

# TRANSDISCIPLINARITY IN ENGINEERING EDUCATION. A MUST FOR SUSTAINABLE DEVELOPMENT IN TECHNOLOGY EDUCATION

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## Abstract

Sustainability issues are widely recognized as wicked problems, which should not be considered as problems to be solved, but as conditions to be governed. There is a general agreement on the need to reform scientific expertise as it is required to deal with sustainability challenges, by developing new ways of knowledge production and decision-making. Transdisciplinary aspects of sustainability are widely acknowledged as a transformational stream of sustainability science. However, when entering transdisciplinarity, also encompassing social sciences and humanities, engineering researchers enter unfamiliar grounds. 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. Furthermore, the difficulties to change engineering education are broadly analysed: anachronistic pedagogy, mismatched incentives, insufficient expertise, lack of personal commitment, familiar and comfortable patterns for scholars, overcrowded curriculum, etc. Nevertheless, in spite of any old pattern, operationalizing the goals of the field, developing the necessary competencies, and seeking partnerships between society and the academy will position academic institutions to impact on the transition towards sustainability. We have performed a literature review on different ways of applying or bringing transdisciplinarity approach to higher education, in particular in engineering and technology fields. Deepening the argumentation provided by Julie T. Klein on the three discourses on transdisciplinarity -transcendence, problem solving, transgression- we have analysed the different published initiatives under those discourses to approach transdisciplinarity initiatives in engineering education for sustainability.

Keywords: Transdisciplinarity, Sustainability, Engineering Education.

## 1 INTRODUCTION

There is a general agreement on the need to reform scientific expertise as it is required to deal with sustainability challenges, by developing new ways of knowledge production and decision-making. A critical element of sustainability science (SC) is the engagement of different actors from outside academia into the research processes. Transdisciplinarity (Td) goes a step further, to the science/society interface. It implies identifying the transitions of relevant societal problems through knowledge integration in mutual learning processes, which results socially robust and transferable. Td can thus be associated with a type of reasoning that is more fluid and ad hoc than problem solving in most sciences. 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 [1].

When entering transdisciplinarity, also encompassing social sciences and humanities, engineering researchers enter unfamiliar grounds. 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 [2].

But 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 [3]. Furthermore, engineering education (EE) is usually structured around the search for specific technological solutions. Moreover, some studies point to a perverse effect of training, suggesting a culture of disengagement. Cech [4] found that students' public welfare concerns decline significantly over the course of their EE. On a 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.

## 2 METHODOLOGY

The methodology consisted in reviewing the literature of peer-reviewed journal articles. Table 1 shows the search strategy (key words) and the taxonomy used to cluster the experiences. First, the ones related to higher education in general. Articles regarding experiences in an EE context were grouped in 2 and 3, being the last dedicated to Transdisciplinary Case Study approach. Aspect 4 was destined to general perspective on Td for sustainability. Next steps consisted on read and extract information from the whole text, about different manners on applying or bringing Td approach to engineering and technology fields from the 24 papers identified.

Table 1: Data search strategy.

Databases	Keywords used for search	Aspects on Td (num.)
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 engineering (15)
	(transdisciplinar*) AND (sustainability) AND (higher education). Refined by: engineer*	3- TCS approach (9) 4- General perspective (20)

In the other hand the authors deepened the argumentation provided by Klein [5], taking this argumentation to approach Td initiatives in EE for sustainability. Next section shows an overview on the three discourses on Td and will attempt to assign the different initiatives to those.

## 3 TRANSDISCIPLINARITY DISCOURSES

To historically frame Td, we need to go after the first international conference on interdisciplinarity, held in France in 1970. At this time, higher education was being pressed worldwide by calls for reform. Td was defined then as “a common system of axioms for a set of disciplines” that transcends the narrow scope of disciplinary worldviews through an overarching synthesis. As example anthropology is explained as a broad science of humans [5]. Two participants developed the concept further into respective interests. Jantsch [6] imbued Td with a strong sense of social purpose, introduced in his model of a system of science, education, and innovation. On the other hand, Jean Piaget focused on internal dynamics of science, treating Td as a kind of mature stage in the epistemology of interdisciplinarity relationships, based on reciprocal assimilations capable of producing a “general” science [7]. Klein [5] argues that the wide current ascendancy of Td has shaped three major discourses on Td: transcendence, problem solving, and transgression.

### 3.1 Transcendence discourse

The idea of unity, traced in the West to ancient Greece is the core epistemological issue in the discourse of *transcendence*. The idea of the unity of the knowledge has been longer pursued. In the Middle Ages, there were universities divided into “faculties”, which all answered to the School of Theology. This responded to the wish to create a synthesis between the different branches of knowledge to reach its unity [8], with an ideological aim. In the same way we can find the idea of the unity of knowledge behind the Enlightenment ambition of universal reason, later movements as transcendentalism, the search for unification theories in physics or the concept of holism in biology, physics, social theory, systems theory, and philosophy. Td, although not fully identified with this idea of unity, appears pointing to the need for new syntheses at a time of growing fragmentation of knowledge and culture [5]. This synthetic connotation, also persisted in interdisciplinary fields such as area studies, cultural studies, and religious studies; disciplines characterized by broad scope such as philosophy, history, and geography; and new paradigms such as feminist theory, cultural critique and sustainability.

Relevance is placed on a sense of social purpose of science. Kockelmans [9] aligned Td with the work of a group of scientists trying to systematically determine how negative effects of specialisation can be overcome to make both education and research more socially relevant. Later but in the same line Frodeman [5] associates Td with co-production of knowledge by actors beyond academic walls in the public and private sectors, even wondering whether trans-disciplinary works consist of “one-offs” that resist generalization.

## 3.2 Problem solving discourse

In education, an OECD study [10] declares the need for universities to prioritize its pragmatic social mission addressing problems coming from society. Jantsch's education model exemplifies an education/innovation system based on coordinated activities at all levels, towards a common social purpose [6]. This vision continues in the Academy of Transdisciplinary Learning and Advanced Study [11], organization that promotes transdisciplinary structures in universities.

By the end of the last century, three currents of alignment with problem solving Td gained wide attention. All were drawn notions of Td as a research methodology: Real world; Wicked Problems and Transcendent interdisciplinary research.

### 3.2.1 Real World

The philosophical-underlying premise is the "real-world" argument. 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' [12]. Scholz, at Leuphana Summit [13] refers to Mittelstraß as: "Science becomes Td if it reflects on real life problems". In this discourse Td is aligned with "real world" argument in technical development fields and in these areas of human interaction with natural systems and cultural values. The emphasis is co-production of knowledge with society.

### 3.2.2 Wicked problems

A wicked problem is a complex issue that defies complete definition, for which there can be no final solution, since any resolution generates further issues, and where solutions are not true or false, or good or bad, but the best that can be done at the time [14]. Environmental and sustainability issues can be directly positioning in this framing.

### 3.2.3 Interdisciplinary research

At the end of last century, the 'transdisciplinary science' connotation appeared in the USA in the field of cancer studies and well-being [12]. Its claim to "transcendence" lies in its attempt to generate new methodological and conceptual frameworks in order to influence human health and wellness, from analyzing all affecting factors (social, economic, political, environmental and institutional). Nowadays, The National Academy of Science reports a roadmap for innovation through "convergence"<sup>1</sup> that promises new inventions, treatment protocols, and approaches to education and training. This concept points towards transformative integration of life sciences, physical sciences, medicine, and engineering. It is signaling a break from older linear models of application to new combinations and integration generating new spin-offs, tied closely with engineering and manufacturing [5].

## 3.3 Transgression

This discourse moves beyond instrumental integration to critique, reimagine, and reformulate the status quo, remaining idea in the connotation of being "sceptical" [5]. Silvio Funtowicz and Jerome Ravetz deal with the concept of post-normal science, arguing that science must engage in dialogue with all those who have a stake in a decision of high uncertainty [15]. The most important transdisciplinary fields under this discourse have been gender, native/aboriginal, cultural communications, regional, circumpolar, urban and environmental studies [16] and human rights [5]. When lay perspective and alternative knowledge are recognized, a shift occurs from solely "reliable scientific knowledge" to inclusion of "socially robust knowledge" [5].

## 4 TRANSDISCIPLINARITY LIMITS

In his work, Balsiger [16] mentions that Td has focused much more on research than on teaching, and that recognizing the varieties and limits of Td could usefully contribute to better incorporating Td in teaching. At the same time, the practical constraints imposed by a classroom context highlight the limits of Td, while pointing to some opportunities for improvement.

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<sup>1</sup> Convergence: Facilitating Transdisciplinary Integration of Life Sciences, Physical Sciences, Engineering, and Beyond (Committee on Convergence. National Research Council of the National Academies, 2014)

Balsiger proposes a brief discussion on two conceptualisations, namely *collaboration* and *integration* to argue how Td can be subject to limits. He proposes four *varieties of Td*, understood as just analytical categories. Any feature of Td could be combined into a matrix to develop the varieties of Td, as showed in Table 2. In this context, collaboration is referred to “procedural questions,” as coordinating complex tasks between different people and institutions. Meanwhile, integration is referred to crossing boundaries limitations between fields and research and practice. He propose using the matrix as a tool to identify ways for moving from one type to another as circumstances change: intensify its collaborative dimension to “inclusive” by increasing the number of stakeholders, or move towards “reflexive”, strengthen 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 [17]. Also any “hard” can regress along dimensions to simplified “soft Td”.

This framework has been used to approach the experiences identified in the literature review (see Table 3). Fig. 1 shows whether its location is in the range between hard, inclusive, reflexive and soft Td.

Table 2: Varieties of transdisciplinarity (adapted from [17]).

		Collaboration	
		<i>narrower</i>	<i>broader</i>
Integration	shallower	soft transdisciplinarity	inclusive transdisciplinarity
	deeper	reflexive transdisciplinarity	hard transdisciplinarity

## 5 RESULTS

Transdisciplinary education appears in many contexts, widening its conceptualization. The analysis shows that beyond 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 related or not to formal programmes, training courses or activities for professionals and other academic modalities. A few universities have implemented experiential learning environments. A central role that project work and mutual learning play in transdisciplinary education is viewed in master and doctoral programmes.

The analysis has been synthetized in Figure 1, which shows the integration of the analysed experiences in the Balsiger matrix, where the limits of Td are present and Table 3, where the experiences are clustered under the Td discourses and arguments, showing their format and main characteristics.

The investigation indicates that most of the initiatives in EESD Td fit in the scheme of broad collaboration and deep integration understood as Hard Td (see Fig. 1) and under the problem solving discourse (see Table 3).

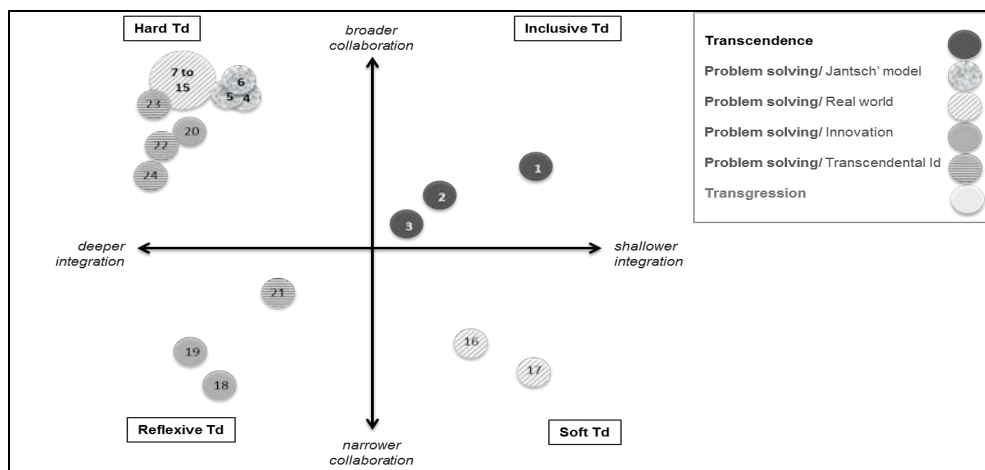


Figure 1: Location of EESD Td experiences in the collaboration/integration Balsiger matrix.

Find articles in Figure 1 and Table 3, listed as: 1- [19]; 2- [20]; 3- [21]; 4- [22], 5- [23]; 6- [24]; 7- [18]; 8- [25]; 9- [26]; 10- [27]; 11- [28]; 12- [29]; 13- [30]; 14- [31]; 15- [32]; 16- [33]; 17- [16]; 18- [1]; 19- [34]; 20- [35]; 21- [36]; 22- [37]; 23- [38]; 24- [39].

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

Real world paradigm approaches usually involved Hard Td by means of the co-production of knowledge with stakeholders to achieve solution to problems and integrates field and areas of research. The method-driven aspect is relevant here. Experiences related to "innovation" fit in the Reflexive Td area, which are more depending on the education entities efforts. It is relevant that none of the experiences analysed seems to fit under the Transgression paradigm, although num. 24 (global service learning) might belong to, as likened to human rights and emotional intelligence.

Table 3: EESD initiatives according to discourses on transdisciplinarity.

Discourse/ Argument	Experiences	Format	Characteristics
Transcendence	1	LDA: Negotiated Learning Development Agreements	- Transdisciplinary individual - Process-related/emotional balanced learning
	2	Problem-based learning course on technical and emotional learning	
	3	Lifelong learning transdisciplinary niches	- Lifelong learning
Problem Solving/ Jantsch' model	4, 5, 6	Sustainable design master course, with research activities (laboratories) in industry	- Coordinated activities in structure industry/university - Common social purpose
Problem Solving/ Real world	7, 8, 9, 10, 11, 12, 13, 14, 15	TCS: Transdisciplinary case study approach. "Swiss-German school"	- Method-driven process - Case study based - Co-creation of knowledge - Social accountability
	16, 17	Atelier: Intensive teamwork performance courses (16). SDIE: teaching classroom simulation (17)	- "Transdisciplinarity in the class-room" - Single exercise from TCS
Problem Solving/ Innovation	18	Instructional modules to address and self-report empathy	- "Convergence": the 3rd revolution <sup>2</sup>
	19	Robotics-for-Theater project: Team-based 3 consecutive weekly courses	
	20	CES capstone project: collaboration students/ staff, fine-arts/ engineering	
Problem Solving/ Transcendent interdisciplinary research	21	Team-based approach: blended learning course. Innovation	- Team-based process
	22	Team-based capstone design course in medical centers	
	23	Project-based BINK1: seminars in service and incidental learning	- Service learning
	24	Service-learning and global engineering programs	
Transgression	-		- "Socially robust knowledge"

## 6 CONCLUSIONS

Much personal and social interest and efforts have been invested to achieve Td. This enlarged force has led to speculation about whether a meta-Td might unify separate approaches. As Klein [5]

<sup>2</sup> 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

concludes, Td work move between boundaries. These boundaries give emphasis to the different manners to apply Td, especially regarding education; emphasis in Td approaches in EESD will continue to vary across discourses, and also across deepening connotations.

In this manner, different contexts and relationship will contribute to express differently any initiative. As an epistemological project, Td will be aligned more closely with the discourse of transcendence; as a method of knowledge production, it will be linked with utilitarian objectives, health, environment and sustainability; as a form of critique, it will continue wondering about logic of the university's role in society [5]. As suggested by Balsiger [6] 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, with respect to the goals that are being sought. Amplifying any of the core features is subject to diminishing returns, meant to cover the range of direct and indirect benefits attributed to Td.

Professional engineers are assumed to “hold paramount” the well-being of the public more broadly, even while working on specific design tasks for specific clients [4]. If engineering programs can challenge transdisciplinarity, it appears that engineering programs could produce a new brand of engineer, one that thinks critically about the co-construction of public welfare and the technological systems on which he or she works.

This analysis is a starting point to analyse Td in EESD, much research is needed to see the education framework (curriculum structure, faculty competences, pedagogical approaches, etc.) that best facilitates the practice of Td in Engineering Education. The declared need for universities to prioritize its pragmatic social mission addressing problems coming from society [10] towards a common social purpose [6], should be the key to address the transgression path through “socially robust knowledge”.

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