

THE T-SHAPE OF FEMALE DESIGN ENGINEERS: STUDYING HOW THE DESIGN SKILLS OF FEMALE DESIGN ENGINEERS EVOLVE THROUGH THEIR CAREERS

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ABSTRACT

This study explores how female design engineers' skillsets evolve across career stages, how development pathways differ by gender and experience compared with previous data, and the implications for engineering education. Thirteen female design engineers were interviewed and grouped into Novice, Intermediate, and Expert categories to simulate a quasi-longitudinal view of how skills develop over time. Using an established skill-card method from two prior studies, participants identified and scored their skills before categorising them as Specialist or Multidisciplinary, and their profiles were analysed through T-shaped model theories. Findings showed both skill depth and the number of specialist skills typically increasing with experience, especially early in practitioners' careers. Many profiles did not fit predefined T-shapes. Compared with the previous results (that were almost entirely male), female participants selected fewer skills with larger gaps between their self-assessed and researcher-assessed scores confirming internalised gender bias. Overall, the study highlights the need for engineering education to counter stereotype-driven self-doubt, make technical achievements more visible to validate skills, ensuring that women are not unintentionally steered into 'soft-skill-heavy' roles at the expense of technical progression. Engineering education should support flexible, individually varied skill development rather than expecting students to conform to rigid models of expertise.

Keywords: Skill profiling, female design engineers, career progression, inclusive curriculum design

1 INTRODUCTION

This study explores how female design engineers' skillsets evolve across career stages and how development pathways differ by gender and experience compared with previous data, with implications for engineering education. Wider, and important, diversity issues associated with race, cultures, locations, ethnicity or age were not the focus of this study. In this paper, design engineers are defined as practitioners whose roles focus on the research and development of ideas for new products and systems, or the redesign of products and processes to improve their performance.

1.1 What is the T-shaped design engineer?

The 'T' represents desirable design-engineering capability: the vertical bar signifies deep expertise, while the horizontal bar indicates breadth across disciplines and the soft skills needed for collaboration. Companies such as IDEO, Google, Apple and Toyota endorse this structure [1]. Other variants of the model—including the I-shape, pi-shape, and X-shape—also feature in industry; for example, Airbus describes its ideal engineer as pi-shaped, showing *deep* technical experience and innovation competency and able to work *across* business functions [2].

1.2 How T-shaped theories have been discussed in education research

Design engineering relies on both technical and interpersonal skills, requiring curricula that balance technical proficiency with communication and open-ended problem-solving. Literature suggests engineering programmes often produce I-shaped graduates who broaden into T-shaped profiles over time [3],[4]. Developing T-shaped capability earlier requires educational experiences that simulate professional practice rather than traditional lectures. Industry places strong emphasis on soft skills such as communication, teamwork, leadership and creativity [5], yet higher education frequently undervalues

them. While most authors discuss skill-shape theories conceptually, only our previous studies [6],[7] have attempted to construct quantified individual skill profiles.

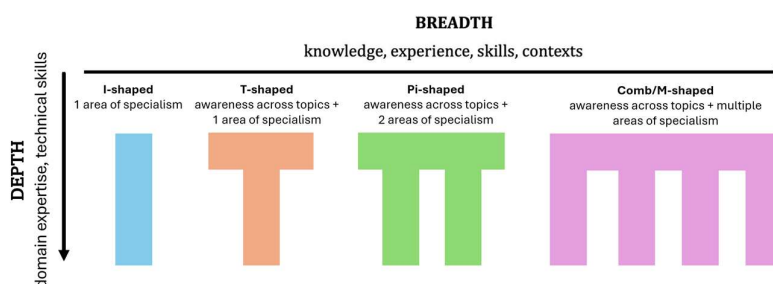


Figure 1. Basic visualisation of the 'T-Shape' model theory and the variations in the literature

1.3 Findings from previous studies using the method

Our previous studies (in 2019 and 2023) examined how design engineers' skills develop across a career and whether real-world profiles reflect T-, Pi- or M-shapes. Across 33 participants—11 novices, 11 intermediates and 11 experts—over 33 hours or 220,000 words of transcribed text were analysed, generating detailed profiles. Findings showed M-shaped profiles were most common, characterised by multiple specialist areas supported by broad multidisciplinary capability, with both skill depth and number of specialist skills increasing with experience. However, the data set was not gender-balanced: only one female participant was included. Figure 2 illustrates a sample of the dataset showing the profile shapes generated (labelled in red the 2019 participants, in black the 2023 participants).

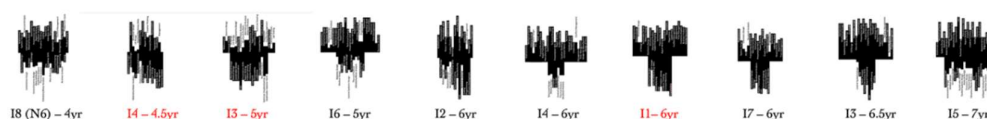


Figure 2. Sample of Intermediate skills profiles from the methodology [7]

1.4 What we know about female design engineers' skillsets across their career stages

Prior research identifies persistent gendered patterns: women often experience lower professional confidence and underestimate their technical abilities despite equal performance. Cech et al. [8] used longitudinal panel data to show that women's lower professional role confidence—rather than family plans or maths self-assessment—significantly reduces the likelihood of remaining in engineering, with women often underestimating their technical abilities despite equal performance. Naukkarinen and Bairoh [9], using cross-sectional survey data from over 4,000 early-career Finnish engineers, similarly found systematic gender differences in valued skills and professional identities, with women prioritising social and interpersonal skill development and facing identity-related pressures that may heighten attrition.

This study adopts a mixed qualitative–quantitative approach to construct skill profiles for female engineers for comparison with our previous studies where 32 out of 33 participants were male. Addressing the lack of gender diversity in engineering design education requires understanding the experiences of female design engineers. This study therefore examines how the skillsets evolve across career stages to inform recommendations for curricula and support.

2 METHODOLOGIES

Cederberg et al. [3] conducted before-and-after studies using questionnaires and interviews, showing that participants in Saab Aeronautics' Advanced Engineering Training Program (AAETP) expanded their T-shaped competencies effectively; one senior systems engineer, studied in detail, developed considerably greater breadth and depth. However, the methodology for the present study mirrored our own previous work [6],[7] as closely as possible, but this time thirteen female design engineers were recruited through academic networks, professional contacts, and social media. All participants were categorised into Novice, Intermediate, or Expert groups based on years of practice, using thresholds

aligned with job descriptions and the premise that professional expertise typically requires around ten years' experience [10]. This produced a sample of four Novices, five Intermediates, and four Experts.

2.1 Data collection process

Data was collected through semi-structured interviews conducted via Microsoft Teams. This provided a consistent framework aligned with the previous studies while allowing flexibility for participants to elaborate on their experiences. Interviews were recorded, anonymised and structured into four sections. The first gathered contextual background—educational history, job role, industry sector and career trajectory—to confirm each participant's experience classification and contextualise later analyses.

Table 1. Anonymised description of the UK-based research participants

Participant	Experience (years)	Education Level	Job Description
N1	1.5	5th Year IDE UG	Design experience with a global product design and technology company.
N2	1.2	5th Year Aero Eng UG	Design experience with a robotics company in the aerospace industry.
N3	1	4th Year IDE UG	Design experience with a design consultancy specialising in electrical power systems
N4	1	4th Year IDE UG	Design experience with a medical design company
I1	5	MEng	Design experience in the cosmetics industry
I2	9	MEng	Senior mechanical and project engineer for an engineering and design consulting
I3	7.5	MEng	Design experience in the medical device industry
I4	2	MEng	Design experience in the household appliances company
I5	3.5	MEng	Design experience in the automotive industry
E1	18	BEng	Design experience in the automotive industry
E2	16	BEng	Design experience in the building services industry
E3	14	PhD	Design experience for a design company
E4	11	MEng	Design experience in the structural design consultancy industry

The interview used a set of 47 design-engineering skills, grouped into 13 categories to help participants identify which skills they possessed. These categories included: Mathematics; Fundamental Engineering Design Skills; Specialist Engineering Skills; Dynamic and Static Analysis; Practical and Manufacturing Skills; Design Communication; Creative Skills; Software Skills; Interpersonal and Personal Skills; Management and Leadership; Business and Economic Skills; and any Additional Skills participants wished to add. Each category contained specific skills (e.g., CAD, FEA, Concept/Sketching, Report Writing, Rapid Prototyping, Leadership, etc), which participants sorted into 'Possessed' or 'Not Possessed' before rating proficiency. This produced a comprehensive inventory of each participant's perceived skillset and allowed comparison with the previous studies. In the third interview section, participants completed a structured assessment for every skill they identified as possessed. For each, they provided a self-rated proficiency score from 1 to 10, described how frequently they used the skill, and gave a brief workplace example illustrating its application. These three elements formed the core quantitative dataset: proficiency scores represented perceived capability, utilisation descriptions were later converted to numerical utilisation scores, and examples were used to allocate assessor-derived bias scores. Together, these captured both depth of skill and practical workplace use. In the fourth participants sorted their skills into specialist (skills they believed they had specialised in) and multi-disciplinary (more general skills used across engineering design disciplines or projects). This enabled construction of individual skill profiles, with multidisciplinary skills positioned at the top of the diagram and specialist skills at the bottom, and bar depth proportional to normalised proficiency. These visualisations supported interpretation of each participant's skill 'shape' (e.g. T-shaped, I-shaped, etc).

2.2 Data analysis method

Data analysis followed the procedures used in previous studies to ensure compatibility. Proficiency scores were normalised through a multi-step process addressing self-assessment bias and variation in skill-use frequency. First, a Weighted Proficiency Score was calculated by combining the self-assigned proficiency score with a numerical utilisation score derived from the participant's description of frequency of use. Second, a Bias Assessment Score was assigned by an assessor to moderate variance in self-reported skill levels. For this, four skills selected by all participants—Mechanical Design, CAD, Rapid Prototyping and Responsibility—were assessed using the participant's descriptive examples and predefined marking schemes based on Choulier and Weite's framework [11].

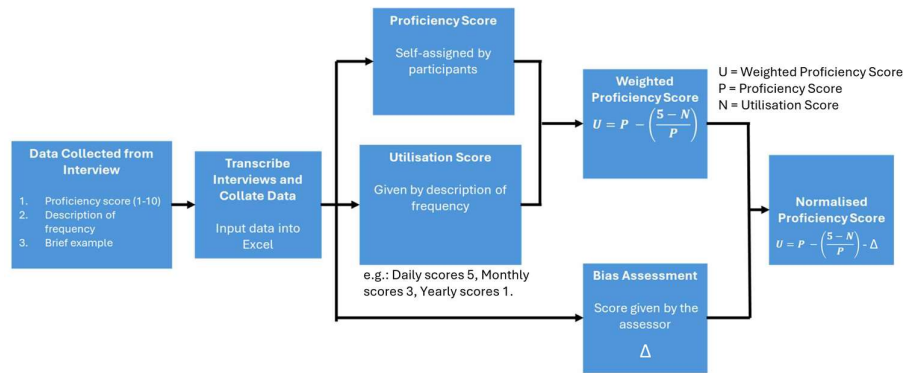


Figure 3. Data analysis and normalisation process

Third, the difference between each participant's weighted score and assessor's score was averaged, and this correction factor was applied across all skills to generate the final Normalised Proficiency Scores used for analysis. Individual skill profiles were then produced by plotting the normalised scores for each participant's specialist and multidisciplinary skills. These profiles visually represented the relative breadth and depth of skills within and across experience groups and enabled evaluation of whether each participant's pattern aligned with established skill profile 'shapes'.

3 RESULTS AND DISCUSSION

Figure 4 shows an example of the T-shaped profile produced by the method. The height or depth of each bar presents the score for the selected skill. Participants place their *specialist* design skills pointing downwards to form the vertical bar of the T, in line with the theory, while *multidisciplinary* skills are shown across the breadth at the top. The colours correspond to the 13 skill categories, although these are not analysed in this paper. Reviewing the full set of profiles visually supports a qualitative discussion of how the specialist skills of female design engineers change over time and what types of specialisations emerge across career stages.

However, analysing the differences in skill scores between this study and the previous studies allows exploration of how skill evolution differs between females and males across career stages. For example, Figure 5 shows that participants in the previous studies consistently selected *more* Multidisciplinary and Specialist skills than the female participants in the equivalent experience categories. However, the female participants averaged *higher scores for all skills* (except the Novice group's Multidisciplinary skills).

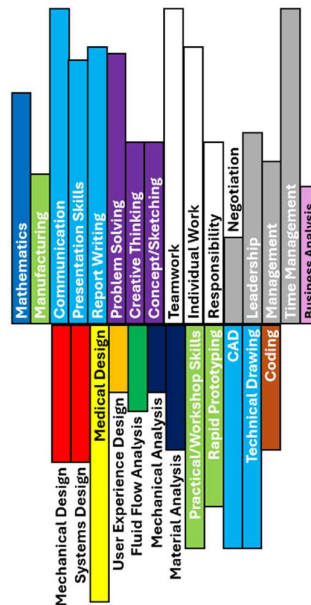


Figure 4. Example of one participant's T-shaped design skill profile

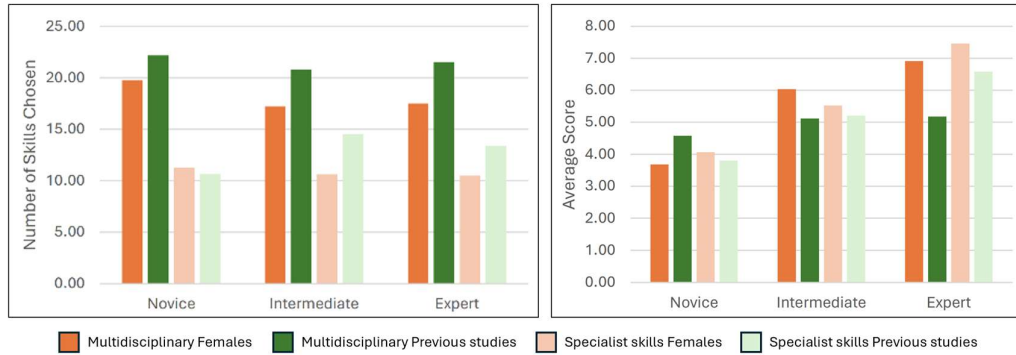


Figure 5. Comparing the average **number** of Multidisciplinary and Specialist skills selected (left) and their average **score** across career stages (right)

In terms of how skills develop across careers, we see in both the female participants and the previous cohorts that several skills increase through the different career stages as expected (for example, creativity, report writing, problem solving and communication skills), while many specific skills peak during the intermediate stage (such as workshop, prototyping and CAD skills). There are also notable patterns in management and leadership skills. Figure 6 shows that Expert female participants scored higher than their Expert counterparts in the previous studies in Leadership (8.04 vs 6.29), Conflict Management (7.64 vs 5.31) and Management (8.17 vs 6.57), whereas the previous cohorts consistently scored higher in Economic Analysis (2.88 vs 4.80) and Business Analysis (2.80 vs 4.60). This may indicate that female careers in engineering design place greater emphasis on managing people.

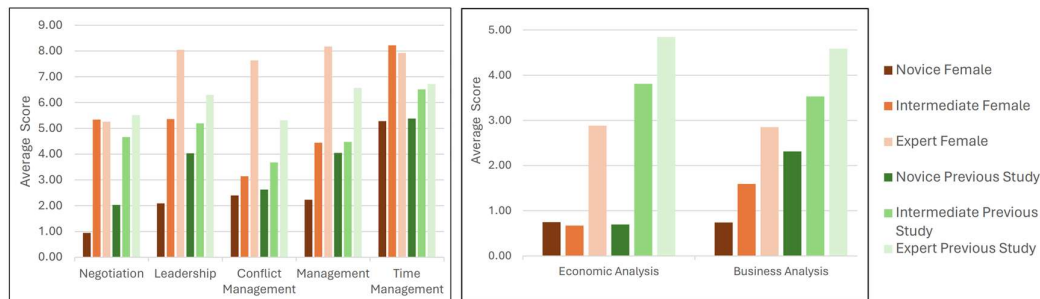


Figure 6. Average Management Skills/Leadership score (left) and Average Business Skills score (right)

The bias-assessment scoring also showed notable differences between the studies. Expert and Intermediate female participants *under-scored* their proficiency by an average of 0.66 and 0.65, whereas participants in the previous studies were more accurate in their self-assigned scores. Their Intermediate and Expert self-assessments *over-scored* their proficiency by only 0.16 and 0.01 respectively. In the novice cohorts there was no clear directionality in the data, some *over-scored* some *under-scored*.

4 DISCUSSION AND CONCLUSIONS

The results suggest a difference in the T-shapes of female design engineers compared with the mostly-male cohorts from previous studies. The findings echo Cech et al.'s work showing that women disproportionately underestimate their engineering competence despite equivalent performance [8],[12]. This indicates that women may benefit from educational environments that counter stereotype-driven self-doubt and make technical achievements more visible to validate skills.

In later career stages, female design engineers often showed stronger interpersonal and management skills, aligning with research suggesting women tend to value and develop social, collaborative and leadership capacities [9]. Educational programmes should recognise these strengths while ensuring they do not unintentionally steer women into 'soft-skill-heavy' roles at the expense of technical progression. Intentional changes to curricula, activities and faculty culture such as frequent low-stakes feedback,

iterative skill validation in technical tasks and technical specialisation pathways in later years, may help female engineers develop stronger professional engineering identities.

Engineering education may help broaden career outcomes for female engineering designers by embedding objective, multi-method skill assessment and clarifying their technical capability. However, as this research shows that real-world skill profiles rarely map neatly onto idealised shapes such as the T-profile, education should aim to support flexible, individually varied skill development rather than expecting students to fit rigid models of expertise, as also proposed by Tranquillo [1].

4.1 Limitations of the study and future work

Although this procedure produced rich data, interpretation was constrained by the small sample size. Given the time limitations of this research, a cohort-based method was selected to explore skill profiles across career stages. How closely it mimics longitudinal data can only be determined by conducting a longitudinal study and comparing results. Future work should therefore involve a larger and more diverse sample, ideally tracking design engineers through key career stages, to map skill evolution more accurately. Nevertheless, close adherence to the previous methodology and the structured interview format ensured that the results were robust enough to support meaningful comparisons.

Examining the T-shaped profiles across the studies showed they were useful for qualitative discussion, but they have not been effective in detecting patterns across career stages. A key issue is that allowing participants to define which of their skills they consider ‘specialist’ and which ‘multidisciplinary’, means the profiles have no common framework. Future work should establish which skills should be considered specialist (downward) and multidisciplinary (across the top) and reorganise the data accordingly. This may reveal clearer patterns in how skills evolve through career stages when using these cohort-based studies.

REFERENCES

- [1] Tranquillo J. (2013). The T-shaped Engineer: Connecting the STEM to the TOP Paper presented at 2013, 120th ASEE Annual Conference & Exposition, Atlanta, Georgia. <https://doi.org/10.18260/1-2--22622>.
- [2] AGUPP. 2018. The Engineer of the Future. *White paper*, Airbus Global University Partner Programme.
- [3] Cederberg L., Axehill J. W. and Herzog E. 2019. Experience from a Program for Accelerating the Creation of T-shaped Technical Leaders. INCOSE Int. Symp. 29, 707–722. <https://doi.org/10.1002/j.2334-5837.2019.00630.x>
- [4] Rogers P. and Freuler R. 2015. The “T-Shaped” Engineer, in 2015 ASEE Annual Conference and Exposition Proceedings. Presented at the 2015 ASEE Annual Conference and Exposition, ASEE Conferences, Seattle, Washington, p. 26.1507.1-26.1507.18. <https://doi.org/10.18260/p.24844>.
- [5] Kokoç M. and Ersöz S. 2020. T-Shaped Engineer: Horizontal Component Comprising of Soft Skills. *End. Mühendisliği* 31, 180–197. <https://doi.org/10.46465/endustrimuhendisligi.728405>
- [6] Lowe S. 2023. The T-Shaped designer – studying how the design skills of design engineers change throughout a career. MEng Dissertation, Mechanical Engineering, University of Bath.
- [7] Dekoninck E. and Bridge L. 2023. The T-shaped design engineer—using cohorts to explore how skills profiles differ through career stages. *Proceedings of the Design Society (ICED23)*, <https://doi.org/10.1017/pds.2023.354>.
- [8] Cech E., Rubineau B., Silbey S. and Seron C. 2011. Professional Role Confidence and Gendered Persistence in Engineering. *Am. Sociol. Rev.* 76, 641–666.
- [9] Naukkarinen J. and Bairoh S. 2022. Gender differences in professional identities and development of engineering skills among early career engineers in Finland. *Eur. J. Eng. Educ.* 47, 85–101. <https://doi.org/10.1080/03043797.2021.192985>.
- [10] Ericsson K. A., Krampe R. T. and Tesch-Römer C. 1993. The role of deliberate practice in the acquisition of expert performance. *Psychological review*, 100(3), p.363.
- [11] Choulier D. and Weite P. A. 2011. A coherent and discriminating skills standard for innovative design. In *DS 68-8: Proceedings of the 18th International Conference on Engineering Design (ICED 11)*, Lyngby, Denmark.
- [12] Cech E. A. 2013. Ideological Wage Inequalities? The Technical/Social Dualism and the Gender Wage Gap in Engineering. *Soc. Forces* 91, 1147–1182. <https://doi.org/10.1093/sf/sot024>.