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Transdisciplinary Engineering Versus Transdisciplinary Research: Differences, Similarities, Lessons and Opportunities

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Abstract. Transdisciplinary engineering (TE) emerged in the wake of renewed interest in transdisciplinary practice, rooted in the fields of health and environment research. This paper explores the relationship between transdisciplinary engineering and transdisciplinary research (TR) arguing that there is a good conceptual basis for both terms to exist as they differentiate important practice considerations in the same way science is differentiated from engineering. Using bibliometric methods, I explore the relationship between the two groups of literature, mapping where they interface, and revealing their different conceptual framings. TR is associated with research in the fields of sustainability, and health, and features approaches aligned with scientific research, but also participatory and related social science designs. TE is closely identified with product design, industrial engineering, and education, revealing a stark contrast between the two domains in terms of the implied goals of transdisciplinary practice. Finally, a deeper comparison of approaches, definitions and frameworks between key bodies of research enables an exploration of lessons that might be drawn from one to the other. In particular, the opportunity for TE to incorporate the more strategic societal, environmental and health goals associated with TR and bring TE capacities of design and industrial engineering to TR, generating a paradigm shift in both TR and engineering.

Keywords. Transdisciplinary, Engineering, Research, Bibliometric, Conceptual Frame.

Introduction

In 1962, historian of science, Thomas Kuhn published *The Structure of Scientific Revolutions* [1] a book which introduced the term 'paradigm shift' into the dictionary of thought about how science progresses – itself something of a paradigm shift. For Kuhn, in describing how science progresses, he identified phases of 'normal science' – identifiable via the accumulation of facts, use of a specific range of instruments, addressing an identified set of problems – would every now and again be punctuated with a 'paradigm shift' where 'extraordinary science' would take place. Such moments – such as the development of Einstein's theory of relativity, or the oxygen theory of combustion – lead to a completely new perspective which leads to a chaotic realignment with multiple competing ideas shifting to make sense of the new ideas as they transition into the new paradigm. In reflecting on how we understand the progress

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of science, we can think similarly about the progress and change of paradigms in engineering. The emergence of 'transdisciplinary engineering' is a key example of a possible paradigm shift in engineering. Notably, the concept of 'transdisciplinary practice' in science, research, medicine and education also appeared around the same time, giving us the opportunity to understand how 'transdisciplinary engineering' relates to other related forms of 'transdisciplinary practice', and what it might learn from them or transfer too them. Here I briefly explore the early history of the term 'transdisciplinary' to trace any evidence of engineering being part of that conceptual development, before going onto map the research fields of 'transdisciplinary engineering' in relation to 'transdisciplinary research'.

In Scopus – one of the foremost indexing databases for academic research, coding over 90 million records from pre-screened sources – a simple search in the titles, abstracts and keywords for the term 'transdisciplinary' returns nearly 13,000 citations, with the first published in the mid 1960s[2] – a study about coronary disease by Raab [2], illustrates the underappreciated roots of the term in medical research. The subsequent decades reveals a shift in emphasis for papers deploying the term. As Lattanzio et al. [3] note, this is initiated by a paper by Erich Jantsch [4] focused on thinking about the role of universities and education for innovation, and deploying a 'systems approach'. Most of the papers from the 1970s referencing the term are focused on health-related issues. Almost hidden in this early literature is the first appearance of 'engineering' alongside the term 'transdisciplinary' in a 1972 conference paper by Kasarda and Hillman [5] – the conference for the Association for Computing Machinery. Here the interest in creating a document search capability "oriented toward the transdisciplinary use of science and engineering". Here the implication is that the engineering research undertaken by the authors is in some sense not transdisciplinary itself, in developing the search system, but nevertheless supports others in deploying whatever 'transdisciplinary science and engineering might be'. The indications from these early uses of the term indicate that conceptually it was synonymous with multidisciplinary, cross disciplinary or even interdisciplinary, though Jantsch is explicit in differentiating transdisciplinary from these other terms. For him, the distinctive nature of transdisciplinarity lies in what he called 'multilevel co-ordination of [the] entire education/innovation system' (p.410). Importantly transdisciplinarity rests on both disciplinary and interdisciplinary approaches. His argument is about science policy, and the way in which society should or can guide education, science or innovation – indeed he argues for an 'education/innovation system' – and places 'transdisciplinarity as the 'ultimate degree of coordination' in this system. Fundamentally, one can read Jantsch's argument as transdisciplinarity being a means for enabling science, education and innovation to serve what he calls the 'self-renewal of society'.

The 1980s sees further development in these lines, in particular the use of systems thinking, cybernetics, and other instances we would recognise as the emergence of transdisciplinary engineering. Hartman and Hartman [6] document collaboration between engineers and physicians in accident prevention. This carries forward the emerging concepts of working across disciplines, working with a social purpose identified earlier. But likewise, many of the remaining papers in this decade are focused purely within education or health sectors. An emergent theme is the degree to

[2] At the time of writing Scopus returns the Jantsch 1970/1972 paper – there are multiple entries for the same paper ascribed to different journals on different years – as dated 1947. This is clearly a coding error as the source details point to a journal that only started in the 1970s.

which transdisciplinary is used to mean 'collaboration across disciplines' in the delivery of health services [7] or managing information in engineering databases [8].

As Lattanzio et al. [3] note, the modern emergence of the term can be traced to the late 1990s/early 2000s. By 2001, more publications using the term 'transdisciplinary' had been indexed in one year than in the entire 1980s. This raises the question about how 'transdisciplinary' is being understood across these emerging, potentially divergent streams, and what that means for 'transdisciplinary engineering' (hereon 'TE') in particular. What is at stake here is the future of the concept and its successful application within the field of engineering. Here I argue that a more strategic understanding of TE is necessary to enable the development of the practice to grow and connect to other communities seeking to develop the concept. At the same time, it is clear that a significant amount of work in developing the notion of 'transdisciplinarity' is based on science perspectives, rather than engineering. A key part of this analysis is therefore to assess the degree to which TE differs from applications of transdisciplinary thinking outside engineering, and what might be learnt from it, but also how TE might uniquely contribute to the wider community of researchers and practitioners utilising the concept to guide their work. To capture a broad but distinct sub-field that closely matches the nature of engineering but is distinct. I have focused on the the term 'transdisciplinary research' as a means of capturing non-engineering transdisciplinary practice. This is the term visible in the most highly-cited paper returned from Scopus [9], based on a search term TITLE-ABS-KEY (transdisciplinary) and choosing the highest cited paper which had the term 'transdisciplinary' in the title. Two bodies of published academic research, 'transdisciplinary engineering' and 'transdisciplinary research' as indexed by Scopus are then mapped against each other to explore commonalities and differences in the topics and approaches. Finally, I explore the implications of these findings for the future development of 'transdisciplinary engineering' (TE) and what lessons can be learnt from 'transdisciplinary research' (TR) and the potential value of TE approaches to TR.

1. Methods

Using Scopus as the single source of citations for each group of academic publications has pros and cons. Scopus is recognised as one of the largest abstracting databases for academic research with over 9 million records [10], but it is much smaller than others such as BASE[3], with over 240 million. However, Scopus actively curates which sources are included and provides high quality metadata (and metadata analysis and export tools) as well as a sophisticated search function. Further, although there are biases within the database that have been identified [10], for my purposes here – comparing between two bodies of research – these biases are less important. The data generated by Scopus was then exported from the web interface into a text file, which was then read by the bibliometric mapping software tool VOSviewer v1.6.18 [11].

1.1 Search terms and citation data handling

Two initial search terms were generated and entered into the Scopus search bar in April 2023. Initial searches were undertaken using the default search fields for Scopus

[3] See: https://www.base-search.net Accessed 27 April 2023.

– the title, abstract and keywords of entries, coded in Scopus as TITLE-ABS-KEY ( ). The two bodies of research were initially characterised with “transdisciplinary engineer*” and “transdisciplinary research*”. This phrasal search syntax with the inverted commas (“”) ensures only entries where the two words appear contiguously are returned. The wildcard syntax (*) ensured that the search was not unnecessarily narrow enabling variant terms like ‘engineering’ and ‘engineered’ to be included and ‘researcher’ and others forms that might be used.

TITLE-ABS-KEY (“transdisciplinary engineer*”)
TITLE-ABS-KEY (“transdisciplinary research*”)

Following the execution of the search two files were exported from Scopus in .csv format, and imported into Microsoft Excel. The first is the export of all returned records including selecting citation information fields (Author(s); Document title; Year; Source title; Volume, issue, pages; Citation count and DOI) and all Abstract & keywords fields. After that, a record of the returns metadata summary was downloaded via the ‘Export refine values’ or ‘Export filter counts’ option on the bottom of the left menu of Scopus interface.

The .csv export files containing the abstract information was then imported into VOSviewer with the following options. The initial step involved creating a bibliometric map based on keyword data, which allows a clustering of the returns based on terms that co-occur in the keywords (author and index). This has two benefits: first, revealing what the most common terms are in the body of research and second, how they are relate to each other. VOSviewer does a sort of hierarchical coding where clusters of similar terms are colour coded into categories as well as visually linked by a line with categories from inside and outside these cluster groups. The files were imported as files from a bibliographic database to create a map based on bibliographic data, with the Scopus option (built into VOSviewer) selected as the source database. The earlier downloaded .csv file was then selected in the file browser, before finally leaving the default settings for the data extraction fields untouched (abstract as the source of the text for clustering, title and title and abstract options unchecked, and ignoring other abstract labels or copyright statements.

This first stage resulted in a disproportionate number of returns for the TR search (2282 returns) versus TE (114). Since the TR text data would overwhelm the mapping of the TE data, a further narrower search for TR, based only in titles was conducted. This resulted in a more balanced 500 returns for the mapping process. This meant that the final combined mapping of TE and TR research was done on the basis of a search in the titles, abstracts and keywords for TE, and just the titles for TR.

1.2 Mapping the data

To map the relationship between the two bodies of research, a single source file was created for the map. The original TR returns from the titles only search, where all the same data fields, including abstracts, were downloaded, was combined with the data from TE returns from the title, abstract and keywords search. The combined file was then mapped as per the parameters above.

Data were imported into VOSviewer using the initial options described above. The type of analysis chosen was ‘co-occurrence’, with full counting of all keywords (author and index). Keywords were chosen for mapping rather than the text from abstracts as the small number of sources overall meant a need to rely on a relatively consistent dictionary of terms, which keywords provide. Due to the overall small number of documents and total number of keywords, the minimum number of occurrences of a term to be included in the map was reduced from the default 10 to 5. This meant 169 terms from a possible 3170 were included in the mapping for the combined TE and TR map. The software then calculates the total strength of the co-occurrence link with other keywords, and places them spatially closer and clustered into colour-coded groups. Each term is represented by a coloured, labelled disc. Terms that have more co-occurrences with other terms have larger discs than those with fewer.

The initial mappings in VOSviewer were undertaken with the default values regarding normalization method. This is set to 'association strength' by default. In the layout of the maps, default values option was left checked, with Attraction at 2, and Repulsion at 0. The initial clustering parameters were left at 1.00 for resolution, with the minimum cluster size left at 5, the 'Merge small clusters' option left checked. No rotation or other visual transformations were used. Small adjustments were made for clarity of the map on the node label text length and maximum number of connection lines shown (700).

2. Results

2.1 Initial search returns and notable features

The initial Scopus search results and the metadata from them is reproduced in Table 1.

Table 1. Search terms used to generate the bibliographic data from Scopus, with the number of returns for each search.

Search term	Returns
TITLE-ABS-KEYWORD ("transdisciplinary engineer*)	114
TITLE-ABS-KEYWORD ("transdisciplinary research*)	2282
TITLE ("transdisciplinary research*)	500

Besides the difference in volume of research returned by the two terms, other differences are visible. The TE search's earliest reference is from 1983, with zero references from the 1990s. By contrast TR (titles only) earliest reference is from 1992, with zero references from the 1980s. The top three subject areas for the TE search are engineering, computer science and business, management, and accounting, compared with social sciences, environmental sciences and economics, econometrics and finance for TR (titles only). This already indicates distinct perspectives on the application of 'transdisciplinary' between these two bodies of research. At the same time, engineering is the 10th most common subject area classification for TR (titles only) with social sciences the 5th most common for TE showing some potential areas of commonality.

Other features of these two bodies of research that are notable are the number and range of publications the papers are published in, and which countries the researchers are based. For the TE literature we see a highly skewed distribution where 71 of the 114 papers were published in one journal – *Advances in Transdisciplinary Engineering*. Only 3 other publications have more than 2 papers – the *ASEE Annual Conference and Exposition Conference Proceedings*, *International Journal of Computer Integrated Manufacturing* and *Journal of Industrial Integration and Management*. Collectively, these top four publications account for over 70% of the work indexed in Scopus with the term 'transdisciplinary engineering'. The top title alone accounts for over 60% of the published research in this area. Overall, 33 different publications are responsible for publishing the research.

By contrast the TR literature (represented by the returns from the TITLE search only) shows a greater spread in the publications where the research is found. The top title - *Gaia Ecological Perspectives for Science and Society* - has 48 publications representing just 10% of all the papers captured by this search. To cover 70% of the publications, 139 publications are involved – that's 87% of the 160 different publications that are responsible for publishing research here.

Finally, Figure 1 shows the relative emergence of publications within these two searches (TE in titles, abstracts and keywords vs TR in titles only). Here we see TR developing rapidly from the mid 2000s, with TE approximately a decade behind. The apparent rate of publications per year is similar after that point though there are signs of TE starting to grow nonlinearly. While in some respects the comparison between a narrow TR search vs a wider TE search could seem biased in favour of TE, the more specific nature of the TE term could put it at a disadvantage relative to a more general TR search. Here at least, we can compare the two bodies of research on the same order of magnitude. Of interest here, either way, is the early emergence of TE in the mid-1980s.

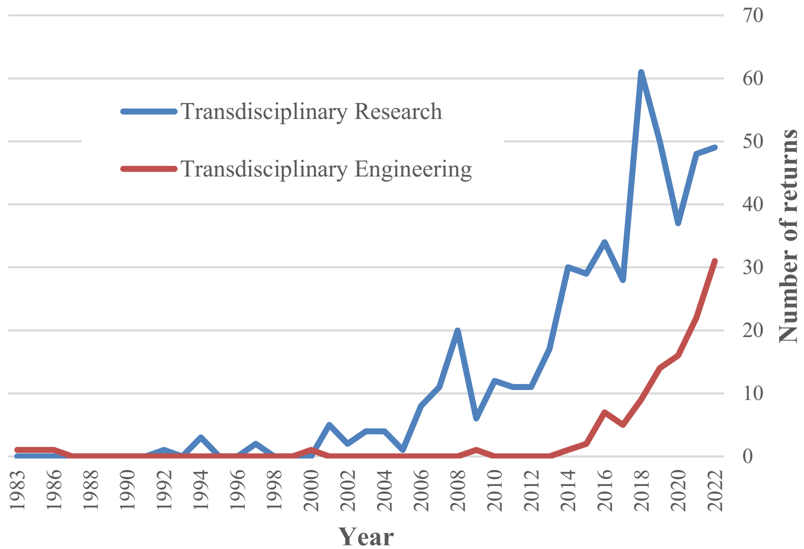

Figure 1. Showing the emergence of papers indexed by Scopus and returned by a titles-only search for TR and a titles, abstract and keywords search for TE.

2.2 Mapping the TE and TR literature using keywords

Figure 1 shows the overall map of the academic research indexed in Scopus for TE and TR searches, and their co-occurrence. When viewing the map, the larger the circle, the frequent the term in the corpus of keywords. Each line represents a co-occurrence of the two terms linked. The closer the circles (i.e., shorter the line) the frequent the co-occurrence between terms. The different colours represent clusters of co-occurring terms into identifiable groups where the frequency of co-occurrence between these groups of terms is significantly different. In the map in Figure 1, we can see four different clusters which are identified in Table 2.

Table 2. Description of the four clusters from the map. The colour is visible in Figure 2, the topic name for the cluster is take from the largest node in the cluster. Size gives the number of terms in the cluster, and indicative terms identifies the top 3 nodes after the main topic node which are the next largest and are content distinctive (so 'transdisciplinary' in the TE cluster is not distinctive from the topic name) and content useful (so article and united states in the Human cluster don't capture the distinct topical flavour of the cluster).

Colour	Topic	Size	Indicative terms
Yellow	Transdisciplinary engineering	33	Product design, engineering education, decision making
Red	Transdisciplinary research	59	Sustainability, interdisciplinary approach, knowledge
Green	Human	40	Interdisciplinary communication, methodology, co-operative behaviour
Blue	Interdisciplinary research	37	Medical research, public health, education

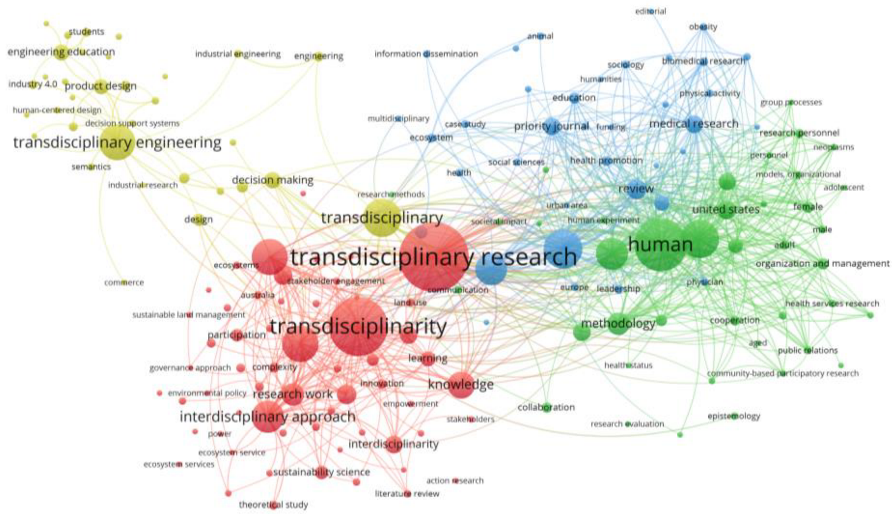

Figure 2. Showing the complete VOSviewer network map of co-occurrence of 169 keywords (author and index) from the sources returned in the two searches in Scopus, set out in Table 2 (titles, abstracts and keywords for TE, and titles only for TR). See text for details.

The four clusters show some characteristics in relation to the topical orientation which also provide a means of understanding the relationships between them. The Human (green) and Interdisciplinary research (blue) clusters both show a focus on medical research and interdisciplinarity. The Human cluster has 'health status', health services research, neoplasms as part of the cluster, as well as significant number of linkages into the Interdisciplinary research (blue) cluster. This latter cluster has 'health', 'health promotion', 'health care organisation', 'biomedical research', 'obesity' in addition to the indicative terms noted in Table 2. These two clusters are linked to the TR (red) cluster but topically this latter cluster is more closely identified with environmental rather than health or medical issues, with terms like 'climate change', 'ecosystem services' and 'land use' visible. Notably, the TE (yellow) cluster sits quite apart from the other three clusters, with a distinctive emphasis on what seem to be more explicitly private sector/business concerns than the other three clusters. Terms like ‘industrial engineering’, ‘commerce’ and ‘product development’ capture the distinctive nature of this body of research.

Some common themes are visible across all four clusters, where some emphasis on the human and/or social aspects of these contexts is visible. For the TE cluster, this is represented by ‘human-centred design’ and ‘decision making’ nodes, whereas in the TR cluster, we see terms like ‘participation’, ‘stakeholder involvement’, ‘co-production’ and ‘action research’ (a kind of social inquiry research design). The Human cluster directly identifies here with this concept but also brings with it ‘organisation and management’, ‘community-based participatory research’ and ‘group processes’. Finally, the Interdisciplinary research cluster has ‘social sciences’ explicitly, alongside ‘sociology’, ‘humanities’ and ‘urban area’.

2.3 Exploring the relationship between TE and TR

One feature of VOSviewer is its ability to highlight the links associated with specific terms in the map, allowing clearer visualisation of how a term within one cluster relates to terms within another cluster. Here I explore how the key node within the TE cluster relate to the TR cluster (and other clusters, where interesting and important) and compare that with out the key node with the TR cluster relates to the TE cluster. Figure 3 (right) shows the map of links highlighted for the TE node.

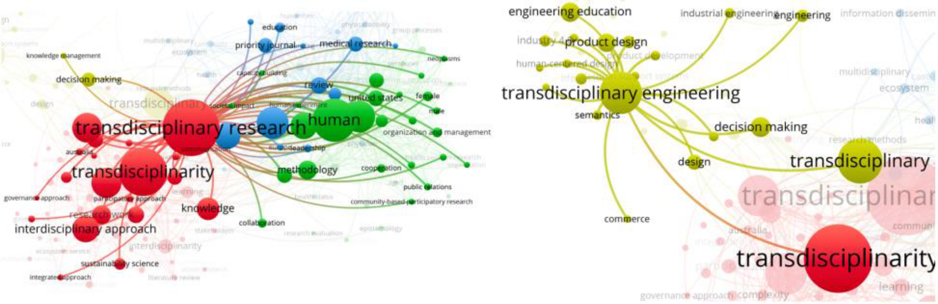

Figure 3. Showing the highlighted links stemming from the key TR cluster (left) and TE cluster (right) node out to other nodes. For more discussion of this see the text.

What we note from this map is the very limited relations that the term TE has with other terms clustered into either the TR cluster or any other cluster. The only other cluster visible on this map is the red TR cluster, but the only term it links to is the heavily overlapping ‘transdisciplinary’ term. Instead, transdisciplinary engineering as a term is one which sits at the centre of a relatively isolated collection of conceptual terms, something that is visible from the overall map.

By contrast the TR node from the red cluster, links across to every other cluster to a lesser or greater extent, as visible in Figure 3 (left). There are 2 direct links into terms within the TE cluster with ‘decision-making’ being the more frequent term, and ‘knowledge management’ also providing a point of contact. We also see very strong relations with the other clusters including direct links to their main nodes, Interdisciplinary research, and human (and the variant ‘humans’). What is interesting about the co-occurrences of terms with TR is how an emergent ‘de facto’ definition of its meaning can be inferred. Within the red cluster we see specific terms connected including ‘interdisciplinary approach’ echoing the link to the ‘interdisciplinary research’ cluster. We also see links to ‘participatory approach’ and ‘governance approach’ which echo links to the green cluster's 'community-based participatory research' and 'cooperation', 'collaboration' and 'capacity building'.

A final way of understanding the relationship between the TE and TR clusters of terms and, by implication, bodies of research, is the nature of terms sitting between the core nodes or at the interface of the two clusters. Figure 4 provides a close-up of this boundary area, identifying 5 terms.

Figure 4. Close up of the original map from Figure 2, showing the nodes sitting between TE and TR cluster (circled).

The terms in Figure 4 can be ordered in terms of their occurrence frequency and cluster. The most frequent TE term is 'decision making'. This term has links across all 3 non-TE clusters, revealing it to be, topically, an important term that connects across from TE to TR. The next most common TE term is 'design' has connections two of the other 3 clusters. In part, design here might be invoking two meanings – design as 'technical design' (related to the TE cluster) or as 'research design', linking to the TR cluster (i.e., via the 'research work' linkage). The third TE term, 'project management' has fewer links and connects only to terms in the TR cluster, (academic) research work, learning and sustainability. The two final terms are interesting in that, although they sit directly between the clusters, they are hardly linked at all. 'Risk assessment' is firmly linked only to TE not TR – which is interesting given the obvious links to sustainabnility challenges like climate change, a key concern in TR. 'Systems thinking' is clustered as a TR term, yet is not directly linked to any other TR term. This lack of visible link may be a consequent of infrequent occurrence overall, but where it occurred it was split almost evenly between terms from the two clusters, with a slight preference for the TR terms. But, like 'risk assessment' it is interesting that it is coded as a TR term, yet it is conceptually closer to the practice of engineering.

The key summary point from this analysis and comparison between the nature of the TE body of research and that of the TR body is how central and connected the latter is to the overall research, and how disconnected and relatively isolated the transdisciplinary engineering body is. In the next section, I discuss the implications of this observed pattern of research and explore the potential for the transdisciplinary engineering community to grow and leverage influence across the wider community of researchers identifying as 'transdisciplinary'.

3. Discussion

Is TE on the brink of creating a paradigm shift? The analysis above reveals a set of interesting and important findings for the way TE is emerging in relation to the wider use of TR in the academic literature. What is clear now is that TE is a distinct branch of the transdisciplinary field, one which is dominated by a broad field that foregrounds medicine, environmental concerns and social/human sciences. When mapping according to the keywords used in papers indexed by the Scopus database, the field sits in relative isolation from TR. The potential for TE to create a paradigm shift, possibly within the broader field of transdisciplinary projects is there, in that sense, since it provides the basis for a new perspective from the almost ‘normal’ or ‘routine’ transdisciplinary research world. This new perspective means bringing in concepts from engineering more generally, but also incorporating a more direct and open relationship with private sector stakeholders. In the rest of this section, I consider the differences, similarities, lessons and opportunities that the analysis above reveals, and finally consider future directions to take advantage of these opportunities and avoid risks that might undermine the future of TE.

3.1 Key differences

Besides the simple scale and volume of published research – with around 20 times more returns using the term ‘transdisciplinary research’ than ‘transdisciplinary engineering’ when searching across titles, abstracts and keywords – there are a number of key features that distinguish TE from TR. The general focus of TE research, as captured by the keywords, is on engineering topics such as product development, design engineering and industrial processes. This is visible in Figure 5 (right) where the abstracts from all 114 TE returns are combined into a single corpus of words from which a word cloud is generated (removing some common but unimportant terms to clarify the content of the research more).

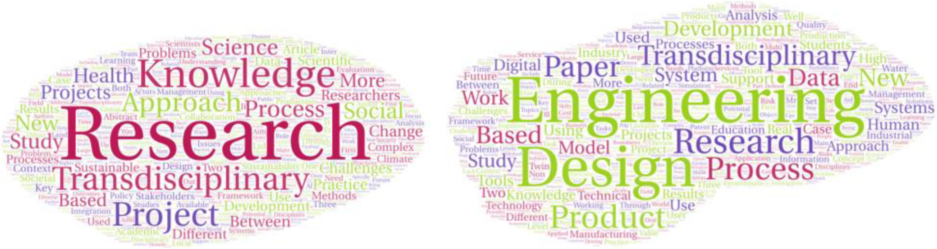

Figure 5. Word clouds for TR (left) and TE (right), based on the abstracts from all returns in each search.

For TR the focus is much more on what might be characterised as ‘scientific’ concerns: the generation of knowledge, application of science, studying processes, data and developing frameworks. The concerns, as identified above are much more on health and environmental topics, such as climate change and obesity in contrast to TE. These are visible in the word cloud in Figure 5 (left), created from the abstracts of 500 returns from the titles only search in Scopus, again with some of the common but uninformative words removed for clarity.

One key difference hinted at and remarked on earlier is the nature of who is part of the transdisciplinary work. For the engineering community, this is implicitly mainly focused on the business or industrial sector – that is, mainly private sector interests. This sits in some contrast with the TR community who seem to focus more at the community level, governance level or organisational level. None of these directly rule out private sector interests, but their focus on major challenges such as health and climate, tends to imply a greater emphasis on public sector or third/community sector actors.

3.2 Key similarities

Despite the differences between the two areas, there are of course key points of overlap and similarity which are worth noting. A key one identified above is the presence or focus on social or human concerns. For TE this tends to be expressed in relation to concepts such as 'human-centred design' or 'decision-making', whereas for TR this can come down more to forms of governance and participation, such as co-operation, community participation, as well as focusing on particular types of people such as adolescents, adults, or more generally group processes including management. It's also perhaps reasonable that the general 'health' focus tends to bring people more centrally into focus.

Beyond that we can also see an emergent set of connections around knowledge and knowledge management, especially when early (i.e., 1980s) considerations of TE are taken into account. This fits well with the emphasis on knowledge within the TR community and in particular concepts such as 'information dissemination', 'learning', and interdisciplinary research itself. This similarity is likely more implicit within the TE community on account of the engineering focus tending to centre more on products and processes than knowledge. However, as scholars in science and technology studies have argued, technology is knowledge [12] meaning that there may well be more overlap between these two communities than there appears at first glance.

3.3 Key lessons

What is clear from both the original search and the network maps of publications is how extensive the range of publications, and authors there are in TR vs TE. There is also arguably a more tightly-bound and clearer idea of what constitutes 'transdisciplinary' within the TR community than there is with the TE community. Two central basic concepts stand out across all the non-TE clusters: a concern with the human or social, and a concern with wider societal goals – be they environmental or health threats or risks. Layered on top of those two is a more reflect set of concepts and concerns about interdisciplinary working – which gives rise to terms relating to methods of research.

For TE, these concerns are hardly visible in the TE cluster. There are hints at the focus on the human or social, but – and perhaps this is a consequence of the size of the overall cluster – very limited coverage on anything other than human factors and decision-making. Similarly, the more societal-level concerns – such as climate change, sustainability more generally or health outcomes are almost entirely absent. There are some reflections on methods, and modes of practice visible in the full list of terms in the TE cluster (not visible on the map) such as digital twin, life cycle and risk assessment but with limited reflection on the more participatory elements visible in TR-related clusters. This presents a foundational challenge for TE as there is a risk that the 'transdisciplinary' prefix in engineering becomes a kind of 'washing' of engineering, implying the concerns visible in TR but not actually acting on them.

3.4 Key opportunities

The risk identified in section 3.3 above, that the 'transdisciplinary' prefix in TE becomes meaningless unless it incorporates in some significant way the wider community meanings of the term is itself an opportunity, and an opportunity in two parts. The first part is the opportunity for TE to be a bridgehead into transforming engineering practice – the Kuhnian paradigm shift with which I opened this paper – by integrating more of the concerns of the wider TR community: greater social and human perspectives, including in the methods, and a stronger focus on wider societal and environmental concerns. Collaborating across the TE and TR boundaries can provide the means by which to do this.

The second part of the opportunity is the capacities and concerns that TE uniquely brings to TR and are visible in the interfacing nodes discussed above. Key among these is the capacity of design within TE but also risk assessment and the natural interface with business and industry. Further opportunities are present in the role of systems thinking – and the recognition of the need for it in the TR community. The advanced capacity to think in systems rather than in simple lists or linear logic, is essential to tackle challenges facing society. TE is well-placed to create a paradigm shift in TR as well.

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