Concepts of Transdisciplinary Engineering: A Transdisciplinary Landscape

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Abstract

The term 'transdisciplinary' is receiving increased attention within engineering academic and research funding communities. We survey authors of papers presented at the 27th ISTE International Transdisciplinary Engineering Conference (TE2020) to answer two research questions: 1) How do authors define transdisciplinary engineering? 2) What do authors perceive differentiates interdisciplinary engineering research from transdisciplinary engineering research? Responses from thirty-four participants (50%), are qualitatively analysed. Results show that for the three characteristics commonly used in characterisations of transdisciplinarity (goal, collaboration and integration), multiple concepts exist. These range from generic expressions which overlap with how interdisciplinarity is defined within the general literature, to stronger, more definitive expressions. Conclusions find that rather than a single definition a transdisciplinary landscape exists. To enable users to define where they sit in the transdisciplinary landscape, we create a framework enabling users to map their position under the three key characteristics of goal, collaboration and integration.

Keywords: transdisciplinary; transdisciplinary engineering; definitions; transdisciplinary engineering landscape

Introduction

The 1990s saw an increased environmental awareness and focus on issues of sustainability. To address this complex challenge required new ways of working. As a result, transdisciplinary (TD) research gained traction (Augsburg, 2014, Bernstein, 2015). More recently, new technologies and the advent of Industry 4.0 has seen the engineering domain become increasingly complex. As a means to tackle the challenges this presents TD research has gained increased attention within the engineering academic literature (Lattanzio et al., 2020a, Wognum et al., 2019).

Although there is an increasing reference to TD within the general literature the term remains without a universally accepted definition. Rather, a plurality of definitions persist both across and within fields (Lawrence, 2010, Pohl, 2011, Pohl and Hadorn, 2007, Swiss Academies of Arts and Sciences, 2018). Although it may be argued that having different definitions for disciplinary states is to be expected and accepted (Thompson Klein, 2013, Kockelmans, 1979, Pohl, 2010), a lack of common understanding of research concepts has been found to impede the progress of projects (Tress et al., 2004). To overcome this barrier there is a call for research concepts generally, and TD specifically, to be clearly defined (Stichler, 2018, Tress et al., 2004). The difficulty is that without understanding the range of TD concepts which are held, constructing a statement which clearly and precisely communicates how TD has been defined is challenging.

The purpose of this study was to understand how transdisciplinarity is conceptualised within the engineering community. Within our study authors of papers presented at the 27th ISTE International Transdisciplinary Engineering Conference (TE2020) were surveyed to capture their definitions of transdisciplinary engineering, and their perceptions of what differentiates transdisciplinary from interdisciplinary engineering research. Responses are qualitatively analysed against the three characteristics commonly used within characterisations of TD: goal, collaboration and integration.

The paper is structured as follows. First, background literature relating to TD, and TD within an engineering context is explored (Section 1). Second, the method used in collecting and analysing the data is described in detail (Section 2). The results are presented and discussed in the context of the wider literature (Section 3). Finally, conclusions are formulated (Section 4), and future work identified (Section 5).

1. Literature

The 1960s saw a growing rhetoric around the appropriateness of traditional single disciplinary teaching. In response there was increasing support for interdisciplinary (ID) research within both the academic community and research funding bodies (Carr et al., 2018, Huutoniemi et al., 2010, Klein and Falk-Krzesinski, 2017, Raasch et al., 2013). In the 1970s the work of Jantsch and others presented at an education conference in France (CERI, 1972) added to the disciplinary discourse by conceptualising transdisciplinarity (TD) as a level of working which exceeds ID.

Within his original work Jantsch asserted that for education/innovation to have societal value it needed to incorporate a range of dimensions including the social, economic, political, technological, psychological and anthropological. Applying a systems approach his thinking culminated in the creation of a multi-level, multi-goal education and innovation system (Figure 1).

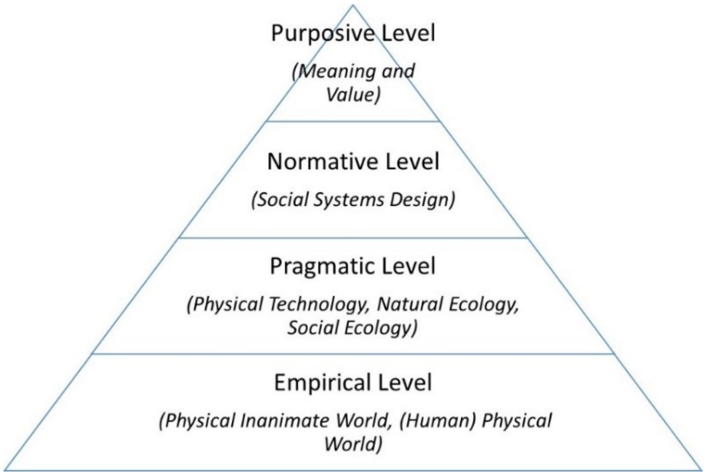

Figure 1. The education/innovation system, viewed as a multi-level multi-goal, hierarchical system. Adapted from CERI (1972).

The model identifies four key levels of working: purposive, normative, pragmatic and empirical. Applying this model ID is characterised as coordinated effort across two levels. On the other hand TD working requires the coordination across all four levels, generalised axiomatics (from the purposive level down), and emerging epistemological patterns (Jantsch, 1970).

Although generally accepted that the origins of TD are in the 1970s, the term was practical uncited until in the 1990s (Bernstein, 2015, Kessel and Rosenfield, 2008) (Figure 2).

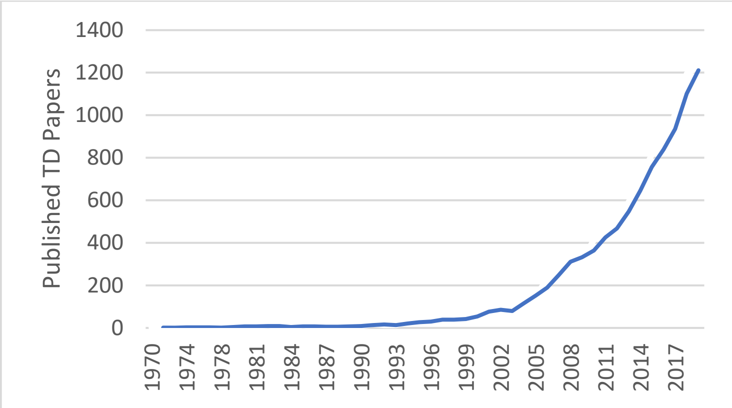

Figure 2. Moving average of papers appearing on Scopus with the term "transdisciplin" or "trans-disciplin*" within the Title, Abstract, or Keywords. Extracted 7/8/2020*

In the 1990s globalisation and increased environmental awareness brought with it a demand for new ways of working capable of addressing complex issues. TD re-emerges, but with two discourses: unity of knowledge – a theoretical ideology of going beyond the disciplines to incorporate ethical, metaphysical and mystical perspectives (Kockelmans, 1979, Nicolescu, 2002), and problem solving – a more practical approach with a focus on real-world problems and co-production of knowledge with stakeholders (Bernstein, 2015, Augsburg, 2014, Pohl et al., 2021).

Although Figure 2 shows there to be a demonstratable rise in the use of the term, the question remains: What is transdisciplinarity and how is it different from interdisciplinary approaches?

Transdisciplinarity

Although it is generally acknowledged that transdisciplinarity (TD) comes at the end of a list which includes multi- (MD) and interdisciplinarity (ID), the characteristics which make research transdisciplinary rather than another level of disciplinarity are debated (Lawrence, 2010, Pohl, 2010, Pohl and Hadorn, 2007, Swiss Academies of Arts and Sciences, 2018). Although, over the years, authors and institutions have attempted to provide guidance (Bruce et al., 2004, Bruun et al., 2005, CERI, 1972, Huutoniemi et al., 2010, Kockelmans, 1979, National Research Council, 2014, Ramadier, 2004, Tress et al., 2004), TD remains without universal consensus.

Tress et al. (2004) found that a lack of common terminology was one of the main obstacles to disciplinary integration (Tress et al., 2004). To improve communication and information exchange they seek to characterise the different disciplinary concepts. They propose that the main differences between disciplinarities centres on the level of integration and participation (Figure 3).

	Low Integration	*High Integration*
Academic and non-academic participants	Participatory (may not be research)	Transdisciplinary
Academic participants	Multidisciplinary	Interdisciplinary

Figure 3. Disciplinarities by level of integration and stakeholder involvement according to Tress et al. (2004)

Within this model integration is the extent to which unrelated disciplines are brought together to create new knowledge and theory. Figure 3 shows multidisciplinary research to have low integration between disciplines, but both ID and TD to have high levels of integration. Where ID and TD differ is on participation. ID has a requirement for academic participants in research projects, whilst TD requires the involvement of both academic and non-academic participants. Thus, the differentiating factor between ID and TD is the involvement of non-academic participants. Despite offering these definitions Tress concludes that whether they are accepted is not important. What is important is that effective communication and evaluation of research is possible. As such, care and precision should be taken when using research concepts in projects and papers.

Wickson et al. (2006) sought to improve disciplinary understanding by analysing definitions found in the academic literature. Their findings identify three recurrent characteristics of TD research: problem focused, collaboration, and evolving methodology.

Problem Focused: Wickson et al. (2006) findings show broad acceptance that TD has an explicit intent to solve a 'real-world' problem. They describe this as 'consequential', which reflects Jantsch's description of 'purposive' research (Jantsch, 1970). If having an explicit focus on solving a societal problem was exclusive to TD, then it would provide a useful feature to differentiate between disciplines However, Wickson et al. (2006) recognised that although some authors agreed that MD is not problem focused (Balsiger, 2004, Gibbons et al., 1994) there is not universal consensus to this (Hammer and Söderqvist, 2001). Additionally, research perceived as ID has been presented as both knowledge focused, and problem focused (Balsiger, 2004, Hammer and Söderqvist, 2001, Huutoniemi et al., 2010).

Collaboration: Similar to Tress et al. (2004), Wickson et al. (2006) found support that TD should involve collaboration between academics and external stakeholders e.g. industry, customer, general public. However, it is also recognised that the extent of participation can vary. Whilst some authors propose that the experiences of those affected by the research should be considered, others extend this further for example requiring their involvement in defining the project criteria, objectives and resources (Mauser et al., 2013, Thompson Klein, 2004, Balsiger, 2004, Gibbons et al., 1994, Pohl, 2010, Tress et al., 2004). The classification of academic and non-academic collaboration is addressed in the work of Mobjörk (2010). They propose that there are two levels of TD collaboration: consulting and participatory. In consulting TD academics consider the thoughts and perspectives of stakeholders. Whereas in participatory collaborations stakeholders are fully included in the knowledge production process.

Evolving Methodology: The third of the characteristics identified by Wickson is methodological interpenetration (Wickson et al., 2006). That is, there should be a dissolution of disciplinary boundaries and the creation of new or unique methodologies which reflect the context. This is in contrast to MD research whereby there is loose cooperation but disciplinary methods are retained (Horlick-Jones and Sime, 2004, Ramadier, 2004), and ID which involves the creation of a common framework within which epistemological approaches are shared and mixed (Gibbons et al., 1994, Hammer and Söderqvist, 2001, Lawrence, 2004, Ramadier, 2004).

The work of Pohl et al. (Pohl, 2010, Pohl and Hadorn, 2007), proposed by the Swiss Academies of Arts and Sciences td-net, bears many similarities to that of Wickson et al. (2006). Again, Pohl's papers seek to understand TD through of analysis of definitions taken from the general literature. Analysis of twenty definitions, from the leading authors in the field, across three decades, groups similar characteristics: relating to socially relevant problems; transcending and integrating disciplinary paradigms; participatory research; and search for unity of knowledge. Where the studies diverge is that Pohl creates clusters of these characteristics and proposed that three alternative conceptualisations of TD are being employed (Table 1).

Table 1. Concepts of transdisciplinarity (Pohl and Hadorn, 2007)

Characteristic	**Concept A**	**Concept B**	**Concept C**
Relating to socially relevant issues	✓	✓	✓
Transcending and integrating disciplinary paradigms	✓	✓	✓
Participatory research		✓	
Search for unity of knowledge			✓
Examples of theorists representing this concept	(Jantsch, 1970, Rosenfield, 1992)	(Lawrence, 2004, Mobjörk, 2010)	(Nicolescu, 2002, Ramadier, 2004)

The literature shows that across the general set of academic disciplines there are different interpretations of TD. We now ask, 'do those working within the engineering field have a common understanding of the term'?

Transdisciplinary within an Engineering Context

The changing nature of engineering brought about through new technology and industry 4.0 mean that it is becoming increasing complex (Wognum et al., 2018). Although not considered mainstream, funding agencies are supporting and encouraging transdisciplinary engineering research (National Science Foundation, 2016, The University of Bath, 2018, UKRI, 2019). The number of academic papers referencing TD has also been increasing (Figure 4).

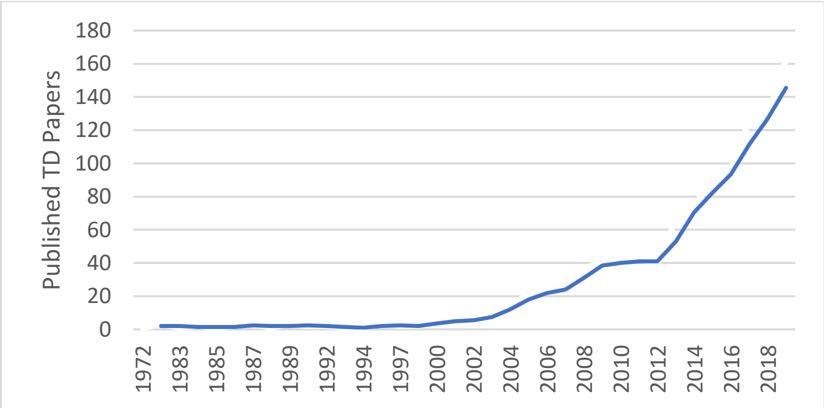

Figure 4. Moving average of papers appearing on Scopus with the term "transdisciplin" or "trans-disciplin*" within the Title, Abstract, or Keywords and with an engineering subject field. Extracted 28/8/2020*

As with the general TD literature, although there are increasing numbers of engineering journal papers referencing transdisciplinarity there appears to be a lack of consensus on the definition. Indeed, the question of what is transdisciplinary engineering was the unresolved focus of a panel discussion at the 2019 ISTE International Transdisciplinary Engineering Conference (The University of Tokyo, 2019).

Research conducted by Lattanzio et al. (2020b) provides further support for this hypothesis. Within their study engineering papers which reference TD were assessed to see whether they met the definition of TD as defined in the original work of Jantsch (1970). The results found only 24% to be TD. The majority (64%), were categorised as ID. The coding discrepancies were unknown, and Lattanzio et al. (2020b) propose two potential explanations. First, there may be a desire for work to be presented as TD in order to appear novel in publications, or to align with a funding call. Second, although not meeting the definition of Jantsch the work may meet an alternative definition. Although suggesting that alternative definitions of TD may exist the study does not look to capture how TD is being conceptualised.

Irrespective of the reason, inconsistency in defining the term is problematic for academia and beyond. First, disciplinary 'language' must proceed the creation of techniques and methods which make the approach useful. Without this understanding the discipline cannot evolve (Shneider, 2009). Second, without the ability to determine what is and what is not TD, tracking outcomes and making evidenced based decisions over why a transdisciplinary approach should be selected over another type of disciplinarity is impossible (Tress et al., 2004).

In summary, the literature shows that there is a plurality of definitions for TD. Although across disciplines different definitions are expected and accepted, when they exist within a group, they create a barrier to integration. Although, over the decades academic efforts have explored definitions and concepts of TD generally, studies which look to understand how TD is conceptualised within engineering are lacking. The research presented in this paper addresses that gap.

2. Method

This work aims to examine how transdisciplinarity is currently defined within the field of engineering and what differentiates it from interdisciplinary research. Details follow, but in summary the work targets authors who presented papers at the 27th International ISTE Transdisciplinary Engineering Conference (TE2020). Two questions were asked:

RQ1. How do you define transdisciplinary engineering?

RQ2. In your view what distinguishes interdisciplinary engineering research from transdisciplinary engineering research?

Comparison of the work by Tress, Wickson, and Pohl shows the TD characteristics they identify as aligning around three themes: goal, collaboration and integration (Table 2). Accordingly, the textual responses were qualitatively analysed against these three characteristics.

Table 2. Characteristics used to define transdisciplinarity

Characteristic	**Tress et al. (2004)**	**Wickson et al. (2006)**	**(Pohl, 2010, Pohl and Hadorn, 2007)**
Goal		Explicit intent to solve a 'real-world' problem.	Relating to socially relevant issues.
Collaboration	Involvement of both academic and non-academic participants	Involvement of both academic and non-academic participants. Extend of participation by participants.	Participatory research.
Integration	High level of integration required.	Dissolution of disciplinary boundaries and the creation of new or unique methodologies which reflect the context.	Transcending and integrating disciplinary paradigms.

Sample

The literature shows that previous studies which have explored concepts of TD are generally based on analysis of definitions found in the literature. Within this work this approach was not considered appropriate. First, although increasing in number, journal publications referencing TD within engineering are low in real terms and obtaining a large enough sample to undertake meaningful analysis would necessitate the inclusion of papers published over several years. A longitudinal study is inappropriate as the meaning of transdisciplinarity has been evolving (Pohl, 2010, Thompson Klein, 2013, Mobjörk, 2010). Longitudinal analysis would produce findings which do not capture the current understanding of TD, but rather the different perceptions of authors at the time their research was conducted. Second, the term TD may have been used in general papers, but there is no guarantee that TD research has been conducted. The term could have been used without full consideration or understanding. To overcome these challenges, the survey included only those authors presenting their research at the International Society of Transdisciplinary Engineering (ISTE), annual conference (TE2020). The sampling approach provided an overview of the current perspective of the meaning of TD and, as papers were peer reviewed, assurance that the publications fell within the scope of the transdisciplinary conference.

The International Society of Transdisciplinary Engineering (ISTE)

The International Society for Productivity Enhancement (ISPE), founded in 1984, aimed at enhanced productivity and competitiveness of product and service providers through the transfer and integration of new knowledge with new and existing technology. In 2017 the ISPE changed its name becoming the International Society of Transdisciplinary Engineering (ISTE). The mission of ISTE extended the mainly technological focus of the ISPE. The ISTE assert that although engineering innovation can be beneficial, it can also have significant adverse effects and that engineering products should be needed and wanted, whilst causing minimal environmental and societal damage. This requires an understanding of users and context achieved through the integration of natural and social sciences, inputs from user and practitioner communities, and the use of mix methodologies. The ISTE aims to create an awareness that engineering practices need to evolve into transdisciplinary engineering practices and spreads its message through numerous channels including a website, newsletters, special issues publications, and International conferences.

The 27th International ISTE Transdisciplinary Engineering Conference (TE2020)

The Transdisciplinary Engineering Conference (TE2020) was held as a virtual Webex conference and hosted by the Warsaw University of Technology (Poland) on the behalf of the ISTE. The approach of holding a virtual conference was in response to the Coronavirus pandemic which placed restrictions on travel. The theme of the conference in 2020 was Transdisciplinary Engineering for Complex Sociotechnical Systems in the Context of Real-life Applications. Papers submitted to the conference were subjected to peer review by one member of the ISTE Council at the abstract stage, with a further review of the full paper by two academics who were assigned by the conference committee. Consequently, the assumption made was that accepted papers fall within the scope of the transdisciplinary engineering conference and they are transdisciplinary.

The format of the conference was that accepted papers were uploaded to Webex with an accompanying ten-minute video. During the month of July 2020, attendees of the conference were able to access the papers and ask questions of the authors.

Approach

The two research questions were posted against each of the papers on the TE2020 Webex conference site and the written responses qualitatively analysed. To ensure that the analysis was conducted in a determined and rigorous manner the six stage process defined within the work of Braun and Clarke (2006) was followed (Table 3) and NVivo computer-based software utilised (Hoover and Koerber, 2011).

Table 3. Phases of thematic analysis (Braun and Clarke, 2006)

	Stages	Description
1	Familiarising yourself with the data	Reading and rereading the data and noting down initial ideas
2	Generating initial codes	Coding interesting features in a systematic fashion across the entire dataset, collating the data relevant to each code
3	Searching for themes	Collating codes into potential theme, gathering all data relevant to each potential theme.
4	Reviewing themes	Checking if the themes work in relation to the coded extracts and the entire dataset.
5	Defining and naming themes	Ongoing analysis to refine the specifics of each theme, and the overall story the analysis tells, generating clear definitions and names for each theme.
6	Producing the report	The final opportunity for analysis. Select vivid, compelling extract examples, final analysis of selected extracts, relating back of analysis to research question and literature, produce a scholarly report of the analysis.

3. Results and Discussion

As of the 2nd July 2020, 72 papers appeared on the TE2020 conference site. Of these, ten were excluded as they were either publications by the first author of this paper, or duplicate papers by the same first or corresponding author. The remaining sample comprised 62 papers.

In total 35 responses, from 34 discrete authors (one author responded twice*) were received against 31 papers (50%). The discrepancy arises because on four of the papers more than one author responded. In total 34 responses were analysed. *To avoid one author's 'voice' having more weight than another the duplicate response from the same author was combined into a single response. Table 4 presents a breakdown of the responses by country.

Table 4. Participation by Country of Affiliation

Country of Affiliation	Responses	%
Australia	3	9%
Brazil	9	26%
China	1	3%
Denmark	2	6%
Germany	2	6%
Italy	1	3%
Japan	1	3%
Netherlands	1	3%
Poland	3	9%
Singapore	1	3%
Slovenia	1	3%
Sweden	3	9%

Taiwan	1	3%
UK	5	15%
Total	34	

Table 4 shows that authors with affiliations based in 14 countries participated in the survey. Of these, the highest participation was from Brazil (26%). This was not unexpected as Brazil had the highest number of papers (17), representing almost a quarter of all accepted papers.

RQ1. How do you define transdisciplinary engineering?

The responses indicate that some participants found research question 1 difficult '*I would like to state it is hard to provide a unique answer and definition*' (Participant 33), '*it is a complex concept*' (Participant 17). This difficulty may reflect that, as evident in the literature, there are a plurality of definitions and '*researchers are in fact adhering to a multitude of definitions*' (Participant 6), or as identified by the literature (Huutoniemi et al., 2010, Pohl, 2010, Pohl and Hadorn, 2007), it is possible for a single author to hold different conceptualisations of the term. Comments made by Participant 28 supports this explanation '*I define TE [transdisciplinary engineering] in a couple of ways*'.

Although, the multitude of transdisciplinarity definitions provides one explanation for the challenge of definition, difficulty may also have arisen because authors have not fully engaged with the academic literature and, as proposed in the work of Lattanzio et al. (2020a), may be using the term without having fully considered its meaning. There is limited support for this within the responses '*During the research project we did not really ask ourselves do we have interdisciplinary engineering or transdisciplinary engineering research…Till recently I have treated the upper terms as synonyms [sic]*' (Participant 19). Of the 34 responses only one (Participant 2), made reference to a specific paper (Wognum et al., 2019), with another three making nonspecific reference to previous works of Jantsch (Participants 5 & 28), and Lattanzio and Newnes (Participant 33). Although limited references would indicate limited engagement, it is acknowledged that the question asked the participants for their definitions and did not specifically ask them to reference any previous literature which had influenced their view.

Goal

Within the literature there is broad consensus that transdisciplinary research has an explicit intent of solving a real-world problem. Within the responses there was wide support for this characteristic: '*It aims to solve a issue from the world [sic]*' (Participant 23), '*address* *society-relevant problems*' (Participant 7), '*solve complicated problems that involve various topics in our lives*' (Participant 15). Others expand this view seeking not only to address a problem, but specifically acknowledging the quest for societal benefit: '*aimed at solving a problem for which the solution has societal impact*' (Participant 34), '*to make the life of humans easier*' (Participant 23), '*continuous search of improvement that ultimately generates a better world for our children*' (Participant 18).

These comments point to an interesting division identified within the work of Newnes et al. (2020) and Lattanzio et al. (2020a). Whereas traditionally TD has been associated with sustainability and impact which is to the 'common good', within engineering the approach has been used to address operational as well as 'grand challenges'. Therefore, when considering impact, there is a distinction to be made between TD which seeks to benefit a subset of society, and TD which seeks to benefit society as a whole.

Collaboration

Wickson et al. (2006) found that in defining TD there was much support for the need for collaboration between academics and non-academics. First, the question of the need for and type of different academic disciplines that should be involved in collaboration arose. In responding some comments were ambiguous, making no explicit reference to specific disciplines '*includes input from a wide variety of disciplines*' (Participant 1), '*a range of disciplines*' (Participant 5), '*all necessary disciplines*' (Participant 9), '*several disciplines*' (Participant 13), '*two or more disciplines*' (Participant 17).

Although several of the responses did not reference specific disciplines, some were more prescriptive '*all engineering disciplines*' (Participant 9), '*engineering sciences as well as social sciences*' (Participant 7), '*incorporates social sciences*' (Participant 11), '*in collaboration with social sciences*' (Participant 14). Though identified as a theme within the analysis, the inclusion of social sciences disciplines is not a significant feature in the work of Wickson et al. (2006) or Pohl and Hadorn (2007). The focus is on whether there is academic and non-academic involvement, rather than seeking to define the disciplines which must be present.

Across the general TD literature, the inclusion of social science disciplines is discussed at length. Indeed, the work of Carey et al. (2020) identifies social sciences as a theme which appears within the abstracts of TD papers. That this does not emerge as a characteristic within the previous studies is intriguing and raises a number of questions, for example: (1)

Was the inclusion of social sciences not explicit in the definitions analysed? (2) Was the inclusion of social sciences within the definitions but not drawn out as a characteristic? (3) or have definitions of TD evolved to be more explicit around the inclusion of social sciences and if so, why has that occurred?

Whilst the analysis showed broad consensus for the need for different disciplines to collaborate, and to a lesser extend for inclusion of social science disciplines, only limited reference to non-academic stakeholder collaboration was made '*transcends scientific disciplines, professional disciplines as well as organisational boundaries*' (Participant 4), '*bringing together a range of disciplines and stakeholders from outside of academia…with involvement from policy makers, industrialists and the stakeholders or end users themselves*' (Participant 5). Regarding the depth of these collaborations, although comments by Participant 6 suggest that non-academics would play a participatory role "*[In TD] it would be necessary to have a societally focussed aim for such an engineering project and this may be defined by industries, policy makers and stakeholder engagement*" comments are more suggestive of consultative collaboration and the use of social science methodology and '*case studies, surveys and action research to gather information*' (Participant 11).

The lack of acknowledgement of non-stakeholder involvement is perhaps contrary to the general literature. One possible explanation is that the requirement for collaboration between academics and non-academics is a concept which has been widely promoted within European research (Pohl, 2010). The participants within this study are a split between European (53%), and non-European (47%) countries.

With regard to the level of non-academic involvement (consulting rather than participatory) this may reflect the wording of the ISTE definition which talks about acquiring knowledge from stakeholders '*Research incorporates then also social science methodologies to acquire the necessary knowledge about users and context*', but collaboration as being between disciplines '*Most importantly, collaboration between different disciplines is needed to realise this approach*' (ISTE, 2017).

Integration

Within the literature MD research is often characterised as being unintegrated, retaining its disciplinary autonomy (Ramadier, 2004). ID research requires a shared problem formation and common methodological framework (Gibbons et al., 1994, Lawrence, 2004, Wickson et al., 2006). In contrast TD has been characterised by an interpenetration, or fusion of methodologies (Lawrence, 2004) with some extending this to include a requirement for an evolving methodology which develops over the course of the project (Jantsch, 1970, Wickson et al., 2006).

The survey responses show broad agreement that within transdisciplinary engineering the disciplines come together in some way. Comments ranged from general expressions of cooperation and coordination '*cooperation of several different disciplines…combining two or more disciplines with one activity*' (Participant 31), '*cross-cutting knowledge between subjects aligned in a systematic and organized way*' (Participant 10), to stronger definitive calls for methodological fusion or transcendence. For example, '*[transdisciplinary engineering] aims on the maximum integration of these different disciplines*' (Participant 13), '*tearing down barriers between knowledge areas*' (Participant 8), '*the integration of multiple disciplines (not just cooperating side by side)*' (Participant 7) and '*That gathering must throughout the boundaries of each discipline, becoming a single approach that enables us to know a new vision of the nature, reality and the problems*' (Participant 23).

In summary the responses to question 1 highlight that there is currently no universally accepted definition of TD, nor seminal paper behind which the community has coalesced. Analysis shows that within the three characteristics (goals, collaboration and integration), different concepts persist which range from 'weak' general expressions to 'strong' definitive expressions. For example, there is broad agreement that transdisciplinary engineering research should address a real-world goal. Some comments suggest that addressing a real-world goal is sufficient, whilst others make a more definitive statement that TD projects must address a real-world goal and create societal impact. Table 5 summarises the concepts identified under each of the three characteristics.

Table 5. Themes and concepts of Transdisciplinary Engineering

Characteristic	Level of Support	Concept A	Concept B	Concept C	Concept D
Goal	Wide	Addresses a real-world goal	Addresses a real-world goal and creates societal impact for a sub-set of society	Addresses a real-world goal and creates societal impact which is for the common good	
Collaboration (between disciplines)	Wide	More than one discipline	Engineering plus another discipline(s)	More than one discipline; to include social sciences	More than one discipline; to include engineering and social sciences
Collaboration (between academics and non-academics)	Limited	Consultative collaboration academics and practitioners	Consultative collaboration between academics and stakeholders (industry, government, end users etc)	Participatory collaboration academics and practitioners	Participatory collaboration between academics and stakeholders (industry, government, end users etc)

Integration	Wide	Cooperation and coordination	Fusion and / or transcending		

Table 5 highlights that according to the general literature, some concepts found under the TD themes would better be described as ID. For example, under the integration theme previous authors have considered cooperation and coordination to be ID. To be considered TD there would need to be fusion and / or transcending of methodologies. This raises the question: what is the feature(s) which differentiate interdisciplinary engineering from transdisciplinary engineering research?

RQ2. In your view what distinguishes interdisciplinary engineering research from transdisciplinary engineering research?

The comments suggest that the academic community perceive interdisciplinary engineering and transdisciplinary engineering research to be closely related 'We feel that the two terms are very similar' (Participant 2), '*While other disciplinaries are quite distinct from transdisciplinarity, interdisciplinarity and transdisciplinarity seem to have a lot of overlap*' (Participant 5), '*it is far easier for researchers to clearly define the difference between MD and TD work that TD and ID work*' (Participant 6). This finding aligns with the conclusions of a recent study by Carey et al. (2020). Based on a text analysis of the abstracts and keywords of 8834 papers they suggest that trans- and interdisciplinary research are more closely aligned than trans- and multidisciplinary.

Although difficult for some, 31 (91%) of participants did provide a response to this question. Table 6 presents an analysis. Within the table the "✓" indicates how responses have been attributed to the three characteristics (goal, collaboration and integration).

Table 6. Differentiators of interdisciplinary and transdisciplinary engineering analysed against three characteristics (goal, collaboration, integration)

Participant	Goal	Collaboration	Integration
1			✓
2			✓
3		No response	
4		No response	
5		✓	✓
6	✓	✓	✓
7	✓	✓	
8			✓
9			✓
10			✓
11		✓	✓
12		✓	✓
13			✓
14		✓	
15			✓
16			✓

Participant	Goal	Collaboration	Integration
18			✓
19		No response	
20			✓
21			✓
22*			
23			✓
24			✓
25			✓
26			✓
27			✓
28			✓
29		✓	
30			✓
31			✓
32	✓		✓
33			✓

17			✓	34		✓	

*Excluded as response was unclear

Goal

Support for the goal being the sole feature that differentiates transdisciplinary from interdisciplinary engineering was limited. Although there were participants who acknowledged that TD research should have a real-world goal, this was one feature within a longer list. For example, Participant 7 highlights a need for a purposive goal, plus collaboration between different disciplines and non-academics '*My understanding is that it [the difference between TD and ID] is the attention to the wider society-relevant problems with their ill-structured nature and with multiple stakeholders from both academia and practice*'. On the other hand, Participant 32 states that there should be a purposive goal, plus integration '*integration goes beyond and two or more disciplines transcend their perspectives to form a new holistic approach…often focuses on critical and real-world problems [sic]*'.

Collaboration

Although collaboration receives more support, in contrast to much of the literature it is not universally acknowledged as a differentiator. One possible reason is that within the general literature it is accepted that ID research will involve several disciplines. The inclusion of non-academic participants increases its state from ID to TD. However, the responses to question 1 highlight that concepts of collaboration within transdisciplinary engineering tend to focus on disciplinary collaboration. Only limited reference is made to academic and non-academic collaboration.

Although, collaboration receives only limited support question 1 identifies that the inclusion of social science is a feature of TD. As such, might this stand as a potential differentiator? There are comments to support this hypothesis '*Interdisciplinary processes could be limited to only different technical disciplines. Transdisciplinary processes explicitly incorporate people not only from technical disciplines but also from social-science disciplines*' (Participant 34), '*Design and development should be done by people having a foot print in both social science disciplines and technical disciplines*' (Participant 11), '*Transdisciplinary engineering research seeks to solve problems with the help of social sciences. In contrast, interdisciplinary engineering research seeks to solve problems using more than one discipline. And this problem will not necessarily involve social sciences*' (Participant 14). Although appearing promising, it is recognised that not all TD conceptualisations acknowledge a specific requirement to include social sciences. As such its usefulness as a differentiator is dependent on the concept of TD which is held.

Integration

Of the three characteristics the results show that the broadest support was for integration as a differentiator between interdisciplinary and transdisciplinary research. TD integration is proposed to exceed that of ID '*The main differences: how deep is this knowledge modeling and how much modeling across disciplines' borders is done and present'* (Participant 26), '*Interdisciplinary research also focuses on the integration of disciplines… transdisciplinary research aims to give a next step'* (Participant 13). Analysis of how TD might exceed ID identified three key themes: systems perspective; weighting of disciplines; transcending of disciplines and disciplinary knowledge.

Systems perspective: The original work of Jantsch (1970) takes a system approach in its conceptualisation of TD. It asserts that for something to be considered TD, there must be coordinated effort across four defined systems boundaries (purposive, normative, pragmatic and empirical). Within the responses the requirement for a systems approach within TD is seen '*The differentiation between interdisciplinary engineering and transdisciplinary engineering lies in the innovation of all cells in the discipline and begins to consider each discipline as part of a larger subject'* (Participant 25), '*The differentiation between interdisciplinary engineering and transdisciplinary engineering lies in the breakthrough of every discipline cell and start to look at every discipline as part of a bigger matter'* (Participant 18), '*In transdisciplinary engineering, the integration goes beyond and two or more disciplines transcend their perspectives to form a new holistic approach'* (Participant 32), ' *[TD] is focused on developing new methods and processes in order to create a holistic and common understanding of the problem, solution and the world'*. Some comments expand on this idea. Making specific reference to the multi-level multi-goal, hierarchical education / innovation system created by Jantsch they identify the specifics of the system with ID is differentiated from TD based on the number of levels involved. '*Interdisciplinarity is about collaboration and coordination only across two out of the four levels, while Transdiciplinarity can be achieved by integrating all four levels of the pyramid [sic]*' (Participant 5), *'Projects can exist on four disciplinary levels; purposive, normative, pragmatic and empirical. To be interdisciplinary there is a need to work and coordinate across 2 or three of these levels. To be transdisciplinary there is a need to work and coordinate across all four of Jantsch's levels*' (Participant 28). Applying the conceptualisation of Jantsch both ID and TD operate a system approach, but for TD the system has a broader 'holistic' scope which specifically considers context.

Equal weighting of disciplines: The second of the themes calls for disciplines to be equally weighted: '*Conceptually, interdisciplinary engineering research would have one or two dominant engineering disciplines leading the research work, while transdisciplinary engineering research may not have any dominant engineering discipline. Every discipline in the research work is equally crucial to producing outcomes'* (Participant 2), '*all disciplines have the same level of importance, contrasting to interdisciplinary engineering that which somehow ends up giving greater importance to a certain area of knowledge'* (Participant 9), '*Inter there is still a tendency to bias a singular mental model and use that lens to interpret the other disciplines whereas with Transdisciplinary working that pre sorting is in theory reduced And a more holistic embodiment is provided'* (Participant 27). The identification of this theme raises an interesting point: If all disciplines are equal within a transdisciplinary engineering research collaboration, why would it be considered engineering. Is it not simply transdisciplinary research? Does engineering require there to be the creation of an engineered artefact or is the designation of 'engineering' dependent on some other characteristic? Perhaps, the more pertinent question lies not in what differentiates TD from TD conducted within an engineering context, but rather does the inclusion of social sciences improve the 'success' of complex engineering projects? Although worthy of enquiry, answering these questions will require substantial research effort which take it beyond the scope of this study."

Transcending of disciplines: The last of the three themes was that of transcending disciplines and disciplinary knowledge. Within the responses this included the framing of the problem: '*I believe that what differentiates transdisciplinary engineering from interdisciplinary engineering is that, in transdisciplinary engineering, the disciplines involved and their perspectives transcend one another, creating complex reflections and can also create a new approach on the subject'* (Participant 9). Methodologies: '*In interdisciplinary engineering one defaults to the different methodologies of the disciplines working together to achieve something which lies inbetween or partly within each of the contributing disciplines. Transdisciplinary Engineering and its researchs aims to develop new methodologies which are a fusion and extension of existing methods within singular disciplines [sic]'* (Participant 30). Research fields: '*The transdisciplinary form of research assumes the accidental contact of individual scientific fields on the fringes of their interests, which gives the possibility of* *creating completely new research fields*' (Participant 17), and knowledge: '*transdisciplinary uses knowledge and information from each discipline to develop new knowledge*' (Participant 11), '*interdisciplinary engineering is using the knowledge from two or more disciplinary to solve a certain domain problem…transdisplinary engineering emphasizes the 'transformation of the knowledge' that provides new ideas/solutions to a certain domain'* (Participant 20).

Although integration received strong support as the differentiator between TD and ID there are challenges in adopting this feature. On a theoretical level previous works have pointed out that in the hierarchy of disciplines TD is generally seen as exceeding ID. Therefore, there are underlying notions of valuing one form of integration more than another. Additionally, there is criticism that it separates methodologies from epistemologies (Mobjörk, 2010). On an operational level integration is a multidimensional concept which can occur between all or some of the participants, and include the sharing of insights, practices, frameworks, or concepts Pohl et al. (2021). This multidimensional nature makes the creation of assessments which differentiate between disciplinarities based on integration more challenging.

In summary, of the three characteristics goal received limited support as a differentiator between ID and TD. There is support for collaboration as a differentiator. However, unlike the literature the most support is not for the involvement of non-academics as a differentiator, but the inclusion of social sciences. Although integration received the widest support as a differentiator, there are acknowledged theoretical and operational challenges with its use.

4. Conclusions

The results of our analysis show that rather than one universally accepted definition for TD there exists a TD landscape encompassing multiple conceptualisations. Within the three characteristics commonly used to identify TD working (goal, collaboration and integration) various concepts were employed. These concepts range from generic expressions which can overlap with concepts of ID found in the literature, to stronger more definitive statements surpassing that generally required for ID. Our findings support the view expressed in the general literature that there is not one universal definition of TD. Moreover, they show that even between those presenting work at a transdisciplinary engineering conference multiple concepts can exist.

As identified in the work by Tress et al. (2004) having a plurality of definitions for research concepts can lead to misunderstandings and confusion within and across projects. Therefore before one can analyse whether TD has brought about success or whether TD is required, there needs to be an agreed definition of TD, or as suggested by Pohl (2010) a structuring of definitions to clarify the different perspectives held.

The purpose of this study was not to enforce a particular definition of TD but rather to understand how transdisciplinarity is conceptualised within the engineering academic community. In mapping the concepts, we have created a framework (Table 5) which enables users to define where they sit within the TD landscape. This framework provides a first step to improved communication and acts as an aid to the identification of differences and similarities of definitions within and across projects.

Ultimately, the framework provides a structured approach which allows the engineering community to enter more constructive discussions around the characteristics and concepts which are, and conversely not TD. Although we agree with the literature that it is unlikely that a strict definition will ever be possible, through this approach we would hope to see a move towards community consensus.

5. Future Work

Within this work we examined how transdisciplinarity is conceptualised within engineering, and specifically targeted those publishing papers at the Transdisciplinary Engineering Conference (TE2020). The framework represents a first step rather than finished piece. Future studies will look to enhance the framework based on verification and validation studies conducted within a wider population.

Further work will focus in the following areas:

1. Studies which verify and validate the framework in an engineering academic setting.
2. Studies which verify and validate the framework across academic disciplines.
3. Studies which verify and validate the framework in an industry setting.

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