2026 ASEE ANNUAL CONFERENCE
June 21–24, 2026 | Charlotte Convention Center, NC
Host Sponsor UNC Charlotte

Paper ID #51402

Case Study Introducing the Knowledge, Capabilities, Mindset Framework

Dr. Alexander Pagano, University of Illinois at Urbana - Champaign

Alexander Pagano, PhD, is the Engineering Education Lead for the Siebel Center for Design at the University of Illinois Urbana Champaign. His research focuses on collaborative design teams and the integration of human-centered design with existing engineering methods and pedagogies.

Case Study Introducing the Knowledge, Capabilities, Mindsets (KCM) Framework

1. Introduction

Engineering education has traditionally prioritized technical knowledge and analytical problem solving. Although these competencies remain essential, contemporary engineering practice increasingly involves ill-structured problems, diverse stakeholders, and complex sociotechnical systems [1], [2]. Human-Centered Engineering (HCE) responds to this reality by positioning human needs, values, and contexts as integral components of engineering design rather than as secondary considerations addressed after technical decisions are made [3].

Despite broad consensus on the importance of human-centered approaches, educators often struggle to operationalize HCE in courses and co-curricular settings. Learning objectives may reference empathy or societal impact, yet instructional activities and assessments frequently remain focused on technical outputs alone. This misalignment can obscure expectations for students and limit opportunities to develop the reasoning practices associated with expert design.

This paper introduces the Knowledge, Capabilities, Mindsets (KCM) Framework as a structured approach for designing, implementing, and analyzing HCE learning experiences. The framework synthesizes findings from design expertise research, cognitive psychology, and situated learning theory into a form that is actionable for instructors. A short case study of an undergraduate workshop is used to illustrate how the framework can guide lesson design and assessment in practice.

2. Background and Theoretical Framing

2.1 Expertise in Engineering Design

Studies comparing novice and expert designers consistently show that expertise involves qualitative differences in problem framing, information use, iteration, and stakeholder engagement, not merely greater technical knowledge [4], [5], [6], [7]. Experts devote more effort to early conceptual phases, construct richer problem representations, and strategically revisit earlier decisions. Novices, by contrast, often converge prematurely on solutions and rely on surface features of problems. These findings suggest that design education must address more than procedural competence. It must also support the development of adaptive capabilities and orienting values that shape how designers approach complex, human-influenced problems.

2.2 Cognitive and Situated Learning Perspectives

Cognitive Load Theory emphasizes that learning depends on the construction of organized knowledge structures that reduce cognitive load and support transfer [8], [9]. From the perspective of Predictive Coding, learning can be understood as iterative model refinement driven by feedback and error [10]. Situated Learning theories further highlight that knowledge and skill develop through participation in authentic activities and social interaction, with reflection playing a central role in consolidating experience into transferable understanding [11], [12]. Together, these perspectives support instructional approaches that emphasize contextualized tasks, external representations, collaboration, and reflection, all of which are central to human-centered engineering pedagogy.

2.3 Other related frameworks

Across education and workforce psychology, many related frameworks represent the same shared idea; expertise develops through the interaction of what people know, what they can do, and how they orient themselves toward action. Each of these frameworks uses slightly different

Table 1 – Related Frameworks			
Framework	**Knowledge**	**Capabilities**	**Mindsets**
KSAO [13]	Knowledge	Skills, abilities	Other characteristics
Bloom domains [14]	Cognitive	Psychomotor	Affective
OECD Learning Compass [15]	Knowledge	Skills	Values, Attitudes
OBE/CBE [16], [17]	Knowledge	Skills	Other components

language to better situate their representation in their own domain or discipline, see **Table 1**. The KCM Framework similarly extends this prior work to better capture the breadth of Human-Centered Engineering and offers additional clarity and grounding to modern psychology.

Typically, the first domain represents knowledge or cognition. The second domain often captures skills, abilities, or some form of applied practice. The third domain captures what is often left over and may include the affective layer, values, attitudes etc. In the KCM framework we have chosen to adopt the label capabilities rather than skills or abilities to imply growth along with spectrum rather than attainment of binary attributes. The selection of the term mindsets was in alignment with prior Human centered design terminology.

3. The Knowledge, Capabilities, Mindsets (KCM) Framework

The KCM framework organizes learning goals into three analytically distinct but interrelated domains: Knowledge, Capabilities, and Mindsets. The purpose of this separation is not to suggest independence, but to make differences explicit so that instruction and assessment can address each intentionally. An example representation of the KCM framework as it relates to Human Centered Engineering Design learning is shown in **Figure 1**.

Figure 1 - Example representation of the KCM framework as it relates to Human Centered Engineering Design learning

3.1 Knowledge

Knowledge refers to information encoded in long-term memory that can be brought to bear during design activity. In engineering education, this includes both declarative knowledge, such as principles and concepts, and procedural knowledge, such as methods and processes [18]. Of particular importance is conditionalized knowledge, meaning that learners understand not only how to apply a method, but when and why it is appropriate [19]. Human-centered learning experiences emphasize contextualization and social situatedness. Technical concepts are anchored to real or realistic needs, and people are treated as legitimate sources of information alongside quantitative data. Reflection and comparison across cases support the development of richer mental models and facilitate transfer.

3.2 Capabilities

Capabilities describe what learners can do with their knowledge in practice. These include framing and reframing problems, generating and transforming ideas, evaluating alternatives, and translating ambiguous information into actionable design requirements [20], [21]. Drawing on design cognition research, capabilities can be characterized as divergent, transformative, and convergent activities that occur throughout the design process [22]. In HCE contexts, capabilities are developed through experiential activities that require learners to externalize thinking through sketches, diagrams, prototypes, and models. Immediate feedback and structured reflection help learners connect actions to outcomes and build adaptive expertise.

3.3 Mindsets

Mindsets refer to enduring orientations that shape how and why learners engage in design work. In human-centered contexts, these include empathy for stakeholders, comfort with ambiguity, ethical awareness, collaborative orientation, and curiosity [23], [24], [25]. Mindsets influence which knowledge and capabilities are activated in a given situation and how tradeoffs are navigated. Mindsets develop over time through repeated experience, social cues, and reflection. Instructional strategies that surface value tensions, encourage perspective-taking, and normalize uncertainty are particularly important for cultivating human-centered orientations.

4. Case Study: Renaissance Artifact Workshop

4.1 Context and Objectives

The KCM framework was applied in an extracurricular workshop designed for undergraduate students from multiple engineering disciplines. The workshop centered on a Renaissance-era mechanical bookwheel, selected because it embodies clear human needs while requiring minimal prior technical expertise. Learning objectives were mapped to the layers of the KCM framework, as shown in **Table 2**.

Mapping the workshop to the KCM framework clarified alignment between objectives, activities, and assessment. Knowledge goals included understanding the distinction between needs and solutions, familiarity with the Function–Behavior–Structure modeling, and the role of

Table 2 - Learning Objectives from KCM Framework

Knowledge:	DK1	*Needs outlast solutions*
	DK2	Definitions of *function, structure, behavior as in FSB Framework*
	DK3	Utility and meaning of *problem framing*
	DK4	Utility and meaning of *abstraction*
	DK5	Utility and meaning of *needfinding*
	PK1	How to use FSB to explore alternative problem framing through abstraction
	PK2	Ways to consider the interaction between problems and solutions
	PK3	Need-finding methods
Capabilities:	DC1	Ideation by analogy (analogical thinking)
	DC2	Need-finding
	TC1	Problem framing
	TC2	Abstraction and decomposition
	CC1	Qualitative analysis - observation and description
Mindsets:	M1	Collaborative
	M2	Human Centered
	M3	Creative

abstraction in problem framing. Capabilities emphasized qualitative observation, abstraction, analogical reasoning, and reframing. Mindsets included empathy, comfort with ambiguity, collaboration, and creative engagement.

4.2 Workshop Learning Activities

Students worked in small groups to model the function, structure, and behavior of the book wheel [26]. One group focused on function, identifying the underlying needs addressed by the device. A second group examined structure, considering components and construction. A third group analyzed behavior, including user interaction and assumptions embedded in use.

Groups then reframed the artifact at different levels of abstraction and identified contemporary analogues addressing similar needs. Throughout the activity, students externalized reasoning through sketches and diagrams and participated in facilitated discussion. For examples of participant's thoughts on the underlying needs met by the bookwheel, see **Figure 2**.

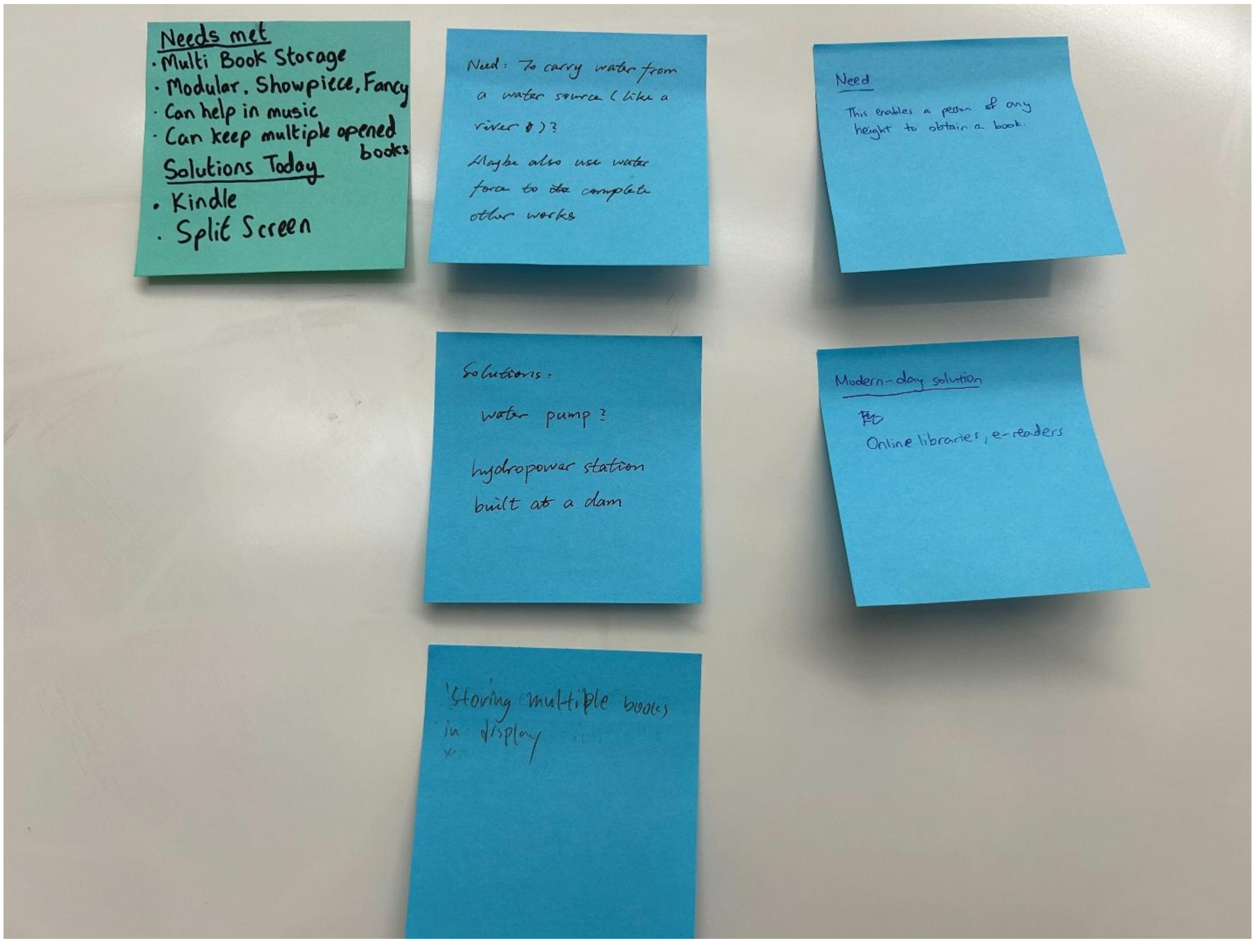

Figure 2 – Post its showing participant thoughts on the underlying needs met by the bookwheel

4.3 Workshop Outcomes

Evidence for the efficacy of this alignment was drawn from multiple data sources collected during the session, including pre- and post-lesson questionnaires, artifact-based responses, and facilitated group discussion. The questionnaire data (n = 11 respondents) showed consistently high post-lesson ratings for engagement, instructional quality, and perceived learning. A summary of questionnaire results can be found in **Table 3**, and the questions as they were provided to participants are included in the appendix. Mean ratings for engagement, informativeness, and instructional quality were all in the upper range of the 10-point scales used, with most students reporting that the session was *better than* or *far better than* an average

Table 3 – Summary of Questionnaire Results					
Section	**#**	**Question**	**Scale**	**Mean**	**Mode**
Pre-Lesson Self-Assessment	1	I can explain the difference between Function, Structure, and Behavior (FSB) in the FSB framework.	Likert Lo(1)-Hi(5)	2.81	2
	2	I can apply FSB modeling to analyze an unfamiliar artifact or system.	Likert Lo(1)-Hi(5)	2.81	2
	3	I understand how problems and needs interact with design solutions.	Likert Lo(1)-Hi(5)	3.72	4
	4	I understand how abstraction helps deepen insight into need finding.	Likert Lo(1)-Hi(5)	3.45	4
Section A: Clarity and Engagement	5	My pre-lesson self assessment was accurate (True / False). If not, please explain.	True/False	n/a	n/a
	6	Briefly describe the purpose of the lesson in your own words.	Open-ended	n/a	n/a
	7	On a scale from 1 (low) to 10 (high) how engaging was the session?	Numerical Lo(1)-Hi(10)	7.63	8
	8	On a scale from 1 (low) to 10 (high) how informative was the session?	Numerical Lo(1)-Hi(10)	8.09	8
	9	On a scale from 1 (low) to 10 (high) rate the quality of the instructional material.	Numerical Lo(1)-Hi(10)	8.72	10
	10	Group discussion helped me better understand the material.	Likert Lo(1)-Hi(5)	3.81	4
	11	The use of a historical artifact as an example helped me better understand the material.	Likert Lo(1)-Hi(5)	4.63	5
	12	This learning experience was ______ average	Likert Lo(1)-Hi(5)	4.09	4
Section B: Direct Assessment	13	Applied function modeling	Open-ended	n/a	n/a
	14	Applied structure modeling	Open-ended	n/a	n/a
	15	Applied behavior modeling	Open-ended	n/a	n/a
	16	How do abstraction and problem framing contribute to effective design, and do you see yourself applying them in your future engineering design work? Explain.	Open-ended	n/a	n/a
	17	Describe how problems and needs interact with design solutions.	Open-ended	n/a	n/a
Section C: Mindsets	18	The activity encouraged me to think creatively and make connections.	Likert Lo(1)-Hi(5)	4.18	4
	19	When identifying unmet needs, it is important to consider many varied options and perspectives even if the problem appears well-defined.	Likert Lo(1)-Hi(5)	4.72	5
	20	The activity encouraged me to consider the human impact of design work.	Likert Lo(1)-Hi(5)	4.72	5
	21	When designing engineering systems, human impact is one of the most important considerations even when the system does not have human end-users.	Likert Lo(1)-Hi(5)	4.45	5
	22	The collaborative format contributed to my learning.	Likert Lo(1)-Hi(5)	3.90	4
	23	It is important to work closely with others while learning and practicing design.	Likert Lo(1)-Hi(5)	4.36	5

learning experience. Likert-scale items further indicated strong agreement that group discussion and the use of a historical artifact supported understanding.

Direct assessment items provided evidence of knowledge and capability development. In post-lesson responses, students were generally able to distinguish between function, behavior, and structure when modeling an unfamiliar artifact, and written explanations reflected increased use of abstraction and problem framing language compared to pre-lesson need-finding responses. Artifact-based comparisons of initial and final post-it notes showed a shift from surface-level descriptions of the bookwheel toward more abstract statements of underlying needs, such as information organization, accessibility, and parallel task management.

Mindset-related items indicated strong agreement that the activity encouraged creative thinking, consideration of human impact, and collaborative learning. Open-ended responses and group discussion further reinforced these findings, with students frequently noting that the historical context helped them recognize their own perspective-driven assumptions and appreciate how needs persist even as solutions change.

Assessment relied on triangulation across self-report, performance evidence, and discussion rather than technical correctness alone. This approach made explicit to students that human-centered reasoning, abstraction, and reflection were valued outcomes of the activity, consistent with the goals of the KCM framework.

5. Discussion

The case study illustrates how the KCM framework can make the distinctive aims of human-centered engineering explicit. By articulating knowledge, capabilities, and mindsets separately, instructors can design learning experiences that extend beyond technical skill development and assess outcomes that are often implicit or overlooked.

The framework also supports transfer and reuse. While specific artifacts and contexts may vary, the underlying KCM mapping provides a reusable template for designing other lessons, modules, or workshops, particularly in early design settings where students may lack technical depth but can meaningfully engage with human needs and context.

6. Conclusions and Future Work

Human-centered engineering requires more than adding empathy-focused activities to existing curricula. It demands explicit attention to what students know, what they can do, and how they orient themselves toward design work. The Knowledge, Capabilities, Mindsets framework offers a practical, evidence-informed approach for aligning learning objectives, instruction, and assessment in HCE education.

Future work will examine how these dimensions develop over time across courses and co-curricular experiences and how the framework can support longitudinal assessment of human-centered learning outcomes.

References

[1] L. L. Bucciarelli, *Designing Engineers*. in Inside technology. MIT Press, 1994. [Online]. Available: https://books.google.com/books?id=ECSKxrTrHPsC

[2] C. L. Dym, A. M. Agogino, O. Eris, D. D. Frey, and L. J. Leifer, "Engineering Design Thinking, Teaching, and Learning," *J. Eng. Educ.*, vol. 94, no. 1, pp. 103–120, 2005, doi: 10.1002/j.2168-9830.2005.tb00832.x.

[3] B. Craft *et al.*, "Advancing Human-Centered Engineering (HCE): A Framework for Defining and Building the Emerging Discipline," in *2025 ASEE Annual Conference & Exposition Proceedings*, Montreal, Quebec, Canada: ASEE Conferences, Jun. 2025, p. 57578. doi: 10.18260/1-2--57578.

[4] S. Ahmed, K. M. Wallace, and L. T. M. Blessing, "Understanding the differences between how novice and experienced designers approach design tasks," *Res. Eng. Des.*, vol. 14, no. 1, pp. 1–11, 2003, doi: 10.1007/s00163-002-0023-z.

[5] C. J. Atman *et al.*, "Engineering Design Processes: A Comparison of Students and Expert Practitioners," *J. Eng. Educ.*, vol. 96, no. 4, pp. 359–379, 2007, doi: 10.1002/j.2168-9830.2007.tb00945.x.

[6] N. Cross, "Expertise in design: an overview," *Des. Stud.*, vol. 25, no. 5, pp. 427–441, Sep. 2004, doi: 10.1016/j.destud.2004.06.002.

[7] C. J. Atman, "Design timelines: Concrete and sticky representations of design process expertise," *Des. Stud.*, vol. 65, pp. 125–151, Nov. 2019, doi: 10.1016/j.destud.2019.10.004.

[8] J. Sweller, "Cognitive Load During Problem Solving: Effects on Learning," *Cogn. Sci.*, vol. 12, no. 2, pp. 257–285, Apr. 1988, doi: 10.1207/s15516709cog1202_4.

[9] J. Sweller, J. J. G. Van Merriënboer, and F. Paas, "Cognitive Architecture and Instructional Design: 20 Years Later," *Educ. Psychol. Rev.*, vol. 31, no. 2, pp. 261–292, Jun. 2019, doi: 10.1007/s10648-019-09465-5.

[10] K. Friston, "A theory of cortical responses," *Philos. Trans. R. Soc. B Biol. Sci.*, vol. 360, no. 1456, pp. 815–836, Apr. 2005, doi: 10.1098/rstb.2005.1622.

[11] J. Lave and E. Wenger, *Situated learning: Legitimate peripheral participation*. Cambridge university press, 1991.

[12] D. A. Schon, *The reflective practitioner : how professionals think in action*, Paperback ed. Aldershot, U.K: Ashgate, 1991.

[13] N. Schmitt and D. Chan, *Personnel selection : a theoretical approach*. in Foundations of organizational science. Thousand Oaks, Calif.: Sage Publications, 1998.

[14] B. S. Bloom, M. D. Engelhart, E. J. Furst, W. H. Hill, and D. R. Krathwohl, *Taxonomy of educational objectives*, vol. 2. Longmans, Green New York, 1964.

[15] M. Taguma, K. Makowiecki, and F. Gabriel, "OECD Learning Compass 2030: Implications for Mathematics Curricula," in *Mathematics Curriculum Reforms Around the World*, Y. Shimizu and R. Vithal, Eds., in New ICMI Study Series. , Cham: Springer International Publishing, 2023, pp. 479–509. doi: 10.1007/978-3-031-13548-4_32.

[16] A. M. Morcke, T. Dornan, and B. Eika, "Outcome (competency) based education: an exploration of its origins, theoretical basis, and empirical evidence," *Adv. Health Sci. Educ.*, vol. 18, no. 4, pp. 851–863, Oct. 2013, doi: 10.1007/s10459-012-9405-9.

[17] N. Fernandez, V. Dory, L. Ste-Marie, M. Chaput, B. Charlin, and A. Boucher, "Varying conceptions of competence: an analysis of how health sciences educators define

competence," *Med. Educ.*, vol. 46, no. 4, pp. 357–365, Apr. 2012, doi: 10.1111/j.1365-2923.2011.04183.x.
[18] M. T. H. Chi and S. Ohlsson, "Complex Declarative Learning," in *The Cambridge Handbook of Thinking and Reasoning*, Cambridge University Press, 2005, pp. 371–399.
[19] J. Bransford and National Research Council, Eds., *How people learn: brain, mind, experience, and school*, Expanded ed., 9. print. Washington, DC: National Academy Press, 2004.
[20] R. P. Loweth, S. R. Daly, A. Hortop, E. A. Strehl, and K. H. Sienko, "An in-depth investigation of student information gathering meetings with stakeholders and domain experts," *Int. J. Technol. Des. Educ.*, no. 0123456789, 2020, doi: 10.1007/s10798-020-09595-w.
[21] R. P. Loweth, S. R. Daly, A. Hortop, E. A. Strehl, and K. H. Sienko, "A comparative analysis of information gathering meetings conducted by novice design teams across multiple design project stages," *J. Mech. Des. Trans. ASME*, vol. 143, no. 9, 2021, doi: 10.1115/1.4049970.
[22] K. Dorst, "The core of 'design thinking' and its application," *Des. Stud.*, vol. 32, no. 6, pp. 521–532, Nov. 2011, doi: 10.1016/j.destud.2011.07.006.
[23] C. S. Dweck and D. S. Yeager, "Mindsets: A View From Two Eras," *Perspect. Psychol. Sci.*, vol. 14, no. 3, pp. 481–496, May 2019, doi: 10.1177/1745691618804166.
[24] D. A. Norman, *The design of everyday things*, Revised and Expanded edition. New York, New York: Basic Books, 2013.
[25] J. L. Hess, N. D. Fila, E. Kim, and S. Purzer, "Measuring Empathy for Users in Engineering Design," *Int. J. Eng. Educ.*, vol. 37, no. 3, doi: 0949-149X/91.
[26] J. S. Gero and U. Kannengiesser, "The situated function-behaviour-structure framework," *Des. Stud.*, vol. 25, no. 4, pp. 373–391, 2004, doi: 10.1016/j.destud.2003.10.010.

Appendix

Pre-Lesson Self Assessment

1. I can explain the difference between Function, Structure, and Behavior (FSB) in the FSB framework.

Strongly Agree　Agree　Neutral/No Opinion　Disagree　Strongly Disagree

2. I can apply FSB modeling to analyze an unfamiliar artifact or system.

Strongly Agree　Agree　Neutral/No Opinion　Disagree　Strongly Disagree

3. I understand how problems and needs interact with design solutions.

Strongly Agree　Agree　Neutral/No Opinion　Disagree　Strongly Disagree

4. I understand how abstraction helps deepen insight into need finding.

Strongly Agree　Agree　Neutral/No Opinion　Disagree　Strongly Disagree

Post-Lesson Questionnaire

Section A: Clarity and Engagement

1. My pre-lesson self assessment was accurate (True / False). If not, please explain.

2. Briefly describe the purpose of the lesson in your own words.

3. On a scale from 1 (low) to 10 (high) how engaging was the session?

4. On a scale from 1 (low) to 10 (high) how informative was the session?

5. On a scale from 1 (low) to 10 (high) rate the quality of the instructional material.

6. Group discussion helped me better understand the material.

Strongly Disagree   Disagree   Neutral/No Opinion   Agree   Strongly Agree

7. The use of a historical artifact as an example helped me better understand the material.

Strongly Disagree   Disagree   Neutral/No Opinion   Agree   Strongly Agree

8. This learning experience was _____ average

far worse than   worse than   about the same as   better than   far better than

Section B: Direct Assessment

9. Consider the *phillips head screwdriver* shown below:

Using the FSB framework, briefly (1-3 sentences each) describe its:

a. Function:

b. Structure:

c. Behavior:

10. How do abstraction and problem framing contribute to effective design, and do you see yourself applying them in your future engineering design work? Explain.

11. Describe how problems and needs interact with design solutions.

Section C: Mindsets

12. The activity encouraged me to think creatively and make connections.

Strongly Disagree Disagree Neutral/No Opinion Agree Strongly Agree

13. When identifying unmet needs, it is important to consider many varied options and perspectives even if the problem appears well-defined.

Strongly Disagree Disagree Neutral/No Opinion Agree Strongly Agree

14. The activity encouraged me to consider the human impact of design work.

Strongly Disagree Disagree Neutral/No Opinion Agree Strongly Agree

15. When designing engineering systems, human impact is one of the most important considerations even when the system does not have human end-users.

Strongly Disagree Disagree Neutral/No Opinion Agree Strongly Agree

16. The collaborative format contributed to my learning.

Strongly Disagree Disagree Neutral/No Opinion Agree Strongly Agree

17. It is important to work closely with others while learning and practicing design.

Strongly Disagree Disagree Neutral/No Opinion Agree Strongly Agree

Section D: Open-Ended Questions

18. What stood out to you about this lesson (positive or negative), and what suggestions do you have for improvement?