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Advancing engineering design problem-exploring practice: interviews with industry professionals

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ABSTRACT

Studies highlight that conceptualising and identifying a new engineering design problem (EDP) is vital, as the solution can benefit society. However, this essential activity, referred to as engineering design problem-exploring (EDPE), is lacking in practice in engineering design. Design engineers appear to focus on providing an engineering design solution (EDS) while their role in EDPE is rarely practised. A new EDP drives innovations and inventions, and there is a need to encourage, advance and sustain the practice of identifying new EDPs. The aim of this study is to empirically highlight the underlying determinants of the scarce practice of EDPE and suggest how to advance and sustain the practice. Interviews were conducted with 32 professionals within the engineering design community, comprising 28 practitioners and four specialists – a lecturer, an inventor, and two expert trainers in creativity and problem-solving. The results of the analyses informed the suggested approaches in this study to advance and sustain the EDPE practice.

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Problem-exploring; engineering design; conceptual design; creativity; concept generation

1. Introduction

Innovation and invention remain essential for significant engineering design outcomes (Jin et al. 2024; Sanberg 2024). They directly depend on an engineering design problem (EDP). According to NIPO (2022), an 'invention must represent a practical solution to a problem'. Hence, the engineering design solution (EDS) realised depends on the EDP solved, and not all problems solved result in an innovative or inventive solution. As widely acknowledged, 'not all problems are created equal' (Nagel et al. 2011). An EDP can be 'created' (conceptualised), discovered, or identified in engineering design (Getzels 1979). Conceptualising or identifying a new EDP is an essential aspect of engineering design and a standard expectation from design engineers (Lee et al. 2021; NRC 2012). However, the practice of conceptualising or identifying new EDPs (Headrick et al. 2020), referred to as Engineering Design Problem-Exploring (EDPE) in this study, is lacking attention in academia and industry. This is unlike the engineering design problem-solving (EDPS) practice

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(Shekhar et al. 2024), which has been extensively explored (Chen, Xiao et al. 2024; Chen, Zhang et al. 2024).

In the fourth industrial revolution, the need for new and useful ideas continues to grow (Han et al. 2020; Jaussi and Topaloglu 2020). Hence, engineering design practitioners desire to create new possibilities and opportunities (Mahon et al. 2017). Although these new ideas, possibilities, and opportunities drive innovation and invention, what is seemingly obscure is that a new EDP drives them. Conceptualising and identifying new EDPs creates new possibilities, which requires creative imagination but initiates scientific advancement (Fantin 2014; Gündüz and Sincar 2024). Despite its importance, the practice of EDPE receives scarce attention in engineering design (Abdulla et al. 2018).

This study aims to highlight the determinants of the scarce practice of EDPE and suggest how to advance and sustain the practice in engineering design. Hence, the research questions addressed are: 'What factors contribute to the scarce practice of EDPE, and how can these factors be mitigated?' To assist in answering the research questions, semi-structured interviews were conducted with 32 participants within the engineering design community. The interviews helped to understand (1) the influence of engineering design education on professional practice, (2) experts' opinions on supporting EDPE skills in academia, like EDPS skills, (3) how problems solved with inventions are identified, and (4) what design engineers can achieve with creativity.

2. Engineering design education and practice

Engineering design provides design engineers with the method to conceptualise, identify and solve problems (ABET 2021; NRC 2012). Design engineers are considered innovators who can identify a societal problem and offer potential solutions (Molecke and Pache 2019). In a recent strategic development plan in Massachusetts to address local, regional, and national needs, the roles of engineers in identifying a new EDP and providing an EDS are recognised (Charette, Archer, and Brodeur 2020). Conceptualising or identifying a new EDP allows design engineers to explore the problem space (Rieken et al. 2023, 2; Storm, van Maanen, and Gonçalves 2019).

To perform the activities of a professional design engineer, including identifying a new EDP and providing an EDS, an engineering design (or design engineering) degree is a prerequisite (Dowlen 2019). For clarity, the terms 'engineering design' and 'design engineering' can be used interchangeably (Childs 2019, 4; Steinmann et al. 2014). The terms refer to design within the engineering discipline, differentiating it from design in other fields (Heskett 2005; Rogers 1983). In theory, the engineering design profession includes identifying a problem and providing a solution. However, the focus on identifying an EDP before exploring the problem and solution spaces is lacking in practice. Moreover, the skills are not taught in academia to support the industry practice.

Studies addressing the rare focus on EDPE in academia and industry are lacking, while engineering design education and practice remain popular for EDPS only (Abdulla et al. 2018; Pretz, Naples, and Sternberg 2003, 9; Shekhar et al. 2024). EDPE requires creativity (Wilson 2017), a critical engineering skill (Han et al. 2023; Nolte et al. 2023). Ding et al. (2019) stated that 'being creative includes both finding creative problems and subsequently solving them'. They highlighted that the concept of creativity in identifying creative problems is neglected while focusing on creative problem-solving.

Indeed, several models explained the EDPS process, including the Total Design process model (Pugh 1991), the general engineering design process model (Kroll, Condoor, and Jansson 2001), and the product development design process model (Ullman 2010). In most of these models, the first step is understanding a given EDP or exploring the problem space to provide a satisfactory or satisficed solution (Guo and Chen 2023; Horvat et al. 2024). However, no specific model describes the EDPE process or how to come up with a new EDP to solve it. Although EDPS and EDPE involve similar cognitive activities, it is suggested that the EDPE process is relatively more challenging (Kershaw et al. 2019). Wilson (2017) mentioned three creativity levels of thought initiated by three questions, which might be adapted to explain the conceptualisation or creation of a new EDP. The first question is 'What is it?' the second is, 'How was it put together?' and the third is, 'Why do the phenomenon and its preconditions exist in the first place?' These three thought levels could be mimicked to model EDPE or create a new phenomenon by modifying the questions as 'What would it be?' 'How could it be put together?' and 'Why does the phenomenon or product and its preconditions not exist in the first place?'

The nature, types and sources of EDPs

An EDP could be described as 'any important, open-ended, and ambiguous situation for which one wants and needs new options and a plan for carrying a solution successfully' (Treffinger 1995). An EDP is not necessarily a situation that calls for urgent attention, does not have to exist, and can be created even when none is apparent. As summarised in Table 1, there are different types of EDPs and ways they might emerge. An EDP could be 'presented', 'discovered', or 'created' (Getzels 1979). A presented EDP is a problem that exists and has a known formulation, method of solution and solution that may be known or unknown to whom the problem is given. A discovered EDP is a problem that exists with or without a known formulation, method of solution, or solution and is observed by oneself rather than being presented or presenting itself to one. As earlier mentioned, a created EDP refers to a problem that does not exist but is conceptualised and made apparent by oneself (Fadeyi 2021; Fantin 2014).

An EDP could also emerge from serendipity discovery. Serendipity is a phenomenon that describes the discovery of a concept by chance (Darbellay 2020). It contributes to

Table 1. Types of EDPs and their descriptions.

	Type of EDP	Description
1	Presented EDP	An EDP with a known formulation, method of solution and solution presenting itself or being presented to someone for an EDS.
2	Market pull EDP	A market-informed or society-informed EDP for an EDS.
3	Crowdsourced EDP	An EDP is identified in a collection of various obscure EDPs contributed by unspecified persons or a crowd.
4	Technology push EDP	An EDP that results from a search to apply a breakthrough technology or solution to address other problems.
5	Serendipitous EDP	A randomly or accidentally discovered EDP.
6	Apophenia EDP	An EDP that emerges through imaginary connections of unconsciously observed random or unrelated data.
7	Discovered EDP	A personally identified EDP that may or may not have a known formulation, method of solution, or solution. It could result through 4, 5, or 6.
8	Created EDP	A consciously conceptualised EDP, uninspired by any observation and independent of any EDPS process.

innovation and invention (Ishikawa 2010), and an example of serendipitous discovery is the 'ground effect' in aircraft (Hubbell et al. 2010). In addition, an EDP could result from apophenia – a phenomenon that describes the natural inclination to produce a meaningful and valuable concept through invisible connections of random or unrelated data (Thaler 2020). Further, an EDP could emerge through market pull and technology push (Marxt and Hacklin 2005). A market-pull EDP is an apparent market-informed or society-informed EDP for an EDS (Heikkilä and Heikkilä 2017). A technology push EDP is identified due to the search for a problem that a radical or breakthrough solution could address (Arifin 2019). Recently, crowdsourcing has been suggested as a promising source of an EDP (Obieke, Milisavljevic-Syed, and Han 2023). A crowdsourced EDP is a contribution of unspecified individuals or a crowd of the problems they discover through their daily activities, experience, and knowledge for which they believe the solution is lacking.

The lack of focus on EDPE in academia and industry appears to have resulted in design engineers who see the profession as all about EDPS and are not conscious or aware of EDPE. Design engineers, in practice, seem to focus on providing EDS to clients' problems. However, in academia and industry, adequate support could be provided to improve the skills of design engineers in EDPE, like in EDPS. The education of a design engineer is a competitive advantage in identifying new EDPs in society. EDPE is a proactive act or an act of 'intentionality' – 'a perspective that considers purposeful thoughts and actions' (Jaussi and Topaloglu 2020). It is a conscious effort to discover, identify, create, or conceptualise a new EDP independently of any EDPS process, breakthrough solution, or market demand.

This section presents the professional roles of design engineers in society and the lack of attention to the EDPE aspect of the roles in academia and industry. Information on how an EDP might be identified or conceptualised is presented, as summarised in Table 1.

3. Methodology

This study aims to highlight possible determinants of the scarce practice of EDPE and suggest how to encourage the practice within the engineering design community. An effective way to achieve this is through social interactions with practitioners and experts within engineering design. Hence, qualitative research methodology is a good approach because it is suitable for studying a phenomenon requiring stakeholder interactions (Flick 2008; Thai and Miyazaki 2024). A structured, semi-structured, or unstructured interview is one of the methods in qualitative research (Brinkmann 2022).

This study used a semi-structured interview method recommended for phenomenological studies because it 'uses fixed questions which may be adapted as the interview progresses' (Howell 2016). Hence, it combines the advantages of structured and unstructured interviews. Semi-structured interviews may be combined with other methods or used as the sole method in a research design (Galletta and Cross 2013). We used questionnaires to support the interviews in this study and collect information about the participants' knowledge relating to their professional practice (Prost, Gross, and Prost 2024).

Participants

An invitation for participation in the interview was sent through an online advert, specifying the criteria, which included an engineering design background and a basic understanding of creativity. Thirty-two participants responded to the advert, comprising 28 novice and experienced industry practitioners and four specialists: a lecturer, an inventor, and two expert trainers in creativity and problem-solving. The participants' details are presented in Tables 2 and 3.

The 28 practitioners in Table 2 work in different countries, including, in alphabetical order, Canada, France, India, Russia, the United Kingdom, and the United States. One of the Design Engineer practitioners has worked as a design engineer for seven years but is studying for a PhD qualification. The Design Consultant practitioner has a college degree and other advanced qualifications and registered patents considered equivalent to a bachelor's degree in this study. The overall mean, standard deviation, and range of the participants' work experience in Table 2 are 8.39, 9.19, and 49, respectively. However, the Design Consultant's experience, which is relatively an outlier, should be noted.

Researchers recommend teaching 'creativity' in schools as a method of science to allow students to remember that science is an activity that involves creativity (Hong, Park, and Song 2022). Hence, the 28 practitioners were asked if they considered themselves creative and if they were formally taught creativity at the University or work, as presented in Table 2. A participant responded, 'I do not know' whether they were formally taught creativity, which is classified as a 'No' for uniformity and considering that creativity is a phenomenon that should be remembered if taught.

For identity protection, the four specialists in Table 3 are referred to as *Specialist A*, *Specialist B*, *Specialist C*, and *Specialist D*. The 28 practitioners in Table 2 were asked the same questions during the interview. However, being a semi-structured interview, a degree of flexibility was allowed to probe for further details. Comparatively, although the interview was also semi-structured for the four specialists, the questions were based on their areas of specialisation and not entirely the same for each specialist.

Table 2. Details of practitioners for the semi-structured interview.

Number of Participants = 28						
Job Title (Participants' Number)	Work Experience [in years]	Qualification			Creativity (Participants' Number)	
		BS	MS	PhD	Creative	Taught
Design Engineer (15)	1 - 12	7	6	2	Y (15); N (0)	Y (8); N (7)
Industrial Designer (5)	3 - 8	3	2	0	Y (5); N (0)	Y (0); N (5)
Mechanical Designer (1)	3	0	1	0	Y (1); N (0)	Y (1); N (0)
Mechanical Engineer (2)	9 - 21	0	2	0	Y (2); N (0)	Y (2); N (0)
Product Designer (2)	8 - 11	1	1	0	Y (2); N (0)	Y (1); N (1)
Product Manager (1)	15	1	0	0	Y (1); N (0)	Y (0); N (1)
Project Manager (1)	7	0	1	0	Y (1); N (0)	Y (0); N (1)
Design Consultant (1)	50	1	0	0	Y (1); N (0)	Y (0); N (1)

BS – Bachelors, MS – Masters, Y – Yes, N – No.

Table 3. Details of specialists for the semi-structured interview.

Number of Participants = 4			
Specialist (Job Title)	Years of work experience	Qualification	Location
Specialist A (Lecturer)	7+	PhD	France
Specialist B (Renowned Inventor)	40+	BS*	United Kingdom
Specialist C (Expert problem-solving trainer)	36+	BS	United Kingdom
Specialist D (Expert creative thinking trainer)	23+	PhD	United Kingdom

*Honorary doctorate holder, BS – Bachelors.

Data collection

Data was collected through interview responses of 32 participants. Interviews lasted 30-60 minutes, and all participants gave verbal and informed consent to use the data. The practitioners' and specialists' interview questions are presented in Tables 4 and 5. A questionnaire was sent with the practitioners' interview invitations, which they responded to in text before the oral interview. As it supplemented the interview questions, the questionnaire contained two questions subtly reiterating the required knowledge of engineering design and creativity. This study received ethical approval from the University of Liverpool Faculty of Science and Engineering Research Ethics Committee (Reference: 6416). The research team comprises the authors.

Data analysis

The qualitative data obtained in this study was analysed using NVivo software, which provides a platform for qualitative data analysis (Phillips and Lu 2018). The data (interview transcripts and questionnaire responses) was imported into NVivo, coded, queried, reflected, and visualised. A priori coding was used, as the codes were prepared based on the interview questions (Fallin 2019). The data was coded by grouping responses into themes and queried for insights. Memoeing was used within the NVivo environment to note insights and interpretations during the data analysis. The data analysis helped to identify and observe patterns/trends in the participants' responses. One of the trends is the high use of specific words in the participants' responses, identified through a word frequency analysis (WFA). Some interview responses were analysed complementarily, including

Table 4. Practitioners' interview questions and questionnaire.

	Questions
	Questionnaire
1	Where do you get inspiration from?
2	Describe your typical design process and methods.
	Interview
3	How would you describe your core responsibilities or roles as a design engineer?
4	How do you think the problems we solve in engineering design come about?
5	How do clients present/communicate their design problems to you?
6	Have you ever consciously tried to come up with a new problem?
7	Could you think of a new problem in one minute?
8	Does your personal background/experience/knowledge play a role in your inspiration through combining different solutions?
9	When you see a need [like this] without additional information, does it prompt you to think of possible solutions based on your experience, background, and knowledge?

Table 5. Specialists' interview questions.

	Interview Questions	Specialist
1	How do you think the problems we solve in engineering design come about?	A, C, D
2	Do you think it is possible to teach EDPE in academia the same way we teach EDPS?	A, C, D
3	What is the basis for your inventive skills?	B
4	How would you describe the problem that your invention solves?	B
5	Would you consider identifying the problem more important or finding the solution?	B
6	Would you describe the problem you solved as a random/accidental, created, or discovered problem?	B
7	How did you verify that there would be a need for your product or invention?	B
8	In your opinion, what can creativity help us to achieve?	D

Questions 4–5 and 6–9 in Table 4. Results were visualised with bar charts, word tree plots, and a joint plot of heat maps and vertical bar charts.

4. Results

4.1. Practitioners' inspiration sources

Figure 1 shows the word tree of the coded practitioners' responses to Question 1 of Table 4 on the sources of their design inspirations. Inspecting the responses revealed that some practitioners' key explanations are closer to the pronoun 'I'. Hence, the occurrences of 'I' in lines with key explanations are replaced with 'I personally' without affecting the analysis. This strategy allowed the term 'personally' instead of 'I' to be the root term to capture the practitioners' explanations. Using the pronoun 'I' as the root term will lead to unnecessary references to other lines where it does not refer to a key explanation. Also, where necessary, the term 'personally' was introduced in a line to capture the expressions of the practitioners' actions. For example, a practitioner mentioned, 'Going to look at the items on display, taking photos, reading descriptions … ' This is modified as '[Personally] Going to look at the items on display, taking photos, reading descriptions … ' This made it effective to capture core explanations without altering or impairing the participants' responses.

4.2. How practitioners describe their EDPS process

Question 2 in Table 4 requires the practitioners to describe their typical design process and methods. The participants' responses reflect the general concurrent and iterative engineering design process taught in academia, as illustrated in Figure 2. In Figure 2,

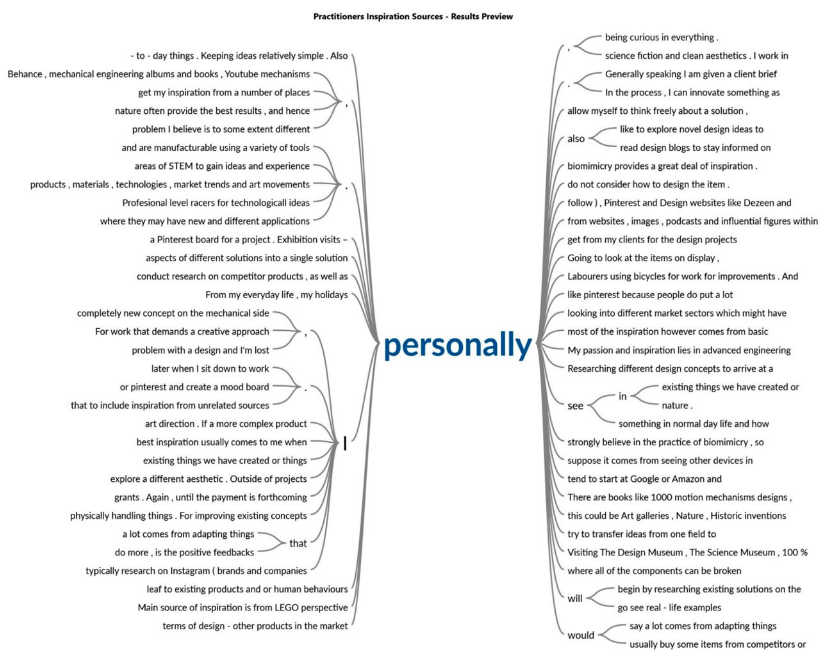

Figure 1. Results of practitioners' responses to their sources of inspiration.

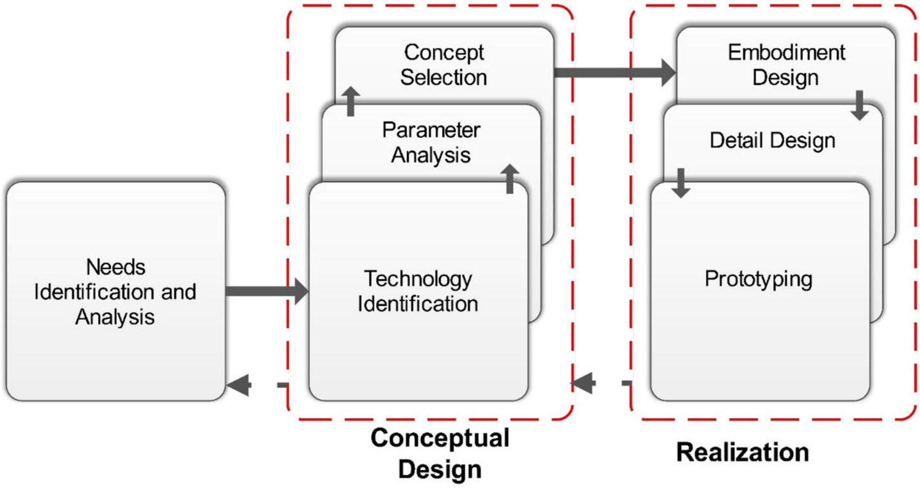

Figure 2. General engineering design process (Kroll, Condoor, and Jansson 2001).

the 'Need Identification and Analysis' refer to investigating a given EDP to identify any underlying need for a satisfactory EDS. The 'Conceptual design' stage comprises technology identification, parameter analysis, and concept selection. Technology identification refers to concepts, including technologically inspired ideas, for solutions. Parameter analysis involves analysing the appropriateness of the potential EDS concepts. Concept selection is where a final concept that best addresses the EDP is selected. The 'Realization' activity entails embodiment design – considering the selected concept's technical aspects, such as size and weight. The design is taken further into detail design with prototyping and manufacturing considerations.

4.3. How practitioners describe their roles

In Figure 3, the joint heat maps and bar plots show the practitioners' top 11 most frequently used words to describe their roles based on Question 3 Table 4. The words are obtained through a word frequency analysis in NVivo after removing stopwords – words that do not contribute meaningfully to the analysis, such as 'like' and 'just' and words less than three characters. Words like 'designs' and 'designing' that stem from one word – 'design' are considered the same. Figure 3 shows that Practitioner 7007 used the word 'design' 10 times, while Practitioner 7016 used 'understand' six times. The bar plots in Figure 3 show the total word frequencies. For instance, 'design' is used 74 times, while 'idea' is used 13 times. For a better insight, the term 'EDPS' is suffixed in a practitioner's response where the response implies or refers to providing a solution or solving a problem, as done in this example: 'Assist the clients in coming up with new concepts that solve their problems [EDPS] … ' Comparatively, there is no explicit reference to EDPE by the practitioners in explaining their roles. Hence, there is no suffix of 'EDPE', and the frequency is zero, as indicated in Figure 3.

4.4. Practical sources of EDPs

Based on Question 4 in Table 4, the word tree of the practitioners' understanding of EDP sources is shown in Figure 4. The word tree is based on a text search with the top words

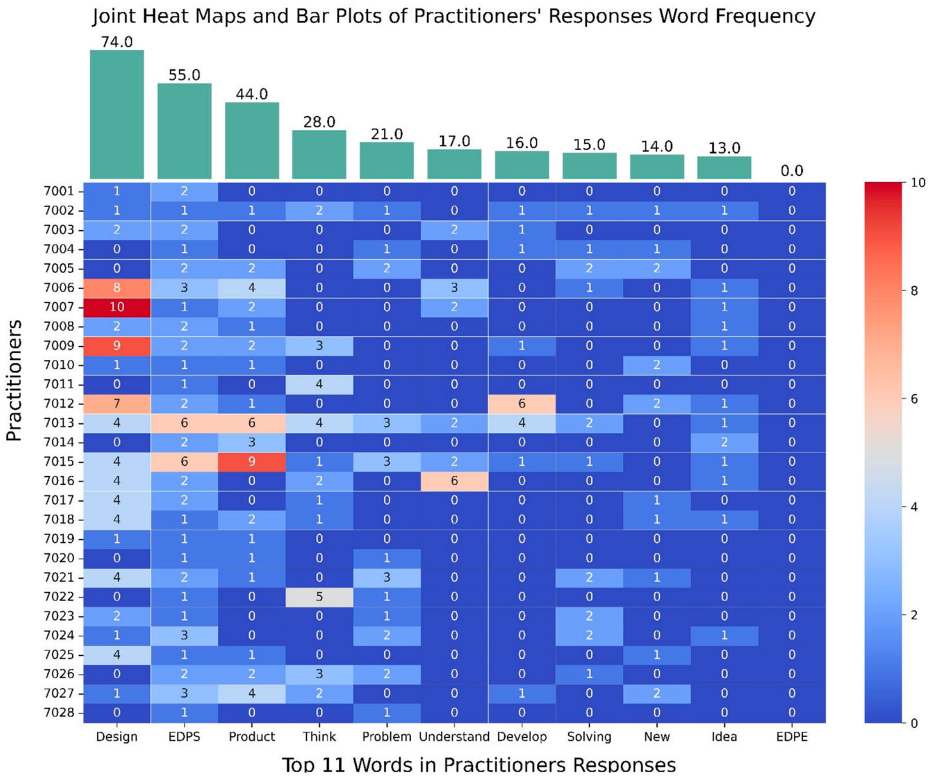

Figure 3. Word frequency descriptions of the practitioners' roles.

'problem', 'something', 'people', and 'client' obtained through a WFA. As 'people' represents individuals in society, including the clients, it is used as the root term for the word tree. For example, as highlighted in Figure 4, a practitioner said, 'I guess the problems are really identified through people's discomfort or difficulties or failures'.

Questions 4 and 5 in Table 4 are complementarily analysed or triangulated – a strategy for validating interview responses (Gall, Borg, and Gall 1996; Obrovská et al. 2024). The practitioners referred to receiving EDPs from people, including clients, in Question 4. They were asked in Question 5 how they received the EDPs. The practitioners reveal they receive EDPs mainly in a text form, although some are received verbally or as an image. The information obtained from Question 5 helped to validate the practitioners' responses to Question 4 that they receive EDPs from clients.

4.5. Relative practical challenges in the EDPE and EDPS practices

Questions 6–9 of the practitioners' interviews presented in Table 4 are complementarily analysed, as shown in Figure 5. For Question 9, either of two EDPs or line briefs was shown to the practitioners. One of the briefs, used in a study (Koronis et al. 2021), is 'Design a device to improve mobility for low-income persons with physical disabilities'. The other brief, 'Design of an automatic self folding dining table', was computationally generated (Obieke et al. 2023; Obieke, Milisavljevic-Syed, and Han 2021). The complementary questions aim to

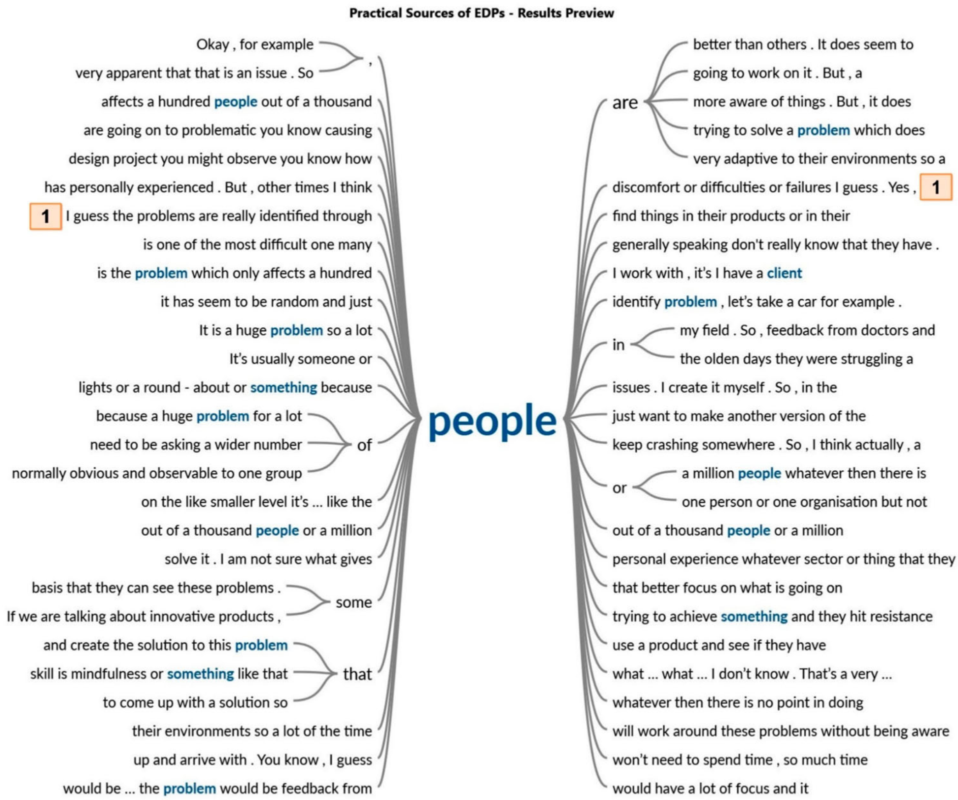

Figure 4. Descriptions of sources of EDPs in engineering design.

practically observe the relative challenges involved in EDPE and EDPS activities. For Question 7, the practitioners who responded with a 'Yes' were asked to think of a new EDP in about a minute. Questions 7 and 9 are used as triangulation or validation for Questions 6 and 8. Discussions are given in Section 5.

4.6. Specialists' interview responses

Table 6 presents the responses to the common interview Question 1 for *Specialists A, C,* and *D*. Where possible, the participants' responses are quoted verbatim. Otherwise, they are accurately summarised for brevity. Similarly, the responses to the common interview Question 2 with *Specialists A, C,* and *D* are presented in Table 7. Questions specific to *Specialists B and D* are presented in Tables 8 and 9. Some details from *Specialist B* are masked in square brackets, where they compromise identity.

5. Discussion

5.1. Impact of engineering design education on practitioners

The education of a design engineer is an important factor influencing the practice of the engineering design profession. Questions 1 and 2 in Table 4 are intended to check the level of adherence to the engineering design skills and methods taught in academia and

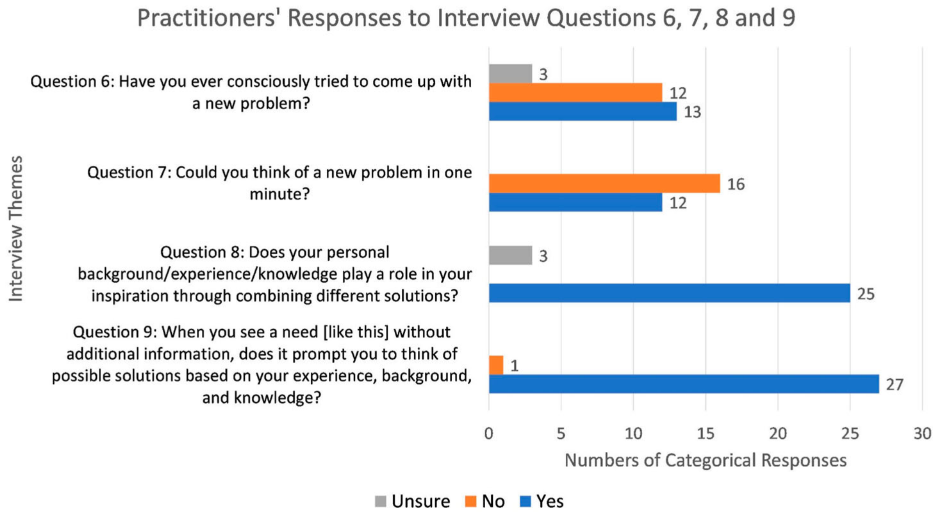

Figure 5. Relative challenges between EDPE and EDPS.

Table 6. Responses to Interview Question 1 (Specialists A, C, and D).

Interview Questions and Interpretations of Responses
Question 1: How do you think the problems we solve in engineering design come about?
Specialist A mentioned that the EDPs they solve or give their students are received from big aircraft manufacturing companies and other local companies. *Specialist A* highlights that how the problems are identified is not their focus because, as an engineering school running various degree programmes incorporating engineering design projects, they believe in solving a problem.
Specialist C expressed that the attention in engineering design is not on EDPE but on EDPS. *Specialist C* mentioned that EDP emerges because 'somebody either has a direct request for something that does something, or they have a need and they have no idea what the solution to that need is'. *Specialist C* explained that design engineers generally react to requirements in a product design brief or expressed needs where there is no current solution. This response shows that design engineers do not proactively identify a new EDP in society because their education does not focus on EDPE, as *Specialist A* highlighted.
Specialist D states that, firstly, in one dimension, EDPs 'come from life because people, as they go about their life, have problems that get in their way or through things they can't do'. Secondly, *Specialist D* states that an EDP could emerge 'where people have things they want to do better. It sounds related, but these are improvements, aren't they? We have things aren't very good we want to improve them, that is clearer'. *Specialist D* highlighted another source of EDP based on 'fresh thinking' where there is no need to improve anything but to come up with what has never been thought about, leading to a huge opportunity. *Specialist D* also mentioned, 'Seeing something as a problem when nobody realised it was a problem before is a characteristic of some of the inventions people would say were the biggest breakthroughs'. This response corroborates the breakthrough success *Specialist B* achieved with their inventions based on the problems they identified, as presented in Table 8.

available in the literature. Responses to Question 1 Table 4 (Figure 1) show that practitioners follow taught skills and methods for EDPS, which are also available in the literature. Some of the design inspiration sources mentioned by the practitioners include biomimicry and in-shop or online competitor product analysis. For example, Participant 7024 mentioned, 'I will conduct research on competitor products, as well as looking into different market sectors'. The professional EDPS practices performed by the practitioners conform to methods such as design-by-analogy (Jin and Zhang 2022), benchmarking (Aalders 2023), and product matrix analysis (Wang, Wang, and Wu 2015).

Responses to Question 2 Table 4 show the practitioners' design process approaches conform to the EDPS models mentioned in Section 2. However, the skills and methods to support EDPE are comparatively lacking in engineering design education and the literature.

Table 7. Responses to Interview Question 2 (Specialists A, C, and D).

Interview Questions and Interpretations of Responses
Question 2: Do you think it is possible to teach EDPE in academia the same way we teach EDPS?
Specialist A agreed that some EDPS approaches could be adapted to teach EDPE. However, *Specialist A* stated that it would be difficult to answer if it is possible to teach about coming up with a new problem without any channel of where it stems from, adding that 'in engineering school, that's absolutely not what we taught to engineers. We taught them that there is a problem, and they have to find a way to solve the problem. We are not there to create problems, I think'. The uncertainty expressed by *Specialist A* about teaching EDPE highlights a potential challenge in EDPE and the need for computational support.
Specialist C agreed that EDPE could be taught. This question intends to know the possibility of teaching EDPE, like EDPS, and not how EDPE will be taught. Hence, no further questions are asked on the response of *Specialist C,* who also highlighted the importance of understanding a given EDP for solution purposes.
Specialist D agreed that it is possible to formally teach EDPE thinking in academia, stating the need for creative thinking. According to *Specialist D*, 'very little is taught, certainly in the universities, about how to use mind, what thinking is, what the structure of thinking are to help people as opposed to just pick that up along the way. So, most of thinking can be taught in the same way that we do teach mathematics. If we understand the mind and understand the limitations of mind and therefore we can force us as in force ourselves onto different, onto new ideas. We have to force ourselves because it doesn't feel natural because we become comfortable with existing patterns'. *Specialist D* added, 'We look for problems more openly and so forth'. Understating the mind and its limitations is a subtle revelation in *Specialist D*'s response, which can help mimic the mind computationally to support EDPE practice. Computational support can overcome natural limitations.

Table 8. Responses to Interview Questions 3–7 (Specialist B).

Interview Questions and Interpretations of Responses
Question 3: What is the basis for your inventive skills?
Specialist B attributed their inventive skills to their upbringing and not particularly a skill taught in academia.
Question 4: How would you describe the problem that your invention solves?
Specialist B clearly described the problem their invention solved and mentioned that 'there was nothing in the market that [provided that solution] … and that was really what I saw as the problem that needed to be solved'. *Specialist B* mentioned that although some products were on the market then, the problem they identified and their invention solved subsisted in those products.
Question 5: Would you consider identifying the problem more important or finding the solution?
Specialist B strongly agreed that identifying the problem is more important as the design engineer would not come up with a solution until one identifies a problem.
Question 6: Would you describe the problem you solved as a random/accidental, created, or discovered problem?
Specialist B said they identified the problem through a random occurrence, which triggered memories of their experience, making it powerful to think about a solution. Other problems described by *Specialist B*, as discussed in Section 5, reflect discovered and serendipitous EDPs (Table 1).
Question 7: How did you verify that there would be a need for your product or invention?
Specialist B revealed that they gave the prototype of their invention to a group of individuals to try out. The individuals expressed readiness to buy the product when ready. *Specialist B* also mentioned doing a patent search for any prior existence.

This suggests that the scarce practice of EDPE is fundamentally connected to the lack of attention to skills and methods to support the practice in academia. As *Specialist A* revealed in Table 6, the attention in engineering design education is not on EDPE. Consequently, as discussed next, design engineers seem to lack the active knowledge that EDPE is a standard role in engineering design.

5.2. Design engineers' roles in practice

The practitioners show an active knowledge of EDPS as their roles based on their responses to Question 3 Table 4, as presented in Figure 3. There are 55 references to EDPS as the practitioners describe their roles, with no explicit reference to EDPE. This result corroborates *Specialist C's* statement in Table 6 that design engineers respond to apparent needs or

Table 9. Responses to Interview Question 8 (Specialist D).

Interview Question 8 and Interpretations of Responses
Question 8: In your opinion, what can creativity help us to achieve? ***Specialist D*** mentioned two important aspects where creativity plays a role. *Specialist D* stated, 'The main thing is to see the situation, genuinely see it differently. Either to see new problems where people don't appreciate there is a problem but that is why it is as bad as it is because we can't see the problem. Or, to take existing problems everyone is stuck with and to help us see them in a different way or to apply or to see the context that we have available to us in a different way to be able to suddenly see a solution to the problem' *Specialist D* added that 'seeing something new and differently is actually very hard'. Again, this highlights the need for computational support in EDPE as a difficult task.

requirements in a product design specification. This is more like responding to a market-pull EDP, as discussed in Section 2. Studies suggest that a market-pull EDP is a self-evident problem that probably goes unnoticed over time, leading to reactive measures and incremental development (Brem and Voigt 2009; Dixon 2001). The practitioners' responses in Figure 4 show that they react to the expressed EDPs of the clients with little or no knowledge of how to identify or conceptualise a new EDP. This reflects the design engineers' university education, as mentioned in Section 5.1, and influences the scarce practice of EDPE. As mentioned by *Specialist A* in Table 6, EDPE is not the focus of engineering design education. Regarding teaching EDPE skills and methods, *Specialist A*, who lectures in France, also mentioned, 'We don't teach them how to find a correct and good idea', highlighting the case in other universities.

The information on the websites of various universities in the United Kingdom offering degree programmes in 'engineering design' or 'design engineering' suggests that engineering design education is focused on EDPS. The universities explicitly describe engineering design as an EDPS profession, with no explicit reference to conceptualising or identifying new EDPs as a standard practice. The notion that engineering design is all about EDPS has propagated over the years, affecting the practice of EDPE within the engineering design community. Despite being a standard practice (Section 1) and an important aspect of the engineering design profession, design engineers are not supported to practice EDPE, unlike EDPS.

Creativity is necessary to conceptualise new concepts (Han, Forbes, and Schaefer 2021), including new EDP and EDS, as highlighted by *Specialist D* Table 9. In responding to Question 1 Table 6, *Specialist D* also mentioned that 'other people are more creative than you are because they have different problems to you that they are trying to solve that you don't have', highlighting the importance of creativity in EDPE. However, the teaching of creativity in engineering design education may not be adequate or comprehensive (Han et al. 2022). The data presented in Table 2 shows that approximately 57% of the practitioners are not formally taught creativity. The lesser percentage taught creativity, it appears creativity is taught as an EDPS phenomenon, as the responses in Figure 3 suggest. Much of the literature focuses on EDPS in explaining or describing the concept of creativity (Kaplan 2019; Romero Caballero et al. 2024; Tekmen-Araci and Mann 2019). This influences design engineers' understanding that creativity is only an EDPS phenomenon. Creative thinking for a new EDP is challenging, as *Specialist D* highlighted in Table 9, suggesting computational and academic support for EDPE.

Like EDPS ability, EDPE thinking ability can be formally supported in academia, and much is not done in this aspect, as *Specialist D* mentioned in Table 7. In the case of *Specialist B,* as presented in Table 8, their EDPE skill is not based on academic support. Similarly, Practitioner 7006 mentioned that they have the potential ability to detect things that could be considered an EDP and usually think, 'What if I did find a solution to that this could that be a good idea'. Also, Practitioner 7010 mentioned, 'I sometimes do contemplate about certain problems that exist or some things that people would be glad to have. And, once you have a problem, you never stop thinking about a solution'. Other practitioners also mentioned that they can conceptualise or notice obscure EDP, as the response to Question 6 in Figure 5 indicates. These statements highlight that design engineers have EDPE or creative abilities even without being formally taught creativity, as presented in Table 2.

Like every other natural ability that requires formal teaching and support, EDPE or creative ability requires formal teaching and support in academia. For example, there are individuals who, without teaching and support, display good football skills. Yet, football academies exist to formally teach and support these individuals to practice at a professional level and be conscious of their skills in the professional world of practice. EDPE skills and methods can be taught in academia to support design engineers in challenging practice, as *Specialists A, C,* and *D* agreed upon in Table 7.

5.3. Sources of problems solved in engineering design

Based on the responses to Question 4 in Table 4, as presented in Figure 4, the practitioners believe that EDPs come from the clients. Responses to Question 5 validate that the practitioners rely on EDPs from clients who communicate the details of the EDPs mainly in text form. Most practitioners mentioned that the clients' EDPs are usually incremental innovations or modifications to a previous product version, reflecting market pull EDPs (Table 1). In the literature, the source of problems solved in engineering design is also attributed to the clients. For example, Becker and Mentzer (2015) acknowledged that the education of design engineers shapes their primary role in receiving and solving EDPs from clients. This translates to the norm for design engineers practising in the industry who focus on solving problems directly from the clients or indirectly through their superiors (Agyemang, Andreae, and McComb 2023; Herrmann and Schmidt 2002). However, a design engineer or an engineering design firm should not rely on clients for an EDP. They can come up with an EDP to drive radical innovation and invention. Unfortunately, the possible ways to do this, as presented in Table 1, lack attention in academia and the industry.

Formal EDPE support in academia would give design engineers a competitive advantage in conceptualising and identifying obscure EDPs with societal benefits. Practitioner 7009 mentioned in this study that the salespeople who relate with the customers are not technically minded enough to interpret the EDPs expressed by the customers as a design engineer would. This highlights the unique ability of a design engineer to recognise, understand, conceptualise, discover, or identify an obscure EDP, which can formally be supported in academia.

Contrary to the practitioners' perspectives on how EDPs come about, the opinions of the specialists in this study support the need for design engineers to practice EDPE. The specialists' opinions and experience align more with discovered, created, serendipitous and apophenia EDPs (Table 1). *Specialist D* advised that design engineers or inventors must actively go out and find problems (Table 7). Otherwise, that mental structure or stricture stops design engineers from tripping across interesting things, *Specialist D* warns. During the response to Question 5 Table 8, *Specialist B* revealed how they identified or discovered the problems three of their inventions solved. One was through observation at a friend's place, which triggered the memory of their knowledge. This could be described as a serendipity discovery, as explained in Section 2. Another was through a challenge around their dependent's need, for which a search shows that other people are facing the problem with no solution available. The third was through encountering a personal challenge. The motivation for *Specialist B* was that if they could create something that solves the problem, they would be fulfilling that need and have a market to buy their product (Table 8).

How *Specialist B* discovered some problems their invention solved corroborates the information the practitioners provided on some EDP sources. This is mainly based on people identifying problems through their challenges, supporting the crowdsourced EDP concept discussed in Section 2. Some individuals discover EDP, based on their circumstances, which could have global commercial benefits. These individuals may lack the interest or ability to pursue a solution and are willing to present the EDP through crowdsourcing to those who can solve it for societal benefits.

In responding to Question 8 (Table 9), *Specialist D* said it is a hallmark of this world that 'once you see an answer to a problem, it seems obvious, or a new idea, it seems obvious once you've seen it. But, before you see it, it is impossible to even see that there is a problem there'. Similarly, in Table 8, *Specialist B* supported the idea that conceptualising or seeing the problem is the most important thing, after which it is a question of skills to solve the problem or its commercial success. However, EDPS has established methods that incorporate testing the success of a product, as highlighted by *Specialist B* in Table 8. EDPE supports invention, which is time-consuming and offers no guarantee of return on invested time, resources, and assets in the future (UKIPO 2021; Zakaryan 2024). Inventions have economic benefits (Jiang, Atherton, and Sorce 2023; Sipe 2019) but are not all driven by financial profit (Papazoglou and Nelles 2023). Although not impossible, 'it is difficult to identify a design problem for which no benchmark solutions exist' (Kershaw et al. 2019). Hence, academic, industry computational, and crowdsourcing interventions are necessary to support design engineers in EDPE.

5.4. Relative difficulties in EDPE and EDPS

The relative difficulty between EDPE and EDPS can be seen in the result presented in Figure 5. As the result shows, 16 practitioners said 'No' to Question 7 in Figure 5, while 12 said 'Yes' and were put on the spot to come up with a new EDP. However, seven of the 12 practitioners who said 'Yes' mentioned that they had thought of the EDP previously before the interview. Only five of the 12 practitioners who said 'Yes' brainstormed briefly to mention an EDP. Hence, 23 of the practitioners could not come up with an EDP on the spot, which did not expressly validate the practitioners' response to Question 6 Figure 5. The response to Question 7 suggests that a conscious effort to come up with a new EDP is difficult. Comparatively, when the practitioners were presented with an EDP in Question 9 Figure 5 and asked if it prompted an EDS, almost all responded with a 'Yes' except one practitioner. The practitioners were not put on the spot for their responses to Question 9 because nearly all of them responded with a solution concept promptly as they said 'Yes', expressly validating their responses to Question 8.

Concerning Question 6 Figure 5, some practitioners shared their experiences in conceptualising a new EDP. Participant 7009 said, 'It is more difficult than you think. When you are just actually trying to find a problem … to sit actually and think, what is a problem? is really hard to actually just think about it'. The participant mentioned that they once wished a product could help them discover a problem. Similarly, Participant 7001 stated, 'It's a pretty difficult process, I guess, coming up with something that is, you know, wholly … you know, you thought of all aspects of it'. *Specialist A* also mentioned that students find it difficult to identify or come up with a societal problem to solve and ended up not finding or coming up with any in an instance they were asked to. This is because students are not taught EDPE skills. Albeit also challenging, EDPS would be more difficult if the skills and methods were not taught in engineering design education. Hence, academic, industrial, and computational interventions are necessary to support EDPE due to the difficulty in the process.

5.5. Academic and industry implications

5.5.1. Academic implications

The findings of this study are relevant to assist or guide engineering educators in reviewing or improving engineering design education. A fundamental goal of engineering design education is to teach students to think more like professional or expert design engineers (Tafahomi and Chance 2024). In addressing the research question posed in Section 1, this study has flagged the lack of attention on supporting EDPE skills in academia as a factor contributing to the scarce practice of EDPE within the engineering design community. Information shared by the specialists underlined this academic determinant and expedient academic measures to address the situation. As *Specialist D* pointed out, much needs to be done regarding creative thinking or creativity in engineering design, mainly to reflect its importance in EDPE.

New strategies in engineering design education that recognise the importance of teaching and supporting EDPE skills are necessary to give the students the expected professional-level EDPE skills. The interview results in this study show that this fundamental skill is lacking in knowledge and practice within the engineering design community. Teaching, encouraging, and supporting EDPE abilities is an important but neglected aspect of engineering design in academia. The experiences shared by the practitioners provide a rare empirical insight into the difficulties design engineers experience in EDPE practice, previously unavailable in the literature. This empirical evidence will guide and inspire academic research towards a computational intervention in EDPE.

5.5.2. Industry implications

The industry has relied mainly on market pull and technology push as sources of EDPs. *Specialist A* mentioned they receive EDPs from companies. *Specialist C* shared a similar opinion that EDPs result from expressed needs from clients, individuals, or firms. These EDPs are mostly market pull or technology push EDPs, where a client or company seeks product improvement due to market demand or applies a breakthrough technology to innovate a product. However, this study highlighted the other sources of EDPs that could be leveraged in the industry. For example, the industry could leverage crowdsourcing as a source of EDP. The information shared by the practitioners and *Specialist B* in this study supports crowdsourcing as a source of EDP. Although market pull or technology push did not inspire the problems solved by *Specialist B*, their solutions are of global success and benefit.

Empirical evidence in this study would enable companies to consider initiating EDPE practice to facilitate conceptualised and discovered EDPs for radically innovative and inventive products. As *Specialist D* mentioned, 'Seeing something as a problem when nobody realised it was a problem before is a characteristic of some of the inventions people would say were the biggest breakthroughs'. Although three specialists in this study are in the UK, which may likely influence the data, data from the 28 practitioners corroborates that of the specialists, especially regarding crowdsourcing EDPs.

6. Conclusions

This paper contributes towards advancing and sustaining the EDPE practice, which is lacking (Ding et al. 2019). Our research examines the factors contributing to the scarce practice of EDPE and suggests how to mitigate them. As presented in this study, the unique knowledge and experiences shared by the practitioners and specialists are significant contributions. The findings in this study show that over the years, engineering design education has focused on EDPS while neglecting the equally important EDPE aspect, which plays a fundamental role in innovations and inventions (Mahon et al. 2017; Sanberg 2024; Shekhar et al. 2024). Although few studies point out the scarce attention and practice of EDPE, the determinants presented in this study are lacking in the literature. This highlights the novelty and contribution of this study. The data obtained from the interviews in this study revealed that engineering design students are not taught the skills or supported for EDPE practice, contributing to scarce EDPE practice in engineering design. For example, results show that some universities do not formally teach creativity, which is fundamental to conceptualising or discovering a new EDP (Wilson 2017). The universities and literature teaching and discussing creativity focus on EDPS and not EDPE, as the results of this study show.

Hence, the knowledge provided in this study has vital implications in academia and industry. It will guide engineering design educators in reviewing and improving engineering design education by equally focusing on EDPS and EDPE, which are expected roles for design engineers. Also, it will reveal to practitioners other sources of EDPs that can lead and have led to inventions besides market pull and technology push, which the industry has relied upon over the years. The study would facilitate academic and industry interventions, including computational interventions, on the scarce practice of EDPE. Consequently, this would increase radically innovative and inventive products of greater societal and economic benefits.

There are limitations to this research. First, the sample size for the specialist interviews was small, with just four agreeing to be interviewed. Second, three specialists are from the UK, which may influence the data as their knowledge and experience are predominantly in the UK context. However, the data provided by the specialists corroborates data from the 28 practitioners. We manually transcribed the participants' responses verbatim to ensure accuracy. Where the responses were not quoted verbatim, we summarised and presented key information to reflect the participants' opinions. Future studies will focus on the structures for teaching and supporting EDPE in academia. Structures for enabling crowdsourced

EDPs and computational support for EDPE will also be explored, and more specialists will be interviewed.

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