Td in Engineering Education. Different levels of application of Td approaches have to be well managed in the classroom environment to be able to be further applied in the real life work with society.

The next steps to take in our research will be to focus on the application levels of Td in education, in order to determine how to classify educational experiences in Td, with regards to the limits conferred by learning circumstances, and so further work will entail mapping limits in the Varieties of Td Matrix.

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