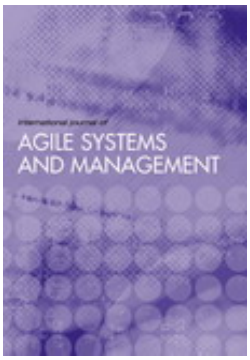

International Journal of Agile Systems and Management

ISSN online: 1741-9182 - ISSN print: 1741-9174
https://www.inderscience.com/ijasm

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DOI: 10.1504/IJASM.2025.10069158

Article History:

Received:	22 September 2024
Last revised:	01 October 2024
Accepted:	18 October 2024
Published online:	04 February 2025

A model of disciplinarity: literature conceptual differences

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Abstract: Industry and society face disruptive change, from digitalisation, net zero challenges, and rising costs. Industry supplies complex solutions to such societal problems, and literature claims to address such future need, inter or transdisciplinary is key. A means to differentiate disciplinarities is still elusive, but to find its value we need know what each disciplinary level looks like. This contribution suggests a disciplinary model, to evaluate the level of disciplinarity being used in a project. We use literature content analysis finding identifiers of disciplinary levels and develop a disciplinary model. To show how we created this model, the work is first placed in the context of research, we then describe the approach used to show how the data informs creating the model. The paper discusses future work needed to evaluate such models and widen the scope of its applicability.

Keywords: disciplinarity; transdisciplinarity; industry; manufacturing; disciplinary model; transdisciplinary engineering; disciplinary concepts; definitions; disciplinary definitions; key identifiers; disciplinary evaluation.

Reference to this paper should be made as follows: Carey, E., Newnes, L.B., Hultin, A.O., Imani Asrai, R. and Lattanzio, S. (2025) 'A model of disciplinarity: literature conceptual differences', *Int. J. Agile Systems and Management*, Vol. 18, No. 5, pp.1–23.

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1 Introduction

It is an expectation that the next generation of industry will supply manufacturing prosperity and value that is world encompassing, and that in running still meet necessary environmental and societal efficiencies (Despeisse et al., 2022; European Commission, 2021). In recent years operations have been most impacted by globalisation and environmental factors (Gunasekaran and Ngai, 2012). In fact, the impact of globalisation has been seen since 2008, during the last recession (Buehlmann and Fricke, 2016). As a result, industry is now being driven more by societal needs for change (Despeisse et al., 2022; European Commission, 2021; Wognum et al., 2019). This disruption adds demands to manufacturing industries, requiring more resource (material costs) (Desing et al., 2020), wider experts, closer collaboration and integration (Varela et al., 2022; Zolotová et al., 2020). Ever more efficient methods tackling increasing production costs, drives to digitise and connect humans, and more integrative demands are needed (Liu et al., 2019; Zolotová et al., 2020; Sajdakova et al., 2022; European Commission, 2021; Lattanzio et al., 2022; Carey et al., 2020; Desing et al., 2020; Buehlmann and Fricke, 2016). There is increased research in two novel areas that aim to overcome industry challenges, one is digitalisation to provide automation (European Commission, 2021; Lattanzio et al., 2022; Varela et al., 2022; Zolotová et al., 2020), and the other is optimal integration of expertise in working practices, or disciplinarity (Sajdakova et al., 2022). Revolutionary solutions, encompassing all, to date do not exist but transdisciplinarity (Lattanzio et al., 2020; Sajdakova et al., 2022; Carey et al., 2022; Wognum et al., 2019), operational value (Liu et al., 2019; Porter, 1985; Petrevska et al., 2015; Noroozi and Wikner, 2016; Lattanzio et al., 2022) and people (Zolotová et al., 2020; Shuttleworth et al., 2022), are all considered enablers to achieve societal/environmental aims and industry optimisations (European Commission, 2021; Gimenez et al., 2012).

The paradigm of disciplinarity has been used since the founding of science (Jantsch, 1972; Areekkuzhiyil, 2017), but until recent years with a greater merging and hybridisation of ‘disciplines’ (Rodgers and Bremner, 2011), it has been unnecessary to understand explicitly the ‘what’ or ‘how’ of these expert combinations or to differentiate specific or potential benefit. Convergence paradigm research considers combining the ‘what’ or knowledge in disciplinarity, finding less collaboration occurs where the disparity is greater, for example combining single disciplines rather than applied disciplines (Li and Yu, 2024). This becomes a circular issue, as knowledge disparity is not always identifiable (Li and Yu, 2024) or how best to combine knowledge for better outcomes. In fact, Hall et al. (2008) were unable to differentiate interdisciplinarity (ID) from transdisciplinarity (TD) and Sugimoto and Weingart in 2015 present ‘disciplinarity’ as a kaleidoscope of elements. More recent studies again (Vienni-Baptista, 2023; Lattanzio et al., 2022; Carey et al., 2020) find that to differentiate between disciplinary combinations, especially ID or TD is not yet possible. Without this differentiation however, while it is clear and widely agreed that higher disciplinary approaches supply optimisation, there is no agreement ‘what’ best constitutes or ‘how’ one might measure achieving specific disciplinary status.

The overarching need for revolutionary engineering approaches (European Commission, 2021; Sajdakova et al., 2022) and recent theory developments mean many now claim to use these higher levels of ‘disciplinarity’ (ID/TD) (Vienni-Baptista, 2023;

Sajdakova et al., 2022; Lattanzio et al., 2021; Carey et al., 2022). Researchers offer guidance for building TD teams, presented as "team science", highlighting the importance of strong leadership, diverse groups and communication (Waite et al., 2023). Frequently guidance is tied with loose definition of what TD is, such as broad expertise working on shared goals (Waite et al., 2023; Sajdakova et al., 2022). But scientific measurement of perceived cost efficiencies or value need clear definition of 'what' constitutes achieving such aspirational levels (Lattanzio et al., 2022; European Commission, 2021; Carey et al., 2022; Sajdakova et al., 2022). This is not yet solved, and only scientific evaluation of benefit can translate any operational value of disciplinarity, to be able to apply it appropriately for industry. The need for clear and impartial distinction between disciplinarities remains, this conceptual disciplinary model is the challenge this paper addresses.

To overcome this and supply a robust theoretical basis for evaluating and differentiating disciplinarity in practice, this paper describes the rationale and literature studies carried out to find a conceptual model of disciplinarity. Thus, this paper contributes a disciplinary model, to evaluate the level of disciplinarity being used in a project. The rest of the paper is structured as follows, we first supply the background to research about disciplinarity, finding the gaps and need for such a model. This is followed with a description of the reasoning for literature analysis to find the key disciplinary concepts and outline the method used to create the disciplinary model. The paper concludes with a discussion of the disciplinary model findings and the work that still needs to be done to test the model and extend any value to industry practice.

2 Research identifying levels and types of disciplinarity

To aid with assessing trends in current literature on disciplinarity and commonly used levels, the authors have compared literature indexed in the Scopus database. Scopus is a suitable disciplinary database and sample serving as an index to journal and conference literature reaching across all subject areas. It is considered to have 20% more coverage, hence suitable for studying trends in disciplinary publications (Aghaei Chadegani et al., 2013). Search strings designed to find literature seeking to pertain to specific disciplinarity (Carey et al., 2020) is extracted to show publication trends. The searches relate to common levels of 'disciplinarity', 'multidisciplinarity' (MD), 'interdisciplinarity' (ID) and 'transdisciplinarity' (TD). The trends are illustrated in Figures 1 and 2. Figure 1 shows the growth over time of publications that claim to be a specific disciplinarity, and the growth in interest for disciplinarities. Figure 2 shows the publications over time that reference themselves as TD and either MD or ID. Figure 2 is insightful showing the clear confusion, in publications that appear to claim to TD, but also claim to MD or ID at the same time. Figure 1 shows the changing trends in disciplinary publications over time, the relative lack of publication in 'disciplinarity' itself, that MD/ID are populous and have been for a long time. It also shows that while we know TD has been referenced as far back 1972, its growth in research is in relative infancy so is likely immature.

Figure 1 Growth of Scopus publications with disciplinary keywords (see online version for colours)

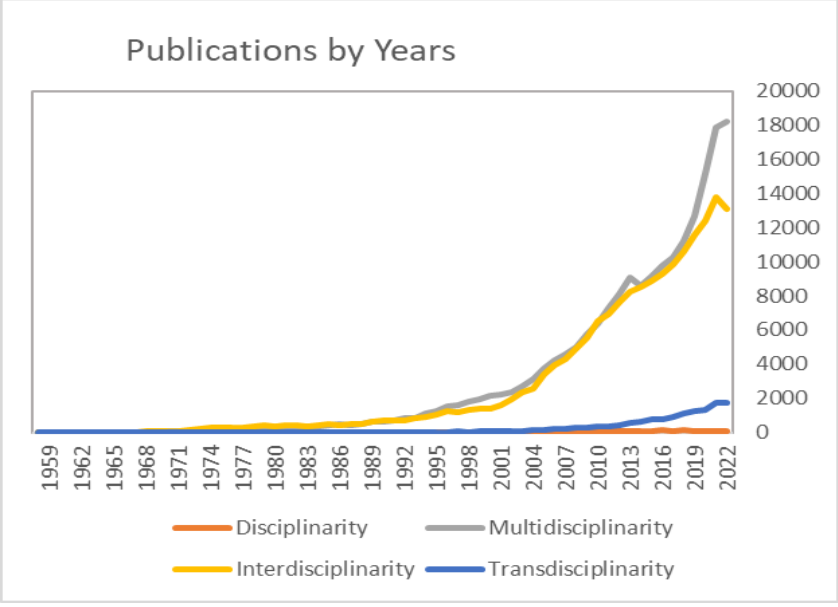
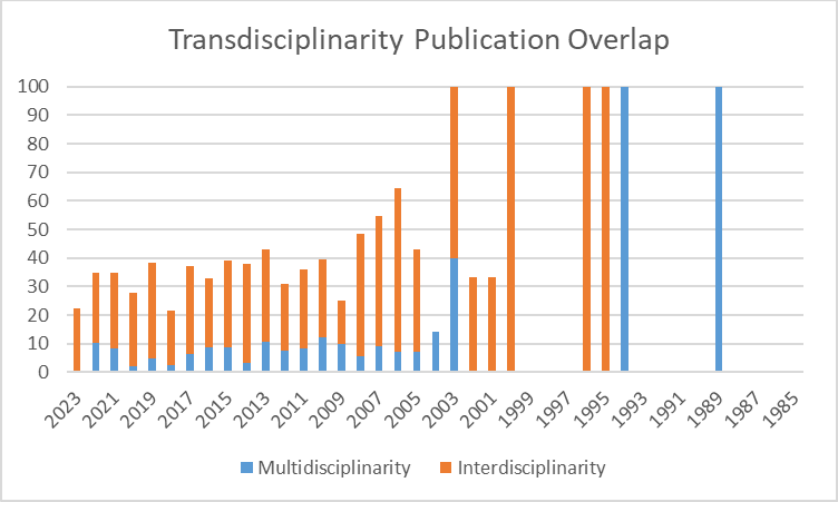


Figure 2 Overlap in Scopus publications: transdisciplinary keyword with multi or interdisciplinary keywords (see online version for colours)



Key points arising from this analysis are that while funding bodies are showing more interest in TD working (Wognum et al., 2019; European Commission, 2021; Make UK, 2021; Sajdakova et al., 2022; Lattanzio et al., 2020; Carey et al., 2020) most literature still focuses on longstanding disciplinarities, MD and ID. This is where a large majority of publications associate to date. Interest in TD, first began in depth in the 1970's (Jantsch, 1972; Apostel, 1972; Hayman, 1974) but the topic has only been taken up by research after 2005. Evidence of confusion exists even in 1974 in the work of Hayman,

working problems finding clear differences between MD and ID as more recent works of Vienni-Baptiste (2023) show between ID and TD. This is despite Jantsch's definitions of three forms of ID, teleological, normative and purposive (Jantsch, 1972). In Hayman's (1974) original work the two forms of ID presented may be considered forms of ID and TD respectively, or two forms of ID according to Jantsch (1972). We are left wondering if the lack of TD association is an understanding challenge, an appropriation issue, or if the TD approach is not as relevant or useful in supplying the value called for by funding bodies.

It is clear where work claims to be TD it still often associates to being ID or MD as well. This is a problem if we want to be able to answer whether being TD offers value for the higher investment needed in bringing diverse experts together (Waite et al., 2023; Carey et al., 2022). Using Figure 2, we illustrate a high proportion of TD publications, mixing the concepts of levels of disciplinarity. This would be expected if confusion is present about defining each level. In earlier years such as 1995, where the number of TD publications was negligible, authors associated 100% of the time with also being ID. This potentially illustrates and distorts levels of confusion. However, examining years since 2005, as TD publications have grown, still between 30% and 40% of publications still cross reference being ID and MD. This confusion is still weighted heavily to a TD and ID association. This suggests a lack of distinction between ID and TD approaches, and that researchers are still unable to differentiate.

The small number of publications solely focussing on 'disciplinarity' in Figure 1, shows little research openly addresses the topic itself. Examples that do address the nature of disciplinarity appear to take a historical, abstract, and philosophical stance. Such as those building a picture of emerging and more acceptable hybrid disciplines, in the 'Alterplinarity' of Rodgers and Bremner (2011), the 'kaleidoscope' offered by Sugimoto and Weingart (2015), and 'hybridisation' in Areekkuzhiyil (2017). Approaches that discuss combining disciplines may not name the disciplinary term. Examples in literature are the convergence paradigm and its direct application to combining disciplines. Researchers here find less collaboration occurs where a knowledge disparity is greater (Li and Yu, 2024). There is obvious correlation to the knowledge systems in disciplinary texts (Jantsch, 1972), but few if any empirical studies of the nature of disciplinarity exist.

Publications pertaining to address explicit disciplinarities, are shown in Figure 1, a huge majority addressing MD, is followed by ID, thus in comparison leaving TD in its infancy. A review of publications of this scale becomes difficult to conduct, but differences between disciplinarities are rarely addressed explicitly and scientifically (Lattanzio et al., 2020), leaving claims of being from a disciplinarity left to researchers' perspective (Carey et al., 2020; Rodgers and Bremner, 2011; Sugimoto and Weingart, 2015). More recent literature focuses on the definition of disciplinary approaches in particular aspirational TD or ID approaches (Ertas, 2010; Gooding et al., 2022; Lattanzio et al., 2021; Carey et al., 2020; Wickson et al., 2006; Pohl, 2011; Hall et al., 2008; Wognum et al., 2019; Bruun et al., 2005; Tress et al., 2003; Vienni-Baptista, 2023; Hirsch Hadorn et al., 2008; Huutoniemi et al., 2010; Bina et al., 2019; Pohl and Hirsch Hadorn, 2007). Often research opts not to distinguish clearly between them or finds difficulty in separating higher level approaches (Hall et al., 2008; Vienni-Baptista, 2023; Sajdakova et al., 2022; Lattanzio et al., 2021; Carey et al., 2022; Bina et al., 2019).

Alongside this difficulty there is specific research written to guide TD teams, aiming for key elements such as strengthening interactions, supporting diversity and

communication (Waite et al., 2023). These works claim a similar TD agenda and aims such as communication, shared goals, and bringing together different experts (Waite et al., 2023; Wognum et al., 2019; Lattanzio et al., 2020; Jantsch, 1972). But differentiating publication content and approaches becomes troublesome, where key elements and aims are not consistent, especially as many works have similar terms and characterisations (Lattanzio et al., 2020). Few examples of work with distinct features of TD exists, but the work of Lattanzio et al. (2021b), suggest there are distinct potential identifying features.

It is accepted that differing schools of thought exist for TD work leading to divergent definitions (Wognum et al., 2019; Vienni-Baptista, 2023; Sajdakova et al., 2022). There is also argument that this lack of distinction is valuable in the creation of useful discourse (Vienni-Baptista, 2023). The authors here would argue that this leaves disciplinary concepts highly abstract and indistinct, both making it difficult for researchers to understand 'what' might be expected of their suggested approach and supply little scientific basis upon which to hypothesise and assess any real-world value. This is especially true for seeking objective measure of disciplinarity (Carey et al., 2020). A convergence of sorts is overdue to make sense of value, create meaningful empirical measures (Maxwell, 2022; McGaghie et al., 2001; Varpio et al., 2019) and for us to truly define transcending methods.

While some research has tried to define specific disciplinarities, a clear conceptual definition of disciplinary levels is yet to be converged upon. There is a gap in research understanding of what each disciplinarity constitutes, especially without impartiality of personal perspective. This limits the scope of ID and TD work where the differentiation appears to be most troublesome. The contribution of this paper is the extraction of concepts from disciplinary literature to find an agreeable list of key elements to describe and model common disciplinary levels. The most frequent literature derived concepts and associations are used to create the disciplinary model independent of the author's own view. The method undertaken to carry out this literature led inquiry and the sequence of studies used to build the disciplinary model are outlined in the next section.

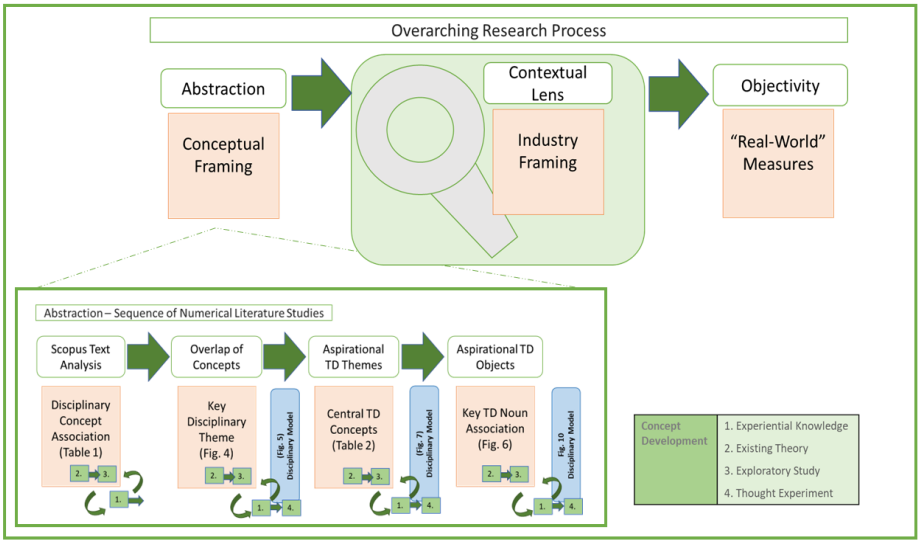
3 Research method

The purpose of this paper is to create an agreeable theoretical and academic consensus on 'what' disciplinarity should be concerned with, using empirical experiments from established theory and literature (Maxwell, 2022; McGaghie et al., 2001). The use in the future of an agreeable conceptual model for disciplinarity needs to be used to investigate with industry their current need and understanding, forming a contextual basis and application of disciplinary 'things' (Jabareen, 2009). In the future this will distil objectivity to scientifically develop and test 'real-world' disciplinary best practice and create benchmarks for industry optimisation and support.

The illustration in Figure 3, outlines the wider research that is needed to optimise and understand industry disciplinarity and value. Figure 3 also supplies a sequence flow of the literature studies conducted in this paper and shows how each is used to create and develop the disciplinary model. The types of study used from conceptual theory development are outlined and then sequenced to create the methodological framework used in this work. In Figure 3, the first step, labelled abstraction has the literature processing in this paper, to construct a conceptual model to show the key aspects core to

disciplinarity. This is then used to expand on and differentiate common levels of disciplinarity. The process uses the four main types of study outlined in the conceptual theory development by Maxwell (2022), sequencing research studies that build upon each other. The second step in Figure 3, describes the need for a contextual industry perspective on current disciplinary challenges, and the third step would contrast and compare findings to supply an objective and robust 'real-world' basis for developing support for industry optimisation. The steps two and three are outside the scope of the work presented here but are supplied to add context to the overarching aim of the research.

Figure 3 Overview of literature evaluation: stepwise literature text processing (see online version for colours)



3.1 Distillation of disciplinary characteristics

Very few apart from Jantsch (1972) sought to create a framework for thinking about and combining all disciplinary things (Sajdakova et al., 2022; Lattanzio et al., 2020; Kharlamov et al., 2019). Most literature seeks to pertain to disciplinarities without real measure (Carey et al., 2020), this is influenced even more in current trends by the move towards higher levels of disciplinarities seen in literature (Lattanzio et al., 2021) and funding expectations (Lattanzio et al., 2022). Figure 1 shows the exponential growth of the term TD in literature, prior to 2005 the term was not commonly found. As discrepancies in the literature and current thinking suggest confusion, it is necessary to find a common conceptual frame and research suggests that all academic studies begin with such (Leshem and Trafford, 2007; McGaghie et al., 2001). This is synthesised from literature using content analysis, text analysis, language association modelling, machine learning for clustering terms and brought together using postprocessing of text and conceptual thought experiments. This uses literature concepts and associations to robustly converge upon 'what' is agreeable and understood, thus removing purely opinion-based findings. In this way consensus can be progressed rather than opening wider divisions in

opinion. This will confirm and verify studies that are needed for concept framing (Maxwell, 2022).

Similarly holistic systems approaches use top-down deconstruction of theory combined with bottom-up construction to arrive at an agreeable middle ground in complex theory development, the literature and text is used here in a similar manner, using language association to common disciplinary terms and nouns to find labelled objects as descriptors (Bennett et al., 2002). This gives a starting basis for understanding a 'real-world' baseline. The approaches presented in this paper first deconstruct literature into its constituent content in Table 1 and post processing with frequency analysis is then used to create a Venn diagram of key disciplinary associated terms in Figure 4. Figure 4 is then used to construct a model of important disciplinary concepts modelled in a commonly accepted disciplinary levels hierarchy (Maxwell, 2022). This is used to manually create a model of key disciplinary associated things in Figure 5. These concepts are built on using natural language associations in engineering literature to delve into specific content of higher levels of disciplinarity currently seen as aspirational (TD). In Figure 6 the most frequent TD associated nouns (or things) are shown, these are then used to add depth and detail to the model in Figure 5. As a result, of the frequent terms shown in Figure 6, a revised disciplinary model is created and shown in Figure 7. Further processing of the frequent terms from Figure 6 use machine learning methods or clustering to overcome synonyms in natural language. An overview of this clustering process is shown in Figure 8. This result of a textual cluster is shown in Figure 9 to supply an example of how synonyms are grouped. A best central clustering for synonyms is not possible, but a manual card sorting method is used with experts to create three optimised clusters that are shown in Table 2. The central terms in Table 2 are used to confirm findings and add further to the disciplinary model, the resulting and optimised disciplinary model is shown in Figure 10 (Jabareen, 2009; Varpio et al., 2019).

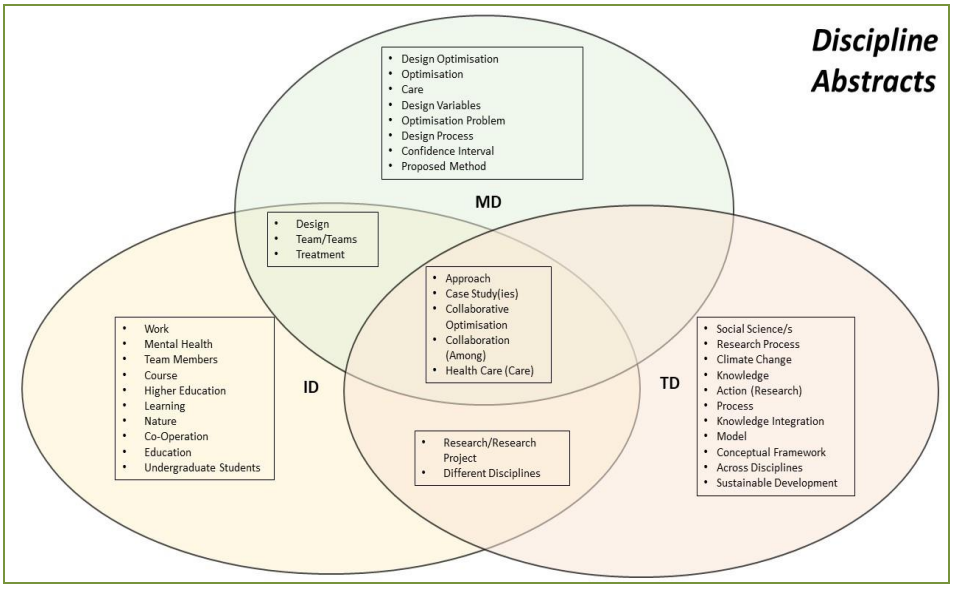
Table 1 Percentage of term occurrence in each disciplinary sample

MD terms	*%*	*ID terms*	*%*	*TD Terms*	*%*
Design	8.3	Research	5.4	Research/research project	11.5
Team/teams	7.1	Team/teams	4	Approach/approaches	7.1
Design optimisation	5.7	Approach	3.6	Case study/ies	4.7
Approach	4.4	Case study/ies	2.5	Social science/s	2.6
Optimisation	2.1	Healthcare	2.4	Research process	1.5
Healthcare	2.0	Collaboration	2	Climate change	1.5
Care	1.9	Work	1	Knowledge	1.3
Treatment	1.7	Mental health	0.9	Healthcare	1.3
Design variables	1.4	Different disciplines	0.9	Action research	1.3
Optimisation problem	1.3	Team members	0.8	Process	1.1
Design process	1.3	Treatment	0.8	Knowledge integration	1.1
Case study	1.2	Design	0.8	Model	1.1
Collaborative optimisation	1.2	Course	0.8	Conceptual framework	1.0
Confidence interval	1.2	Higher education	0.8	Across disciplines	1.0
Proposed method	1.2	Learning	0.7	Different disciplines	1.0
		Nature	0.7	Sustainable development	1.0

Table 2 Cluster central term

	C (*1*)	*C* (*2*)	*C* (*3*)
Central Term (1)	Teams/Organisation	Research	Education
Central Term (2)	Model	Communication	Action
Central Term (3)	Knowledge	Process	Program
Central Term (4)	Communication	Action	Model
Central Term (5)	Project	Development	Character
Central Term (6)	Process	Teams/Organisation	Communication
Central Term (7)	Action	Model	Environment

Figure 4 15 most frequent disciplinary terms from 8834 Scopus abstracts with 76,522 text terms for MD, ID, TD and their intersection (see online version for colours)



4 Resulting transformation

Here we supply the results of a sequence of findings from literature sampling that have been conducted to build upon the experience of academic literature to find the core content of disciplinarities i.e., the 'what' is disciplinarity (Maxwell, 2022). Throughout this section, each literature investigation is described in turn, each adding its findings to contribute to an evolving disciplinary model. This disciplinary model is changed in simple steps using the findings from each investigation (Jabareen, 2009).

Figure 5 Model of most associated text terms for disciplinarity, MD, ID and TD (see online version for colours)

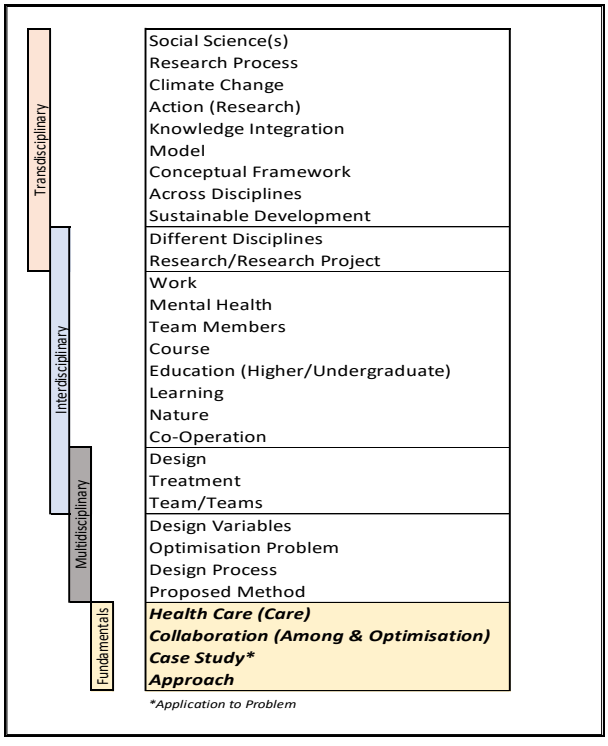


Figure 6 25 most frequent transdisciplinary nouns from 4497 abstracts as a percentage of the 1149 text terms found in engineering literature from Scopus (see online version for colours)

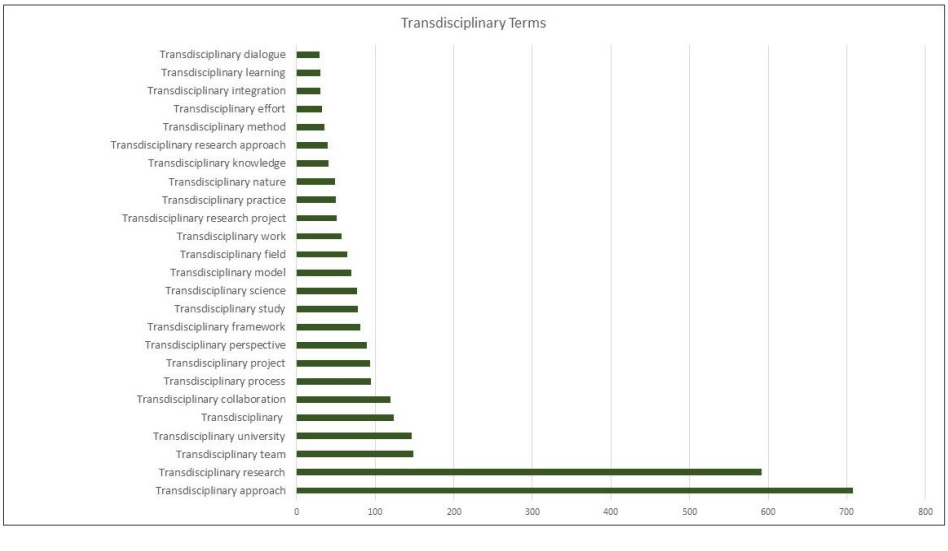


Figure 7 Revised model of most associated text terms for disciplinarity, MD, ID and TD (see online version for colours)

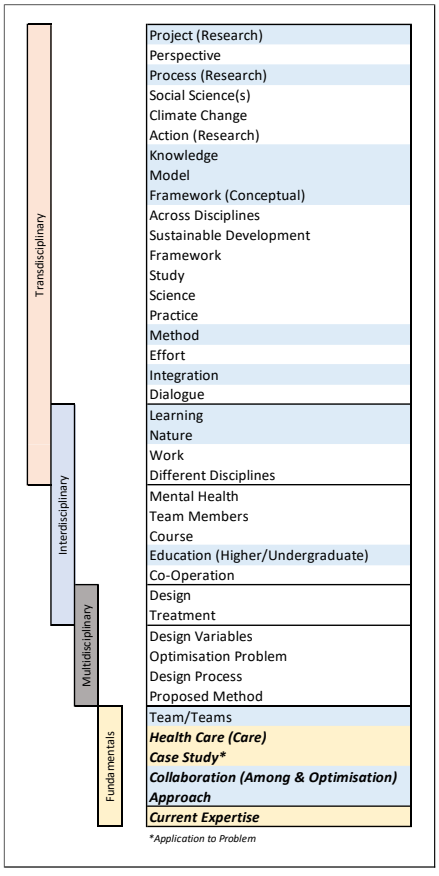


Figure 8 TD text term clustering process for key transdisciplinary characteristics (see online version for colours)

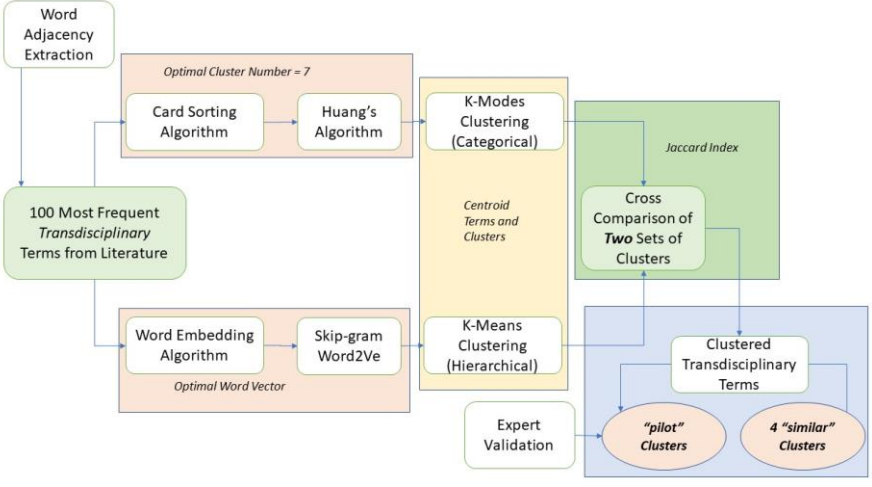


Figure 9 Word cloud of examples for transdisciplinary text clusters

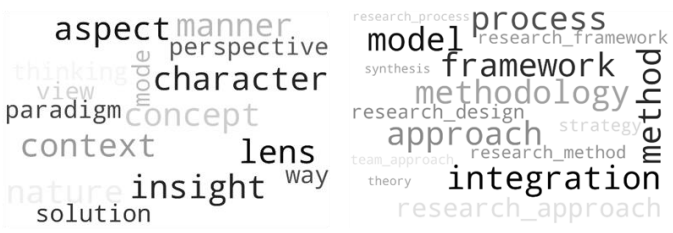
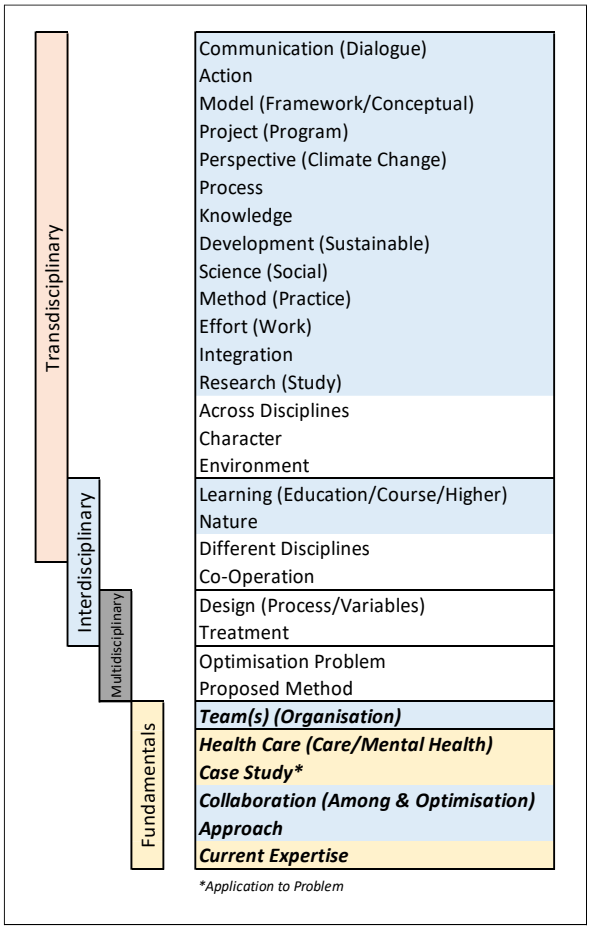


Figure 10 Disciplinary model to find disciplinary levels: final model of most associated text terms for disciplinarity, MD, ID and TD (see online version for colours)



4.1 Disciplinarity in engineering: key aspects from content

We first need to numerically quantify the content of literature the core content or aspects involved in disciplinarity; hence it makes sense to use the body of academic literature to derive key aspects or frequent themes. The current lack of consensus that pervades disciplinary theory requires a method independent of perspective to derive core content

aspects. The utilisation of Scopus as a focus of literature analysis supports the need for combining knowledge from more than broad disciplines. The purpose of this study is to find key aspects of common disciplinarities. In Jantsch's defining model for disciplinarity the types of ID are differentiated, for example 'normative ID' and 'teleological ID' would encompass engineering works, while 'purposive ID' would encompass core science expertise with humanities. In future works the capture explicitly of differentiating concepts associated only with 'purposive ID' may be useful, but literature does not yet differentiate. One interpretation could be is researchers associating with approaches do not yet understand these nuances (Sajdakova et al., 2022). The secondary use of engineering literature for aspirational TD in this paper, does not exclude the works encompassing 'purposive ID' as the use of Jantsch's TD would encompass all. It is possible its close association with TD may prove to be more difficult to differentiate in the future, as TD defined engineering may strongly associate with policy focussed works (Sajdakova et al., 2022).

The process of automatic text extraction and frequency analysis supports evaluation of content frequencies independent of bias and are used to form the basis of the first conceptualisation of disciplinarity in Figure 5. The original literature content analysis and natural language processing method is reported fully in Carey et al. (2020), with a summary in this paper of process, content frequencies, disciplinary associations and content overlaps supplied below in Table 1 and Figure 4.

A process of literature search and extraction was designed to find author disciplinary association. The search assumption was that the disciplinarity of a text pertains to the inclusion of a disciplinary term such as 'multi,' 'inter' or "trans", if it is present in the abstract, keywords and title of the literature in Scopus. The abstract text was downloaded in .csv format and associated with its disciplinarity for further analysis to substantiate the approach. The abstract text was pre-processed using established natural language processing methods, reducing syntax to lowercase, removing stop words (such as "and," "or") and applying word stemming (normalising syntax variations such as "arity" or "ary"). A search of the Scopus database for literature that pertained to at least one disciplinarity yielded a dataset of 8834 abstracts dating from 1970 through to 2018. The abstract text of these papers was analysed using pairs of words or 'bi-grams' to create a corpus of 76,522 terms associated with either MD, ID or TD. The resulting list of terms extracted produced a list of terms associated to each disciplinarity and ranked by importance using frequency ratios to show relative sample significance. These results were manually post-processed to standardise singular and plural forms, merge synonyms, nouns, gerunds, abbreviations and acronyms. The original ratio frequency values are normalised to the number of documents in each disciplinary sample to enable their direct comparison. The normalised percentage contents are shown in Table 1. The normalisation is based upon each respective disciplinary sample size (number of documents), allowing for direct sample proportion comparisons to be made.

The results from Table 1 are manually analysed to find any overlaps in key topics related to each disciplinarity. As a result, a Venn diagram is created in Figure 4 showing the top 15 most common concepts for each disciplinarity. Figure 4 details those topics most often associated by authors for each disciplinarity. It highlights where there are terms that occur commonly for more than one disciplinarity. There are concepts that appear in all disciplinarities, this could suggest they are the overarching focal point of disciplinary methods, such as to define an 'approach', or provide 'collaboration/ collaboration optimisation' and 'case study'. Contextual terms also arise such as

'healthcare', but the significance of these cannot be derived other than they feature highly in disciplinary literature for this period. Contextual terms may appear as a future trend, or the topics emerging may evolve over differing time periods. Figure 4 does show a clear distinction between MD and TD approaches in the lack of overlapped terms, but far less differentiation between MD and ID, or ID and TD is seen. This suggests a scale exists with MD and TD being distinguishable polar points rather than overlapping.

Differentiation of the key content for each of the disciplinarities shown is possible using the terms extracted in Figure 4 and this forms the basis for creating a disciplinary model of the key concepts associated with each disciplinary level. This model shown in Figure 5, is created manually using the terms and associations found in Figure 4. The model follows the accepted disciplinary levels, with the addition of a core disciplinary level. This is reinforced by the findings in Figure 4, that a scale exists where MD is highly distinguished from TD. The model terms are listed and pass through, a historically agreeable disciplinary scale, namely MD, through ID to TD (Lattanzio et al., 2020). Each term added to the model is associated with the disciplinary association found in literature frequencies. Terms occurring most often are considered of higher importance and placed higher in the disciplinary model. Frequent terms occurring in more than one disciplinarity are marked grey showing less clarity. Common to all 'disciplinarities' is 'collaboratively optimising' or 'collaboration among', giving rise to a notion this is the overarching purpose of any 'disciplinary' working practice or denoting a special type of collaboration. A separate category of central terms for disciplinarity is hence added.

4.2 Transdisciplinarity in engineering: key aspects from content

The model in Figure 5 and in Figure 4 we find concepts or terms that are used to describe more than one disciplinary category, highlighting where it is difficult to clearly distinguish one disciplinarity from another. Research investigating the highest levels of disciplinarity (ID and TD) also cite they are harder to distinguish and more often misappropriated (Carey et al., 2020; Sajdakova et al., 2022; Lattanzio et al., 2020; Vienni-Baptista, 2023). So, finding 'what' constitutes aspirational TD is useful to verify Figure 5 (Jabareen, 2009; Maxwell, 2022) and build on the key differences in content of higher disciplinary levels. A second literature study seeking 'concepts' described as TD using word association from natural language processing is conducted. The nouns next to TD in engineering literature are extracted from text abstracts and a frequency analysis suggests those most associated terms. The sampling of engineering limits the number of resulting literature texts to make the sampling manageable and ensures that multiple disciplines are included in the resulting TD literature.

In this study the Scopus database was searched to find all research papers that described themselves as transdisciplinary in the keyword, abstracts, or title. This yielded 4639 documents on 30th March 2020, and of these documents 142 abstracts were unavailable, leaving a sample of 4497 abstracts for evaluation. The relevant terms were extracted using Natural Language Processing (Loper and Bird, 2002), first reducing the data to a set of individual words. The words next to (word adjacency) the word 'transdisciplinary' were annotated and extracted. This list of words was reduced to the root derivative and grouped for sense making (or lemmatisation). For example, 'approaches' becomes 'approach' and grouped with all instances of the 'approach' concept. This created a list of 1149 TD terms and frequency occurrences, the 25 most frequent are shown in Figure 6. The 100 most frequent terms in this sample occur at least

eight times each and form 70.3% of the overall extracted terms. This shows confidence in the sample being representative of most 'transdisciplinary' concept possibilities. This process was confirmed using three academic experts to independently examine a sample of 90 randomly chosen abstracts, to compare the terms manually extracted. The comparative accuracy was 99.9% and hence the method considered robust.

The conceptual terms in Figure 6 expand our knowledge directly from the TD literature and used to expand the disciplinary model in Figure 5. The terms in Figure 6 are added to those in Figure 5 expanding the TD concepts and clarifying any differentiating concepts. The resulting is an evolved disciplinary model shown in Figure 7. Our assumptions are to compare and add each of the top 25 terms in order of frequency, using a common-sense approach to find the applicability of each term. For example, 'approach' is the most frequent term but occurs in Figure 5 core to defining disciplinarity, hence this confirms its importance in the model (shown in Figure 7 with blue highlighting). Another example is 'teams', this already occurs between MD and ID, but appears related to TD and is moved down the model becoming core to all disciplinarities.

Whilst not exclusive, newly identified terms include 'dialogue' or 'perspective', and these are placed as a concept fitting to transdisciplinarity. The occurrence of the term 'process' indicates importance and hence becomes an important and independent feature of transdisciplinary.

4.3 Transdisciplinarity in engineering: aspirational themes

The use of language from literature to derive concepts, introduces the element of synonym interpretation to the findings. This is notable in Figure 7, in the separate terms such as 'education' and 'learning'. This evaluation is subjective, and rationalisation based upon researcher perspective. To conduct this objectively the artificial intelligence method, machine learning, was used to create clusters of related words. The optimised clustering method being driven by manual expert perspectives collated in a card sorting process. The full study conducted using both manual and machine learning methods for comparison is published in Carey et al. (2022). The aim being to cluster TD terms finding potential central concepts, these concepts guide the key TD content needed in any disciplinary model. This paper supplies an overview of the work (shown in Figure 8) and suggests how this contributes to the development of a disciplinary model. The full method would be outside of the scope of this paper.

In this step of the research, the top 100 most frequent transdisciplinary terms (see Figure 6) are utilised, each standing for a single data point for clustering to other closely related terms. This data was needed to suit both a manual card sorting algorithm and an automated machine learning algorithm, serving the purpose of directly comparing results for each approach. The manual expert approach of associating words (Paul, 2008; Nawaz, 2012; Spencer and Todd, 2004), was designed to be compared to that of an automated algorithm (Mikolov et al., 2013; Miller, 1998; Devlin et al., 2019), finding similarities to relate and hence validate any central terms that result. The clustering or card sorting process results are neither right or wrong but can be compared to a mindset or metric. In this case comparison of card sorting central TD concepts supports finding the best automated algorithm list of central TD concepts. The process shown in Figure 8 involved using Natural Language Processing techniques (Loper and Bird, 2002), machine learning (Mikolov et al., 2013; Miller, 1998; Devlin et al., 2019) and manual (card sorting using

20 subject experts) (Paul, 2008; Nawaz, 2012; Spencer and Todd, 2004) methods to create word associations resembling synonyms. These primitive synonym sets were then used in later automated algorithms to cluster the terms based on each of the predetermined synonym datasets (Kaufman and Rousseeuw, 2009; Ketchen and Shook, 1996). The types of data that were processed from each comparative set of synonyms means that two clustering algorithms were needed, namely k-modes (categorical) (Huang and Ng, 1999) and k-means (hierarchical) (Huang, 1998), the results were iteratively optimised to produce representative sets of clustered terms. Two example clusters that result from the card sorting process are shown in Figure 9. The clusters overlapping by 50% or more in topic had terms related to, 'research environment', 'communication', 'perspective' and 'method'. This process resulted in differing sets of clustered terms, each optimised to stand for a particular mindset or view of the corpus of data. When comparing the results of the card sorted cluster results to those of the word embedding, overlap in terms appear in 50% of terms in clusters, giving rise to four hypothesised themes that recur, namely 'research environment', 'perspective', 'method' and 'communication'. A sample of three clusters and the themes the collective terms stand for are shown in Table 2 for comparison.

The common themes that occur in the clusters in Table 2 show the significance of each concept in literature. The importance of these concepts is used to verify and add to the disciplinary model. Clear and common themes occur, but central concepts occurring most often (three or more times) are considered most significant.

4.4 Disciplinary model to find disciplinary levels

The central concepts in Table 2 are manually used to expand our knowledge from the literature about the defining text terms or concepts of TD and thus used to separate the literature thinking about ID concepts. This is used to evolve the content of the disciplinary model (to create Figure 10), comparing those already associated in the disciplinary model Figure 7 and using the central concepts in Table 2 to expand and refine the concepts that describe and differentiate disciplinarities. The resulting disciplinary model is shown in Figure 10, and the concepts can be used to evaluate a level of disciplinarity that a researcher or projects may be working at. Changes made from Figures 7–10 include, using the results of the literature and clustering analysis process the term 'teams' becomes 'teams/organisation' to accommodate synonym terms and already features as key to disciplinarity fundamentally. The term 'research' becomes a separate concept, and 'communication', 'model', 'action' become more significant. Terms repeated from prior results become verified and are highlighted in blue. Terms added from the central concepts in Table 2 are aggregated to simplify especially where there are strong associations (or occurring across the clusters). The resulting model shown in Figure 10 has then been simplified to stand for single themes where possible or to adapt terms such as 'sustainable development', becoming 'development (sustainable)'. This clarifies the core concept without losing the detail from literature text and these concepts can be compared to evaluate the level of disciplinarity being achieved.

In creating the disciplinary model in Figure 10, we have used robust and empirical approaches to distil key disciplinary aspects from academic literature. These key concepts iteratively been collated from the literature in this paper. These concepts and their association are used to add to the disciplinary model, verifying, adding, or comparing to other results. These concepts are drawn upon from academic literature, meaning they will

be useful and understood best by academic researchers. Steps two and three detailed in the overarching method in Figure 3, consider contextual elements important to industry, aiming to make disciplinary methods accessible to manufacturing in the future, these studies form future work focused on industry support requirements.

5 Summary, discussion, and implications

The academic literature content analysis and language processing outlined in this paper have together created a robust approach to find key terms or concepts that are associated with specific levels of disciplinarity. It has also enabled the iterative creation of a model of disciplinarity with concepts that have been confirmed and prioritised key disciplinary concepts (see Figure 10). This suggests it is possible to model with accuracy key concepts that differentiate between levels of disciplinarity contrary to difficulties reported in prior studies (Hall et al., 2008; Lattanzio et al., 2021; Vienni-Baptista, 2023), especially for ID and TD levels. It also becomes clear in Figure 10 that there are aspects that are fundamental when discussing any levels of disciplinary work, such as 'Teams', 'Organisation' and 'Approach', but there are terms appearing to relate to the context of theoretical application, such as 'healthcare'. This could suggest in future work however, that to study disciplinarity, we may need to study a 'healthcare' context, where approaches may already be applied.

This type of experimentation using automated approaches from text extraction and artificial intelligence process to synthesise concepts from large data samples, that through a traditional literature review would be difficult to achieve (Kaufman and Rousseeuw, 2009). This both collects data from broad and representative samples, but creates content in an unbiassed manner, reliably capturing more possibilities and hence academic opinions (Ketchen and Shook, 1996; Loper and Bird, 2002; Jiang et al., 2021). The model created in Figure 10, could thus be considered an agreeable representation of complex academic mindsets, which are considered challenging to merge (Vienni-Baptista, 2023). This agreement can now be used to form a baseline for future research and can be used to scientifically develop on disciplinary theory (Jabareen, 2009), forming the basis for comparative analysis (Jabareen, 2009; Varpio et al., 2019; Maxwell, 2022).

It is important to acknowledge that all modelling poses limitations and in suggesting a disciplinary model this paper uses academic theory to make samples manageable. A wider non-academic mindset could raise new concepts or change the priority of key aspects and while the purpose here was not verification, the limitations of this model would be the academic mindset rather than industry focus. Similarly, Leshem and Trafford (2007) suggest that a conceptual basis would pass the scientific test, but Jabareen (2009) rightly extends to showing for this to be robust the next steps would have to be verify this model in any future work and this extends to industry application (Carey et al., 2021). This could mean that the disciplinary model produced is representative of an academic conceptual basis and requires validation before suggesting it is all encompassing. Without verification, the risk is this could also represent just another view in the convoluted disciplinary disagreement that exists (Vienni-Baptista, 2023; Hayman, 1974; Sajdakova et al., 2022; Carey et al., 2020; Lattanzio et al., 2021; Gooding et al., 2022) adding to the 'alterplinarity' or 'kaleidoscope' terms coined in the work of Rodgers and Bremner (2011), and Sugimoto and Weingart (2015) respectively. Nonetheless, given the empirical and automated approach to modelling used it is purposely not swayed by

any individual schools of thought. This uses it as the unbiased centralised theoretical meaning, and it can be relied upon for comparison to be drawn on in future research.

Clear examples in Figure 10 differentiate distinct levels of disciplinarity, such as the unique finding of 'perspective', 'integration' and 'action' in TD work. Overlap does exist if we compare to the seven characteristics of TD work in Lattanzio et al. (2021b). We notice common TD terminology, is 'knowledge' and 'communication', or in fundamental disciplinary terms such as 'approach' and that these are highly relevant as are also challenges reported directly by industry (Carey et al., 2021). More abstract however, is the overlap also found in ID work where 'learning', 'different-disciplines' and 'cooperation' are important. It appears that synonyms or potential descriptors of scale occur at disciplinary levels, such as the ID related term 'learning' is progressed to the TD term 'knowledge'. Another example is where the ID term 'cooperation' becomes the TD term 'integration'. Couple this with the knowledge that industry and manufacturing problems and projects are becoming more abstract (Sajdakova et al., 2022) and that some terms in Figure 10, are arguably abstract, such as TD 'perspective', we find that much work needs to be done to elaborate and simplify 'what' this might mean for designing meaningful support to provide immediate value. It is possible that works that do not label themselves as disciplinary are solving similar TD issues, such as 'integration' needs in digitalisation, integrating technology and people (Shuttleworth et al., 2022). Shuttleworth et al. (2022) find in investigating institutional digitisation that transformations cannot happen in a vacuum and human aspects such as knowledge and communication should be used with digital support useful only for optimising enabling industry factors. Progressed research such as this should be acknowledged explicitly as potential solutions in future research, thus leveraged and prioritised if we are to meet the TD agenda.

6 Conclusions

In this paper found that research has not yet agreed upon clear defining concepts for each level of disciplinarity and that the higher levels of disciplinarity are more challenging to distinguish. This is particularly true for researchers attributing their work to one approach or another in literature. The authors suggest this is necessary before we can use disciplinarity to evaluate what the real-world value might be for using higher levels of disciplinarity such as TD. It is even more important to be able use this to support industry with suitable and value laden approaches or to benchmark their current practice. Hence in this paper we have used a sequence of literature content analysis studies to find the most used research concepts and their disciplinary association. Using this we have created a robust model of disciplinarity that differentiates between common levels. The findings in this model also includes core defining concepts of all disciplinary approaches.

Our results show it is possible to derive a disciplinary model using literature concepts and associations. It has been possible to find differentiating concepts for ID and TD literature, and in the future it may be possible to find a scale of how to apply disciplinary concepts. However, the limits are that the samples used do not stand for the full extent of literature, wider disciplines or disciplinarity in an industrial context. The model now needs to be verified by extending the research to include wider samples of literature that includes all disciplines and hence perspectives. Further work will need to focus upon the defining the separate application of "purposive ID", to separate it from truly TD works. It is also necessary that the context of industry and meaning of disciplinarity is investigated

to be able to apply and evaluate aspirational levels of disciplinarity and consider the value that may be possible to achieve in applying it. The focus of research now needs to be upon two key areas; firstly, verifying the disciplinary model; secondly evaluating the potential for using the disciplinary model in industry, considering challenges such as language and organisational concerns.

Acknowledgements

The authors would like to acknowledge the contributions from our wider TREND research group for their participation in expert studies and continued guidance throughout this project, without this, this work would not have been possible. The authors also acknowledge, 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.

Data availability statement

The authors confirm that the literature related data supporting the findings of this study are available for a period upon request or can be reproduced providing they can be retrieved according to the search process and processing described in the paper, through the open Scopus repository, correspondingly, at https://www.scopus.com/search/. In instances, due to the sensitive nature of commercial information it is unable to be released.

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