Proposal of a Self-Assessment Competency Framework for Transdisciplinary Engineering.

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Abstract. Transdisciplinary working is claimed to be critical to meet future societal needs, with engineers being at the core to provide solutions to these challenges. However, there is little available that enables one to assess whether they or their team have the competencies required. Within this paper we propose a self-assessment framework to ascertain whether design engineers have the competencies which enable transdisciplinary working. We describe how the competencies were identified using a systematic literature review, we then describe how we utilised coded decision trees to classify which disciplinary level a particular competency can enable. In total 76 competencies were classified; the results of the analysis show 20 of these displaying transdisciplinary attributes as defined by Jantsch. The novelty of the approach: (1) In this paper we propose a novel way to map the identified competencies against the levels of Jantsch's hierarchical framework. (2) The proposed framework enables self-assessment of individual or team competencies to assess whether they have the competencies which enable transdisciplinary working. (3) It enables a move towards incorporating transdisciplinary practices in engineering projects.

Keywords. Transdisciplinarity, Transdisciplinary Research, Transdisciplinary Engineering Research, Design Engineer, Competencies, Skills, Trasdisciplinary Competencies

Introduction

Literature highlights that practical solutions to complex societal problems such as Grand Challenges (Ferguson et al., 2017, NAE, 2012) and meeting 2050 climate change targets (UN IPCC, 2014; UN IPCC, 2019; WEF, 2019) will require a transdisciplinary (TD) approach (Bernstein, 2015; Brandt et al., 2013; Lattanzio et al., 2020; Mitchell et al., 2015; Mogles et al., 2020; Mollinga, 2009; Norris et al., 2016; Tejedor et al., 2019; Wognum et al., 2018; Wognum et al., 2019). TD approaches involve the integration of a range of technical and social disciplines, and wider stakeholders all working towards a common goal for societal good (Jantsch, 1970; National Academy of Engineering, 2012; Peruzzini and Stjepandić, 2018a, Peruzzini and Stjepandić, 2018b; Stokols et al., 2008; Wognum et al., 2018). Complex engineering problems such as the design of large-scale engineering systems and industry 4.0 smart manufacturing require knowledge integration from a range of stakeholders. The work by Peruzzini and Stjepandić, (2018a);

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Peruzzini and Stjepandić, (2018b); Wognum et al., (2018) and Wognum et al., (2019) highlight that this requires transdisciplinary engineering (TE) approaches.

Increasing societal value is arguably one of the main benefits of a TD approach. However, implementation of TD working faces a number of inherent, institutional and team working challenges (Gaziulusoy et al., 2016). Challenges related to team working include collaboration and knowledge sharing across disciplinary boundaries, across different professional cultures and cultural backgrounds (Beckett and Mo, 2019; Beckett and Vachhrajani, 2017; Frescoln and Arbuckle, 2015; Gaziulusoy et al., 2016; Hall et al., 2008; Hall et al., 2019). Other identified challenges include communication and language barriers (Frescoln and Arbuckle, 2015; Gaziulusoy et al., 2016), different geographical locations of development activities (Mathiasen and Mathiasen 2017), conflicting goals among team members (Charnley et al., 2011) and team formation (Norris et al., 2016). Specifically, in an engineering context the implementation of TD working in practice faces additional challenges because TD approaches are not generally considered in engineering projects (Goudswaard et al., 2020; Kharlamov et al., 2019). Furthermore, there is a gap in digital skills required to analyse and understand increasingly complex multidimensional data and knowledge produced and used by complex TE processes (Abdallah et al., 2021; Peruzzini and Stjepandić, 2018a, Peruzzini and Stjepandić, 2018b). Training of engineers for collaboration and knowledge sharing with other disciplines and stakeholders to generate solutions that increase societal value is crucial to overcoming these obstacles (Wognum et al., 2018). Hence, to transition to ways of working that are societally focused TE design engineers will need to acquire specific competencies.

The purpose of this paper is to understand what competencies design engineers require to work as part of TE projects. The aim is to compile current design engineers' competencies and classify them based on disciplinarity to understand if they can be identified as showing multidisciplinary (MD), interdisciplinary (ID) or TD characteristics. From this we seek to catalogue the competencies critical for design engineers working on TE projects. The work requires answers to three research questions:

RQ1. What are the evidenced competencies for design engineers in the literature?
RQ2. Can these identified competencies be classified based on disciplinarity using the TD hierarchy of Jantsch?
RQ3. Do any of the identified competencies enable TE working?

The paper is structured as follows: section 1 provides the motivation for selecting competencies related to design engineers. In section 2, Jantsch's TD hierarchical system that provides the framework for this study is described. A research approach adopted in this study follows in section 3, with the results presented in section 4. A TE competency framework is proposed in section 5 and results are discussed in section 6. Finally, the implications of the results for TE education, practice and future research are discussed.

1. Design Engineers and Competencies

The term "competency" used in this paper refers to a capacity to effectively perform both task and role and is linked to the designer's skills, knowledge, motives, values, and personal traits (Ahmed, 2007; Robinson et al., 2005). Designers have been classified as one of the three main engineering roles for the future (Ravesteijn et al., 2011), with emphasis placed on the ability to design new innovative products, processes, and solutions (Hicks et al., 2009) and the ability to meet societal needs as a core competency (Dym et al., 2005).

Designers are increasingly collaborating in activities using complex working environments with different stakeholders involved in every aspect of the product lifecycle (Robertson et al., 2007). They are relying on a range of non-technical skills, in particular collaboration with others (Passow and Passow, 2017; UKSPEC, 2013). Technical work only takes up 47% of a typical designer's time, with collaboration skills such as team working, intercultural communication and knowledge management becoming indispensable (Robinson et al., 2005). While technical competencies remain important, they are inseparable from social competencies linked to effective collaboration (Passow and Passow, 2017).

A large body of research focuses on competency requirements of engineers (Passow and Passow, 2017; Robinson et al., 2005), however there is a lack of studies specifically focusing on design engineers (Robinson et al., 2005). It is notable that a large part of engineering competency literature focuses upon engineering education, specifically on closing gaps between skills acquired in higher education and skills required by industry (Abbas et al., 2013; Passow and Passow, 2017).

While engineers have been identified as being integral to solving real-life societal problems (Ferguson et al., 2017; National Academy of Engineering, 2012), TD skills and competencies has received little attention in engineering academic literature. The small number of papers that discuss TD skills and competencies generally focus on education, specifically course design, to encourage TD innovation-thinking (Bender and Longmuss, 2003; Bosman and Arumugam, 2019; Sharunova et al., 2019a; Sharunova et al., 2019b). There is a lack of literature focusing on skill requirements in TE projects, and specifically focusing upon enhancing skills of practicing engineers, which is like the trend observed in engineering design literature. While preparing future designers for TE working is critical, to make an effective TE designer requires competencies beyond those acquired in higher education and will require life-long professional development to address evolving challenges linked to TE projects (Wognum et al., 2018). The research presented in this paper suggests design engineer competencies that are critical for TE projects and hence addresses that gap.

2. Jantsch's TD System

The term TD was first proposed by Jantsch at a conference in 1970, as a hierarchical multi-level, multi-goal education and innovation framework, for an education system (Jantsch, 1970). Within this framework (Figure 1) Jantsch defines four levels: empirical, pragmatic, normative and purposive. The base of the pyramid is the empirical level, composed of individual scientific disciplines i.e., physics. The pragmatic level contains applied sciences, where theories from the empirical level are applied in individual disciplines i.e., engineering. Above this is the normative level, which represents social systems constructs such as norms, laws, and regulations. At the top of the pyramid, sits the purposive level with societal values and meanings.

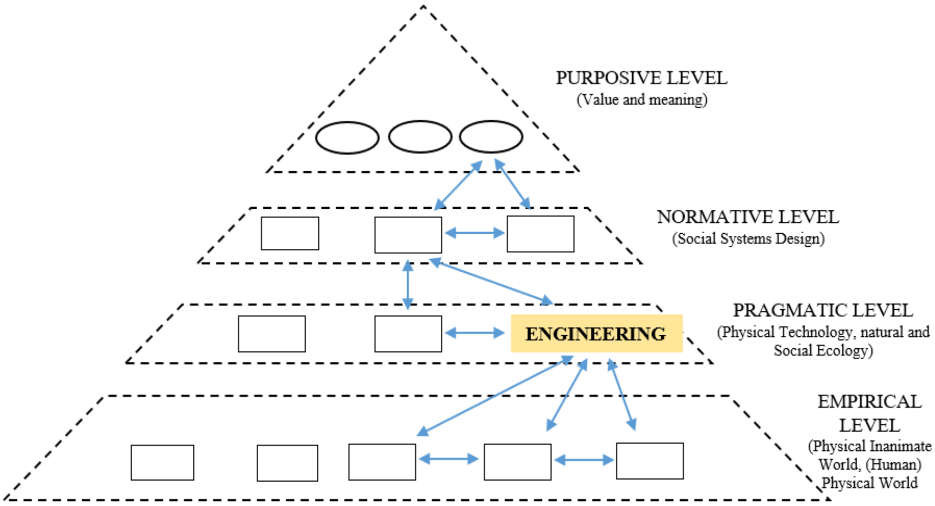
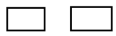
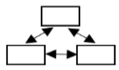
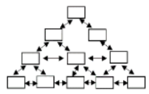


Figure 1. Multi-level, multi-goal, hierarchical system adapted from Jantsch (1970).

The different types of co-ordination and interactions take place within and across the levels, defining the individual disciplinary levels. Based on this framework Jantsch defines six disciplinarities: monodisciplinarity, multidisciplinarity, pluridisciplinarity, crossdisciplinarity, interdisciplinarity and transdisciplinarity (Table 1).

Pluridisciplinarity, crossdisciplinarity and MD involve groups only on one level of the pyramid without co-operation and integration (Jantsch, 1970), hence, from here forwards MD will be used to represent all three. Focus is on ID and TD levels as at these levels disciplinary contents, structures and interfaces change to enable working towards a common goal and new knowledge creation (Jantsch, 1970). ID introduces collaboration and co-ordination of disciplines across two levels of the pyramid, with TD being achieved by transcending boundaries of traditional disciplines and crossing the boundaries between disciplines, across projects, between academia and industry. In TD all levels are integrated; it considers the interactions up and down and across all levels (Jantsch, 1970).

Table 1: Definitions of disciplinarity

Disciplinarity	Definition by Jantsch	Disciplinary rules	System Configuration
Monodisciplinary (M)	Specialisation in isolation One-level, single-goal; no co-operation	One level of Jantsch's framework. No involvement of engineering as an applied science. No involvement of disciplines or stakeholders.	
Multi, pluri and crossdisciplinary (MD)*	One-level, variety of disciplines, no co-operation	Combination of approaches from different disciplines without coordination from higher level.	
Interdisciplinary (ID)	A common axiomatics for a group of related disciplines is defined at the next higher hierarchical level or sub-level, thereby introducing a sense of purpose Two-level, multi-goal; coordination from a higher level.	Two-levels of the Jantsch's framework engaged. Coordination of at least two disciplines	
Transdisciplinary (TD)	The co-ordination of all disciplines and interdisciplines in the education / innovation system on the basis of a generalized axiomatics (introduced from the purposive level) and an emerging epistemological pattern. Multi-level multi-goal; coordination toward a common system purpose.	All levels of Jantsch's framework are engaged. Involvement of more than one discipline at the pragmatic/empirical levels. Collaboration with stakeholders at the normative level. Societal meaning and value are explicitly considered.	

(*) *Within this paper MD for the purpose of mapping encompasses pluri-, cross- and multi-disciplinarity*

While both ID and TD approaches require the crossing of boundaries (Klein, 2008), TD has the highest level of integration (Stokols et al., 2008). For designers, this means they need to effectively interact across all levels of the pyramid and integrate requirements and values of different stakeholders to create societal value.

While this framework is the original TD model (Mitchell et al., 2015) it has not been universally accepted. There exists a plurality of definitions of TD (Pohl and Hadorn, 2007; Swiss Academies of Arts and Sciences, 2018; Tejedor et al., 2019), and a plurality of approaches to differentiate between disciplinary levels (Bruce et al., 2004; CERI, 1972; Pohl and Hadorn, 2007). TD is commonly accepted as the highest level of disciplinarity and exceeds other disciplines including MD and ID (Jantsch, 1970; Lattanzio et al., 2020; Pohl and Hadorn, 2007). Within this work we overcome these difficulties by utilising Jantsch's hierarchical system to classify competencies for design engineers.

3. Research Approach

The overarching purpose of this study is to identify and characterise, in disciplinary terms, the design engineers' competencies within published literature to understand the competencies design engineers may require when working in TE projects. Three steps have been necessary, the approaches for which are introduced below, but in summary;

(i) A literature review to create a comprehensive list of design engineering competencies, (ii) Creation of a disciplinary classification method using Jantsch and (iii) Classification of competencies to derive a list of TD specific competencies for TE projects. The research approach adopted within this research is summarised in Figure 2.

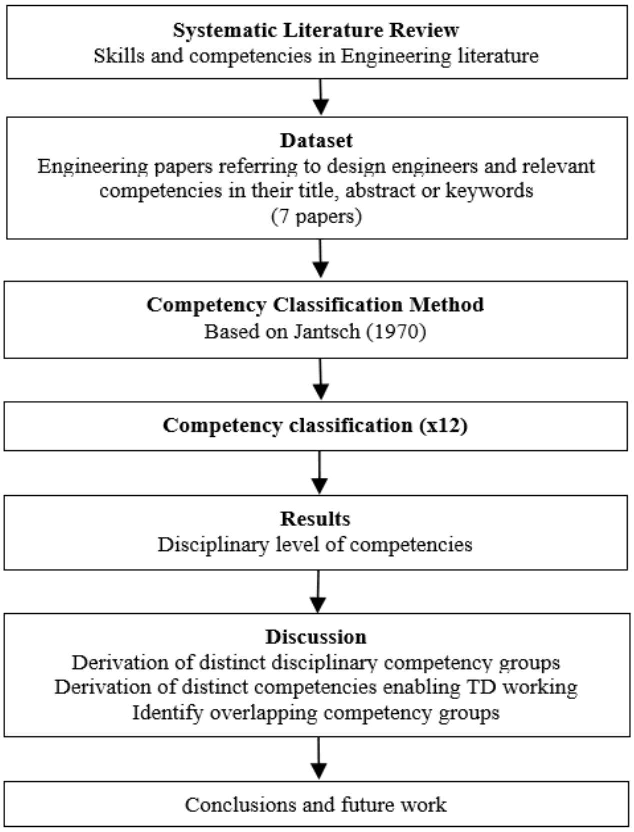


Figure 2: Research Approach

3.1 Literature review method

The review strategy follows the steps of the systematic literature review (SLR) process outlined by Tranfield (2003). The systematic procedure was chosen because it helps to increase rigour, validity, transparency and replicability (Tranfield et al., 2003), by thorough documentation of literature search and review procedure (Denyer et al., 2008; Tranfield et al., 2003). In addition, the stages of the review protocol include feedback loops to enable incorportion of new information and accommodate any changes. This section discusses how the review process was implemented in this study.

The authors formed a review panel composed of experts in a range of disciplines and research interests to guide the process (Table 2). The review panel helped by directing the review process, formulating research objectives and research questions, recommending relevant literature, and contributing to literature inclusion/exclusion decisions (Denyer et al., 2008; Tranfield et al., 2003).

Table 2: Review panel

Name	Role and Title
Profesor Linda Newnes	Professor in the Department of Mechanical engineering. Expert in whole life costing (monetary, environment and societal) which feeds into transdisciplinary engineering specialising in tools, people and processes for effective transdisciplinary working, University of Bath
Profesor Glenn Parry	Professor in Digital Transformation, specialising in value and business models. Expertise in Lean manufacturing, blockchain, complex engineering service systems and supply management. University of Surrey.
Dr. Vimal Dhokia	Reader in Engineering Design and Co-Founder and Director of Gen3D, specialising in the interface between innovation, design and manufacture, personalised design and advanced manufacturing technology. Expert in design and manufacturing spaces. Universtity of Bath and Gen3D.
Dr. Emily Carey	Expert in design engineering knowledge management, transdisciplinary knowledge management and transdisciplinary engineering people and projects, Universtity of Bath

An initial exploratory investigation of research related to engineer's competencies elicited the terms "engineer" "competency" and "skill". These were expanded to include specific keywords used in the literature, constructing the search string in Figure 3. However, due to the large volume of results a pragmatic approach is necessary, so that appropriate search terms and literature resources are captured and employed. The search string was combined in a specific way to address RQ 1: *What are the evidenced competencies for design engineers in the literature?*

"Design engineer"

AND

competenc* OR abilit* OR *skill* OR capabilit* OR *behaviour* OR *knowledge* OR *attitude*

Figure 3. Search strategy

There are limitations to using specific keywords, for example using the term "design engineer" may miss literature not explicitly using this term. Hence, a step was included to add any key references that may have been missed by the systematic search process. The electronic database SCOPUS was selected as it provides a characteristic sample of broad trends in research and covers a wider range of publications compared to the Web of Science (Aghaei Chadegani et al., 2013). As per Tranfield (2003) the different phases of the SLR review are summarised in the process flow diagram in Figure 4:

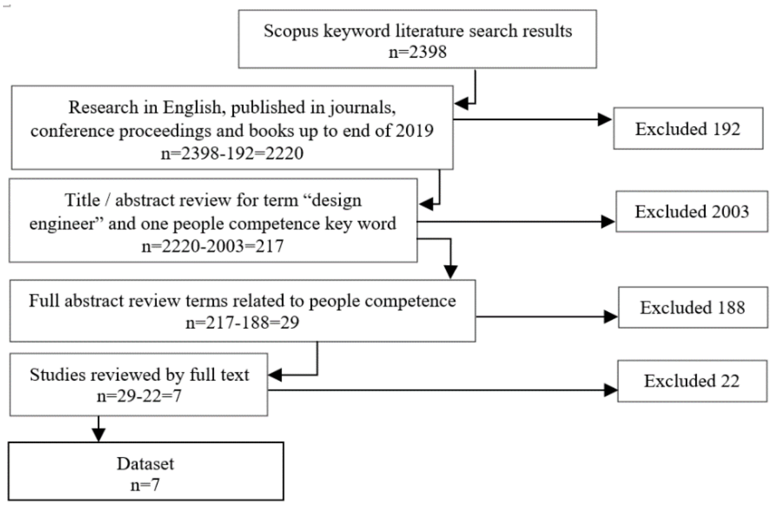


Figure 4. Literature search process

Seven papers addressing specific competency or skill profiles related to design engineers were relevant to our analysis. Three of the seven papers were written by a group of same autors on a similar topic (Leseure et al., 2004). Examination of the three papers revealed that they covered different aspects of competencies and were all relevant to this study review. Hence, the panel decided to include all three studies, in the further analysis. To provide a systematic approach to analysing qualitative data, the thematic analysis method allowed integration of competency data from the seven papers for further analysis (Saunders, 2019). Based on the way the data was provided the overall method used was semantic data extraction (Saunders, 2019) directly from listed competency profiles and from the text. The competencies from seven papers were synthesised into a list of 117 competencies as published in Sajdakova et al., (2020). This original list has since been reviewed and revised, to repeat the prior approach and to reduce overlap in the competency list. This has resulted in a further synthesised list, reducing the competency list from 117 to 76. This additional step in the processing required examination of the compiled competencies, revealing some overlap in terminology, hence duplicates and similar worded competencies have been excluded. This step has enabled a succint condensed final list to be derived without loss in the range of skills represented from the literature. The definitions of competencies have been compiled from the original literature and the Oxford Dictionary where definitions were not originally provided.

3.2 Competency Classification Method

The key to preparing engineers for TE working is understanding their current disciplinary competency level to assist in identifying competency gaps. To achieve this a classification model for the disciplinarity of competencies was proposed in Sajdakova et al., (2020) (Table 3). This model has been formulated using questions for each level of disciplinary working to describe the nature of interactions based on definitions of different disciplinarities in the framework of Jantsch.

Table 3. Competency classification schema

Multidisciplinarity	Teleological Interdisciplinarity	Normative Interdisciplinarity	Transdisciplinarity	General competencies
Is the competency necessary for working in disciplinary isolation?	Does the competency enable capitalization of scientific knowledge from empirical level?	Does the competency demonstrate knowledge of rule and norms?	Does the competency demonstrate purpose consideration?	Is the competency necessary for working in any job?
Does the competency enable awareness or experience of other disciplines without integration of knowledge?	Is the competency necessary for working in engineering discipline on engineering task?	Does the competency enable working with experts from other disciplines/ stakeholders from outside science?	Does the competency demonstrate value recognitions?	Would the competency be in a job description for most jobs?

In total 117 competencies have been mapped using this model, with three identified as MD, 33 as Teleological ID, 26 as Normative ID and five as TD competencies. The remaining 50 competencies were found to be general (G) comptencies or lack context and hence were unable to be clearly classified based on disciplines (Sajdakova et al., 2020). We found that 42% was a high number to be unclassified, hence the motivation for refining this method and new classification tool development.

To build upon this model the original method was refined to ensure replicability, to simplify usability, increase rate of classification and minimise multiple answers. To overcome these problems, increase transparency and comprehensibility a decision tree approach was selected (Delen et al., 2013). The decision tree consists of three levels to elicit the relevant questions that need to be answered for each disciplinary level based on interactions across the levels of the Jantsch's pyramid. This allows a final classification to be assigned with competencies being sorted into groups as questions are presented in the decision tree. Starting from the root of the tree each competency is tested against a disciplinary attribute described by Jantsch and formulated as a question. Classifications associated with each of the decision tree leaves in this instance are clear *Yes* or *No* answers. Answering *Yes* or *No* moves the decision down each level of the tree and is repeated for all questions and levels. Disciplinarity is the classification that is applied within the groups.

3.3 Competency Classification

Having refined the competency classification method, an assessment of each of the 76 competencies was carried out to identify which disciplinary levels the competency can enable. This refined classification activity has been undertaken by 12 experts associated with the TREND research project; each participant has expertise in TD and the works of Jantsch but originate from different disciplinary knowledge. The rationale behind this is to find if resulting commonality can be found and if any distinct disciplinary competency groups can be identified by the group of experts. This method of peer review produces a more reliable final classification for each of the competencies.

The activity was conducted in a form of virtual meetings with a main author being present to introduce the task, record experts' responses and to respond to any questions. The author was present during the entire activity, which on average took about 50 minutes to complete. The experts were presented with a list of 76 competencies with accompanying descriptions and asked to individually classify each competency by following the decision tree. While it was only possible to select one category for each competency, there was no restriction on revisiting individual competencies if participants wished to change answers. The author did not discuss the decisions being made by participants and the results were created working in isolation, hence the classification method generated different results from each expert.

4. Results

The results of the classification are presented in Figure 5 with a list of individual competency groups presented in Table 4. We hypothesised that the mode of participants will observe each competency either to be MD, ID, TD or G, hence the figure and the table below are representative of the mode result values. The results show that of the total of 76 competencies 38 (50%) were classified as showing ID attributes, this should not be a surprise considering competencies are from engineering and engineering is generally considered to be an ID discipline (Mogles et al., 2020). 20 (26%) were classified as showing TD attributes, with only one (1%) classified as MD. Only six (8%) of all competencies were found to be G competencies or lack context and in the case of the remaining 11 (14%) competencies there is no clear mode and an overlap between two categories with the highest response rate exists.

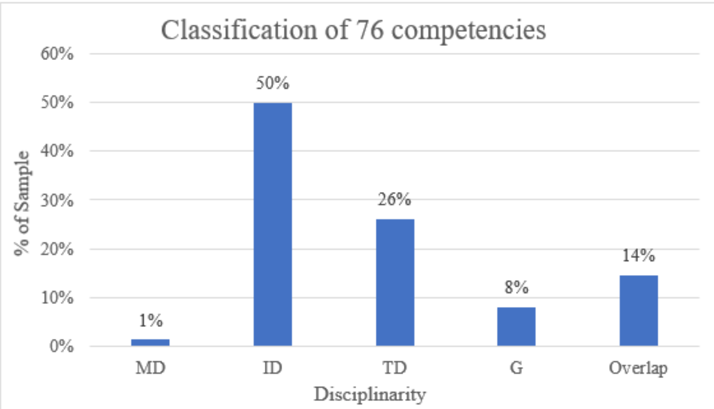


Figure 5: Results of disciplinary classification using refined method

It is notable that overlap exists with 10 competencies appearing in two categories and one appearing in three categories. This is illustrated in the Venn diagram in Figure 6. The rate of overlap between disciplines appears the highest between TD and ID categories, while lower overlap exists between ID and MD competencies. This is in line with existing research where boundaries between TD and ID concepts are not as clearly defined as between MD and ID (Carey et al., 2020). Overlap also exists between ID and G but there is no overlap between TD and G. Competency "seeks support from others" appears in TD, ID, and G category. One reason for this overlap could be the different mental models of experts from different disciplines who may interpret competencies differently.

Table 4: Disciplinary competencies

Multidisciplinary Competency	Interdisciplinary Competency	Transdisciplinary Competency	General Competency
Personal honesty and ethics	Visualization Tendency to work alone focus creativity purely on technical aspects Ability to use different tools for collaborative design Ability to provide technical supervision Understanding product and system complexity Uses latest engineering processes, methods and tools Understanding modern design environments Effective learner willing to learn new things Seeks simplest solutions Effective interaction in distributed engineering teams Judges importance Design of major complex facilities Higher degree of business understanding Customer focus Effective knowledge management Enjoys challenges Ability to interact in virtual and face-to-face situations Inter-cultural skills (focus on communication) Teamworking skills Collaboration and knowledge sharing of experts from different domains during the design tasks Applies engineering knowledge Project management skills Critical thinking Abstract thinking Uses appropriate communication formats Ability to lead/ participate in discussions Design process moderation Vision/goal setting managerial skills Coping with change Self confidence Creative problem solving Ability to contribute to design of major project Thinking from product-use point not solutions. Effective Facilitation and conflict management skills Skill to deal with Clients Professional ethics Assertiveness Risk taking attitude	Open Mindedness Ability to communicate with non-engineers Clarifying needs, checking existing solutions, investigating contexts, verifying Good communication skills Value improvement Creativity/thinking out of the box Effective Communication at all levels Ability to build partnerships Relevant environmental requirements Managing multi-disciplinary teams/projects Negotiation skills Ability to generate multiple alternative solutions Dealing with paradox Design for service Analytical abilities to evaluate worth of an idea Concern for community Learns from mistakes Functional re-use of design principles Empathises with audience Diplomacy and flexibility	Career ambition IT skills Thinks intuitively Constructive criticism as a way of thinking Being aware of their role in the system Anticipate multiple problems

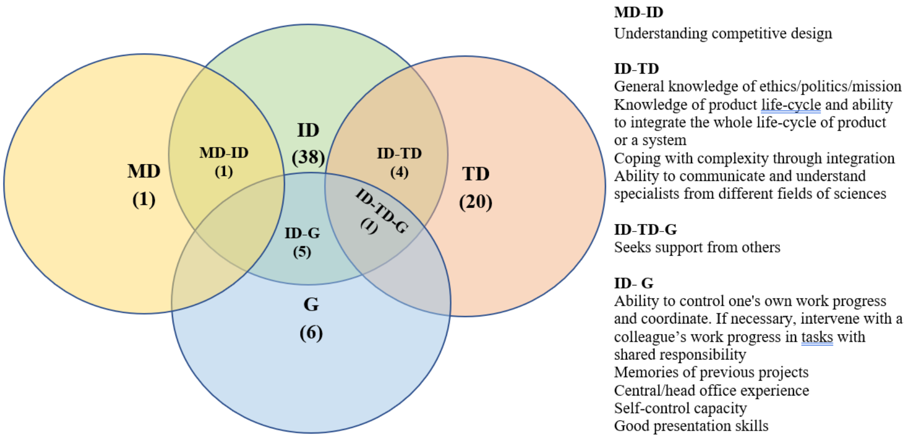


Figure 6: Disciplinary overlap

Our findings were compared to the findings by Sajdakova et al., (2020) shown in Figure 7. The comparison of results is summarised in Table 5. The results are normalised by the number of competencies, with this method yielding 47% of the same results or 36 of competencies classified in the same category in both studies. The revised method notes improvement in disciplinary classification with 32% (24) competencies originally being too general or lacking discipline now found to show disciplinary attributes. The explanation for this change might be that the decision tree offered a better method to provide context. Furthermore, more competencies were classified as TD, with an increase from 4% to 26%. Only 3% changed from TD to ID, ID to G, and MD to G.

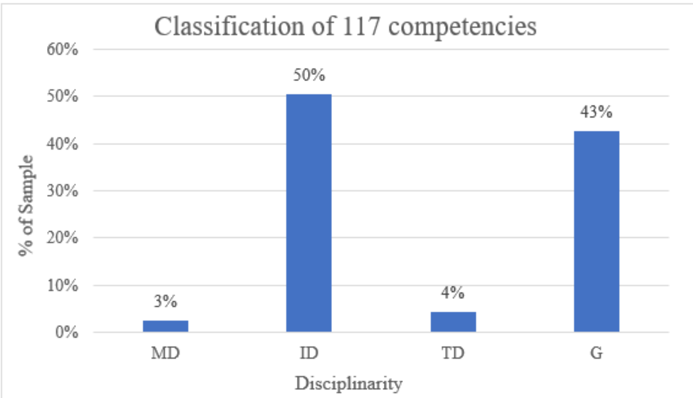


Figure 7: Results of disciplinary classification of 117 competencies

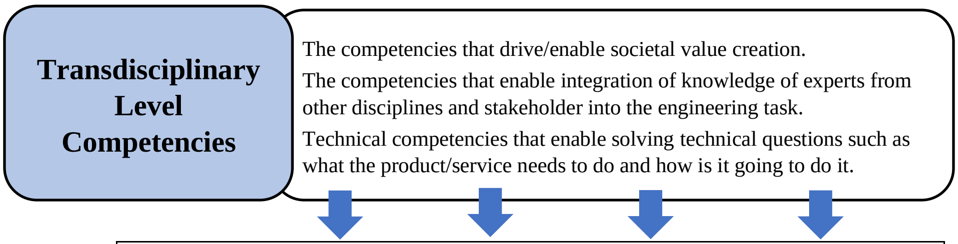
Table 5: Comparison of results

Classification comparison	Number of competencies	Percentage change
Competency is in the same category in both studies	36	47%
Change from general to disciplinary competency	24	32%
Change from TD to ID	2	3%
Change from ID to TD	13	17%
Change from MD to LD	1	1%

The notable findings from competency classification are that 20 competencies were found to cross all levels of Jantsch's framework and display TD attributes, and hence enable TE working, 38 are ID competencies and only one was found to be MD. 6 competencies were found to be G and in the case of the remaining 11 competencies there is overlap with competencies appearing in two main categories.

5. TE competency Framework

The TE competency framework (Figure 8) is proposed based on the findings from the analysis presented in results in Section 4. Of the assessed competencies, 20 were found to cross all levels of the Jantsch's framework hence enable TE working. These include competencies that enable solving technical problems and creating value for different contexts by integrating knowledge from a range of disciplines and stakeholders. TE competencies appear predominantly to be made up of facets that demonstrate design competencies, communication competencies, personal attributes, cognitive ability, and behaviour competencies.



Competencies that enable TE working	
Competency group	**Competency**
Design, requirements, and resource management competencies	Ability to re-use design principles in different contexts Ability to generate multiple alternative solutions Design for service Value improvement Clarifying needs, checking existing solutions, investigating contexts, verifying Relevant environmental requirements
Communication competencies	Good communication skills Effective communication at all levels Effective communication with non-engineers
Personal attributes and cognitive ability	Open Mindedness Dealing with paradox Creativity/thinking out of the box Analytical abilities to evaluate worth of an idea
Behaviour skills	Empathises with others Concern for others Negotiation skills Diplomacy and flexibility Ability to build partnerships Learns from mistakes Managing multi-disciplinary teams/projects

Figure 8: TE Competency Framework

6. Discussion

This section considers the key findings from the analysis and the framework presented to explore the implications of these results for future research and industrial projects.

The skills related to the ability to work across disciplinary boundaries and ability to engage in meaningful collaboration by sharing knowledge and responsibilities, are referred to as integrative skills (Charnley et al., 2011; Guimaraes et al., 2019; Mollinga, 2009), that can be divided into conceptual and instrumental. The conceptual skills allow thinking across boundaries, while the instrumental skills allow thinking of solutions for a range of uses and users (Mollinga, 2009).

Pohl and Hirsch Hadorn (2008) in the study exploring collaboration in TD research acknowledged the importance of learning more about the diversity of perspectives in a team, clarifying the differences to open the way for shared dialogue, collaboration, and integration of a group. They conclude that the focus of TD collaboration should be on facilitation of group learning, collaboration, and problem solving to enable learning about diversity of perspective(s) and each other's position with respect to a problem (Pohl and Hirsch Hadorn, 2008). To achieve this, communication skills are a crucial enabler to working across disciplinary boundaries and with multiple stakeholders including non-experts and those from different cultures, hence there is strong emphasis of awareness of different perspectives and values. Another competency that becomes crucial, is an ability to build partnerships.

The ability to build networks outside one's own expertise is especially valuable, whilst also being able to suspend personal drive to become a leading expert in the group (Wall and Shankar, 2008). Also important is to be able to participate in a dialogue while abandoning one's point of view (Nienaber and Jacobs, 2011). As Giri (2002) points out it takes courage to venture out of one's comfort zone and areas of expertise, hence a person's attitudes become important. The attitude includes willingness to learn across boundaries (Charnley et al., 2011; Mollinga, 2009), be "open" to own and others' biases, address political questions (Mollinga, 2009), learn from other disciplines and overcome the feeling of being threatened, acceptance of the unknown, adaptability and flexibility, openness to opposing ideas (Guimaraes et al., 2019) and the ability to think systematically (Charnley et al., 2011).

Instrumental integrative skills allow thinking of solutions for a range of uses and users (Mollinga, 2009) or what Pohl (2005) calls the 'engaged problem solver', focusing on a problem within context. The instrumental integrative skills we found include expert design knowledge and requirements management competencies such as "clarifying needs, checking existing solutions, investigating contexts and verifying" and "ability to design for experience". Also, personal attributes and cognitive abilities including open mindedness, creativity, thinking outside of the box and dealing with paradoxes.

To solve complex engineering problems the design engineer needs to be able to design for value in different contexts or to design for experience. This requires being able to creatively rethink one's own professional knowledge and skills depending on the requirements and the complexity of a problem (Mollinga, 2009). This could be problematic as Sharunova et al., (2019a) identifies a gap in skills linked to working with different disciplines such as understanding the standards of other disciplines, limited basic manufacturing process knowledge and its application in real life.

Being open minded enables a person to engage in new modes of thinking and “taking action” (Wall and Shankar, 2008). Dealing with paradox or an ability to deal with conflicting demands is, according to Wall and Shankar (2008), the ability to recognise and respect competing perspectives on a problem as equal. This is crucial to TE working as it highlights the importance of being able to compromise and find an acceptable solution to different stakeholders rather than prioritising perspectives and requirements. Creativity and thinking outside the box have also been noted as important to TD individuals (Augsburg, 2014), perhaps unsurprising given the plethora of challenges and barriers to TD.

TD literature highlights that societal benefit or truly creating value for society is a unique feature which differentiates TD from other approaches (Carey et al., 2020; Jantsch, 1970; Kharlamov et al., 2019; Wognum et al., 2018). Our results show that value improvement or a willingness (and an ability) to engage in improving processes (Charnley et al., 2011; Mollinga, 2009) and concern for community, cross all disciplinary levels and drive the creation of value for society. According to Tejedor et al., (2019), when attempting to engage the public in the design process the emphasis for engineering designers is upon communication and empathy skills as core learning outcomes. They emphasise that this is important because a failure to consider public welfare in a project can be an issue. If engineers are unable to reflect on the social impact of their own work, there are few individuals outside of engineering with the adequate expertise to do so for them.

Literature highlights some other shared skills, traits, and characteristics among TD individuals. For example, Wall and Shankar (2008) find TD individuals are intellectual risk takers, though we find a risk-taking attitude to be an ID rather than TD competency. This shows that while some competencies and skills may not cross all levels of Jantsch’s pyramid they need to be considered. This is further highlighted by our findings that show specific ID competencies directly link to integrating knowledge from other disciplines and stakeholders through collaboration and communication listed in Table 6. It is important to focus on these competencies because they drive awareness and respect for different perspective and values (Pohl, 2005).

Augsburg (2014) argues that a TD individual needs to be socially aware and be able to think in a complex interlinked manner, able to deal with complexity, and the capacity to recognise that it is impossible to perfectly understand and solve a problem (Augsburg, 2014). However, we found competencies linked to understanding and coping with complexity to have ID characteristics.

Current literature on TD skills predominantly focuses on the characteristics of TD individuals that are linked to individual ethics and a desire to improve society (Augsburg, 2014; Mitchell et al., 2015); it includes a TD mind-set and a TD attitude. A TD attitude has been recognised as important to deal with diversity in TD teams (Pohl and Hirsch Hadorn, 2008), and the attitude towards being TD has a significant impact on the nature of a TD project (Mitchell et al., 2015). We found that knowledge of relevant environmental requirements enables TE working; sustainability and environmental requirements are likely front of mind for experts seeking to improve society. We found personal ethics to be an MD competency and professional ethics to be an ID competency. This could be because ethics may not be as clearly associated with creating value for society.

Table 6: ID competencies that enable knowledge integration

Competencies
Ability to interact in virtual and face-to-face situations
Teamworking skills
Willingness to collaborate and share knowledge with others during the design task
Effective interaction in distributed engineering teams
Inter-cultural skills
Uses appropriate communication formats
Ability to lead/ participate in discussions
Effective facilitation and conflict management skills
Ability to use different tools for collaborative design
Design process moderation
Understanding modern design environments
Visualization
Understanding product and system complexity
Effective knowledge management
Higher degree of business understanding
Project management skills
Coping with change
Effective learner willing to learn new things
Judges importance
Vision/goal setting - managerial skill
Enjoys challenges
Risk taking attitude

According to Fam et al. (2017) TD competencies can be learned, with some characteristics being intrinsic, but equally critical to success. The attitude of having a TD mind-set is an emergent feeling (Fam et al., 2017), and links to cultural context and experience (Guimarães et al., 2019). Pohl (2005) concludes it takes several years of TD collaboration to develop respect for the culture and domains of others before groups can develop shared concepts that are critical for transdisciplinary work. Hence, to develop a TD mind-set experience of previous similar projects is important (Hall et al., 2008). We found memories of previous projects to be an ID competency. Correspondingly, some key implications to education and practice can be presented.

To prepare people for working in TE manner they should be introduced to general TD principles. For students this could be delivered as a part of existing course structures such as in case of a TE course proposed by Lattanzio et al., (2020). Our findings show that there is a need for more practical training in collaboration and knowledge sharing with other disciplines and stakeholders to generate solutions and create societal value. This can be delivered through practical TD design courses like project-based learning that brings together students from different faculties to work on live projects and solve real world problems (University of Bath, 2020).

The findings presented within this paper represent results from a sample of experts in TD and this work needs to be “disseminated” to enable its uptake in industry and TE projects. The purpose will be to explore motivations, skills and competencies engineers use in engineering projects that can be considered using TD approaches. This will help to identify if skills and competencies can be considered as enabling TE working. Further research should focus upon exploration of knowledge integration techniques and the development of understanding how value can be co-created, to find compromises and create solutions acceptable to a wide range of stakeholders.

7. Conclusion

The research within this paper sought to understand what competencies design engineers may require for working in TE projects as well as the disciplinary level of competencies they have at present.

To achieve this literature from the Scopus database was reviewed and, following the steps of a systematic literature review and using thematic analysis, a list of 76 competencies of a design engineer were extracted.

To ascertain which of these competencies enabled TD working the hierarchical system proposed by Jantsch was operationalised. This was used to create a means to classify identified competencies based on disciplinarity, and from this to understand if they can be identified as showing MD, ID, or TD characteristics. By using this approach, it has been possible to classify four competency groups.

Our results show that of the design engineers' competencies assessed 20 were found to enable TE working. Of the competencies, 38 which enabled knowledge integration were shown to have ID characteristics. Due to this, they are not classified as TE competencies as defined by Jantsch. However, these and other ID competencies were found to be crucial to effective TE working. The competencies we identified as enabling TE working can be utilised in TE projects to identify a disciplinary level of project participant skills which will assist in identifying competency gaps.

The framework we have proposed will be used to enables the self-assessment of individual or team competencies to assess whether they have the competencies which enable transdisciplinary working. In doing this, it has a potential to create an impact for industry and enable a move towards incorporating TD practices in engineering projects.

The implications of our findings for education and practice are that to prepare for TE working it is essential to ensure people understand TD concepts. Further, focus should be on practical training for value co-creation and collaboration and knowledge sharing with other disciplines and stakeholders.

The next stages of our research will be to build on the framework and apply it within an industrial context.

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