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ABSTRACT

Students are expected to have developed their engineering judgement throughout the course of their studies as part of their accreditation requirements (as stipulated by the Accreditation Board of Engineering and Technology for example), and yet conceptually it is often ill-defined and therefore difficult to teach. This work was carried out in an attempt to better conceptualise engineering judgement for use in higher education. As such, semi-structured interviews were conducted with established members of academic staff who additionally had extensive industrial experience – who were asked to define engineering judgement and which aspects students ought to develop in their studies. A pragmatic grounded theory approach was used, based on the assumption that a theoretical idea/framework could be developed, enabling us to refer to previous literature and the emerging categories from our data set to help clarify engineering judgement. Several terms help define engineering judgement, including accumulated experience, fundamental theoretical knowledge, and imagination/intuition. Essential criteria for developing judgement includes students' ability to identify and reduce complex problems, and embrace failure. A theoretical framework has been proposed accommodating a more enhanced definition and conceptualisation of engineering judgement which can be applied and adapted for use within engineering education for students' ultimate benefit.

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Introduction

Setting the scene

We begin this paper with a hypothetical conversation at a dinner party:

- So, you're an engineer. It seems like a fairly sound and straight-forward profession.
- It certainly can be.
- But not always?
- No, not always. It depends on the problems you're faced with. Some problems can be quite complex.
- Yes, but people find a way to get things sorted?

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- Yes, they use their ingenuity and creativity to solve more complex problems.
- And would it be right to say that some engineers are considered better than others?
- In my experience, that would be a fair assumption.
- And you can tell?
- Engineering judgement has a lot to do with this, because it's not just about schooling. Really good engineers know how and when to apply their engineering judgment. They make good calls. It's a form of intuition and knowing that sets them apart.

This snippet hopefully forms the starting point of an important conversation among engineers, guided by the following important question: How do we understand engineering judgement, and what criteria help students develop such judgement within higher education? As educators in a chemical engineering department, we spend much time discussing engineering judgement and how to foster this capability within our students. This subject area is under-researched and the scope of literature modest (Bruhl et al. 2017; Swenson et al. 2022; Edmondson and Sherratt 2022), and yet it is important for engineers to both have this judgement and exercise it to work effectively. According to Davis (2012), 'Judgment is central to engineering … one who otherwise knows what engineers know but lacks engineering judgment may be an expert of sorts, a handy resource much like a reference book or database, but cannot be a competent engineer'. The most recent Accreditation Board of Engineering and Technology (ABET) accreditation, calls for students to acquire '*an ability to develop and conduct appropriate experimentation, analyze and interpret data, and use engineering judgment to draw conclusions*'. Similarly, one of the 15 outcomes of the American Society of Civil Engineers Body of Knowledge (ASCE BOK) calls for graduate civil engineers to have developed judgement (ASCE 2006). Engineering judgement is also a noted learning outcome or expected attribute of accredited programmes of the Institute of Chemical Engineers (IChemE), and Institute of Mechanical Engineers (IMechE), although what is meant by it is not clarified. Therefore, it is important that a concerted effort is made to conceptualise engineering judgement in higher education, especially when faced with complaints among employers, that new graduates lack high-level analytical and critical thinking skills that are necessary for them to make judgements (Felder 2012). Furthermore, there is an understanding among the engineering community that sound engineering judgement is the backbone to good engineering practice. In this paper, we suggest that engineering judgement as a concept requires careful unpacking to obtain a more nuanced understanding of it. This can be achieved by exploring both definition and conceptualisation.

Before discussing engineering judgement in depth, it is useful to highlight notions of judgement more broadly and how they are considered in other disciplines and fields of study. When considering professional judgement in general, Freidson (2001) suggests that the BOK (body of knowledge) of an ideal-typical profession is based on abstract concepts or theories and that their application requires discretionary judgement to be applied. He argues for the 'extensive exercise of discretionary judgement rather than the choice and routine application of a limited number of mechanical techniques' (p.95). For certain professions such as medicine and law, this notion of discretionary judgement and its importance becomes apparent by the way judgement is referred to. Taking the example of medicine, according to the General Medical Council UK,

> you must use your judgement in applying the principles [based on professional standards e.g. patient consent and the patient being listened to] to the various situations you will face as a doctor, whether or not you hold a licence to practise, whatever field of medicine you work in, and whether or not you routinely see patients. You must be prepared to explain and justify your decisions and actions.

Judgement in this case is based upon specific principles of practice, a mature appreciation of the context, and a traceable line of inquiry and decision making. With respect to how professional judgement is understood and applied by the Law Society UK, the wordage and its ensuing meaning are similar:

> you must exercise your judgement in applying these standards [professional standards including confidentiality of the client and transparency of costs] to the situations you are in and deciding on a course of action, bearing in mind your role and responsibilities, areas of practice, and the nature of your clients.

The examples referred to here, suggest that professional judgement is a somewhat fluid idea that is based on intersectionality between the principles and practices of the profession itself, a situational understanding and sequential reasoning. The manner in which one individual exercises their professional judgement may not be similar for a colleague.

Defining engineering judgement

In this section, examples of definitions of engineering judgement taken from literature are discussed (Ressler, Gainsburg, Swenson et al. and Francis et al.) – aptly highlighting variation and association. Ressler's work on engineering judgement in civil engineering (2011) suggests that any workable model of professional judgement ought to rely on the interplay between context, an appreciation of judgement and appropriate execution of the body of knowledge. Even though the example is taken from civil engineering, it could be argued that such a model is transferable to other engineering-related disciplines. A second definition is taken from Gainsburg (2007) who in her work on the mathematical disposition of engineers, established that 'sceptical relevance' was prevalent within the phenomenon of engineering judgement. Gainsburg's ethnographic study revealed that this scepticism arose when maths-based tools were used to solve real-life problems. Similarly, Swenson et al. (2022) established an initial engineering judgement framework for their student body working on open-ended modelling problems. This framework (based on initial scaffolding) consisted of: making assumptions, assessing reasonableness, using technology tools, and overriding answers (on the basis that calculated answers differed). Recent literature on defining engineering judgement includes the idea of identity production and that engineering judgements are formed at the crossroads of decision making, cognition and identity (Francis, Paretti, and Riedner 2021). Essentially, perception, memory, choice – key aspects in the formation of personal identity – play a part in making judgements, especially in groups which is often the case in engineering-based scenarios.

A useful definition is provided by Bruhl et al. (2017), who claim engineering judgement is '*the ability to recognize and/or predict, through a combination of intuition, insight and experience, the probable outcome of an analysis, design or process*' (p.1). This definition stems from the authors' own awareness of the open-ended, complex nature of everyday problem solving in engineering with the main emphasis being placed on experience. We are expanding the idea of experience to include that which is accumulated through observation and interaction with the world on a day-to-day basis. The definition provided may seem apt, though historically the concept of engineering judgement has been ill-received. Following an investigation of the failed launch of the Challenger Space Shuttle, the physicist Richard Feynman (1988), commented that '*when I hear the words "engineering judgement" I know they are just going to make up numbers*'. Feynman's observation suggests there is scope for personal interpretation, with engineers effectively compromising their judgements, which is problematic as it highlights failings associated with understanding and application of engineering judgement and its use (and often misuse). Exploring the Bruhl et al. definition a little further, we agree that engineers cannot work from non-traceable parameters, but there is value added in having a gut feeling, or intuitive thought that may well defy rational thinking, and is based on perception (for example Dane and Pratt 2007; Epstein 2008).

Other researchers have highlighted different facets that contribute to a more joined-up understanding of engineering judgement, and which also form part of a broad, unwieldy definition. Collectively, and taking all these definitions into account, the literature suggests that engineering judgement comprises of ideas around experience (and the expertise garnered void of personal or political bias) (Bruhl et al. 2017; Hughes 1996; Rush and Roy 2001), habits of mind (Francis, Paretti, and Riedner 2021), trust between engineers and society (Parkin 2000), structured reasoning that avoids speculation (Christian 2004), scepticism (Feynman 1988; Gainsburg 2007; Swenson et al. 2022), personal growth (Francis, Paretti, and Riedner 2021), and making meaningful use of intuition to weigh up the influence of parameters (Dane and Pratt 2007; Epstein 2008). The literature highlights the challenges involved in coherently defining engineering judgement, and accordingly without a comprehensive definition, engineering judgement becomes difficult to both teach and learn.

Empirical studies on engineering judgement

Furthermore, it is worth considering how engineering judgement has been framed by previous empirical studies. As an example, a study exploring how engineers cultivated habits of mind used signature pedagogies, for example problem finding, systems thinking and adapting, to re-think the work and education of an engineer (Lucas and Hanson 2016). Similarly, Trevelyan (2010) explored the broader perspectives of engineers, taking into account peripheral aspects such as human social performance and distributed expertise. His findings suggested that social interactions necessitated and were at the core of engineering practices and that engineering should be taught in such a way that recognised this aspect. In a recent ethnographic study, students working on team projects were found to develop their engineering judgement with embodied experience through visualisation (Weedon 2016). Finally, Miskioglu and Martin (2019), recently reported on the ongoing development of an instrument that will measure engineering intuition – an important facet of engineering judgement – among students, based on theoretical/pedagogical ideas of intuitive thought and problem-based assessments. All these previous studies suggest that specific aspects related to engineering judgement have been investigated, but that a holistic, more encompassing understanding of the broad facets of engineering judgement remains under researched. In this paper, a concerted effort is made to explore engineering judgement holistically so that a more meaningful and applicable conceptual definition is offered. Likewise, the use of a grounded theory approach for this study (unlike the methods of data collection and analysis of previous studies) ensures that the eventual findings are not subject to pre-determined criteria or ideas of engineering judgement.

Methodological approach

As we currently have a limited understanding of engineering judgement, and especially how it translates to teaching and learning in higher education, a pragmatic grounded theory approach is employed to enhance our definition of engineering judgement (McCall and Edwards 2021). Our central research question was 'how can engineering judgement be further defined and conceptualised (for use in higher education)?' The perspectives of professional engineers – working in academia with extensive industry-based expertise were sought – as they could both 1. Expand upon conceptual ideas of engineering judgement (using their experiences of bridging) and 2. Meaningfully theorise upon student development in this area (as educators). As a methodological approach, grounded theory is suitable as it allows for theory generation, enabling us to explore further variables and relationships as was originally conceived by Glaser and Strauss (Glaser and Strauss 1967). Grounded theory works on the premise that due to a lack of theoretical understanding of a phenomenon, a theory or framework can be created through intense and systematic data collection and analysis (Glaser and Strauss 1967; Glaser 1978; Strauss and Corbin 1990). Having said as much, all forms of grounded theory require engagement with literature initially to identify the focus and research questions – often greater conceptual clarity is achieved as opposed to a generated theory (Timonen, Foley, and Conlon 2018). The general steps taken in grounded theory are: identification of suitable participants, participant data collection until nothing new is revealed about the phenomenon, rigorous analysis of the data through categorisation and coding to reveal emergent themes and categories, and proposal of a new theory or framework from that analysis. The emphasis in grounded theory is on exhausting all possible responses until a point of theoretical saturation is reached i.e. no further emergent categories, and on accommodating all the data rather than forcing it into pre-existing categories – thus creating an emergent or new model/framework related to the phenomenon under investigation. Even though there are several types of grounded theory, a number of general, guiding principles must be in place: 1. there is no hypothesis testing per se and the questions, data gathering and ensuing analysis must be open, 2. data generation is aimed at explaining phenomenon within context so the researcher needs to be acutely familiar with the context, 3. engagement with the data needs to be robust through constant comparison and theoretical coding, 4. theoretical sampling (as discussed later) ought to be in place (Timonen, Foley, and Conlon 2018).

Pragmatic grounded theory differs from classic grounded theory in that there is a greater emphasis on the positionality of the researcher who enables their prior knowledge, interaction with participants and interpretation of the findings to guide the final outcome (McCall and Edwards 2021). Ontologically, our own positionality as researchers in conducting this work is that of interpretivist – hence the use of grounded theory – and epistemologically that of pragmatist, in keeping with the pragmatic stance on grounded theory as championed by Corbin and Strauss (Strauss and Corbin 1990; Corbin and Strauss 2008; McCall and Edwards 2021). As mentioned, we are chemical engineers by profession, and teach in a higher education setting, so can make sense of our findings and understand them within their contextual relevance. Another key difference is that the literature review in pragmatic grounded theory serves as a way to ascertain a phenomenon and what is known about it rather than determine a problem (classic grounded theory) or central argument (constructivist grounded theory). The approach taken to pragmatic grounded theory is systematic; data collection and analysis must be fully transparent. Institutional ethical approval was sought and attained for this work. All procedural requirements related to consent and information were followed with research participants willingly contributing to this study.

Use of a vignette

To establish whether the broad research question we were interested in answering was appropriate, a 'snapshot' vignette was used to assist our methodology, as an interesting way to simply introduce the topic; the vignette consisted of a cartoon drawing in which one engineer is speaking to another about the importance of engineering judgement. Admittedly, the cartoon depicts two male engineers, although this did not seemingly affect interviewees' responses as it was not commented upon by any of the participants. Having discussed ideas, we felt a hypothetical (but realistic) opening conversation would be the most accessible design for our vignette, although it was not trialled prior to use. The cartoon drawing effectively behaved as an initial stimulus to which research participants responded (Hughes and Huby 2004) and which we used to ask further questions to draw out participants values, beliefs and perceptions. Our process of data gathering and analysis needed to be internally valid (Gould 1996) – did we answer the question we sought to answer? As we are seeking further clarity on a phenomenon i.e. using grounded theory to conceptualise engineering judgement for use in education, the vignette was employed as a springboard which helped to initiate and focus the conversation on engineering judgement. Vignettes have been found to work especially well for topics that are difficult to discuss (Barter and Renold 2000), allowing for open questioning. The vignette is presented in Figure 1.

Research participants were shown the vignette for a few minutes and were then asked a few questions associated with it, which were used as prompt questions within procedural semi-structured interviews:

- Does the cartoon depict real life?
- Why or why not?
- Have you ever been in a situation like this one?

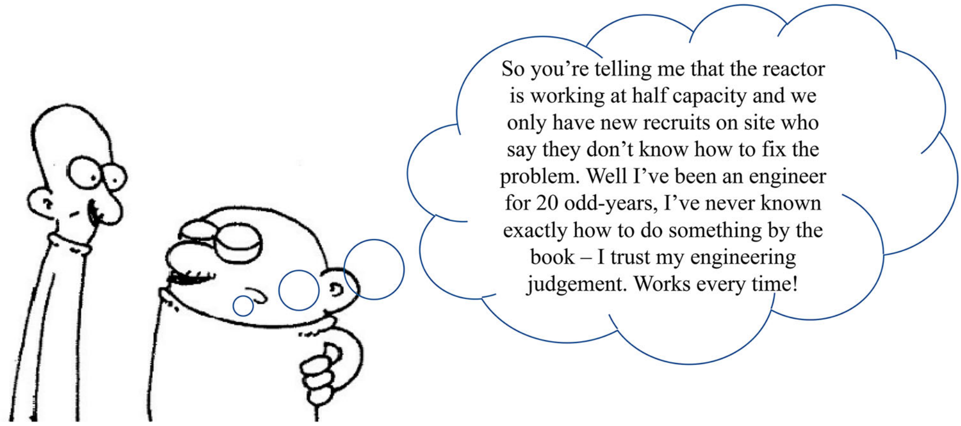

Figure 1. Vignette used as a snapshot for initial interviews with research participants (image adapted from Cartoon Stock).

- How do you go about solving an engineering problem?
- Does the idea of engineering judgement come into it?
- In the cartoon, the engineer mentions that he has developed his engineering judgement over the past 20 years. Can such a quality be learnt in higher education?[1]
- If so, how can students learn engineering judgement and if not, why not?

As the participant interviews were semi-structured, the ensuing conversations covered participants' understandings and professional experiences of engineering judgement, as well as what engineering judgement meant within higher education and the subsequent implications for students' learning.

Selection of the research participants

Our research participants consisted of professional engineers with first (and often second) degrees in an engineering discipline and who worked in academia, but also in collaborative partnerships with industry experts/ on industrial projects. These individuals possessed a good degree of experience of both industry and academia, meaning they were mostly (but not exclusively) above the age of 45 with established careers. The extent of crossover experience was an important criterion for us to fulfil as the literature suggests that engineering judgements are applied in industrial contexts, although students are introduced to these ideas and start developing their engineering judgements in academia (Branan 1994; Buch 2007). Throughout their education, students are expected to be presented with opportunities (mostly via assessed projects) to apply and practice engineering judgement and learn the core, foundational skills necessary for making sound judgements. Therefore, for this particular work we are assuming that the most beneficial understanding of engineering judgement comes from individuals who have been exposed to both settings and who are better able to articulate notions of engineering judgement than current students. As this is a select group of individuals (who in the UK are mostly Caucasian, middle-aged men), recruitment was mostly conducted through pre-existing networks, word-of-mouth, and personal recommendation. For example, the researchers initially considered who was known to each of them that fulfilled the inclusion criteria and had the relevant experience and exposure to meaningfully contribute to this study, and asked participants to recommend others. Additionally, we deliberately aimed for a more inclusive group e.g. spectrum of ages, good female representation, international perspectives. Snowball sampling in this way is appropriate for grounded theory research as the lack of familiarity with the phenomenon ensures greater insider involvement can connect the right people, who can offer a valuable perspective, to the study itself (Glaser and Strauss 1967). Validity is also enhanced through snowball sampling (Walther, Sochacka, and Kellam 2013). Similarly, theoretical sampling enabled us to ensure this work was theoretically valid through a process of verification – by effectively generating a theory with some participants and then testing and modifying it with others. Furthermore, a deliberate attempt was made to ensure younger voices were heard, different cultures were represented and there was a gender balance (although this proved difficult in practice).

These individuals were then emailed directly by the researchers asking them if they would contribute and were sent a consent form, information sheet and the questions at this time. The data was effectively collated during one-to-one interviews in confidential spaces. All the interviews lasted approximately one hour, were recorded using professional devices and were transcribed in full. The use of the vignette and the follow-up questions meant research participants provided definitions for engineering judgement and additionally explored associated teaching and learning strategies, even though these questions were not asked directly – in response to whether engineering judgement can be developed and how. Our findings on the appropriate teaching and learning strategies to develop engineering judgement have been previously published (Chadha and Hellgardt 2022). In total, we interviewed 23 individuals using theoretical sampling to do this (Glaser and Strauss 1967; Corbin and Strauss 2008). After interviewing 12 participants, we analysed the data to develop an initial understanding of engineering judgement, and proceeded to interview suitable participants who could either reaffirm or refute and modify that understanding, and advance our initial conceptualisations until the point of saturation. In accordance with ethical considerations, pseudonyms have been used to protect the identity of the individuals involved (derived from the first initial of the participant and culturally appropriated). Further details on these individuals are provided in Table 1.

Analysis of data through categorisation and coding

The data obtained from professional staff was analysed by repeatedly reading through the transcripts in chronological order and annotating them. Each transcript was read and preliminarily coded/categorised independently by both researchers prior to discussion, in an effort to ensure reliability by exercising consistency whilst analysing the data. Through this process, it was possible to identify particular terms and ideas (sensitising concepts as denoted from the literature review) that can be affiliated with engineering judgement and its associated qualities and characteristics. This was initially a fairly slow process as would be expected due to the richness of data and the detailed analysis that is required for grounded theory. The use of annotation of transcripts enabled emergent categories to emerge in accordance with some broad topics that we had previously identified as significant whilst conducting the literature review, and that helped with answering our research question. These topics consisted of: (1) terms that help us define engineering judgement (2) broader conceptualisation identified through challenges and opportunities (3) strategies related to the teaching or learning of engineering judgement. Findings from topic 3 have previously been published (Chadha and Hellgardt 2022). As categories began emerging, they were assigned a numerical code – 1, 2, 3, etc. for simplicity and ensuring the point of saturation could be detected. Following-on from a secondary analysis of the data, axial coding enabled us to detect broad themes based on patterns and repetition forming within contextualised prose. Subsequent transcripts were analysed in similar fashion to both affirm the existence of these categories and assign numerical codes to new categories that were not revealed in previous transcripts. We considered the use of a software package, such as NVivo to categorise data, but decided against it as the process may become too mechanistic, providing no scope for reflection which is much needed in this work as contextualisation and internalisation are key to understanding the findings (Johnston 2006). An example of annotated text that has undergone categorisation and coding (part of the transcript from Peter's interview) is provided in Table 2. The example provided denotes how the transcript was unpicked line by line, given an appropriately labelled and reflective category and subsequently a numerical code for quick and easy

Table 1. Logistical details of participants including background and level of experience.

Pseudonym denoted	Gender F/M/other	Ethnicity	Industry	Years of professional experience	Level of experience
Khloe	F	British Caucasian	Consultancy	< 3	Recent graduate with considerable amount of work experience. Graduated with 1st class honours, employed as graduate management consultant.
Benedict	M	British Caucasian	Engineering research	< 3	Recent graduate with considerable amount of work experience. Graduated with 1st class honours, working in postgraduate position.
Cecile	F	French Caucasian	Pharmaceuticals	Between 20–25	Professor whose research work has industrial applications
Robert	M	British Caucasian	Process design	> 35	Emeritus research associate who spent most of his career in industry.
Dekel	M	Israeli Caucasian	Engineering research	~ 25	Professor of engineering education
Sunil	M	British Asian	Consultancy	~ 15	Graduate of engineering who has set up own consultancy
Patrick	M	British Caucasian	Oil and gas	~ 20	Senior executive with oil and gas company, currently on secondment in a HEI
Deepak	M	British Asian	Manufacturing	> 35	Recently retired engineer, who recruited and worked with placement students
Daniel	M	British Caucasian	Process design	~ 25	Former lecturer who set up his own consultancy and delivers some teaching at a HEI.
Jake	M	American Caucasian	Biofluids	~ 20	Professor of chemical engineering who has set up spin-off companies.
Costas	M	Greek Caucasian	Solar power	~ 20	Professor of chemical engineering who has set up spin-off companies.
Arabela	F	Spanish Caucasian	Pharmaceuticals	Between 20–25	Professor whose research work has industrial applications
Kadira	M	British Asian	Food manufacture	~ 15	Professional engineer who manages student placement recruits
Peter	M	Irish Caucasian	Bioengineering	>30	Emeritus professor who has set up spin-off companies.
Graham	M	British Caucasian	Oil and gas	>35	Emeritus professor who spent most of his career in industry. Honoured for services to engineering.
Simon	M	British Caucasian	Oil and gas	>35	Emeritus professor who spent most of his career in industry. Honoured for services to engineering.
Toshihiro	M	Japanese Asian	Engineering research	~ 25	Professor at research-intensive HEI in Japan, does a lot of work with industry
Tamaki	M	Japanese Asian	Engineering research	Between 15 and 20	Senior academic at research-intensive HEI in Japan, does a lot of work with industry
Vasima	F	Nigerian Afro Caribbean	Consultancy	~ 20	Works extensively in industry, liaison for local university
Vikas	M	Indian Asian	Bioengineering	~ 10	Newly-appointed lecturer with lab-based research experience (consultancy)
Dhara	F	Indian Asian	Engineering research	~ 25	Senior academic of engineering research with industrial experience
Jonathan	M	British Afro Caribbean	Lab-based research	~ 15	Academic with industrial experience, whose main role relates to practical labs/applications of engineering
Kate	F	American Caucasian	Bioengineering	~ 15	Professor of bioengineering, does a lot of work in industry

identification. The numerical codes could be used to detect patterns e.g. frequency within context amongst participant transcripts.

Table 2. Annotated (to include codes and categories) paragraph from interview transcript.

I'm always loathe to say well I can use my judgement to work out what's going to happen	
and maybe in the back of my mind, based on my experience and understanding,	[10] – accumulated and assimilated experience
I know it's likely to be this.	
But I try and park that and look at each thing and learn from the process I'm going through.	[2] – application of old knowledge to form new knowledge
Now the engineering judgement is important and something to be aware of and	
I think that some of it you learn through training by looking at problems, but a lot of it you learn through experience.	[9] – knowing and understanding the problem [10] – accumulated and assimilated experience
I'm very careful in that I don't let my previous knowledge or experience cloud my judgement	
in looking at the challenge I'm dealing with at the moment	
because there may be things that I don't know or quite understand.	[27] – knowing that it is limited in application

A tabulated version of the categories that emerged from the data after all transcripts were analysed (as per Table 2), in addition to the associated numerical codes we assigned and the broad themes that represented all the emergent categories has been provided as Table 3 in this paper.

Methodological limitations

Of the 23 research participants that contributed to this study, only 6 self-identified as female. Unfortunately, engineering remains a male-dominated vocation and it proved difficult to convince the few women known to us who fulfilled the requisite inclusion criteria to participate. Similarly, the majority of participants are in the 45+ age bracket with 10 of the research participants between the ages and 35 and 45, and 2 recent graduates (younger than 30). It was difficult to recruit younger participants who fulfilled the inclusion criteria or those representing different ethnicities, but equally concerted efforts were made to understand their perspectives as part of this work. Research participants came from within the discipline of chemical engineering and related fields, which may appear limiting. Even though pragmatic grounded theory is contextualised, engineering judgement as a conceptual idea should be similar throughout engineering (Ressler 2011; Weedon 2019; Francis, Paretti, and Riedner 2021), with specific examples being embedded within particular disciplines. Francis et al., for example, acknowledge that there is disciplinary resonance when considering notions such as engineering judgement, but that the cognitive processes that support decision-making are broadly similar within engineering. Similarly, Weedon reflects on engineering judgement as a 'rhetorical competency, one marked by the ability to rhetorically shift or invent standards and considerations in contingent situations' (p.174). Rhetorical competency is a broad notion which is then applied to specific conditions. The framework presented though does need to be appreciated within the context of its methodological limits.

An analysis of the data

It was possible to create an eventual list of all the emergent categories and their associated codes from the data, as mentioned and referenced in Table 3. From the emergent categories, major themes arose which we have labelled: attitudes, behaviours and cognitive capabilities. The categories themselves were labelled in such a way that embodied the central idea and that seemed sensible. In writing up the analysis, particular attention was paid to those terms and ideas that were repeated more often in conversation than others – establishing major (represented by more than half the number of participants) and minor categories (represented by less than half the number of participants). In this section, some of the results are presented as transcript from participants along with their ensuing analysis. The selection of the categories that are included as illustrative examples is based on those that were considered major categories or were of personal interest.

Table 3. Main themes and categories to emerge from the data, and associated numerical codes (Attitudes (A), behaviours (B), cognitive capabilities (C)).

Theme descriptor from staff interviews	Major theme	Categories	Codes	Frequency
Core cognitive approach students ought to take to develop judgement	C	Being able to explain the thought process involved*	1	12
	C	Application of existing knowledge to form new knowledge*	2	18
	C	Basic information is fundamental*	3	15
	C	Competency and theoretical background*	4	21
	C	Use of imagination and/or intuition (related to acquisition of experience)⍰	5	8
	C	Being able to see the wood from the trees⍰	6	7
	C	Common sense and logic⍰	7	11
	C	Understanding the context and consequences beyond the technical scope⍰	8	7
	C	Really knowing and understanding the problem you want to solve before breaking it down*	9	16
Behaviours students ought to enact and required conditions	B	Accumulated and assimilated experience*	10	23
	B	Students needing to take responsibility for their learning⍰	11	7
	B	Unwritten rules and failures ought to be documented⍰	12	1
	B	Asking questions*	13	15
	B	Should be part of a marking criteria e.g. design project⍰	14	2
	B	Failure treated as a lesson*	15	19
	B	Continual process of development involving reflection*	16	12
Attitudes students ought to acquire that foster obstacles and opportunities	A	Learning from mistakes as part of the experience*	17	23
	A	Constraints if students are able to learn by following a recipe⍰	18	6
	A	Understanding that higher education acts as a foundation⍰	19	2
	A	Computer programming can hinder/help understanding of fundamental principles⍰	20	2
	A	Students not being celebrated enough for knowing/applying judgements⍰	21	1
	A	Students engage with assessment strategically – self-assessment could be considered⍰	22	1
	A	Students uncomfortable with making mistakes (feelings of fragility)*	23	12
	A	Confidence and trust in own judgements required*	24	18
	A	Worrying over marks holds students back⍰	25	6
	A	Students are highly competitive⍰	26	8
	A	Knowing that engineering judgement is limited in application⍰	27	3
	A	Students' lack of passion/enthusiasm for engineering⍰	28	2

*Major category (more than half the number of respondents commented on this aspect).
⍰Minor category (less than half the number of respondents commented on this aspect).

Attitudes

The broad theme of attitudes encompasses the mindset or outlook that would help students develop their engineering judgement skills, for example an appreciation of higher education as providing a foundation that needs to be built upon in their working lives. Equally, attitudes that hinder students have also been identified within this broad theme, for example the somewhat competitive nature of students that drives them to focus on outputs rather than learning and which needs to be mitigated against. Analysis and discussion of some of the example categories identified are discussed.

Learning from mistakes as part of an experience

All research participants spoke of the need for accumulating experience (see behaviours), but then followed-up with the importance of making and learning from mistakes or failures (morphing into a behaviour), and that experience became invaluable in developing engineering judgement if it was coupled with learning from mistakes. Similarly, all twenty-three participants reflected on this aspect of engineering judgement in some way. Exemplar comments are provided from Costas, Robert, Toshihiro and Jake and reflect similar ideas of students being comfortable with mistakes/failure:

> They have to make mistakes multiple times until they get it right. In years 3 and 4, do we have, is it something where we consciously set up a problem and let them thrash it out – change your way of thinking, apply a new solution. Costas

> In order to understand the problem, you then really have to go into some depth, not just the calculation, but the mechanics of the process, what has happened, has something gone wrong, have we left something out. So often mistakes can lead to a much better understanding. Robert

> Because in university, you teach the theory right, just the theory. They don't see failures. But in a factory they experience failures. We don't teach any failures. Failure is a very important thing to remember. Experience can only be enhanced by it, in the factory. Toshihiro

> If we want to teach them engineering judgement, you know all you need to remember to do is relate it back to your own experience and just step back. Does this make sense? And yeah, and you know anybody looking at that answer would say no, that doesn't make sense. It's wrong, but it's ok. Start from there. Jake

Admittedly, students do not find it easy to recognise and learn from their failures. An example from entrepreneurship education testifies to the fact that education and the nature of learning itself might have to change if we expect students to be aware of and respond to their feelings rather than their thoughts related to failure (Shepherd 2004). Students need to differentiate between failure of a task and considering themselves failures, which is inherently difficult. Further research argues for the importance of coping mechanisms and that students need to be able to 'bounce back' and use failure in a constructive way if they are to progress beyond their sense of disappointment (Shepherd, Patzelt, and Wolfe 2012). However, acknowledging and learning from failure is a vital component for developing good engineering judgement.

Developing confidence and self-trust

Students need to develop confidence and trust in making judgements and following through on them. Effectively, a supportive learning environment is essential which perhaps is the responsibility of both the student and the educator. Eighteen of the twenty-three research participants commented on the need for students to be confident about the judgements they make and trust their knowledge and ability. Some of the exemplar comments are given, whereby Patrick, Sunil, Arabela and Simon acknowledge the importance of self-confidence:

> For me it's, those that are really good at making engineering judgement are those that have confidence, confidence in their own abilities and can see the wheat for the chaff. So they can see through a complex problem and pick out the bits of data they need to use to make that judgement. Patrick

> They get nervous in showing us what they know, and that's the worst thing because if you don't trust what you have to say so it stops you saying it, you might be doing your colleagues, company, the consumer a great disservice. It's important to have the confidence to put it out there. Sunil

> So that's the first thing that you need and then half of it is having the trust and the confidence to say I can do it, I can solve this. There is a solution for this, I think that's really what engineering is about. It's to say there is a way and then having the confidence to say I can find this way, and it might not be, there will be other ways and that's fine I just have to find one way that gives a reasonable solution, a working solution for this problem. Arabela

> I think it's partly about confidence, but it's not about over-confidence. It's always being prepared, whatever you're doing, to have someone else say, um no. as you get more experience, you'll probably be right more often, but you will probably be wrong some of the time and probably more often early on. So it's 'confidence, but' … I would love to give our students more confidence and without relying on a computer program. Simon

According to Gibbs (1998), self-trust is trust in one's own ability to make decisions on one's own terms with the understanding that one's judgement is valid. With this in mind, the notion of self-trust can be seen as a necessity that enables students to form engineering judgements in the first place; if individuals do not have the informed self-confidence that self-trust makes possible then they end up being fairly vulnerable (Dwyer and Marsh 2017). Trust and an affiliated sense of belief are difficult to foster in that they are considered intuitive (Roghanizad and Neufeld 2015), meaning that the positive, supportive environment mentioned earlier becomes a key ingredient to students developing their self-trust and self-confidence.

Behaviours

As a major theme, behaviours focuses on the activities that students ought to take and the ensuing habits they ought to develop that would support their development of engineering judgement. Examples of suitable or appropriate behaviours include having students take responsibility for their own learning and continually reflecting on learning. Additionally, in this major theme, we have also included the conditions that are important for these behaviours to develop, for example including marking criteria related to engineering judgement in assessments. Analysis and discussion of some of the categories identified in this broad theme is provided.

Accumulated and assimilated experience

Experience that is both accumulated and assimilated was one of the major categories to emerge, for all 23 respondents. Experience has been commented upon in literature previously but was embellished in this current study. The following exemplar comments highlight the role experience plays in developing judgement, with students behavioural patterns being such that they can make sense of new experiences in relation to older ones and use experience as something of a guide:

> So I think that there are 2 ways that you can learn it. I think that one is that over time you will just see everything happening, and then in the future you would be like oh I've seen that before and that kind of thing. And then you'll see other people using it, and start drawing on previous experiences. Khloe

> If by judgement we understand experience, then some of it is your experience and there will be problems that you have encountered before but then you rely on those, basic information that you end up having in your brain and it's almost automatic that you do calculations or you do rough numbers and you know certain sizings of equipment cannot be possible. Arabela

> And then the guys in the factory would say to me, it's because of engineering sense. That's the answer, there's no theories. So all engineering sense is based on their experience. Toshihiro

Recent research concurs with this view that experience is a key ingredient in establishing judgement, with Potts et al. (2020), arguing that 'we might also expect to find more experienced practitioners to have more consistent judgments than less experienced practitioners, or for practitioners with similar backgrounds and experiences to share similar judgments' (p.580). Equally, other research has also pointed to experience as a criterion in development of sound judgement (Bruhl et al. 2017; MacRobert 2018; Swenson et al. 2019).

Asking questions

Participants commented on students being able to ask questions and to continue doing so as a means of developing judgement (also evolving as a good habit). Fifteen research participants commented on this particular behaviour, citing it as an invaluable first step in nurturing confidence in judgement when students know what question to ask. Part of the interview transcripts from Simon and Graham demonstrate such perspectives:

> Problem solution is easy so long as you've got the right problem. Are you asking the right question, and if you're not asking the right question, you will certainly get the wrong answer except by great good luck … What do you want to assure yourself of at the end and it's giving graduates the ability to ask that question. It's having that confidence to ask the questions. Can it be learnt on a 4-year course? No, but can we get them on the right way and having the confidence to ask the right questions? Absolutely. Simon

> Part of that process, what you're asking them to do is to ask the right questions – what's important? What isn't important? If I don't know something how can I estimate it? What analogies can I bring in that are likely to give the best orders of magnitude? By asking the right question, you help students to develop this instinct. By the time we get to final-year design you're in a position where you can see how it all comes together. Graham

Previous research has pointed to this ability to ask questions, whereby researchers found that reverse engineering that encouraged questions, led to students developing their critical judgement (Golding 2011). Very little research is available on the relationship between asking (the right) questions and developing engineering judgement, although Weedon (2016) mentions active examination that involves establishing questions as part of a process through which students eventually develop their judgement-making ability.

Cognitive capabilities

Cognitive capabilities, the third of our major themes, are associated with habits of the mind (thinking skills) that students should possess to further improve their engineering judgement skills. The cognitive capabilities or approaches that we have identified are used to help students solve engineering problems. Examples of categories associated with this theme include developing a threshold competency in engineering fundamentals and having an appreciation of the context and consequences of a proposed solution beyond the initial scope of a problem. Some of the exemplar proposed categories are explored in greater detail.

Awareness of the thought process (accountability)

Somewhat related to this notion of acquiring experience, (although not as readily cited in literature), was being able to unpack and demonstrate a step-by-step process of thinking in having made a particular judgement – objectifying of ones' experience somewhat. When interviewed, twelve of the research participants commented on this articulation of the sequence of events in reaching a judgement. Exemplars of comments that relate to accountability are provided, in which Graham, Dekel and Kadira consider it a necessary attribute:

> Then, how you go about solving a problem – I would say there are 3 or 4 levels you can do it at. The 1st or highest level is purely instinctive, whether something feels right or what appropriate solutions might work … The next level down is orders of magnitude calculations, so not exactly back of an envelope stuff but a rough calculation which you can either do in your head or on paper where you make crude approximations and you put rough orders of magnitude in that are realistic … Now if you go down to the next level, this is where we do the detailed design and modelling. Graham

> No it doesn't [in reference to validity of vignette]. Not at all, because if a person can't explain in any way how he makes his decisions then it becomes invalid, because they can't be traced, you can't check up on anything. It's like taking things out of mid-air. Dekel

> I have to be able to understand where its coming from. Joined up thinking has to be there. The judgement doesn't stand alone. Kadira

This sequencing process of how thoughts come together in ones' mind and the significance of it is rarely reported on, although earlier research on intuitive-judgement formation suggests the importance of a thought process that can be unpacked to establish how sound the judgement is (Glöckner and Wittman 2010). Intuitive-judgement formation is akin to metacognition, which has been researched in engineering education before now (Cunningham et al. 2015; Evans 2018; Vos and de Graaff 2004), although not in the context of engineering judgement.

Sifting through the data and identifying the problem

A major theme that was repeated several times by sixteen of the participants, was this notion of identifying the problem and working meaningfully with available data to do so. This is certainly a key step in developing good engineering judgement, and equally a skill that a good engineer would have at their disposal. The comment made by Deepak serves as a good example of participants' views:

> It's about outcomes, it's knowing that step 1 define clearly what is the problem you want to solve. I think it's very important to know what you're wanting to deliver. So that's the first thing that you need. Deepak

A slightly more nuanced discussion arose around having an implicit strategy in place that allows one to break the problem up, whether it be prioritising, comparing information to theory and practice, taking a step back or identifying what's important. These comments are reflexive of several participants perspectives:

> I think it's interesting, so I think you know a lot of it is about framing the problem, so understanding what the problem is in the first place. And I think judgement does come into that. Because you have to sort of prioritize. Aspects of the problem and you have to have some awareness of what might happen. You know if you try to address 1 issue, what sort of other impacts it could have, so I think you have to use your judgement in that. Cecile

> So you identify an issue, you spend time and effort getting information from the issue and you and you compare that information to theory and you compare that information to what you've experienced before. And then your judgement is based on how you weigh all that up as to where you go next. Daniel

> I think of an example where loads of specialists got together and they couldn't find a solution because they didn't step back a bit and say well, it's the wood from the trees. You also have to have a wider perspective than the problem, not necessarily the entire plant or equipment at hand, but that's true of all problems. You need a way of stepping back a little bit and taking in a different view of things. How you teach that is different entirely. Robert

> So, confidence, competence, gut feel, common sense and just thinking about the problem and the ability to take, as I say, we're usually presented with issues where you're surrounded by a plethora of data, and it's just making sure you can identify the bits of data you need to make that qualified engineering judgement. Patrick

This notion of formulating the right question has been discussed previously; in a study that explored differences between student engineers and professional engineers, the professional engineers spent considerably more time scoping the problem and gathering information (Atman et al. 2007). Students are often faced with incomplete sets of data and ambiguity from which they are asked to exercise engineering judgement (Douglas et al. 2012; Francis, Paretti, and Riedner 2021). Therefore part of students' training is directed towards fully understanding the problem they are asked to solve. Similarly, in medicine, Cristancho et al. (2017), argue that a problem is defined through emergence, with this emergence fostered through conceptualisation and understanding rather than considered an isolated step.

Imagination

To a lesser degree, participants (of which there were eight in total), spoke of an extra ingredient which did not stem from logical thought, and was the use of imagination in moving beyond a right answer to a creative solution. Exemplar comments on the significance of imagination are provided by Tamaki, Sunil and Vikas who suggest imagination is subtle, but necessary:

> [Engineering judgement] is just imagination. I mean that I don't work on a plant, but … of course it is based on some knowledge. Of course the reaction mechanism, the reactor behaviour, of course we know well. However, if we imagine the reality of the plant, I think it is not so simple. [Solving engineering problems] cannot be explained by the simple logical description. Tamaki

> The really good students will show something a bit more to make their work stand out. I'm not sure what you would call it, but they dream big and they add an extra layer – it's creative and imaginative. It's engineering judgement plus, plus. It's a part of engineering judgement I guess, but where you think about it without boundaries and with endless possibilities. Sunil

> I think imagination and intuition have to be there and this is regardless of experience or of time. Vikas

Recent work suggests that making decisions, and therefore forming judgements are more naturally influenced by imagination than we might initially perceive to be the case (Nanay 2016). Choices or decisions are made on the basis of what captures ones imagination, and how the potential outcome of a final decision might play out – whether option A might be better than option B. A relationship exists between imagination, judgement and confidence in that those who can imagine the consequences of making particular judgements express greater confidence in their eventual judgements (Koehler 1991; Nickerson 1998).

Discussion

The proposed framework

As part of this discussion, we propose a theoretical framework that represents a more advanced conceptualisation (and definition) of engineering judgement, for use in higher education settings. In this section, we discuss the framework in greater depth. The framework is represented in Figure 2, and

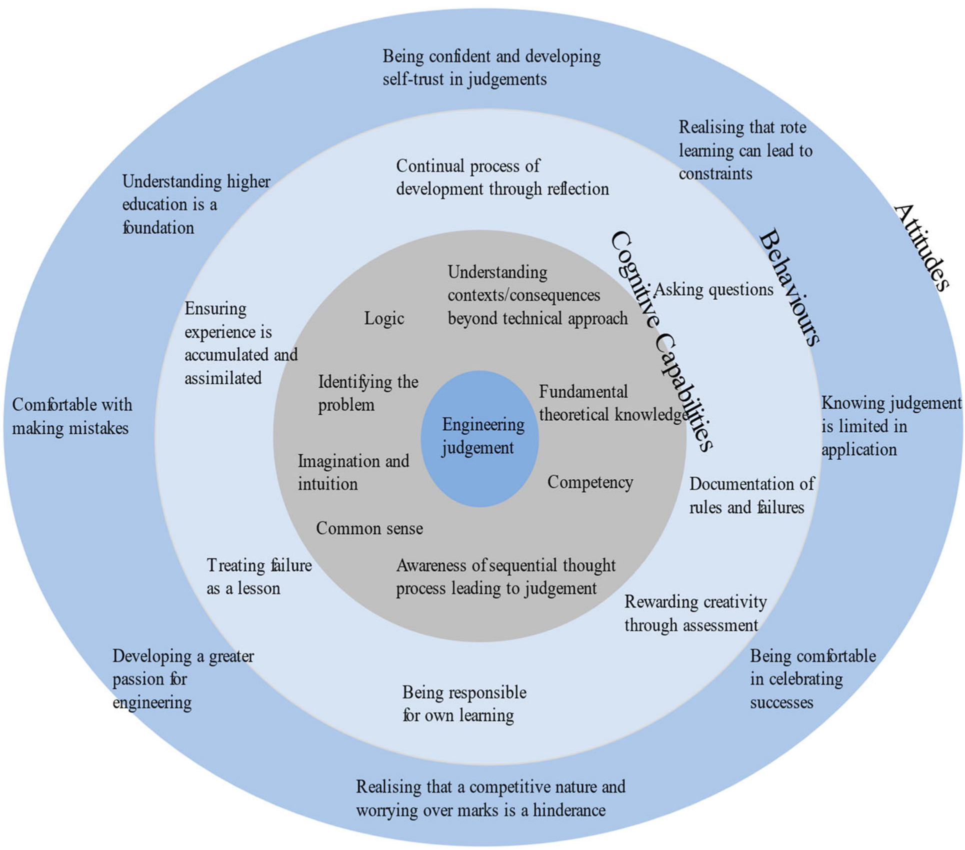

Figure 2. Theoretical competency framework of attitudes (A), behaviours (B) and cognitive capabilities (C) associated with establishing definition and necessary criteria for developing engineering judgement based on a grounded theory approach incorporating principal categories.

consists of three concentric circles (to suggest a relationship between the terms). The most central concentric shape accommodates cognitive capabilities related to habits of mind, that students ought to develop (C). The next concentric shape highlights the behaviours that students ought to acquire (B). The outer-most concentric shape consists of attitudes that students ought to adopt (A). In terms of our suggested relationship of the 3 concentric circles, we propose that cognitive processes related to belief and knowledge informs an individual's attitude. Acting on an attitude formulates certain behaviours. All the ideas represented in the framework collectively help us further define and conceptualise engineering judgement. The framework does not represent a process of learning, but rather the key features (attitudes, behaviours and cognitive capabilities) that go into developing engineering judgement in higher education settings. As expected, we identified some degrees of overlap from previous literature in developing the framework.

In this section, we highlight and further expand on some of the interesting aspects of our framework and what they represent in educational environments. The aspects discussed are: accumulated experience, defining the problem, learning from failures or mistakes, common sense, imagination and intuition. It is important to note that the framework is based on pragmatic grounded theory, which is usually denoted as 'a small t' – contextualised and specific – and can be a descriptive non-theory consisting of conceptual ordering and in-depth understanding (McCall and Edwards 2021). There is no particular structure or ordering within the framework we have proposed.

One of the important features of the framework is accumulated experience and theoretical knowledge, which we would argue can be acquired through educational and every-day opportunities and observations, and encompass every-day phenomena as well as more complex problems. In reference to our framework, experience refers to that which is accumulated (and assimilated) over time – an apprentice model that builds in reflection and co-operative learning and which enables students to develop their expertise (Smith 1988; Chikh and Hank 2016). Relatedly, it has been suggested that the ability to make good judgements is acquired through expertise and wisdom (which comes from developing meaningful insights from experiences) (Hawse and Wood 2018). We would concur with Hawse and Wood's further suggestion that expertise is accommodated within 1. The 'know-what, know-why, know-how and know-who' of foundational, grounded knowledge 2. Activities that are reflected upon, and through which wisdom is cultivated. These more expansive definitions of knowledge (1) and experience (2) support students in developing their engineering judgement by exemplifying the particular types of knowledge required and highlighting what makes experience meaningful.

Our respondents (professional staff) overwhelmingly adopted the idea that defining the problem was a crucial first step in the process for making sound judgements. As part of the ABET 2000 engineering outcomes, students are required to be able to 'identify, formulate and solve engineering problems.' This can essentially be seen as scrutinising the problem through analysis and sense-making (Brophy and Li 2011), and which usually requires individuals to sit with a problem until they have a good understanding of parameters, assumptions, conditions, etc. Associated with this, our framework highlights the importance of a demonstratable and traceable thought process, which is required in formulating judgement. This sequential thought process would include the application of principles systematically, reasoning through key decisions or choices, and exercising logic. Reaching an engineering judgement is not a random process, as was mentioned earlier (Christian 2004), and therefore ought to be highlighted as a significant feature within the framework (as agreed by respondents), even though it does not lead to the formation of the engineering judgement itself. The application of principles and logic is necessary here to undo attempts at causal reasoning – often a consequence of influencing factors (Maule 2001). Building on from this, we would suggest that the sequential thought process needs to be effectively communicated, enabling individuals to interrogate and reflect on solutions (Weedon 2019). Subsequently, it becomes possible to objectively understand where certain judgements come from.

The notion of failure or learning from mistakes came up repeatedly and was often accompanied with statements about the lack of confidence students had in being bold and creative for fear of failing. An important question to ask is: how can students accept failure and build on it to support their learning? At a fundamental level, reflection and communication in a supportive environment are necessary for learning from failure (Jackson et al. 2021). Without sufficient guidance – in the form of monitoring and encouraging, students can hold onto the low confidence they acquire when they fail at something (Koehler 1991; Dwyer and Marsh 2017) Equally, it is important to consider how failure can become part of a learning strategy. Creating spaces for students to be responsible are often discussed. For example, laboratory-based taught sessions that inculcate sophisticated designs of laboratory teaching via scaffolding techniques, provide students with opportunities to develop such judgements early on by assuming responsibility, accepting failure and building confidence (Shah et al. 2020).

In terms of some of the minor categories that feature in the framework and warrant elaboration, common sense, imagination and intuition are considered interesting. Common sense is especially under-researched in literature, although it is suggested that among engineers, common sense is a characteristic developed through training centred on assessing the plausibility of solutions while accounting for error (Tulumello 2019). Imagination is presented alongside intuition and encourages and legitimises notions of dreaming and creation (for example as used by Einstein to help him visualise phenomena), which has a role to play in developing engineering practices (Zhou 2012). For example, complex engineering systems require increasingly creative solutions, meaning that creative thinking and imagination are progressively becoming an inherent feature of engineering judgement. As mentioned earlier, intuitive thought is developed through self-regulation. To develop intuition around engineering judgement, it is not enough for students to come up with answers but for them to continually ask themselves follow-up questions: does this feel right? If not, why not? Information can be processed quickly and integrated through the use of ones' intuition, and alongside analytical thought, intuitive thought becomes a key element in developing any type of judgement (Betsch and Glöckner 2010).

Comparing our framework to other constructs

The novelty of our work is that it provides a nuanced definition of engineering judgement as a construct in higher education contexts. The framework we have developed attempts to conceptualise engineering judgement in a more detailed and robust way for use by engineering educators than has been done previously, although this work borrows from other definitions and constructs related to engineering judgement as well as adding to them. Revisiting the work of Bruhl et al. (2017), there are overlaps between the authors' findings and our framework. For example, one of the qualities that featured in the Bruhl et al. definition was insight, which is denoted as 'the ability to perceive and understand the true nature of something' which, it could be argued, encompasses notions of common sense and intuition. Borrowing from well-theorised aspects of engineering, Paletz et al. (2013), mention the importance of adaptive expertise which depends not only on the performance of a task, but on knowing when variations are necessary. Our framework does not directly refer to expertise, (which may seem unusual given that others have previously mentioned it), but reference is made to experience which is both accumulated (over time) and assimilated (reflected upon routinely) as a way of developing judgement. A more direct link between adaptive expertise and experience is found in earlier work by Hatano and Inagaki (1984), who suggest that 'expertise is based on the accumulation of experience' and refer to the Piagetian notions of constructivist learning in that new understandings are assimilated into pre-existing knowledge. Hatano and Inagaki mention the importance of procedural knowledge (a feature of our framework) and that it becomes conceptual knowledge when it can be explained and a process of internalisation has occurred. Both an awareness of a sequential thought process (cognitive capability) and development through review (behaviour) are highlighted by the framework. In their work on ideological convergence in engineering ethics, Philip et al. (2018), found that ideology impacted on student learning. As mentioned in the literature review, it has been argued that the formation of engineering judgement (based on expertise development) is made as part of a 'value-based' judgement and that the engineer cannot be immune to personal bias and context. This perspective was further reiterated by our findings, although to a limited degree. The importance of discourse in concept negotiation and group knowledge construction, was an important implication of the work carried out by Kittleson and Southerland (2004). Yet, none of our participants mentioned discourse when speaking of the conceptualisation of engineering judgement. These terms have been previously mentioned at length as necessary tools in the development of engineering judgement (Chadha and Hellgardt 2022).

Implications for research

From our findings, it was possible to construct a theoretical framework that accommodates the main ideas to have emerged as categories from the research data. The framework is intended for critique and further refinement as it represents an initial positioning of engineering judgement. It does however build on previous literature and pulls together more attributes than definition alone and extends to notions of criteria. Having said as much, the discussion itself reveals that definition is complex when all the terms are individually unpacked, and students are effectively being asked to develop several qualities and characteristics (for example common sense and imagination). The framework provides a more structured notion of engineering judgement, and helps us to answer the following questions: What else matters? What needs to be in place for this to happen? In relation to answering 'what else matters' in particular, the criteria/characteristics that makeup the framework are not explicitly mentioned in literature with respect to engineering judgement. In suggesting the importance of these factors, we are able to state more clearly how students can develop their engineering judgement. For example, even though reflecting on failure can be useful in guiding learning, it is not cited as a direct mechanism through which good engineering judgement can be developed (Jackson et al. 2021; Edmondson and Sherratt 2022). Similarly, in literature very little has been said about the relationship between students having confidence in their own skills and abilities and developing good engineering judgement. Being able to break a problem down is another important feature, but where is the evidence to support this and convince students of its significance in developing good engineering judgements?

Implications for teaching

Beyond the scope of this work, other questions need to be asked. For example, how do we create a supportive and nurturing environment for students to be able to develop their judgements? Can assessment be modified to allow creativity and for students to develop their engineering judgement? In suggestion to the first question, we argue that normalising failure and acknowledging it among educators themselves could be a first step towards creating an environment in which students learn to accept their own shortcomings (Patel et al. 2015). As educators, we need to appreciate that this will not be easy as there is resistance to fully exploring failure, but may prove necessary. In response to the second question and with respect to assessment, open-book exams, that encourage evaluation rather than repetition (Johanns, Dinkens, and Moore 2017) have been trialled in many higher education institutions (HEIs) following the onset of COVID-19 and remote learning. These exams have invariably become more amenable and an ongoing focus of further research. With these questions and others, we do not have concrete answers, but hopefully this framework encourages a broad and open discussion about the answers.

Concluding remarks

Engineering judgement is not a simple concept as is reflected in previous literature and in this paper. However, we have made a novel contribution to the literature by attempting to further conceptualise it for the benefit of educators in higher education settings. The utility of a grounded theory approach has enabled us to fully explore the phenomenon without solely relying on prior conceptual ideas. The framework that we have proposed is open to scrutiny, but equally is original and unique and provides a more tangible idea from which to work in helping students eventually develop their engineering judgement. Furthermore, we have raised important and significant questions about the right types of teaching-learning environment, the qualities that students ought to possess and how these are nurtured. This work fills a critical gap in the literature by exploring and expanding on previous notions of engineering judgement, and provides the engineering education community with a helpful framework that can be adapted and applied to practice.

Note

1. Part of the response to this question and the succeeding one were analysed and published previously [Chadha and Hellgardt 2022].

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No potential conflict of interest was reported by the authors.

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