Advances in Manufacturing Technology XXXV
M. Shafik and K. Case (Eds.)

doi:10.3233/ATDE220596

Towards a Disciplinary Framework for Engineering and Manufacture

Emily CAREY[a,1], Jana SAJDAKOVA[a], Linda NEWNES[a] and Susan LATTANZIO[a]
[a] *Department of Mechanical Engineering, University of Bath, Claverton Down, Bath BA2 7AY, UK.*

Abstract. This paper presents the need to create a disciplinary conceptual framework. As participants and interactions of expertise in a project rise so too can costs, meaning if a project is transdisciplinary, being at higher levels of disciplinarity could become an expensive option. However, approaches for measuring levels of disciplinarity remain ill-defined and lack structure, so progress in this area is difficult to measure with a multiplicity of disciplinary scales identified. It is our view to guide rigorous scientific progress and meaningful industry support, a definitive conceptual framework, is required to underpin appropriate measures. This is currently lacking and to this end here, we outline interrelated studies to develop a disciplinary conceptual framework, detailing two studies to establish core transdisciplinary concepts for engineering and manufacturing. We conclude detailing ongoing work to measure aspects of disciplinarity in industry, leading to the creation of a disciplinary indexing tool/process.

Keywords. Disciplinarity, Transdisciplinary, Engineering, Manufacturing, Knowledge Integration, Stakeholder Engagement, Conceptual Framework.

1. Introduction

Disciplinarity could be deemed a conceptual measure of expertise and its integration, where participants' engagement and interactions are incorporated to create new knowledge. If this were the case then transdisciplinarity (TD) would be best placed at the highest of levels, where knowledge transactions are paramount to achieve societally focussed successes [1]. Engineering and manufacturing projects have expanded to encompass international working and global challenges [2], increasing costs, in line with rising participants and stakeholders for discipline breadth, incorporating knowledge insights. To meet industry 5.0 challenges, it is claimed that a TD approach is required [3] but a means to ascertain the level of disciplinarity for a project is not yet reported in a meaningful or measurable way [1]. At present key concepts in literature differ, are inconsistent and much overlap between levels of disciplinarity exists [4]. An agreeable conceptual differentiation, towards which this paper contributes, is much needed for disciplinary approaches to be measured efficiently.

The wider research project aims to create a disciplinary framework to develop a tool to index "when" and "where" levels of disciplinarity are most appropriate, with associated industry benchmark measures [5]. This paper highlights part of the conceptual framework creation highlighting two example studies to identify TD specific concepts,

[1] Corresponding Author. emcc20@bath.ac.uk

hence falling under the "Identify and Validate Key Conceptual Differences" in Figure 1. The complete disciplinary conceptual framework will enable users to map what is happening in a project, such as the context of the project, approaches used, and level of discourse required. To create this framework for engineering and manufacture many research activities are required [6] and Figure 1 shows a top-level schematic. Section 2 follows providing a background, then section 3 provides an overview of the disciplinary framework construction and studies to support this, section 4 illustrates the contributions of two studies and a conclusion in section 5 summarizes, with future work to create industry benchmarking measures and tools.

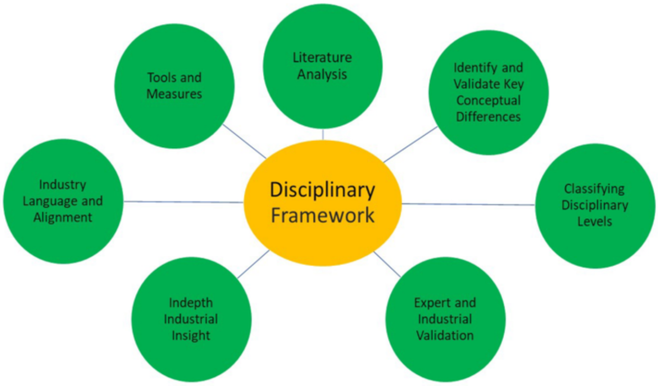

Figure 1. Disciplinary Framing for Engineering and Manufacture

2. Disciplinary Approaches in Design and Manufacture

Some of the challenges for UK manufacture are raising productivity while reducing costs, especially with the current uncertainty and push towards sustainable, manufacturing [7]. UK government policy towards sustainable goals and its digitization and automation agendas with the advent of Industry 5.0 lends focus on people adding to challenges and opportunities industries face [3][7][8]. Together this raises new questions in practice, such as, how we can achieve and maintain reducing manufacturing cost, increase productivity, and reduce environmental impact [8]. To this end, higher disciplinary approaches such as TD are cited to be necessary to assist in optimizing workforce expertise breadth and to conduct more efficient projects [3].

Approaches dealing with how teams integrate expertise and optimize working together focus on combining disciplinary knowledge. The actual "approach" taken to combine knowledge is not often identified explicitly in literature, this is especially true for research [1]. Yet projects will state that they pertain to a particular disciplinary team, such as multi-, inter-(ID) or trans-disciplinary [4]. However, there is little agreement within science or industry of "**what**" defines or constitutes the differences between disciplinary approaches [4]. Literature hints that distinct and possibly scalar differences exist between approaches and that ID and TD are most difficult to differentiate [4]. Hence there is a real benefit scientifically and industrially to understand how to identify and to apply differing approaches to understand the benefits/pitfalls, but the means to do this does not yet exist [1],[2].

A conceptual means to objectively define what constitutes one disciplinary approach or another is required [2], [5], [4]. This conceptual framework could then be used to define overarching methods and best practice for conducting design and manufacturing projects, benchmarking both negative and beneficial costs. The research presented in this paper presents part of the creation of such a framework.

3. Creating a Disciplinary Conceptual Framework

To assist practitioners in assessing the level of disciplinarity required for their project, we need to scientifically establish the core concepts and relations, or "what" we know about disciplinarity [2], [4], [6]. In Figure 1, we specify aspects that potentially contribute to framing the "what" of disciplinarity. For many a conceptual framework starts and remains with academic literature [6]. However, due to conflicting opinion and diverse schools of thought when considering levels of disciplinarity [1], [2], [4], deriving a singular representation becomes impossible from literature alone. A mixed-method approach is required to merge mindsets, iteratively validate findings, learn from industry and to make our findings truly useful [2], [6], avoiding academic centered findings [6]. To achieve acceptable consensus and reflect the important aspects of disciplinarity found in Figure 1, the series of research studies shown in Figure 2 was created.

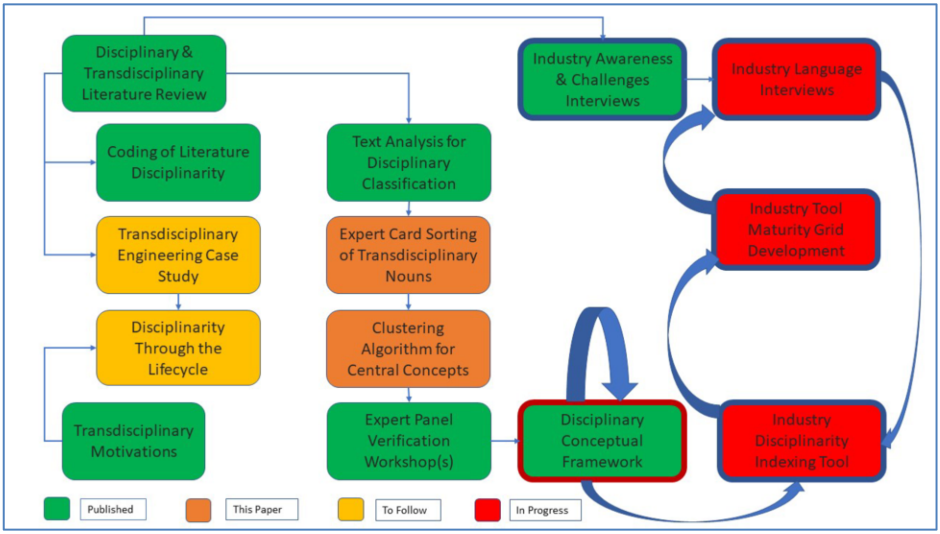

Figure 2. Disciplinary Research Study Sequence

Initial activities such as literature analysis in conjunction with industrial studies illustrate the diversity of thought and lack of structure surrounding disciplinarity, highlighting the lack of awareness of terminology in industry and the conflicting challenges they face [2]. Initial attempts to code levels of disciplinarity pose challenges [1] and this coding is the subject of PhD research in case studies yet to be published, also investigating disciplinary patterns in engineering lifecycles. More structured text analysis approaches illustrate the significant overlaps in disciplinarities being used by researchers, raising a pressing need to establish agreeable definitions [4]. Thus, additional studies described in this paper use robust methods, seeking central concepts aspirational for higher levels of disciplinary working.

In this paper we illustrate defining concepts of TD projects, providing guidance for differentiating disciplinary levels and aspirational concepts for TD working. The concepts are created by cross-validating two studies described in Section 4, namely "Expert Card Sorting of Transdisciplinary Nouns" and "Clustering Algorithm for Central Concepts". The findings of these studies contribute directly to industry language interview investigations, guiding the creation of industry support tools (maturity grid and disciplinary index [5]). Future research needs to elucidate further what the disciplinary concepts look like in industry to benchmark, measure and guide practice.

4. Identifying Transdisciplinary Concepts

A two-part cross-validated approach was undertaken to identify prevalent and significant concepts for TD projects, suggesting important disciplinary aspects. A manual clustering (card sorting) approach and an automated clustering algorithm were employed [9][10]. Scopus was used to extract the abstracts of 4,347 relevant TD engineering manufacture journal articles. Automated extraction identified 1,149 unique nouns with 367 occurring twice or more, and 231 occurring three times or more. To ensure that extracted concepts were representative, TD concepts occurring three times were used for the creation of the TD categories. The significance of these nouns and their central meaning or the concept being represented is derived in the following experiments. The outcome of these two studies is a list of 7 optimal text clusters each representing a key defining concept or feature of TD engineering manufacture in journal research.

4.1. Expert Card Sorting of Transdisciplinary Nouns

This approach uses a card sorting experiment design with subject-matter experts as participants [9]. Card sorting activities are time consuming, thus our approach secured 20 experts time by reducing the original 231 terms. We scaled down to the top 100 most common terms, representing 70.3% of all extracted terms. The task was individualized overcoming personal/group bias and due to COVID-19 work environments. The activity was conducted with no limits to the number or size of sorted groups. The rationale being if sufficient commonality was found between groups decided by experts, then an optimal set of groups could be obtained from them.

4.2 *Clustering Algorithm for Central Concepts*

This approach used topic extraction to identify categories and elicit central concepts. This leveraged word embedding vectors to represent TD concepts in a Euclidean space as this has previously been successful in identifying similarly grouped concepts. A modified approach to document-based topic modelling was used to overcome difficulties in association of unrelated topics. The 231 concepts were grouped by meaning and word embeddings used to create vector representations of each word [11], each of these then represented a similarly grouped category. This two-step approach first creates the TD relevant embeddings specific to TD literature and then performs a clustering algorithm on the resulting Euclidean space, for relevant TD concepts [11].

4.3 *Resulting TD Concepts Identified*

As both approaches employ the use of clustering strategies the output can be directly compared using the Fowlkes-Mallow metric to measure how well the categories match [10]. This closer inspection for similarities and differences, compares the centres of categories using Euclidean distances in the word embedding space [11]. This identifies similar clusters for manual inspection to determine potential common themes between clusters and provides additional sense-checking.

Table 1. Clusters of TD Terms

Cluster 1	Cluster 2	Cluster 3	Cluster 4	Cluster 5	Cluster 6	Cluster 7
area	aspect	challenge	communication	action research	approach	action
collaboration	character	development	conversation	analysis	framework	activity
community	concept	education	debate	program	integration	assessment
cooperation	context	experience	dialogue	project	method	contribution
domain	field	issue	discourse	research	methodology	effort
environment	insight	knowledge		research agenda	process	engagement
group	lens	knowledge production		research program	research approach	initiative
interaction	manner	learning		research programme	research design	inquiry
network	mode	problem		research project	research framework	intervention
partnership	model	scholarship		study	research method	investigation
research team	nature	teaching		sustainability research	research process	practice
researcher	paradigm	training		workshop	synthesis	research effort
space	perspective	understanding				review
system	science					work
team	solution					
team approach	strategy					
teamwork	theory					
university	thinking					
	view					
	way					

In the card sorting task every expert produced different sorted groups (20 resulting clusters), hence it is not possible to find a single solution for experts. However, an optimal cluster number can be derived (7) contributing to finding the optimal cluster arrangement using the automated approach. The automated clustering algorithm produced an optimal clustering of terms shown in Table 1. These clusters each represent a central concept relevant for TD. Later workshop approaches used expert panels to name central concepts for each cluster to represent aspirational concepts for disciplinary working and measures [5]. This work begins the design of a potential tool to evaluate the disciplinarity of an engineering or manufacture project [2], [5] and is iteratively being developed using interviews with industry experts to establish appropriate language, meaning and to benchmark potential measures.

5. Conclusions

In this paper we highlight the engineering and manufacturing sector is faced with challenges such as sustainability, while still requiring increased productivity and reduced costs. We have described how using transdisciplinary approaches can assist in achieving societal benefit – such as sustainability. However, we identify that ascertaining a level of disciplinarity remains unclear and to this end we outline developments of a disciplinary conceptual framework. We illustrate two associated studies to find relevant TD concepts, resulting in 7 central concepts. Ongoing research is now investigating "what" and "where" to apply higher levels of disciplinarity to establish engineering and manufacturing efficiencies. The next stages of the research will continue to build this disciplinary conceptual framework, investigating how best to translate academic terms into meaningful language for industrial users, and to benchmark industry measures. The end goal being a TD index tool for industry use, guiding disciplinary working patterns throughout product lifecycles, optimizing societal value, while creating engineering and manufacture efficiencies.

Acknowledgements

The work reported in this paper was undertaken as part of the Designing the Future: Resilient Trans-Disciplinary Design Engineers Project, at the Universities of Bath, Bristol and Surrey. The project is funded by the Engineering and Physical Sciences Research Council (EPSRC) Grant EP/R013179/1.

References

[1] S. Lattanzio, N. Mogles, E. Carey, A. Kharlamov, G. Parry, B. Hicks, & L. Newnes, Classifying the disciplinarity of engineering academic literature, Transdisciplinary Engineering for Complex Socio-Technical Systems - Real-Life Applications - Proceedings of the 27th ISTE International Conference on Transdisciplinary Engineering, *Advances in Transdisciplinary Engineering*, **12** (9) (2020) 23-31.

[2] E. Carey, L. Newnes, S. Lattanzio, A. Hultin, & N. Mogles, Foraging for transdisciplinary challenges: Emergent industrial themes, Transdisciplinary Engineering for Resilience: Responding to System Disruptions - Proceedings of the 28th ISTE International Conference on Transdisciplinary Engineering, Amsterdam, The Netherlands, *Advances in Transdisciplinary Engineering*, **16** (10) (2021) 23-32.

[3] J. Muller, European Commission, Enabling Technologies for Industry 5.0, Results of a Workshop with Europe's Technology Leaders, *European Commission Research and Innovation*, Sept. 2020.

[4] E. Carey, J. Gopsill, & L. Newnes, Text Analysis of Disciplinary Research Papers, Transdisciplinary Engineering for Complex Socio-technical Systems – Real-life Applications, Advances in Transdisciplinary Engineering, **12** (2020).

[5] S. Lattanzio, E. Carey, A. Hultin, R. Imani Asrai, A. Nassehi, G. Parry, & L. Newnes, The transdisciplinary engineering index: Towards a disciplinary maturity grid, Transdisciplinary Engineering for Resilience: Responding to System Disruptions, Proceedings of the 28th ISTE International Conference on Transdisciplinary Engineering, Amsterdam, The Netherlands, *Advances in Transdisciplinary Engineering*, IOS Press BV, **16** (10) 2021 41-50.

[6] J.A. Maxwell, *Qualitative Research Design: An Interactive Approach*, Thousand Oaks, Sage Publications, CA 2nd Edition, 2005.

[7] C. Rhodes. Manufacturing: statistics and policy, House of Commons library, briefing paper number 01942, 10 Jan. 2020.

[8] Make UK, Manufacturing Outlook 2021, Quarter 3, Environmental, Social and Governance (ESG) spotlight special, Ref. 21.04.POL.JB.FK.NB. 2021.

[9] C. Paul, A Modified Delphi Approach to a New Card Sorting Methodology. *Journal of Usability Studies*, **4** (1) (2008) 7-30.

[10] L. Kaufman & P. Rousseeuw. *Finding groups in data: an introduction to cluster analysis*. John Wiley & Sons. 2009.

[11] G. Miller. WordNet: An electronic lexical database. *MIT press*. 1998.