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Defining Engineering Judgment

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Defining Engineering Judgment

Abstract

In this research brief, we present our methods research on beginning to define engineering judgment. Judgment is critical to the field of engineering. However, when asked to define engineering judgment, engineers, including faculty, often cannot readily do so. Although judgment is a common term, it has been an elusive notion. This elusiveness may be due to the many conceptions of engineering judgment found in the literature. Unfortunately, given the lack of an agreed-upon, concrete definition for engineering judgment that integrates the various conceptions, its assessment relative to the formation of engineers has been limited. In this research brief, we describe our process to begin the development of an expert, consensus-driven definition for engineering judgment using the Delphi technique and the various conceptions for engineering judgment in the literature. A working or preliminary definition, which is being used to develop assessment and instructional materials for engineering judgment, is presented.

Keywords: engineering judgment, ABET, Delphi technique, definition

1. Introduction and Background

This research brief contains a description of our methods to begin to define engineering judgment. The Accreditation Board for Engineering and Technology (ABET) calls for a student to be able to apply engineering judgment upon graduation. Judgment is critical to engineering, particularly for design and data analysis. However, when asked to define judgment, engineers, including faculty, often cannot easily do so. Judgment has been an elusive notion. This elusiveness may be due to the many conceptions of engineering judgment found in the literature. Unfortunately, given the lack of an agreed-upon, concrete definition for engineering judgment that seeks to integrate the various conceptions, its assessment has been limited.

The idea for this research emerged in 2021 when searching the literature for assessment tools for engineering judgment for a design course. This literature search uncovered many ideas about or notions of engineering judgment but no one concrete definition that integrated them. In addition, there were no tools to assess the presence or exercise of judgment during design work. These findings ultimately led to our development of a research proposal to develop assessment tools for engineering judgment. Feedback from the National Science Foundation (NSF) review panel indicated that an agreed-upon definition for engineering judgment was first needed before assessment tools could be developed. The review panel recommended that a Delphi study involving a panel of experts be conducted to determine a consensus-based definition.

2. Methods

To this end, we began exploratory research in the fall 2024 to develop an expert, consensus-driven definition for engineering judgment using the Delphi technique. The expert panel was comprised of a diverse group of 18 professionals and included faculty who had published on engineering judgment, ABET program evaluators, instructors of design and data/computational analysis courses, and industry stakeholders. The engineering backgrounds on the panel were varied and representative of the engineering profession. The Delphi technique is a method to drive consensus among a group of experts or panelists. It involves a questionnaire to which the anonymous participants respond [1]. The researchers process the responses, which are sent back to the participants anonymously in subsequent rounds to drive consensus [1]. This study involved three rounds, which is frequently or typically used [2-4].

Delphi Panel. The Delphi panel for this research was primarily recruited from the publications uncovered during the initial literature search on engineering judgment. We contacted the authors of these publications via email and approached them at American Society for Engineering Education (ASEE) conferences to solicit their support in serving as panel members. Additional panel members were recruited during subsequent searches of the judgment literature and with greater exposure to this area. Various instructors of design and data/computational analysis courses were also approached to be panel members. Industry stakeholders with known interests in the topic of engineering judgment were also approached and secured as panel members. Finally, three ABET program evaluators were recruited in response to feedback from the NSF review panel. The Delphi panel consisted of 18 professionals (i.e., 16 faculty and two industry members) with diverse backgrounds. The faculty members consisted of seven (7) full Professors, four (4) Associate Professors, and five (5) Assistant Professors. The members from industry have over 30 and 50 years of experience in their fields. The engineering backgrounds on the panel included aerospace/astronautics, bioengineering, chemical, civil, software, electrical, environmental, geotechnical, and mechanical. Othegr disciplines represented include engineering education research, secondary education, English, and safety/risk management.

Delphi Study. The Delphi study involved three rounds of data collection over a three-month period in the fall 2024 semester using online Qualtrics forms. The Qualtrics forms sought both open-ended (i.e., qualitative) and closed-ended (i.e., ordinal scale) responses from the panelists. The names of the panel members were not revealed during the study. The research question (RQ) to be answered by the Delphi study was as follows:

RQ: *What is an expert, consensus-based definition for engineering judgment?*

Round 1. Two closed-ended and three open-ended questions were posed to the panelists during round 1. Responses were received from 17 of the 18 panel members recruited. The closed-ended questions were developed using the various conceptions of engineering judgment found in the literature, which are given in Table 1. Specifically, the panel members were asked to assess the degree to which each conception in Table 1 was relevant to defining engineering judgment on a 1 (very small) to 5 (very high) ordinal scale. A "not applicable" option was also available. The panelists were also asked to identify the five most-relevant conceptions and rank them. The references for these conceptions of judgment are given by [5-36].

Table 1: Conceptions of Judgment from the Literature

1. Application of one's knowledge or experience
2. Approximation that achieves reasonableness
3. Assessment of the reasonableness of a solution, assumption, etc.
4. Consideration of societal, ethical, cultural, global, or aesthetic contexts or issues
5. Creativity (within constraints)
6. Critical thinking (i.e., disciplined gathering and use of information to guide action)
7.Decision making (including weighing of issues) amidst complexity and competing demands, objectives, or constraints
8. Identification of important vs. non-important details, including definition of the right problem
9. Foreseeing, anticipating, or predicting potential problems or outcomes with a solution, design, etc.
10. Making assumptions (for simplification, solvability, etc.)
11. Recognition of mistakes or errant conclusions, including via testing
12. Use of feedback for refinement or adjustment
13. Use of tools or standards/codes of practice
14. Effective communication with clarity, accuracy, and justification

The three open ended questions posed during round 1 were as follows:

1. How do you define engineering judgment?
2. From your experience, describe a situation or example in which engineering judgment was (or should have been) used.
3. If you have any additional feedback or thoughts, please provide them here.

The responses to these three open-ended questions were particularly helpful to making progress on a definition for engineering judgment. Although we did not anticipate developing a visual framework, the open-ended responses led to the development of a visual model for engineering judgment after round 1. This model was helpful for thoughts organization and could be translated to a written statement at the end.

Round 2. As part of the Qualtrics data collection form for round 2, we presented the quantitative results from round 1 to the panelists. These results included the degree of relevance of each item in Table 1 to defining judgment and identification of the five most-relevant items. Next, the visual framework based on the round 1 data was presented to the panelists, and they were asked to critique it as follows:

> Please critique, evaluate, or comment on this draft framework/process. Please consider anything that may be missing, unnecessary, or inaccurate as well as the accuracy of the flow or sequence.

Finally, the panelists were again asked the following questions:

1. How do you define engineering judgment?
2. Select the degree to which each item is relevant to defining engineering judgment.
3. If you have any additional feedback or thoughts, please provide them here.

Repeating these questions from round 1 enabled us to determine any shifts that may have occurred in the panelists' perspectives based on the information from round 1. Responses were received from 16 of the 18 panel members recruited.

Round 3. As part of the round 3 Qualtrics form, we presented the quantitative results from both rounds 2 and 1 for easy comparison. The results included the degree of relevance of each item in Table 1 to defining judgment. Second, the panelists' written critiques with highlighted text were assembled in a document and made available from within the Qualtrics form. Certain text that was deemed particularly relevant by the first and second authors based on their experience and preliminary study of engineering judgment was highlighted, although all text was provided to the panelists. This enabled them to read all actual critiques and to see the incorporation of their perspectives. Next, the updated visual framework based on the round 2 data was shown to the panelists alongside the round 1 framework for comparison. The panelists were asked to critique the updated framework as follows:

> Please critique, evaluate, or comment on this draft framework/process. Please consider anything that may be missing, unnecessary, or inaccurate as well as the accuracy of the flow or sequence.

Finally, the panelists were asked the following similar questions in round 3 to assess any shifts:

1. Please propose a concise definition for engineering judgment. Note that we are *not* necessarily asking you to summarize the updated framework but rather want this to be your definition (regardless of whether it coincides with the updated framework or not).
2. Select the degree to which each item is relevant to defining engineering judgment.
3. If you have any additional feedback or thoughts, please provide them here.

In round 3, responses were received from all 18 of the 18 panel members recruited, although not all panelists responded to all questions. The panelists' open-ended definitions for engineering judgment from rounds 1-3 underwent a deductive content analysis by two analysts (i.e., the first and third authors) using the 14 items in Table 1 as the categories of the coding scheme [37-38]. All responses were independently coded by each analyst, followed by a discussion of the codes applied to each response to reach consensus. Thus, all responses were double coded. A Cohen's Kappa value of $\kappa = 0.72$ across all three rounds was achieved, indicating strong inter-rater reliability and agreement beyond chance [39].

3. Results

Since this is a research brief, only the results of the Delphi study after round 3 will be presented next. The full set of results from rounds 1 through 3 will be presented in a forthcoming article.

Relevance Ratings. The average relevance ratings (on a 1-5 scale) and standard deviations (s) for the various conceptions of judgment given in Table 1 during the final Delphi round ranged from 3.00 (s=1.17) to 4.88 (s=0.33) based on n=17 responses. Decision making (item 7 in Table 1) had the highest average relevance of 4.88 and the smallest standard deviation of s=0.33, indicating the relative agreement among the panel members. Application of knowledge/experience had the second highest average relevance of 4.82 (s=0.39), followed by identification of important vs. non-important details and defining the right problem to solve (4.59, *s*=0.71), critical thinking (4.47, *s*=0.62), and assessment of reasonableness (4.35, *s*=0.61). Additional items with an average relevance rating of 4.00 or higher were as follows (in descending order): foreseeing potential problems, reasonable approximating, making assumptions, consideration of contexts such as societal, and recognition of mistakes or errors including via testing. The item with the lowest average relevance rating was creativity (3.00, *s*=1.17). The average relevance ratings served to support (via triangulation) the development of the framework, which was primarily driven by the panelists' open-ended responses.

Content Analysis of Open-Ended Definitions for Judgment. The quantitative data obtained by coding and summarizing the panelists' open-ended definitions of judgment served to further support the development of the framework through triangulation. In the final round of the Delphi study, 76% of respondents mentioned decision making, and 71% mentioned application of one's knowledge or experience in their open-ended definitions for judgment. These were the two most-frequently-mentioned categories or conceptions of judgment. This aligns with the average relevance ratings in round 3. Further, assessment of reasonableness was mentioned by 29% of respondents. Consideration of contexts (including societal) and critical thinking were each mentioned by 24%. Finally, identification of important vs. non-important details and defining the right problem to solve as well as the use of tools, standards, or codes were each mentioned by 18% of respondents. The remaining conceptions of judgment were each mentioned by 12% or fewer of respondents. In general, the quantitative results from the content analysis tended to align with the average relevance ratings. As seen next, the relevance ratings and coding results particularly supported the inclusion of various key elements in the framework.

Example Open-Ended Responses. Several examples of the panelists' open-ended responses are presented to introduce several concepts that were *not* specifically called out in Table 1. For example, the following response suggested the potential inclusion of *life-long learning* as part of the engineering judgment process:

> "…somewhere at the end (perhaps at the Evaluation Cycle), this information is fed back to the "Knowledge/Experience" box in the upper left. After all, you gain/build your knowledge and experience through this process."

The following comment suggested the inclusion of *metacognition* to the judgment process:

> "…but EJ, to me, is something perhaps more metacognitive, that guides the engineering process under conditions of uncertainty."

Finally, this panelist's comment specifically called out *modeling* as part of judgment:

> "Modeling is an important practice and an important part of engineering design and engineering judgment…I think it would be useful to distinguish between aspects that are "within" the engineer (like knowledge & experience and one's identity) and aspects that are 'outside' the engineer."

The panelists' open-ended comments also served to demonstrate how the concepts in Table 1 may be interrelated. For example,

> "…critical thinking includes deciding…"
>
> "…'critically think' and 'decide' seem to be presented as individual activities, when in fact they are both highly collaborative."
>
> "I am also not sure you can separate out critical thinking from evaluation…Evaluation is a form of critical thinking. Maybe a big box with critical thinking with two sub boxes - one for evaluation and one for problem solving/decision making."

Framework. The framework from the final round of the Delphi study is currently undergoing pilot testing in two engineering classrooms during the spring 2025 semester. Following this, the updated framework will be shared with the Delphi panel for additional critique. Given this, the framework is not presented in this article. However, a preliminary, condensed definition for engineering judgment is advanced as follows:

Engineering judgment is the application of an engineer's knowledge, experience, and metacognitive thinking as well as their consideration of the situational context to perform critical thinking, including decision making and evaluation, in support of the design or problem-solving process, ultimately formatively impacting the engineer for life-long learning.

4. Summary and Conclusions

This research brief described the methods used to begin the determination of an expert-driven definition for engineering judgment based upon the Delphi technique. This research aims to eliminate some of the elusiveness associated with the notion of engineering judgment as evident in the pre-existing literature as well as in the lack of tools for assessment in engineering education. The assembled panel for the Delphi study consisted of a diverse group of 18 professionals, including faculty who had published on engineering judgment, ABET program evaluators, instructors of design and data/computational analysis courses, and industry stakeholders. Both quantitative and qualitative responses were collected from the panelists during three rounds of the Delphi study and used to develop a visual framework for the process of engineering judgment. The framework was also translated to a written definition.

The preliminary framework is being pilot tested in the spring 2025 semester in design and data analysis courses. Specifically, the framework is being used to develop educational materials for direct instruction on engineering judgment as well as tools to assess the presence and nature of engineering judgment in the students' work products and perspectives. The framework and expanded definition will be re-circulated to the Delphi panel following the pilot testing. This will be done to establish panel approval of any updates following the pilot testing. Following this, we plan to disseminate our definition and framework more broadly to our education and industry partners, as stated in the NSF proposal. This dissemination will occur in the form of educational/professional development modules and seminars/information sessions with these partners. This will naturally result in further "testing" and validation of the framework and definition. We will recruit additional industry partners (beyond the panel members) at conferences and through our professional contacts to assist in dissemination and validation.

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