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Work in progress: Engineering Judgement: A Model for Teaching

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Engineering Judgment: A Model for Teaching

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Introduction

In this Work in Progress paper, we present preliminary findings from testing a theoretical model on the attitudes, behaviors, and cognitive abilities necessary for engineering students to develop their engineering judgment. The model was produced from research conducted with engineering professors and industry professionals affiliated with Imperial College London, a research-intensive institution in the UK. This paper seeks to explore the relevance and application of such a model among engineering students.

Engineering judgment is a necessary professional skill and yet is considered abstract and unexplored within engineering education. Thus, it is challenging to teach. Nevertheless, there are certain central skills that students can develop to make better judgments that lead to more sound decisions as professional engineers. Anecdotal evidence suggests students are often more limited in demonstrating their judgment skills than educators would either expect or hope. This observation and the ensuing concerns it raises has guided this research.

Accreditation requirements stipulate that graduates ought to have developed their engineering judgment within their degree programs (e.g., Institution of Chemical Engineers, Institution of Mechanical Engineers, and ABET). Despite this requirement, there is not a widely used model, established toolkit, or set of resources faculty can use to help engineering judgment be effectively taught, demonstrated, and assessed.

The model proposed in this paper is currently being explored in various international contexts and engineering disciplines to further develop its relevance and utility for future student learning. Our aim is to test the model with undergraduate engineering students via small focus groups, large group in-class activities, and faculty interviews. The early findings presented in this Work in Progress paper serve as a contribution towards the wider conversation about engineering judgment. Specifically, we aim to expand the conversations such that engineering judgment becomes a more mainstream and explicit topic within engineering curricula. We envision that this model will drive the development of subsequent tools and teaching resources which will further support the use of the model in a diverse set of courses, disciplines, and institutions.

Phase 1: Developing the model

The first phase of this project was to document how professional engineers understood the primary factors that contribute to engineering judgment. The central aim of this phase was to unpack notions of engineering judgment to reach a common understanding (concept and definition) and identify the mechanisms that guide its development. Gaps in knowledge and application could also be detected through this initial phase of work.

A total of 23 professional engineers who are active in both academia and industry, and from relatively diverse backgrounds (namely Europeans, Americans and East Asians), were interviewed to solicit their perspectives on engineering judgment and how it was effectively developed. A vignette was used as a trigger for these conversations, which depicted a cartoon of two engineers discussing the ease of solving an engineering problem using judgment, compared with book knowledge. The resulting interviews were semi-structured in nature, and enabled participants to further develop and articulate their thoughts around engineering judgment.

Based on the data obtained through these interviews, we constructed a theoretical model (Figure 1) that identifies the main elements that contribute to engineering judgment [1]. The original model [1] [2] was created from a grounded theory approach [3] [4] that stipulates that a model should accommodate all the obtained perspectives. We proceeded with the assumption that participants had no prior knowledge about the phenomenon and accommodated all the provided perspectives to the point of saturation – where no new perception is provided.

As the model came together, three main categories emerged: 1) cognitive capabilities, 2) behaviors, and 3) attitudes. The relationship between these categories was also considered. We believe that 'cognitive processes related to belief and knowledge inform an individual's attitude. Acting on an attitude formulates certain behaviors.'

Each of these three main categories contain several sub-categories that provide more granularity to the definition and understanding of engineering judgment. For example, logic and common-sense feature under cognitive capabilities; asking questions and being responsible for one's own learning feature under behaviors and being comfortable with mistakes feature under attitude.

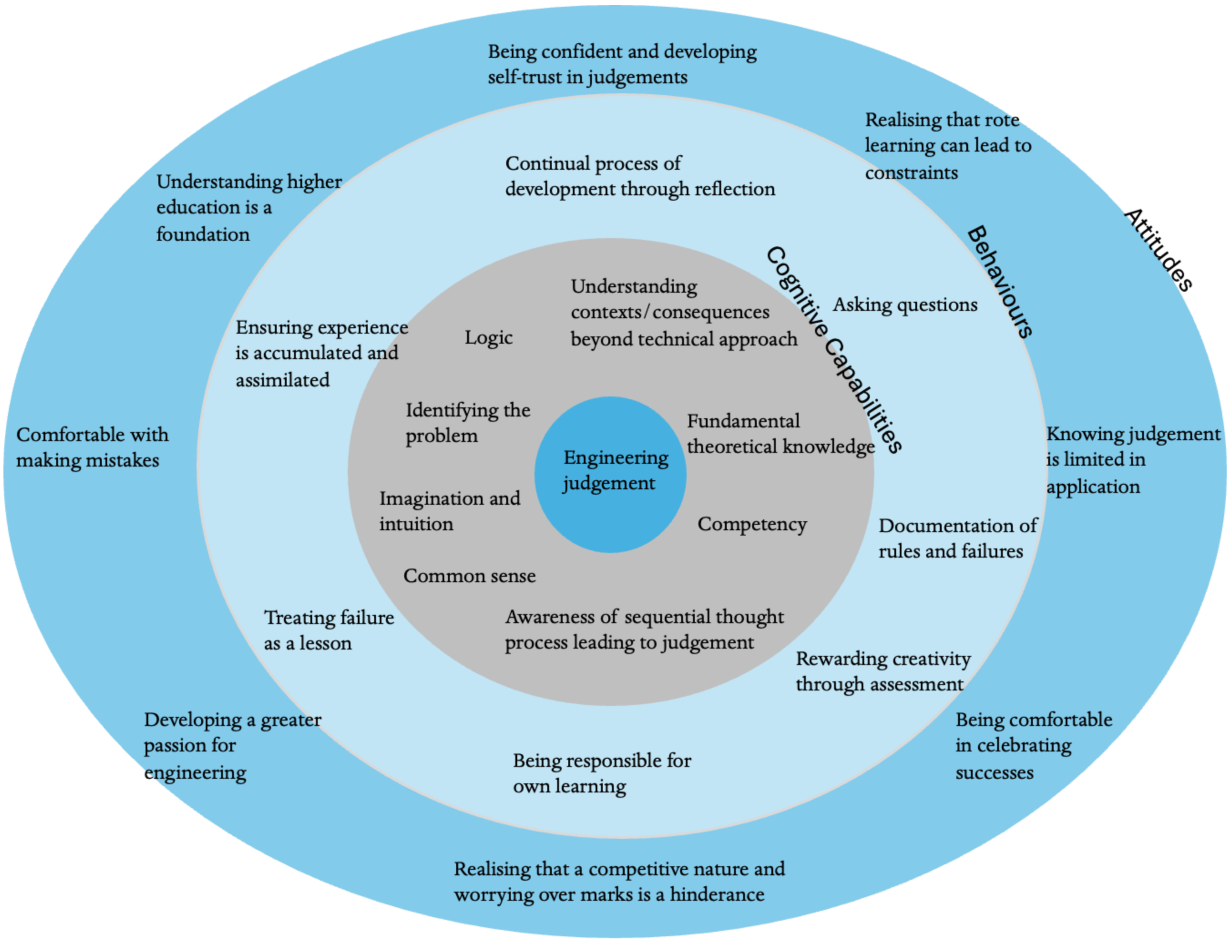

Figure 1: A model for defining and conceptualizing engineering judgment, based on attitudes, behaviors and cognitive capabilities [1].

We understand that the original model shown in Figure 1 is a medley of words and may be difficult to discern order or utility. While creating this model, concerted efforts were made to maintain authenticity and remain true to the views shared with the original participants. We also acknowledge that there is a cross-over with the work of previous scholars [5] [6] [7], but each body of work includes new terms and nuances in how to conceptualize engineering judgment. For example, the relevance of imagination and intuition, and celebrating success are unique additions.

In collaboration with the lead author from the original work in the UK, co-authors in the US reconfigured the model while maintaining the integrity of the original concepts. Some language was revised to adapt British to American English, and the visual layout became three pillars rather than concentric circles (Figure 2).

Attitudes (internal)		**Behaviors (external)**		**Cognitive (internal & external)**
What you feel and believe about a		How you demonstrate and act		What you know about, and are

specific issue.	upon your knowledge and attitudes while addressing a specific issue.	able to do, to address a specific issue.
When you consider applying Engineering Judgment to a complex issue, to what extent is it helpful for you to:	When you consider applying Engineering Judgment to a complex issue, to what extent is it helpful for you to:	When you consider applying Engineering Judgment to a complex issue, to what extent is it helpful for you to:
A1. Realize that rote learning can lead to constraints	B1. Take responsibility for your own learning	C1. Clearly identify a problem
A2. Appreciate that higher education is a foundation for lifelong learning	B2. Ask questions for clarification and deeper understanding	C2. Apply logic to engineering work
A3. Possess a deep passion for engineering as a discipline	B3. Treat failure as a lesson	C3. Use a sequential thought process in engineering work
A4. Know that an individual's judgment is a limited perspective and can limit broad application	B4. Document rules, lessons learned, and procedures throughout the design process	C4. Demonstrate competency in a defined content area
A5. Comfortably respond to making mistakes (yours and others)	B5. Value creative contributions from self and others toward the desired objectives	C5. Apply fundamental theoretical knowledge to engineering work
A6. Comfortably celebrate individual and team success	B6. Reflect on work you have done in the past	C6. Articulate the context and consequences that go beyond merely a technical solution
A7. Feel a sense of self-confidence in making decisions	B7. Engage in the process of continuous improvement	C7. Use imagination and intuition in engineering work
A8. Value collaboration with others over competition with others	B8. Use past experiences to inform future work	C8. Exercise common sense to draw conclusions and make reasonable recommendations

Figure 2: Modified model for defining and conceptualizing engineering judgment, based on attitudes, behaviors and cognitive capabilities

Phase 2: Collecting student input

In spring 2025, we began Phase 2 by obtaining direct student feedback about the relevance and utility of the model in their design projects. Table 1 summarizes the first few courses selected for gathering student input. All courses were offered at research-intensive universities.

Discipline	Level	School	Method of data collection
Chemical Eng	Senior	Imperial College London	Semi-structured focus group (5 students)

Mechanical Eng	Senior	Imperial College London	Semi-structured focus group (4 students)
Eng Leadership* *(multi-disciplinary)*	Senior	UW-Madison	In-class activity (~40 students)
Biomedical Eng	Junior	UW-Madison	In-class survey and activity (86 students)

**Did not apply for IRB approval, therefore the specific findings from this course are not included below.*

Table 1: Summary table of courses used in pilot data collection

Gathering student feedback in the UK, Imperial College London

To test the model at Imperial College London, student focus groups served as the primary mode for gathering student input (Table 1). We were keen for students to get a feel of the model by exploring and playing with the ideas in a bid to establish whether the model resonated with them. They were asked to volunteer their time to attend a focus group of 4-6 students. We did our best to ensure that the selection came from a diverse pool of students from the cohort to ensure cultural, gender, demographic etc. differences were included when validating the model.

The concentric circle model was printed and cut out such that each circle (Attitudes, Behaviors, and Cognitive Capabilities) could freely rotate around a fixed center. This rotation enabled students to interact with a 3-D model and consider words and phrases in parallel and side by side. For example, students could rotate the circles to consider whether their *Attitude* about making a mistake may impact on their *Behavior* of continual reflection and the *Cognitive Capability* of applying common sense.

Rather than posing detailed questions, we invited students to answer broader queries related to the utility of the model. Example questions included:

- What aspects of the model look 'right' or 'wrong' to you? Why?
- Are there ways in which attitudes, behaviors and cognitive capabilities connect? Are you able to explain these connections?

In addition to the two student focus groups, we conducted interviews with two members of teaching staff from these departments to gain insights from instructors.

Gathering student feedback in the US, University of Wisconsin-Madison

Two courses were used to gather initial student feedback in the College of Engineering at the University of Wisconsin-Madison (Table 1). Both courses used similar approaches for an in-class activity that resulted in nearly 100% participation for those who attended class on the day of the activity. After a brief introduction to the model, students were led through four stages of reflection:

1. **Individually review** the entire model and rate the utility of each of the individual elements on a scale of 1-3 (1=not helpful, 2 = somewhat helpful, 3 = very helpful, or 0 = I don't know what this means).
2. **Individually explain** why they rated the elements if they were rated 0 (I don't know what this means) or 1 (this was not helpful).
3. **Design team discussion** of their individual rankings and any questions.
4. **Large group open forum** debrief with the entire class.

For one course, student responses were collected via paper and for the other course an electronic survey and spreadsheet were created by each student group. All student feedback was anonymously submitted.

Preliminary findings

A thorough analysis has yet to be completed for this Work in Progress paper. A cursory review of all feedback from the UK and the US uncovered the following common elements for future consideration as the model continues to be refined.

1. Generally, students found the activity to be a positive experience and saw that it could be a useful tool earlier in the design process.
2. Several commented that the model reinforced a lot of what they already do or know, but it was helpful to see it succinctly captured in a model.
3. Some of the language used was confusing (e.g., "rote memory" was unfamiliar to many and several asked, "what do you mean by 'feel comfortable'").
4. Several of the individual elements seemed redundant and could be combined or deleted (e.g., in the US model, B6 "Reflect on work you have done in the past" could be combined with B8 "Use past experiences to inform future work.")

The focus groups conducted at Imperial College London resulted in additional representative comments that will be further considered during the next phase of this work (Table 2).

Topic	Comments
In response to seeking clarity of language, students commented…	*What is meant by this idea of rote learning leading to constraints? If there's things we have to know, then why is it constraining for us to know it?* *That's interesting. I didn't see it that way, but as a block, an obstacle. I took it with higher education as foundation. To me it means not far enough. Is that what it means?* *I always refer to knowledge from [the] book. It's very correct. I do not understand how to make judgments outside of book knowledge.*

When considering the importance of failure in learning, students remarked…	*I don't see that I would need to fail at things. I can see that learning from mistakes is useful, and that would connect to confidence, but not failing for the sake of failing. That would destabilize my learning. Or maybe you have to be very specific in showing how failure can be a good thing, or that you can learn something from it.* *Yeah. I don't like failing. We're always [going to] try and make sure that's something we don't do. I'm not sure I can learn from it. I would just stew. I know other students who will keep repeating the task until they were 100% sure they did it correctly. You can't learn anything from that … you'll have to make reflection connect to that.*
Students and one instructor had helpful insights on the utility of the model and how to teach Engineering Judgment.	*You have to connect this [model] with a problem and provide examples. I would not necessarily understand it in isolation. Maybe a simple example because I assume you want students to understand the ideas of this model, rather than get carried away by the engineering.* *Logic and common sense. Not every student has it. I've done group projects, and I'd say about half of the students I work with have logic and common sense. It is important for engineering generally. Is this something you can teach? How would you do that?* *I agree. Same with passion. I don't understand why it[s] here. How to teach it? Not every student [is] a passionate engineer.* *I'm not sure how easy any of this would be for students to understand and get their head around. I do see the relevance, but how do you explain these ideas? The model by itself doesn't mean very much unless there are examples that they can think through, that make them understand it. Also, some things seem like they don't mean anything to students, like this comment on assessment … that's for us, not them. [Instructor comment]*

Table 2: Representative comments from UK focus group conversations.

Future work

The general acceptance of the model and acknowledgement that it has utility as a tool for learning provides motivation to continue this work. As we analyze the existing data more completely, we anticipate additional specifics and general trends that will emerge that will inform future revisions of the model and methods to use as a teaching tool.

Building on the progress to date, we propose to pursue the following lines of work:

1. **Refine the model**: Review existing data to inform future iterations of the model.
2. **Gather more feedback**: Expand the number, type, and level of courses where the model is used to gather more student input.
3. **Collaborate with instructors:** Work directly with more instructors to integrate the model into their courses as a core activity early in the design process.
4. **Develop teaching resources:** Create teaching tools and activity guides to help instructors use the model in their courses.
5. **Disseminate:** Openly share the model, tools, and teaching guides to expand the reach and use of the model.

To that end, we are actively seeking partners at other institutions to collaborate on this work and invite you to join us in our next steps. If you are interested, please reach out to any of the authors.

NOTE: *This work was determined to be exempt from further review by the Institutional Review Board at The University of Wisconsin-Madison, US #2025-0513. This work is covered under Protocol #EERP2425-087 by the Imperial College London, UK.*

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