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Guidelines to improve Engineering Education for Sustainability through transdisciplinarity learning processes

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Abstract

Actions for sustainability are promoted from the different areas of environment, society, technology and economy, with the common aspiration to face interconnected crises in a world that can no longer be conceived as "society without nature and nature without society". From this imperative for the integration of epistemics, university is called to restructuring boundaries and processes to properly serve society. Given that engineering principles are aligned with that logic, it is argued that engineering education (EE) have to evolve to being engineering-problem oriented and further developed into socio-technically oriented.

Transdisciplinarity emerged in this context pursuing integration of academic and practical or traditional knowledge outside the academia, to co-produce outcomes both socially robust and transferable, that is, useful for transitioning and scientifically innovative to formulate new guiding principles.

In order to improve engineering education in sustainability (EESD) through transdisciplinary learning approaches, we performed a three phases research. Firstly, we analysed how sustainability was approached in EE, through a co-word analysis and characterization of the keywords' networks of three relevant journals in the EESD field. The journal networks evolution analysis suggested that social concern in engineering is growing . The keywords characterisation showed relevant categories being related to transdisciplinar education strategies for applying sustainability and to cross-boundary schemes. Finally, a modularity analysis showed that keywords related to transdisciplinarity spread throughout all the areas of knowledge addressed by the journals, indicating a widening interest.

The second phase studied how emergent EESD initiatives were approached from transdisciplinarity discourses. Most of them fitted in the problem-solving discourse, where co-production of knowledge and method-driven aspects are also relevant. Deepening this discourse, most initiatives corresponded to the real-world argument promoting science-society collaboration in societal problems (EU contexts); others looked for convergence of sciences in pursuit of human well-being (innovation argument, US contexts); and some initiatives brought together students and entities in a team-based learning process with social purpose (transcendent interdisciplinary research- TIR argument). None of the initiatives fitted the transgression discourse, attempting to reformulate the establishment, no longer for society but with society.

The last phase consisted in the implementation of a transdisciplinary learning environment experience in a 5 ETCS course of the UPC Master degree in Sustainability Science and Technology. Civil organisations, students and educators undertook collaborative research on real-life sustainability case studies, following two cycles of action-reflection. While the course mainly fitted in the real-world argument of problem solving, service learning and CampusLab schemes also reproduced team-based learning with societal purpose (TIR argument). The transgression discourse was addressed through service learning focusing on

social justice. Some students engaged further as professional researchers-activists. Additionally, a well-valued Emotional Intelligence module was developed to help students face some process paralyzing uncertainties.

From the lessons learned, we proposed a set of fundamental features to be considered for an effective scheme for a transdisciplinary approach in EESD, methodically framing the science-society discourse on the issue at stake: work in real-world complex problems; involve diverse disciplines and fields cooperation; involve science-society cooperation and mutual learning processes; integrate types of knowledge; rely on disciplinary and cross-disciplinary practices.

1 Introduction

Since sustainability science appeared in the university arena in the early 1990s, academic faculty have agreed that dealing with the complex problems faced by human society and the natural environment requires a transdisciplinary approach both in research and in sustainability education, and that universities should focus on developing capacity for transdisciplinarity (Jantsch, 1972; Russell, et al. 2008; Ertas et al., 2003).

The research presented in this article aimes to improve engineering education in sustainability (EESD) through transdisciplinarity (td) learning approaches. The research comprised three phases, consisting of looking first at the principal approaches to sustainability in engineering education (EE), being td identified as one of them, then examining different experiences in engineering education for sustainability with a td perspective and finally, piloting a td learning experience in a technological university.

Going through the different phases some elements and factors that repeatedly appear to be relevant to perform a td approach were identified. Consequently, a set of fundamental features to be considered for an effective scheme for a td learning approach are proposed as guidelines, which significantly may facilitate any educational initiative in EESD to undertake a transdisciplinary learning scheme.

2 Research phases

2.1 Patterns and trends in Engineering Education in Sustainability: a vision from relevant journals in the field

The first phase consisted of the analysis of how sustainability is approached in EE through a co-word analysis and characterization of the keyword's networks of three relevant journals in the field of EESD over two decades. We applied a bibliometric approach, adopting a co-word analysis based on co-occurrence of keywords (300) in articles (171) from three indexed journals related to the terms engineering, education or sustainability, previously identified in a structured way, based on the appearance of two of the previous three terms in the journal scope (based on Journal Citation Reports) and the last term in the journal topic and title fields.

Further, the network of keywords was structurally and temporally analysed, and the keywords categorized to identify topological patterns and their evolution. The categorization1 raised two main blocks in terms of

[1] Nine categories were identified (see article, section 2.3, Table 3), namely: Institutional and policies; Curricular structure; Educational strategy; Competences/behavioural aspects; Academic/professional development; Sustainability Pillars topics: techno-environmental; Sustainability Pillars topics: techno-economics; Sustainability Pillars topics: socio-cultural; Contents referring to social and cultural issues; Transdisciplinarity and collaborative networking

corresponding number of keywords: a) relevant categories but decreasing at the end of the period, related to institutional and policy aspects of embedding sustainability in higher education; b) relevance increasing categories related to the professional development of faculty members, implementation and use of learning strategies (real-world learning experiences, educational innovation) and cross-boundary schemes (transdisciplinarity, ethics, networking), suggesting that the concern was growing to move to society.

The analysis of the structural network evolution based on the keywords co-ocurrence, highlighted considerations at two levels: the individualised journal networks and the global network. Regarding the connectivity between the different areas in which research was done for each journal, it is suggested that JCLP presents the higher (globular shape), i.e. the same keywords being used in different articles; IJEE the lower (linear shape), suggesting research made in separate areas, where articles use different keywords from one another; and IJSHE is in between.

The rest of network metrics gave some insight on the networks' evolutionary behaviour and research trends, namely a) three areas constantly dropped along the studied period, related to transdisciplinarity, techno-environmental topics and academic professional development, especially in IJSHE and JCLP; b) IJSHE had a will of reinforcing relationships beyond the university, while IJEE gave relevance to real North-South case studies; and JCLP contributed aspects on competences and educational strategies (Tejedor et al., 2019)

2.2 Transdisciplinarity in higher education for sustainability: How discourses are approached in engineering education

The second phase of the research studied how emergent EESD initiatives were approached from td, as valued competence for sustainability. The initiatives identified were clustered according to the characterization proposed by Julie Thompson Klein's (2014) analysis of one decade of contributions in td (2004 to 2014). Klein identified three recurrent "discourses on transdisciplinarity", namely transcendence, problem solving (which encompass different argumentations, namely real-world argument, innovation argument, transcendent interdisciplinary research argument and the argument of the university framed by purpose) and transgression, which help to understand the evolution and different trends of the td thinking.

An initial literature review showed diverse emergent modalities of learning environments at the technological universities, where a td approach was introduced, from courses in undergraduate programs to workshops in postgraduate levels, often led by committed lone professors aiming to engage with the macro ethical and cross-disciplinary sustainability challenges. To generate an overview, the authors matched the identified initiatives to the discourses on transdisciplinarity. An affinity analysis was performed to validate the first qualitative analysis, grouping the initiatives in homogeneous groups, and showing experimentally what rationality informs: that authors in a group share similar thoughts. Furthermore, the affinity analysis provided a good starting point to identify the discourses on transdisciplinarity, validating the classification proposed.

The research indicated that most of the initiatives fitted in the problem-solving discourse, where co-production of knowledge and method-driven aspects are relevant. Deepening this discourse, most initiatives corresponded to the real-world argument promoting science-society collaboration to solve societal problems (EU contexts); others looked for convergence of all sciences (life, human, physical and engineering) in pursuit of human well-being (innovation argument, US contexts); and some initiatives brought together students and entities in a team-based learning process with social purpose (transcendent interdisciplinary research "tir" argument).

Besides, a few experiences represented the discourse of transcendence. This discourse is related to the need of a synthetic connotation for the production of knowledge within science, known as Mode 1 td (Gibbons et al., 1994). At the individual sphere, the discourse suggest the need of professionals with a transdisciplinary attitude, who "mediates to the result of making sense together" (Klein, 2004). It is noteworthy that none of the initiatives mirrored the transgression discourse, which attempts to reformulate the establishment, no longer for society but with society (Tejedor et al., 2018).

2.3 Action research workshop for transdisciplinary sustainability science

With the aim of piloting our findings, a transdisciplinary learning environment experience was designed and piloted: the course Action Research Workshop on Science and Technology for Sustainability (5 ETCS) of the UPC Master degree in Sustainability Science and Technology, where civil organisations, public administration, students and educators undertook collaborative research on real-life sustainability case studies, following two cycles of action-reflection. Case studies came both from external entities or NGOs and the UPC campus.

When looking at the discourses of td, we realized that while the course mainly fitted in the real-world argument of problem solving, educational strategies like service learning or Campus Lab schemes, which were used related to different case studies, should reproduced a team-based learning with societal purpose (transcendent interdisciplinary research argument). Moreover, some of the Campus Lab case studies aligned with the transdisciplinarity framed by purpose argument since universities as living labs can provide a potential holistic and iterative framework for the co-production of knowledge from the different university systems (Evans et al., 2015).

In order to integrate the discourse of transgression, which relies on an attitudinal attempt of criticism and reformulation of reality, a service learning scheme was used, focusing on social justice, which enhanced the development of complex thinking to achieve social transformation through education (Aramburuzabala, 2013), going beyond observing and analysing societal transformations, but rather taking an active role in initiating and catalysing change processes (Schneidewind et al., 2016). Some of the students continued their final master thesis in the fields, and even some of them engaged as employee-activists at the NGO they were working with. The workshop coordinators' role may fluctuate between facilitators and sometimes catalysts in a way, going beyond observing and analysing societal transformations.

Challenges of their learning process were problem formulation which proved to be one of the most arduous tasks, process uncertainty, stakeholder's interests and roles integration, and interpersonal skills. Students appreciated the td approaches and mixed research methods, the reflection stages with interesting work and discussion sessions, and the possibility to work in real-life projects with real stakeholders, despite regarding challenging both the integration of different interests and perspectives in the problem approach as well as the recognition of stakeholders' roles during the process. Additionally, a well-valued Emotional Intelligence module was developed by the author to help students face some process paralyzing uncertainties (Tejedor et al., 2019b)

3 Guidelines to implement a td approach

Transdisciplinarity was initially envisioned in the OCDE conference in 1970 as a set of axioms to be shared by the different disciplines, evolving to be considered that "transdisciplinary knowledge develops its own distinct theoretical structures" (Gibbons et al.,1994: 5). Td further adopted a popular pragmatic approach

at the 2000 Zurich conference, shifting from theory-science deliberations to wondering what it was for in practice (Russell et al. 2008; Klein, 2008). This shift emphasized the need for bringing internal reflexivity into any process of td knowledge production, as a drive, a claim and even "an attitude and a form of action" (Klein, 2004: 521). Anyway, regardless of the accuracy of defining td, a plurality of understandings of it have been started to be recognized, considered depending on specific thematic and socio-cultural contexts (Klein, 2014; Huutoniemi et al., 2010; Bunders et al., 2010). This plurality exploration interest is aligned with the core values and the transdisciplinary principle of "open encounter" (Pohl et al., 2010).

From the Zurich 2000 inflection point the common ground between the different currents of td are their emphasis on the integration of knowledge and the multidimensionality type of reasoning for the articulation of different realities, while differing in their specific characteristics of the role of science in society. Engagement with society is not central in the US American connotation of td (linked to health social system) but it is considered the receptor of innovation from the integration of theories, concepts and methods that "transgresses or transcends" disciplines (Stokols, 2006; Miller et al. 2008). The German and EU connotation (linked to socio-environment systems) instead emphasizes that the participation of social actors is pivotal (Muhar et al., 2013; Pohl et al. 2010; Scholz et al., 2006).

The former considerations reinforces the idea of td as an approach, not a theory or methodology (Scholz & Steiner, 2015; Jahn et al., 2012), even though it can be method-driven, specially within the problem-solving scope (Lang et al., 2012; Scholz et al., 2006; Steiner & Posch, 2006). Specifically, engineering and technology education enter familiar grounds in the discourse of real-world problem solving (more related to the EU-German connotation), characterized by a high level of methodological aspects. This shift emphasized the need for bringing internal reflexivity into any process of td knowledge production, being at the same time a drive, a claim and even "simultaneously an attitude and a form of action".

Along the research phases some relevant elements and factors to perform a td approach were identified. Taking into account the recognition of td as a drive or a claim for internal reflexivity in any td process (Klein, 2004), a set of fundamental features are proposed to be considered as guidelines allowing to methodically framing the science-society discourse about the issue at stake, which significantly may facilitate any educational initiative in EESD to undertake a transdisciplinary learning scheme (Table 1).

Table 1: Guidelines for Transdisciplinary learning in EESD.

Key features	**Description**
To work in complex problems originated in real-world contexts	The complexity of a real-world problem requires moving beyond scientific expertise, even within such an extended peer community setting or an agora of public deliberation. Any educational engineering experience has to facilitate setting the environment and society in the center, to make them the ultimate goal of technological implementation.
To involve cooperation between various	Different disciplinary perspectives must be included to reach a common ground. Transdisciplinary (td) forms of knowledge should complement, not substitute, disciplinary knowledge, connecting what has been disconnected by the ongoing specification and fragmentation of knowledge production in the disciplinary structure. This implies different disciplines working together without leaving

disciplines and fields	their theoretical and methodological disciplinary framework but adapting common problem formulation and solutions management to specific situation.
To involve cooperation between science and society	Cooperation between researchers and 'practitioners' has to be established both in the way of approaching problems and in the recognition of non-scientific knowledge as equally valuable, enabling conceptual and methodological shared frameworks. Some kind of contract or previous agreement should be defined to establish relationship guidelines. Transdisciplinarity is more than a research approach that is better suited to cope with the complex problems that scientific progress itself continuously creates. Rather, it indeed addresses the relation between science and society. It is interventionist in the sense that it methodically frames, structures, and organizes the societal discourse about the issue at stake.
To enable processes of mutual learning between science and society	The learning experience has to enable processes of exchange, joint generation and integration of existing or new knowledge. The idea behind it is to catalyze achievements by both stakeholders and students, on equal footing, i.e. accepting the otherness, co-leadership and the different interests, epistemics and roles. For this purpose, co-creation processes may facilitate the matching of contributions, interests and needs. One of the key prerequisites for initiating a successful td process is to negotiate and define a proper goal or guiding question; the process in itself of answering provides benefits to all participating stakeholder groups.
To integrate different types of knowledge	Integration has been largely emphasized as an essential cognitive challenge in the td process. Beyond building bridges between disparate disciplines, the need for communicating in an accessible way comes out. Integration, therefore, refers not only to what we know but to how we communicate. Knowledge integration and collaborative methods and tools may be experienced as pills or modules in a td-learning environment. The experience of this different way of knowledge creation surely transforms the perception of quality, competence and value of the different sources, including lay knowledge.
To rely both on disciplinary and cross-disciplinary practices	Transdisciplinary work is based on disciplinary practice as a rule. Yet, despite being distinct, they are complementary and can enrich each other and eventually reshape internal borders. Therefore, the learning experience should encompass disciplinary practice, as well as multi- interdisciplinary ways to approach technological problem solving. Not everyone has all the required experience, thus the working groups must be formed based on the areas of knowledge and expertise represented and the topics to be addressed.

4 Conclusions

Starting with the identification of transdisciplinarity as a relevant approach to sustainability in engineering education (EE), this research analysed EESD initiatives that used a transdisciplinarity approach to

overcome the one-dimension classical training in technological problem solving (Scholz et al., 2006), closer to "applicability" than to "comprehension", which often keeps engineers away from the source of the needs posed to them. In this sense, aligned with the lesson learned from the implementation of a transdisciplinary learning environment it is considered that when the formulation of life-world problems is independent of disciplinary perspectives, the inclusion of the societal context and experience in which they originated, enables providing more socially robust guidance.

Regarding the discourses on t analysis, EESD fits well in initiatives related to the discourse of problem solving, on the basis that a technological problem can include elements from all the different cross-disciplinary ways of approaching problems. The real-world argument, consisting on the co-production of knowledge to address societal problems, was seen mainly based on highly method-driven schemes, as can be action research, considered a precursor of transdisciplinarity. Parallelly, a team-based learning scheme with a societal purpose (transcendent interdisciplinary research argument) can be addressed by means of service learning or team-based CampusLab schemes. Finally, we proposed addressing the transgression discourse in the field of engineering by means of service learning focusing on social justice, which enhances engagement of the students as professional researchers-activists in the participant organisations.

The adoption and development of a td approach in the Action Research Workshop was perceived useful to enhancing the understanding and enabling the learning of sustainability, where students also realized the high significance of taking the research to the community and collaborating with stakeholders.

Finally, a set of of fundamental features was proposed to be considered as guidelines allowing to methodically framing the science-society discourse about the issue at stake, to facilitate any educational initiative in EESD to undertake a transdisciplinary learning scheme.

References

Aramburuzabala P (2013) Aprendizaje-Servicio: una herramienta para educar desde y para la justicia social. *Revista Internacional de Educación para la Justicia Social* **2**(2), 5–11

Bunders, Joske F.G., Jacqueline E.W. Broerse, Florian Keil, Christian Pohl, Roland W. Scholz, & Marjolein B.M. Zweekhorst. 2010. How Can Transdisciplinary Research Contribute to Knowledge Democracy? *Knowledge Democracy: Consequences for Science, Politics, and Media*, 1–397.

Ertas, Atila, Timothy Maxwell, Vicki P. Rainey, & Murat M. Tanik. 2003. Transformation of Higher Education: The Transdisciplinary Approach in Engineering *IEEE Transactions on Education* **46**, 289–95.

Evans, Tina Lynn. 2015. Transdisciplinary Collaborations for Sustainability Education: Institutional and Intragroup Challenges and Opportunities. *Policy Futures in Education* **13** (1), 70–96.

Gibbons, M., Limoges, C., Nowotny, H., Schwartzman, S., Scott, P., & Trow, M. (1994). *The new production of knowledge: The dynamics of science and research in contemporary societies*. Newbury Park, London: Sage.

Huutoniemi, Katri, Julie Thompson Klein, Henrik Bruun, and Janne Hukkinen. 2010. Analyzing Interdisciplinarity: Typology and Indicators. *Research Policy* **39** (1), 79–88.

Jahn, Thomas, Matthias Bergmann, and Florian Keil. 2012. Transdisciplinarity: Between Mainstreaming and Marginalization. *Ecological Economics* **79**, 1–10.

Jantsch, E., 1972. Interdisciplinary and transdisciplinary university. Systems approach to education and innovation. *Higher Education* **1** (1), 7-37.

Klein, T., Julie. 2004. Prospects for Transdisciplinarity. *Futures* **36** (4), 515–26.

Klein, T., Julie T. 2008. Evaluation of Interdisciplinary and Transdisciplinary Research: A Literature Review. *American Journal of Preventive Medicine* **35** (2 Suppl), 116-23.

Klein, T., Julie. 2014. Discourses of Transdisciplinarity: Looking Back to the Future. *Futures* **63**, 68–74.

Lang, Daniel J., Arnim Wiek, Matthias Bergmann, Michael Stauffacher, Pim Martens, Peter Moll, Mark Swilling, & Christopher J. Thomas. 2012. Transdisciplinary Research in Sustainability Science: Practice, Principles, and Challenges. S*ustainability Science* **7** (S1), 25–43.

Miller, T. R., T. D. Baird, C. M. Littlefield, G. Kofinas, F. Chapin, III, & C. L. Redman. 2008. Epistemological pluralism: reorganizing interdisciplinary research. *Ecology and Society* **13**(2), 46.

Muhar, Andreas, Jan Visser, & John van Breda. 2013. Experiences from Establishing Structured Inter- and Transdisciplinary Doctoral Programs in Sustainability: A Comparison of Two Cases in South Africa and Austria. *Journal of Cleaner Production* **61**, 122–29.

Pohl, Christian, Pasqualina Perrig-chiello, Beat Butz, Gertrude Hirsch Hadorn, Dominique Joye, Michael Nentwich et al. 2010. Questions to Evaluate Inter- and Transdisciplinary Research Proposals. *Network for Transdisciplinary Research (Td-Net) of the Swiss Academies of Arts and Sciences, Bern* **41** (0), 23.

Russell, A. Wendy, Fern Wickson, & Anna L. Carew. 2008. Transdisciplinarity: Context, Contradictions and Capacity. *Futures* **40** (5), 460–72.

Schneidewind, Uwe, Mandy Singer-Brodowski, Karoline Augenstein, & Franziska Stelzer. 2016. *Pledge for a Transformative Science*. 191_Wuppertal Paper, 29.

Scholz, Roland W., Daniel J. Lang, Arnim Wiek, Alexander I. Walter, & Michael Stauffacher. 2006. "Transdisciplinary Case Studies as a Means of Sustainability Learning: Historical Framework and Theory." I*nternational Journal of Sustainability in Higher Education* **7** (3), 226–51.

Scholz, Roland W., & Gerald Steiner. 2015b. The Real Type and Ideal Type of Transdisciplinary Processes: Part II—What Constraints and Obstacles Do We Meet in Practice? *Sustainability Science* **10** (4), 653–71.

Steiner, Gerald, & Alfred Posch. 2006. Higher Education for Sustainability by Means of Transdisciplinary Case Studies: An Innovative Approach for Solving Complex, Real-World Problems. *Journal of Cleaner Production* **14** (9–11), 877–90.

Stokols, Daniel. 2006. Toward a Science of Transdisciplinary Action Research. *American Journal of Community Psychology* **38**, 63–77.

Tejedor, G., M. Rosas-Casals, & J. Segalas. 2019. Patterns and Trends in Engineering Education in Sustainability. I*nternational Journal of Sustainability in Higher Education*, **20** (2), 360-377.

Tejedor, G., J. Segalas, & G. Cebrián. 2019b. Correction to: Action Research Workshop for Transdisciplinary *Sustainability Science* (*Sustainability Science*, (2018), **13** (2), 493–502).

Tejedor, G., J. Segalàs, & M. Rosas-Casals. 2018. Transdisciplinarity in Higher Education for Sustainability: How Discourses Are Approached in Engineering Education. *Journal of Cleaner Production* **175**, 29-37.