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TRansdisciplinary ENgineering Design (TREND): Towards a Transdisciplinary Engineering Index

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Abstract. Manufacturing is undergoing rapid change. Whether through the creation of smart materials and products, or utilising data, information and knowledge, the requirement for different ways of working is increasing. To meet future manufacturing needs, design and manufacturing skills and tools must transcend disciplines and industrial sectors. Transdisciplinary Engineering Design (TREND) aims to enable the rapid uptake of emerging technologies across manufacturing sectors and the constitute disciplines. Within this paper, we provide an overview of the TREND research group and their preliminary research towards a Transdisciplinary Engineering Index.

Keywords. Transdisciplinary, Trans-disciplinary, Transdisciplinary Engineering, Transdisciplinary Engineering Research

Introduction

The UK enjoys world leadership in established manufacturing industries such as aerospace, pharmaceuticals, electronic design and photonic technologies. To support continued sustainable growth, UK manufacturing requires cutting-edge research and the development of highly-skilled people [1, 2].

TREND aims to fundamentally change how 21st century products are designed, providing design engineers with a toolkit (models and processes) to support rapid uptake of emerging technologies and enhancement of current technologies across the manufacturing sectors and their constituent disciplines, e.g. Design For Manufacture and Assembly (DFMA) and additive manufacturing in construction. The toolkits will encompass elements such as tools, technologies, processes, and will be data driven and continually evolving.

Such a holistic and evolving approach is necessary to provide the means to rapidly understand and integrate new manufacturing processes, design methods (DfX) and engineering systems and through life support tools into multi-disciplinary engineering teams, in such a way as to transcend disciplines i.e. to be transdisciplinary.

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The ultimate ambition of the TREND team is to design and validate a Transdisciplinary Engineering (TE) Index. The index will provide a practical means through which industry can assess their current TE state, the level of disciplinarity that is required, and then through the toolkit determine the focus of their move towards transdisciplinary engineering.

Within this paper we provide an overview of the TREND research group. First, Section 1 provides an introduction to TREND; their aims and objectives, and theoretical stance with regards to TE. Section 2 details the current research streams within TREND and then describes the progress made towards the creation of a TE Index. Finally, Section 3 outlines the next steps.

1. TREND (TRansdisciplinary ENgineering Design) Research Group

Why focus on Transdisciplinary Engineering? Advances in new technologies such as additive manufacturing (AM), smart materials and digitalisation will result in highly complex systems. Although within the engineering discipline, other approaches have been proposed to deal with complexity (e.g Concurrent Engineering, Collaborative Design Innovation, Design for Sustainability), individually they fail to consider the full range factors which may impact the success of a project. Our hypothesis is that going above and beyond the engineering discipline, TE is best able to overcome this challenge. To this end TREND will create a TE Index and use this to enable TE within industry. Case studies with our industry partners and beyond will be undertaken as a means to test the hypothesis and validate the index.

Fundamental for TREND in its travel towards a TE Index is that the group have a shared mental model for TE. The theoretical stance taken with regard to TE is now presented.

1.1. Transdisciplinary Engineering (TE) - Theoretical Stance

The literature shows there to be a plurality of definitions for transdisciplinarity (TD). TREND adopts the foundational work of Jantsch [3] to inform its theoretical stance for TE. This is due to the fact that Jantsch provides a structure/framework which can be used to assist in the analysis required to apply TE.

Jantsch held that when conducting work in a social context, you need to engage not only the scientific disciplines, but also other dimensions – for example, the social, economic, and political. Using a systems approach, he defined the levels that should be engaged when working towards an objective (Figure 1).

Jantsch's system is coordinated from the top down purposive level, and requires engagement at the empirical, pragmatic and normative levels. The purposive level defines the societal meaning and value which will be delivered by creating a solution to a challenge. The normative level places the challenge in context by considering the social systems e.g. laws, standards and culture. At the bottom of the hierarchy are the empirical and pragmatic levels. The empirical level encapsulates the natural sciences e.g. maths, physics, and psychology. Above this, within the pragmatic level the theories from the natural sciences are merged and trimmed to create the applied disciplines such as engineering.

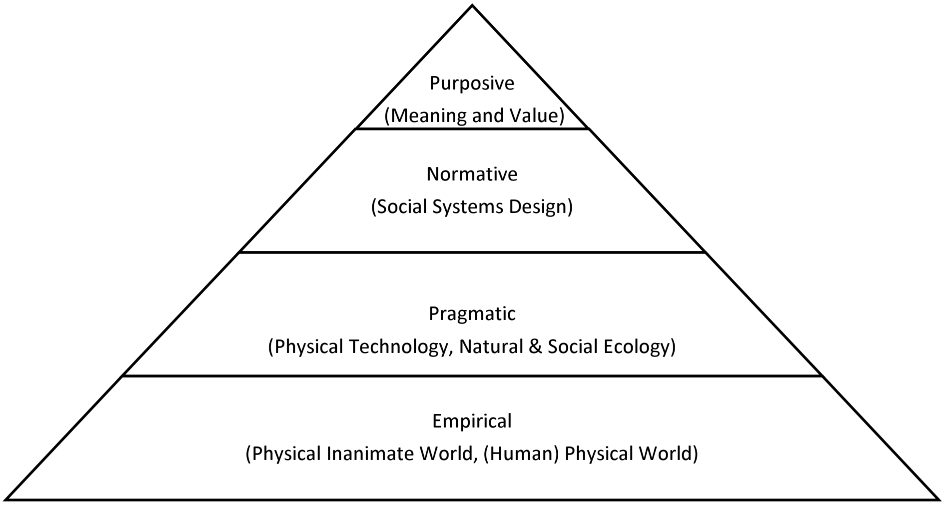

Figure 1. The education/innovation system, viewed as a multi-level multi-goal, hierarchical system. Adapted from Jantsch [3].

Jantsch's works provide TREND with a framework. However, in operationalising the framework, a number of questions arise. One of the key considerations is: at what level should meaning and value be considered? Since its origins in the 1990s TD research has been intrinsically linked to environmental challenges. Within this realm meaning and value is often considered from the perspective of "common good". That is, it is to the public good and of advantage to everyone. However, papers presented within the International Society of Transdisciplinary Engineering Conference have focussed on operational as well as "grand challenge" problems [4] . In this regard the outcomes may not benefit all individuals, but rather a group or subset of society.

When discussing meaning and value within his papers, Jantsch is ambiguous. For example, at one point Jantsch states that the purposive level (the level at which meaning and value is defined), could have a goal of "progress", and then references "progress" from a Christian thought viewpoint which from a western perspective could be economic and technological dynamism. However, elsewhere he describes meaning and value being about a *policy for mankind* – which suggests a grander ambition. The position of TREND is that our research will be independent of specific values. That is, meaning and value will be defined by the context we are working within.

2. TREND Streams

TREND has four work streams, which are coordinated towards creating and evaluating the TE Index (Figure 2).

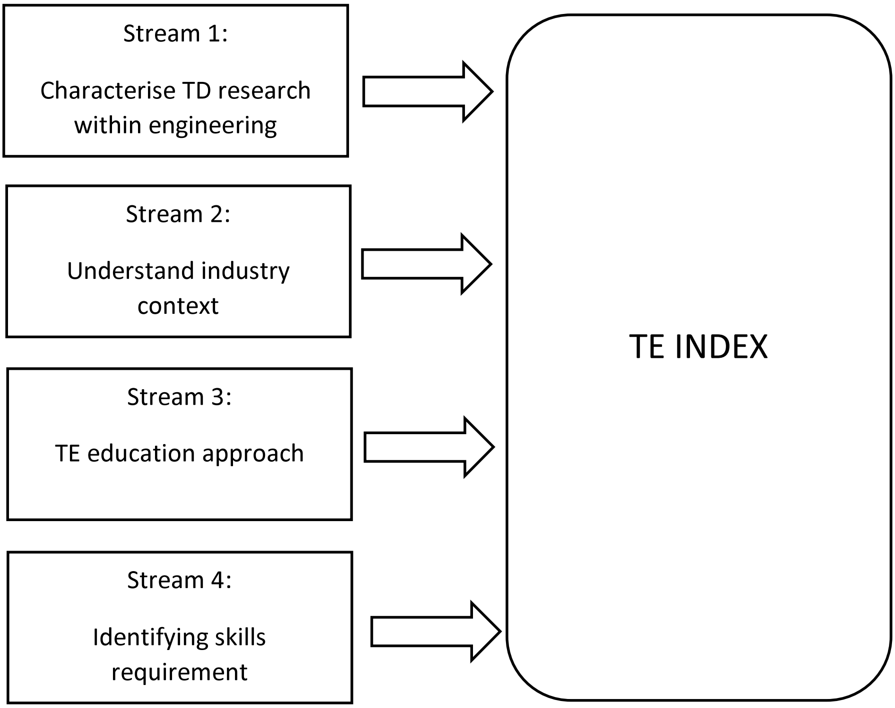

Figure 2. TREND Work Streams

2.1. Stream 1: Characterising TD Research within Engineering

Although there has been an increased discourse around TD research, the assertion was that it had received less attention within engineering [5, 6]. To understand the current state, TREND conducted a study which compared the chronology, comparison of journals, and comparison of text of papers which reference TD within their abstract, to papers which reference TD and fall within the engineering subject area [4].

The research concluded that the referencing of TD within papers is limited both generally, and within engineering specifically. In addition, it identifies that although TD research has historically been biased towards sustainability challenges, within engineering the focus is wider with an increased application towards operational problems e.g. managing the performance of decision support tools within infrastructure organisations [7], the automatic generation of digital twins based on scanning and object recognition [8], a mobile stroke unit for rural Australia [9], efficient design and production of houses [10] and industrial systems modelling [11].

2.2. Stream 2: Understanding Industry Context

The work conducted within Stream 1 provided an understanding of the state of TD within academic engineering literature. It did not provide insights into the awareness, application and use of TD within industry. To address this gap TREND has engaged and is continuing to work with industry through formal research (detailed below) and informal discussions.

Work on a formal research study with the practitioner community is ongoing. This study is being conducted in two stages: Stage 1: semi-structured interviews. Stage 2: questionnaire. Stage 1 is complete. The results of these interviews will be used in conjunction with our findings from the literature review (Stream 1) to inform the design of a questionnaire (Stage 2). The questionnaire enables a greater breadth of industry input facilitating both increased data and international participation.

During Stage 1, the researchers conducted in-depth semi-structured interviews with employees from thirteen engineering businesses. These organisations represented a breadth of sectors and size of organisation. Within the semi-structured interviews five research questions were explored:

Q1. Whether they had heard of the term transdisciplinarity? If so, what did they understand it to mean?

Q2. What levels of disciplinarity they use within their organisations?

Q3. What were the challenges to TD working?

Q4. What were the enablers to TD working?

Q5. What were the inhibitors to TD working?

The research questions were informed by the academic literature and Jantsch's framework. Q1 sought to ascertain whether the term TD was used within industry. Q2, was to determine whether they are working in a TD manner or the level of disciplinarity they are currently working at. This was important as some companies may be working in a TD manner but not referring to it as such. Q3-5 were to determine if working in a TD manner what the challenges were and if not working in a TD manner what the perceived challenges may be.

Early results show that the term TD is not widely used within industry, however evidence of TE approaches are present. Where they are using the term it is often being more narrowly utilised: more akin to inter- than transdisciplinary working. TD working was aspirational for a number of the organisations with a key enabler of TD considered to be effective communication.

2.3 Stream 3: TE Education Approach

To facilitate TD, the emerging literature has called for the expansion of TD education [3, 12-16]. Within Stream 3 TREND looks to create a practical approach for TE education, which can be incorporated into exisiting engineering course designs. The overall aim being to facilitate wider dissemination and engage students from the outset to think wider than a single discipline. The details of the first stage of this research, a pilot with students from the University of Bath's Advanced Automotive Propulsion Systems Centre for Doctoral Training, are presented as a separate paper within this conference [17]. The results, evaluated by way of student feedback, show broad satisfaction with the session. Six of the eight indicated that they were satisfied with the quality of the session (two students were neutral). All students considered that the course material was presented in a clear and understandable way. All students considered that the course was accessible to their level of understanding. Further work to assess the TE education benefits are ongoing.

2.4. Stream 4: Identifying Skills Requirements

Identifying skills requirements to enable TE working and how they may influence the TE Index requires several intermediate considerations. First, how are skills defined? This is a difficult question to answer as skills are often subjectively defined. For instance, LinkedIn allows members to have up to 50 skills, which can either be selected from a database or be entirely user-defined. As researchers we are thus faced with the choice of either defining a set of skills which we will use in the research, or to develop methods to extract skills from data relevant to the system of interest. This research takes the latter approach, where we are developing high-fidelity skills extraction methods. This method includes e.g. creating algorithms to extract and classify concepts from text and then identify which concepts likely belong to a skill, competence, or knowledge class.

This is being done in parallel to understanding the collaboration patterns occurring within and between different organisations. This allows us to analyse the collaborative structures that are driving the work at an organisation, and consequently allows us to understand the communities that are forming, the bottlenecks that may be occurring, and the collaborators most central to the organisation and its various communities.

Applying the skills extraction method to appropriate datasets within our systems of interest allows us to not only consider the organisational affiliation, but also the skills structure within an organisation. Using growth models allows us to extend this to what skills will be more in demand in the future as well as identifying what are the underpinning skills required for working in a TE manner. Finally, as all skills are associated with people, we are able to make evidence-based decisions for the skills requirements for individuals.

3. TREND – Current Findings and Future Steps

The changing landscape of manufacturing make it a designated field for TD. The proposed TE Index will provide industry with a practical approach through which to assess their current level and state of disciplinary working. Then, where desirable, the toolkit will enable their movement towards more effective Transdisciplinary Engineering.

Although, significant steps have been taken towards the TE Index, more research effort is required before the final design of the index can be proposed. A cornerstone of the TE research approach is that it is top-down, with the design of the "solution" informed by the context [7]. Only once the full picture is known can efforts turn to how academic and non-academic insights might be brought together to create an approach which is both rigorous and practical in an industry setting.

To this end, over the coming months we will synthesise findings from the research streams and work with our industry partners and beyond as a way to inform the initial TE Index design. This index will be presented at TE2021 in Bath. The current findings from these streams and future research steps are summarised below:

Although receiving increased academic attention TD remains an emerging, immature field within engineering. The purpose of characterising the literature (Stream 1) was to provide a benchmark of the state of TD within engineering compared to the wider landscape. The study provides insights and highlights that both within engineering and the literature more generally, TD penetration is low. Furthermore, although generally TD has focussed on "grand challenges", within engineering TD has been applied to a broader scope of problems. Although providing some understanding it is recognised that the study presents only one perspective, showing how the term TD is being used within the engineering academic literature. Our future work will explore other perspectives and in doing so add to the richness of the picture. For example, to what extent the academic engineering literature claiming to be TD satisfies the various definitions of TD and whether there is engineering literature which is not identifying itself as TD, but which can be considered to meet the criteria.

The TE Index is intended to be a practitioner-based approach. Key to its uptake within industry is having awareness of the context in which it will operate and incorporating this understanding within the design. From Stream 1 we know that within the academic literature TD is applied across a wide range of challenges. Within Stream 2 interviews we explore where practitioners feel TD might be useful and what are they consider to be the enablers and inhibitors to TD working. Preliminary analysis suggests that although TD working is aspirational with some evidence that indicates it may be being used, TD is not a well recognised term. Although of interest, these findings have limitations as interviews have only been conducted on a small scale. Over the next months we will complete thematic analysis of the interviews and bring this together with insights gained through the other research streams in order to create the industry questionnaire (Stage 2). This questionnaire will enable a wider reach both in terms of sample size and geography.

Recognising that TD is not a well recognised term within industry, research efforts have focussed on creating a practical approach for incorporating TE within higher education engineering courses (Stream 3). A TE session has been conducted and successfully piloted at the University of Bath. Over the next twelve months this session will be delivered to engineering Masters students at the University and later, to PhD candidates within the faculty of engineering at Universidad de los Andes, Colombia. From this activity not only is TE disemminated, it provides scope for additional data gathering. For example, as part of the group discussion element the students are asked to identify enablers and inhibitors for TE. These insights will provide additional data to supplement the questionnaire conducted within Stream 2.

Underpinning the creation of TE education session (Stream 4) is an understanding of the skills which enable TE working. Research to extract the skills sets of engineers is being undertaken. Over the coming months this fundamental work will be built upon in order to define the skills for TE working. This understanding will inform both the TE Index and also to inform a TE Designer Readiness Level, which is the subject of a separate PhD research project.

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