Exploring Transdisciplinary Education

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Abstract

Because wicked Sustainability Problems (WSPs) are complex, multi-scaled, value-laden, ill-structured, and difficult to address (for example see Lonngren et al., 2016), teams that include engineers and others with expert knowledge are needed to effectively manage WSPs relating to environmental stress and declining ecosystem health, including WSPs stemming from resource scarcity, biodiversity loss, and climate change. How do we educate engineers to successfully engage in such transdisciplinary teams? What is transdisciplinary education? This paper explores aspects of these questions.

First, we review areas of education literature relevant to transdisciplinary teaching and learning, including frameworks such as "Threshold Concepts" (Meyer & Land, 2006) and "Empathic Thinking" (Walther et al., 2017), and pedagogies reported in the literature, including "Value Analysis", and "Learning Communities" (McGregor, 2017). We introduce the design-based research methodology (DBR) as a framework for developing transdisciplinary education, and we offer a review of the engineering education literature relevant to transdisciplinary training.

Next, a case study employing DBR is presented. This case, inspired by the work of Tejedor & Segalas (2018a) and others, extends the work presented by Morgan et al. (2018), which reports a novel sustainable development workshop experience for masters-level graduate students, organized and hosted by the Universitat Politècnica de València (UPV) in the spring of 2017. A second workshop was deployed in June of 2018, during which students from a variety of backgrounds and institutions gathered in UPV to create locally relevant, sustainable, conceptual designs for the built environment. The DBR case study focuses on this 2nd workshop, during which survey, interview, and focus group data reflecting both the student and the facilitator experiences, were collected. An initial interpretation of this data is presented.

This paper contributes to engineering education for sustainable development because it emphasizes a meta-framework which conceptualizes the development of transdisciplinary education experiences and which has the potential to enable faculty to reflect on and improve novel transdisciplinary experiences.

1 Introduction

Complex sustainability problems in cities, including those relating to natural disasters, resource scarcities, affordability, equity, biodiversity loss, and climate change, are ill-structured, value-laden, multi-layered, and lacking in definitive solutions. These problems are notoriously hard to address. Yet, transdisciplinarity, which involves enacting 'disciplinary humility' (Byrne et al., 2017, p.14) to undertake a shared search for strategies and actions among stakeholders who recognize that knowledge takes many forms, offers an approach by which cities can successfully navigate sustainability challenges (Ramaswami et al., 2018).

These wicked sustainability problems (WSPs) are changing the nature of work for those engaged in creating the built environment. The authors of this paper recognize the gap between common teaching and learning practices within our fields (which focus on solving structured problems within disciplinary norms), and the demands of the transdisciplinary work environment of engineers and other built-environment professionals. As facilitators of a one-week international workshop, hosted by the Universitat Politècnica de València in June of 2018 and aimed at training students in sustainability, we view our workshop experiences as a case study of transdisciplinary education, and we explore transdisciplinary education from the perspective of engineering for sustainable development.

2 Literature

2.1 Transdisciplinary Education at Universities and Colleges

Since the 1970's, scholarly discourse within the field of transdisciplinary includes discussions relating to the nature of knowledge, research methodologies, and problem-solving methodologies (Klein, 2014). Papers focusing on education in support of student development of transdisciplinary skills appeared around 2000 (for example, see Welch et al., 1996; Ertas et al., 2003; Derry and Fischer, 2005) and, today, the study of transdisciplinary education is an active field.

In her review of transdisciplinary training in higher education (2017), McGregor suggests that transdisciplinary problem solving is

> *"… an educative process that affects professional development whereby, while engaged in transdisciplinary work, individuals are transformed from immature to mature co-participants..."*

For her, transdisciplinary education at universities exists at the nexus between professional development, learning, and knowledge creation within complex situations, and the highest quality education requires transdisciplinary learning experiences that integrate disciplinary knowledge within the larger societal context.

Transdisciplinary education involves the cultivation of transdisciplinary ways of thinking, including empathic thinking, the ability to recognize patterns, the synthesis of different knowledge types (Mishra, et al, 2011), and the ability to metacognate (Derry and Fischer, 2005). These are what McGregor labels "transdisciplinary habits of mind" (2017).

2.2 Transdisciplinarity in Built-Environment Education

Papers describing and investigating transdisciplinary education appear within built-environment disciplines (for example, see Riley et al., 2006; Byrne & Mullally, 2016; Bronwell, 2016; Oliveira and Marco, 2017;

Lonngren et al., 2016; Greenhalgh-Spencer et al., 2017; Payne and Jesiek, 2018). Tejedor and Segalas (2018a) report a ground-breaking "action research workshop for transdisciplinary sustainability science" offered at the Universitat Politècnica de Catalunya, as part of its Masters degree in Sustainability Science and Technology. During the one-semester workshop, students, who typically come with engineering or architecture backgrounds, work in teams on sustainability challenges identified by local stakeholders. Authors report workshop learning outcomes that can be summarized as the abilities to:

- understand various research paradigms, including positivism, interpretivism, critical theory, and pragmatism and are able to apply the appropriate paradigm in a given context.
- participate and contribute in transdisciplinary research.
- apply the action research methodology to complex sustainability problems and understand the interdependencies between, and influences of, local actions on larger scale social and ecological issues.
- practice reflection such that a deeper understanding of social dynamics resulting from the transdisciplinary approach to complex sustainability problems is enhanced.

Tejedor and Segalas also report that, during the workshop, students often face conflict and frustration when working with teammates and community members. To support student development in these situations, a module on emotional intelligence is introduced.

In a second paper, Tejedor et al. (2018b) offer a sophisticated analysis of the transdisciplinary education literature and describe three dominating discourses, namely "transcendence", "problem-solving", and "transgression", and have found that transdisciplinary engineering education experiences exist within the problem-solving discourse. Further, teaching and learning experiences within the problem-solving discourse tend to span disciplinary boundaries timidly, while simultaneously embracing extensive stakeholder participation in the problem-solving process.

2.3 Frameworks of Student Knowledge, Pedagogies, and Faculty Learning

Tembrevilla et al. (2019) propose a conceptual framework, presented in Figure 1, representing the array of knowledge constructed by individuals with transdisciplinary characteristics. Inspired by the work of Walther et al. (2017), this conceptual framework suggests that the potential of a student to work well in transdisciplinary teams depends on three knowledge dimensions, namely "beliefs and values" (i.e. one's professional way of being), "attitudes" (i.e. one's practice orientation), and a basket of "competencies" (skills) that, together, enable an individual to succeed in a transdisciplinary environment. The framework illustrated in Figure 1 demonstrates the interdependent and synergistic relationships between dimensions.

A second working framework, focusing on the *process* of knowledge construction, also supports the design of transdisciplinary education. Because transdisciplinary knowledge can be difficult to develop, and, once obtained, forever changes the learner's perspective, the threshold concept framework, developed by Meyers and Land (2006) may be appropriate. Threshold concepts are initially difficult to comprehend because they challenge the learner's world view, including the learner's sense of identity. As with entering a transformational portal, the learner experiences levels of engagement and knowledge characterized by dissipating un-ease and resulting in the learner's changed state. In the case study presented here, the threshold concepts framework is used to define levels of student development of transdisciplinary characteristics.

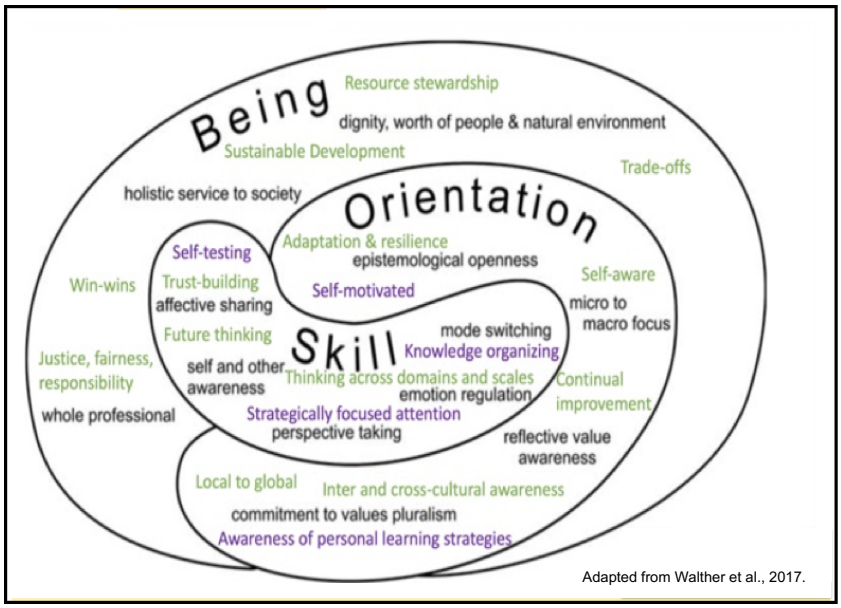

Figure 1: A conceptual framework illustrating selected values and beliefs, attitudes, and competencies associated with empathic thinking (black font), systems thinking (green font), and metacognition (purple font). Together, these attributes represent a proxy for all personal characteristics and abilities contributing to an individual's transdisciplinary characteristics (Tembrevilla et al., 2019).

McGregor (2017) offers a number of pedagogies which may enable students to think "beyond" disciplinary norms, and enabling them to work with those possessing different world views to discover a new understanding (p. 15). Such pedagogies include:

- *authentic curriculum*: where learning activities are "centred on issues that are topical and relevant to the students' lives and the troubles of the world";
- *value analysis*: where "students become aware of other people's values by analyzing others' viewpoints";
- *learning communities*: where groups of learners who "share membership, influence, need fulfilment, events, and connections" as they learn together; and
- *deep education*: which is "context-specific, participatory, holistic, integrative, eco- and learner-centered education….".

In addition to knowledge and learning frameworks, and transdisciplinary pedagogies, we suggest that a foundational component of transdisciplinary education development is design-based research (DBR) (The Design-Based Research Collective, 2003; O'Neill, 2012), a methodology aimed at continually learning about and improving the education experience. DBR is characterized by successive iterations of curricular designs. Similar to some forms of engineering practice, the essential idea of DBR is to use progressive, repeated, refinement of instructional design to drive discovery.

3 Transdisciplinary Education Development Meta-Framework

To support the design of effective and efficient transdisciplinary education, we employ a meta-framework for transdisciplinary education development. The meta-framework, illustrated in Figure 2, includes the material presented in section 2.3 above, namely the conceptual framework of student knowledge (i.e.

"Transdisciplinary Characteristics"), the framework of student development (i.e. "Staged Learning"), effective transdisciplinary pedagogies (i.e., "Transdisciplinary Education Pedagogies"), and an over-arching methodology by which educators continually improve the learning experiences of their students (i.e. "Design-Based Research Methodology").

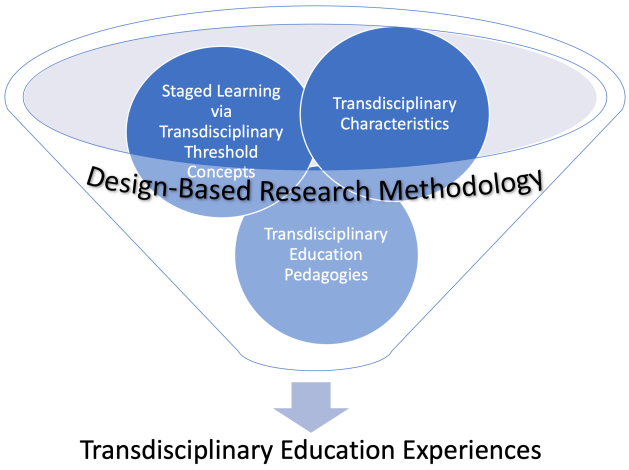

Figure 2. A meta-framework conceptualizing the development of transdisciplinary education experiences

4 Case Study

An annual week-long, intense, workshop aimed at enhancing the transdisciplinary abilities of approximately twenty students is explored in this paper. Engineering, planning, and architecture students from diverse programs offered in European and North America gather with local students (engineering and architecture) at the Universitat Politècnica de València (UPV), España, for the Interdisciplinary Sustainable Architecture (ISA) Lab workshop, during which interdisciplinary and cross-cultural student teams work on sustainability-focused built-environment projects proposed by the Valèncian community (i.e. local community organizations, businesses, and municipalities).

Three workshops have taken place. The first, offered in 2017, is reported by Morgan et al. (2018). The focus of this paper is the 2018 workshop. Experiences reported here informed the implementation of the third workshop, which took place in June 2019.

The learning outcomes or the ISA-Lab 2018 workshop are:

- Synthesize potential solutions to real-world sustainability problems for real clients, based on perspectives-taking and applying sustainability approaches
- Engage in self-assessment and self-reflection in articulating one's own values and understanding how they inform one's perspectives
- Demonstrate and develop capacity for active listening and to work successfully with team members from different disciplines

Learning activities include daily lectures, team project work facilitated by faculty and supported by community partners and local leaders, a city tour, social activities, and scoping field trips for some teams. The week culminates in a presentation and short report given to local stakeholders and project proponents. For a description of these workshop activities, see Morgan et al. (2018).

While this paper focuses on the development of knowledge pertaining to transdisciplinarity, systems thinking, empathic thinking, and metacognition, none of these topics were explicitly discussed during the 2018 workshop learning activities.

5 Workshop 2018 Data Collection and Interpretation

To evaluate student development of their transdisciplinary characteristics, survey and interview data were collected at the end of ISA-Lab 2018. The focus of data collection included assessing student levels of systems thinking, empathic thinking, and metacognition. Data collection and interpretation protocols developed by Nesbit et al. (2017), Tan et al. (2018), and Trembrevilla et al. (2019) were employed.

5.1 Research Question and Data Collection Protocol

The research question developed as part of the DBR methodology is: *Does a multi-day, project-based, sustainability design workshop involving masters-level students from different disciplines taught in different institutions, support the development of transdisciplinary skills?*

A mixed methods experimental protocol (Johnson & Onwuegbuzie, 2004) was employed. Post-workshop self-evaluation survey data from students, statements made during post-workshop student focus group discussions, and reflections on the focus group discussions, written by focus group facilitators, were collected. The qualitative data (facilitator reflections and student statements made during focus group discussion) were first "cleaned" by removing statements not relevant (i.e. not pertaining to the concepts of transdisciplinarity, systems thinking, empathic thinking, and metacognition), and then four authors coded 108 statements (i.e., cleaned data) by first identifying the most relevant concept for each statement and then labeling the statement as aligning with 1 of six levels of knowledge, with 6 being the highest level of knowledge. The average level for each concept was calculated.

5.2 Summary of Data Analysis

Table 1 presents a summary of the survey data, student focus group statement analysis, and the analysis of focus group facilitator written reflections.

Table 1: Summary of Data Analysis

Data Type	Average Level of Transdisciplinary Knowledge (out of 6 levels)	Average Level of Systems Thinking Knowledge (out of 6 levels)	Average Level of Empathic Thinking Knowledge (out of 6 levels)	Average Level of Metacognition (out of 6 levels)
Student Self-Evaluation Survey	***	Improvement as a result of workshop activities	Improvement as a result of workshop activities	Improvement as a result of workshop activities
Focus Group Discussion (FDG) Statements	4	***	***	***
Facilitator Written Reflections on the FDG	5	4.5	4.5	5

*** = no data available

Overall, the data suggests that, upon completion of the workshop, student knowledge of transdisciplinarity, systems thinking, empathic thinking, and metacognition was evident among the participants, even though these concepts were not explicitly discussed during the workshop. Further, as part of the survey, students were asked which learning activity they found most useful in helping them develop their knowledge of systems thinking, empathic thinking, and metacognition. While each activity was identified by at least one student, team discussions were mentioned more than other activities as influential in developing transdisciplinary characteristics, especially for developing empathic thinking.

6 Discussion

6.1 The Transdisciplinary Education Meta-Framework

The meta-framework (Figure 2) contextualizes the ISA-Lab workshop experiences and may inform the continual improvement of future workshops and other teaching and learning experiences. For example, a learning activity selected from the list of transdisciplinary pedagogies offered by McGregor (2017) may be employed to support student development of specific transdisciplinary skills. Workshop developers may determine student progression, while simultaneously learning to continually improve workshop experiences, by applying the threshold concept framework to measure student progress. But, this nascent meta-framework lacks detail and structure. Which pedagogies best support specific transdisciplinary skills? Are some transdisciplinary skills more transformative, and therefore more difficult to learn, than others?

6.2 Case Study

Results suggest an improvement of transdisciplinary skills and that small-group discussions may especially support this development. FGD facilitators' written reflections offer insights into possible indicators of this development. For example, perspective-taking by students during the focus group discussion, and the absence of a dominant disciplinary language during project team discussions, were identified. In one case, the facilitator noted a three-member team speaking in a "fourth language" – i.e. communicating with language accessible to all team members. Also, students appreciated being alerted by faculty to the inherent challenges of working on WSPs. Overall, faculty members observed that most teams produced a deliverable to their client that could not have been created by one discipline only. That is, the final deliverable was an emergent artifact of the team's transdisciplinary experience.

These observations raise further questions. For example, how do they align with threshold concept theory? Is perspective-taking and other observed behaviour, a manifestation of transdisciplinary skill development? If so, can learning activities be introduced to further support this behaviour?

7 Conclusions and Recommended Next Steps

This paper suggests a meta-framework for developing transdisciplinary education that includes a framework for conceptualizing both transdisciplinary characteristics and the development of these characteristics. Using the design-based research methodology (DBR), the paper describes a transdisciplinary education case study, involving a week-long, project-based, sustainability design workshop, in which Masters-level students, trained in different disciplines at different universities in different countries, work together with local Valencian communities to create a conceptual design that aligns with sustainability. Students self-report improvements in their systems thinking, empathic thinking,

and metacognition and, more than other learning activities, identify discussions with teammates as contributing to these improvements. Faculty observe significant levels of student knowledge relating to transdisciplinarity, including systems thinking, empathic thinking, and metacognition. In the spirit of DBR, it is recommended that subsequent workshop iterations emphasize transdisciplinary pedagogies and raise student awareness of transdisciplinary skills via explicit activities aimed at developing systems thinking, empathic thinking, metacognition, and transdisciplinarity.

References

Brownell, B. (2016) "Why Architecture School Needs Interdisciplinary Training", *Architect: The Journal of the American Institute of Architects*, March 24, 2016.

Byrne, E., Mullally, G. Sage, C. (2017) *Transdisciplinary Perspectives on Transitions to Sustainability*. Oxon: Routledge.

Byrne, E.P., & Mullally, G. (2016) "Seeing beyond silos: Transdisciplinary approaches to education as a means of addressing sustainability issues", Chpt 3 in *New Developments in Engineering Education for Sustainable Development.* (W. Leal Filho & S. Nesbit Eds.) Springer International.

Derry, S. & Fischer, G. (2005) "Toward a Model and Theory for Transdisciplinary Graduate Education", *American Education Research Association Annual Meeting*. Montreal Canada.

Greenhalgh-Spencer, H., Frias, K., Ertas, A. (2017) "Transdisciplinary Content Pedagogy in Undergraduate Engineering Education: Being Pulled Up Short", Chpt 6 in *Transdisciplinary Higher Education: A Theoretical Basis Revealed in Practice*. (P. Gibbs Ed.) Springer International.

Ertas, A., Maxwell, T., Rainy, V.P., Tanik, M.M. (2003) "Transformation of Higher Education: The Transdisciplinary Approach in Engineering" *IEEE Transactions on Education, 46*(2), 289-296.

Johnson, R.B., & Onwuegbuzie, A.J. (2004) "Mixed Methods Research: A Research Paradigm Whose Time Has Come", *Educational Researcher, 33*(7), 14-26.

Klein, J.T. (2014) "Discourses in transdisciplinarity: Looking Back to the Future" *Futures*, 63, 68-74.

Lonngren, J., Ingerman, A., Svanstrom, M. (2016) "Avoid, Control, Succumb, or Balance: Engineering Students' Approaches to a Wicked Sustainability Problem", *Research in Science Education*, July, 1-27.

McGregor, S. L. T. (2015) "Transdisciplinary Knowledge Creation", Chpt 1 in *Transdisciplinary Professional Learning and Practice* (P. Gibbs ed.), Springer, London.

McGregor, S. L. T. (2017) "Transdisciplinary Pedagogy in Higher Education: Transdisciplinary Learning, Learning Cycles, and Habits of Mind", Chpt 1 in *Transdisciplinary Higher Education: A Theoretical Basis Reveals in Practice* (P. Gibbs ed.), Springer, London.

Meyer, J.H.F., & Land, R. (2006) *Overcoming Barriers to Student Understanding: Threshold Concepts and Troublesome Knowledge*. Routledge, London DOI: 10.4324/978020396673

Mishra, P., Koehler, M., Henriksen, D. (2011) "The seven trans-disciplinary habits of mind: Extending the TPACK framework towards twenty-first century learning", *Educational Technology*, *51*(2), 22-28.

Morgan, D., Byrne, E., Nesbit, S., Ellis, N., Hemmes, K., Orozco-Messana, J. (2018) "Process, Improvisation, Holarchic Learning Loops, and all that Jazz: Experiences in Transdisciplinary Education for Sustainable Development", *Proceedings of the 9th Conference on Engineering Education for Sustainable Development*, Rowan University, June 3-6., 253-261.

Nesbit, S., Ellis, N., Ostafichuk, P. (2017) "Working with "Others": Developing Sustainability Skills in the First Year Engineering Classroom" *Proc. 2017 Canadian Engineering Education Association Conf.,* Toronto, Canada, June 4-7.

Oliveira, S. & Marco, E. (2017) "Preventing or inventing? Understanding the effects of non-prescriptive design briefs", *International Journal of Technology and Design Education, 27*(4), 549 – 561.

O'Neill, D. K. (2012) "Designs that fly: What the history of aeronautics tells us about the future of design-based research in education", *International Journal of Research & Method in Education*, *35*, 119-140.

Payne, L. & Jesiek, B. (2018) "Enhancing Transdisciplinary Learning through Community-Based Design Projects: Results from a Mixed Methods Study", *International Journal for Service Learning in Engineering, Humanitarian Engineering and Social Entrepreneurship, 13*(1), 1-52.

Ramaswami, A., Bettencourt, L., Clarens, A., Das, S., Fitzgerald, G., Irwin, E., Pataki, D., Pincetl, S., Seto, K., Waddell, P. (2018) "Sustainable Urban Systems: Articulating a Long-Term Convergence Research Agenda", *American National Science Foundation-Supported Report by the Advisory Committee for Environmental Research and Education*.

Riley, D., Thatcher, C., Workman, E. (2006) "Developing and applying green building technology in an indigenous community: an engaged approach to sustainability education", *International Journal of Sustainability in Higher Education, 7*(2), 142 – 157.

Tan, T., Nesbit, S., Ellis, N., Ostafichuk, P. (2018) "Crossing Boundaries: Developing Transdisciplinary Skills in Engineering Education", *Proc. 2018 Canadian Engineering Education Association Conf.*, Vancouver, Canada, June 3-6.

Tejedor, G. & Segalas, J. (2018a) "Action research workshop for transdisciplinary sustainability science", *Journal of Sustainability Science*, *13*, 493-502.

Tejedor, G., Segalas, J., Rosas, M. (2018b) "Transdisciplinarity in higher education for sustainability: how discourses are approached in engineering education", *Journal of Cleaner Production*, *175*, 29-37.

Tembrevilla, G., Nesbit, S., Ellis, N., Ostafichuk, P., (2019) "Enhancing the Transdisciplinary Potential of First Year Engineering Students", *Celebrating SoTL at UBC Conference*, University of British Columbia, October 23, 2019.

The Design-Based Research Collective. (2003) "Design-Based Research: An Emerging Paradigm for Educational Inquiry", *Educational Researcher*, *32*(1), 5-8.

Walther, J., Miller, S. E., Sochacka, N. W. (2017) “A Model of Empathy in Engineering as a Core Skill, Practice Orientation, and Professional Way of Being”, *Journal of Engineering Education*, *106*(1), 123–148.

Welch, M., Sheridan, S.M., Wilson, B., Colton, D., Mayhew, J.C. (1996) “Site-Based Transdisciplinary Educational Partnerships: Development, Implementation, and Outcomes of a Collaborative Professional Preparation Program”, *Journal of Educational & Psychological Consultation, 7*(3), 223-230.