2026 ASEE ANNUAL CONFERENCE June 21–24, 2026 | Charlotte Convention Center, NC
Host Sponsor UNC Charlotte
Paper ID #53121

Design Problem Representation in Engineering Education: A Review of Neurocognitive Links to Cognitive Load and Student Motivation

Logan Izaiah Abraham, Florida Polytechnic University

Logan Abraham is a master's student in mechanical engineering at Florida Polytechnic University and a graduate research assistant in the Florida Poly Design Research (FPDR) Lab. His research focuses on design neurocognition and engineering education, with an emphasis on how design problem representation influences cognitive engagement and performance in novice designers. His work combines physiological sensing methods with traditional educational assessments to inform the development of more effective instructional strategies in engineering design.

Elisabeth Kames Ph.D., Florida Polytechnic University

Elisabeth Kames is an Assistant Professor at Florida Polytechnic University. Her focus is on engineering design and manufacturing, with special focus on engineering education within the mechanical engineering department. Her research focuses on design cognition and neurocognition, the impact of motivation on performance and persistence in mechanical engineering, and manufacturing training in design courses. Elisabeth is an active member of ASEE, ASME, Tau Beta Pi, and Order of the Engineer.

Design Problem Representation and Its Effect on Student Motivation and Neurocognition: A Scoping Review

Abstract

This review gathers evidence on the impact of design problem representation on student motivation or neurocognitive activity during engineering design tasks. Inclusion criteria included studies conducted with students in higher education, design and engineering design, and the use of neurophysiological tools or surveys, and qualitative data. 272 papers were evaluated, with only 5 papers meeting the inclusion criteria for design problem representation on student motivation or neurocognitive activity. Across included higher education studies, changes in representation/modality were associated with changes in brain activity, repeatedly indicating differences in the theta and beta bands and region-specific effects. Student motivation findings suggested that representation can influence constructs such as cognitive value, self-regulation, intrinsic motivation, and anxiety, and that these factors may align with neurocognitive patterns. Perception results further imply that changes in representation can change perceived difficulty in auditory problem-solving conditions. While the overall evidence remains limited by small samples, the findings support that problem representation is not a neutral design choice and can potentially affect both cognitive engagement and motivational experience.

Introduction

Engineering design pedagogy underwent a major shift that began shortly after World War II, in favor of science and mathematics being rooted in theory. This perturbation caused practical, more industry-applicable classes, such as shop, manufacturing processes, and engineering design courses, to be removed to accommodate the shift in academia. Through this, elements of problem-solving and decision-making were neglected, causing budding engineers to lack the skills to apply the knowledge acquired through higher education [1], [2]. Although little has changed in the first two years of the engineering curriculum, which mainly focuses on theory, capstone courses have become standard due to strong recommendations from ABET and industry's perception that engineering students lack the practical skills necessary to practice in the field [2], [3]. Over the years, capstone courses have also undergone an evolution, going from primarily arbitrary tasks derived by faculty in favor of more collaboration on industry-sponsored projects involving real life design problems[2], [3], [4]. One method that has been employed to enhance students' design capabilities early in an engineer's academic career is to implement an early design experience, colloquially known as "cornerstone courses"[5]. This is from the idea that design should be a cornerstone of the engineering curriculum, which coincides with ASME's Vision 2030, encouraging programs to allow students to experience practice-to-application and engineering design all four years. This ideology has become known as the design spine or the design portfolio approach to engineering education. [3], [6], [7].

Background and Foundation of Research

Design Problem Representation

Engineering design can be described as the process of devising a system that meets desired needs by using an iterative decision-making process [6]. Design often encompasses realistic but ill-structured problems that are found in nature, where the solutions cannot be found by applying a mathematical formula in a structured way [8]. Oftentimes, designers lack a definition of the initial problem state or what the goal state may be [9], [10]. This ambiguity is exactly where expertise starts to affect the outcomes. Novice designers tend to focus on surface level features, analogous to a problem that would be found in a standard university physics class. Experts tend to ground themselves in their deep understanding, experience, and organization of the problems, in addition to having a deeper understanding of contextual constraints [11]. It has also been found that experts' cognitive activity and productivity were three times as high as those of novice designers in the overall design process [12].

Open-ended design problems

Solving problems in an open-ended manner that are common to engineering design requires a distinct set of skills and train of thought from those required of closed-ended problems with a single unique solution [11], [13]. ABET states that open-ended problem-solving is a central skill in engineering and one that students must develop [14]. However, novice designers may have the technical knowledge required but lack the experience that is vital for solving these ill-structured problems and becoming an expert in the field [13]. Often, when students encounter these types of problems, they become fixated on gathering information and get stuck on the problem definition rather than continuing with the design process [15], [16], [17].

But how does one define an open-ended problem? Dym and Brown say that design problems are *open-ended* because they usually have many acceptable solutions and paths to said solutions. Due to the variation in potential outputs, the “best” design may depend on priorities and context [8], [18], [19], [20]. Additionally, goals and constraints should be somewhat ambiguous, with some criteria missing, vague, or conflicting, which are left to the designer for clarification [13], [21], [22], [23]. Lastly, due to the iterative nature of design, the problem will require framing and reframing as you learn more about the context of the problem [20], [23]. A good example of an open-ended design prompt was laid out by Chimka and Atman [20], where they asked students to design a playground. The criteria that stick out the most are: it needs to be safe for children, while not costing too much. This captures the breadth of open-ended design problems due to the ambiguity, because what does one consider to be “safe” or “not cost too much”? Design problems like this need framing and reframing depending on context and customer needs.

Alternative

Scaffolded problem representation is an approach that intentionally embeds support into the problem or, in this setting, an open-ended prompt to facilitate engagement with complex tasks that students would otherwise struggle to complete [24], [25]. In the context of design education, scaffolding is framed as guidance that structures learners' work, prompting them to consider criteria that may otherwise be neglected. This can take the form of, but is not limited to, guiding questions, supplying templates, and breaking down steps throughout the design process. Using scaffolding strategies, it is possible to redirect students if they become lost or overwhelmed by complex problems [25]. Ill-structured problems can also impose a high cognitive load on novice designers, causing prior knowledge and experience to take precedence over the design activity itself [26], [27]. In engineering education specifically, the use of question prompts has been used to guide student teams, impacting the quality of problem-solving interactions and solutions [28] .

Visual problem representations are also used to aid students when problem-solving. The logic behind this is to support learning and problem-solving by engaging verbal and non-verbal processing channels, or dual coding, making relationships easier to perceive than in text alone. This can include information portrayed through diagrams, schematics, flowcharts, annotated layouts, or other external visual representations, rather than relying solely on text [29], [30]. From the perspective of multimedia in learning, visual aids are most effective following evidence-based design principles that keep the designer focused on key elements by using labels and text to close to a relevant graphic or using visual cues to direct attention [31], [32]. For engineering education, it is plausible to shape how students interpret and engage with a design problem, as well as improve students' ability to learn [33]. Recent work argues that it is not whether visuals help, but rather which specific features drive differences in how students interpret and solve problems [34].

Design Neurocognition

Design neurocognition has become a promising field of research due to the focus on understanding the brain processes involved in engineering design. Advanced non-invasive neurophysiological tools such as electroencephalography (EEG), functional near infrared spectroscopy (fNIRS), and eye-tracking allow us to measure brain activity and design focus in real-time. EEG has risen to be one of the most used tools in the field, offering high temporal resolution by monitoring electrical activity on the scalp, making it a top choice for tracking cognitive processes like attention, evaluation, and ideation. This allows researchers to explore the frequency and power of each wave across a designer's brain to better understand the neurocognitive effects of constrained and open-ended tasks. Each brainwave offers specific cognitive functions, offering a unique perspective as to how students interact with design problems [35], [36]. In contrast, fNIRS captures the cortical hemodynamics through the change of oxygenation in the hemoglobin, or simply put, it measures how much oxygen flows to a specific part of the brain. Although it may have excellent spatial precision that EEG lacks, it is limited to one brain region at a time, but it is still suitable for observing prefrontal activity during interactive tasks. Through this, it is possible to observe neurophysiological effects like reasoning and planning [35], [36], [37],[38]. Eye tracking allows researchers to capture temporal analysis of visual attention by recording gaze position, time, and movement. These are referred to as fixations, periods of relatively stable gaze, and saccades, quick movements of the eyes that change the point of fixation. Fixation count and duration are commonly used to measure attention allocation during a task, while the path a subject's eyes take, or scan path, can give insight as to how a designer interacts with a representation [39], [40], [41], [42]. Pupillometry, the changes in pupil diameter, is also widely accepted as an indicator of cognitive load and can be compared to survey data to further contextualize what a novice designer may be struggling with [43], [44].

One of the most important brain waves in design neurocognition is the beta wave. Beta waves are primarily associated with attention, problem-solving, and deep cognitive engagement, which are essential for successful design thinking [36]. Previous work has also shown that open-ended design tasks increase alpha and beta activation during initial stages of the design process, such as sketching or modeling [45]. Gamma waves are also correlated to advanced cognitive function, including perception, learning, and memory integration. These are usually seen during moments of peak concentration and mental activity, binding various sensory inputs to formulate a cohesive perception. Although gamma waves have significance in the design process, they are known to be difficult to capture due to muscle artifacts that exist in the same frequency range [37]. Figure 1 displays the different brain waves and the frequency range in which they belong, as well as the states that are usually associated with that frequency.

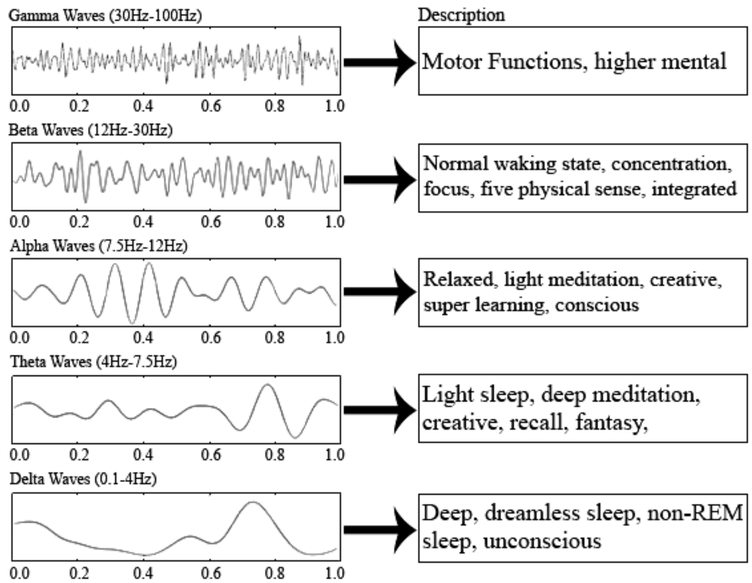

Figure 1: Brain wave chart with associated frequencies and states [35].

The brain regions are also important in the context of design neurocognition to be able to understand the output of neurophysiological tools. The region of interest for this paper is the cerebrum, which is composed of a highly folded surface that is credited with advanced cognitive activity like attention, reasoning, planning, and problem-solving. The cerebrum is further broken down into four regions or lobes, shown in Figure 2: frontal, parietal, temporal, and occipital. The frontal lobe is located at the anterior portion of the brain and is linked to executive functions like decision making, working memory, regulating attention, and voluntary motor control. This region is looked at frequently in design neurocognition, as it is especially active during the evaluative reasoning process [46], [47].

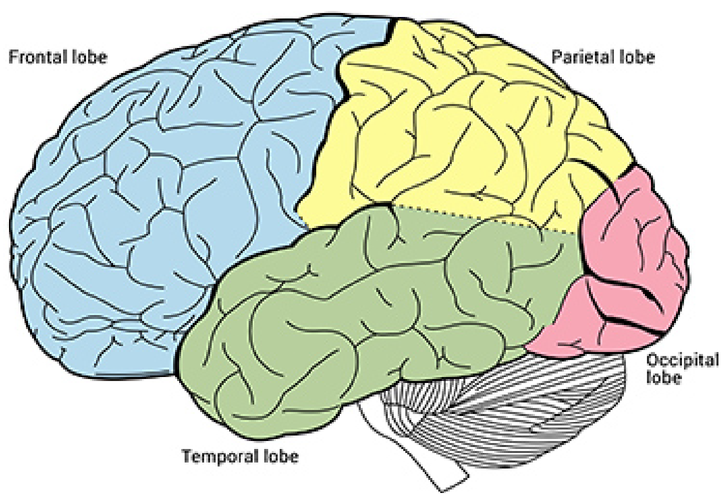

Figure 2: The cerebral cortex divided into four lobes [47].

It is important to consider neurocognition when developing young engineers in academia [48]. This opens the door to analysis on how to present design problems in a way that allows a novice engineer to replicate an experienced designer's thought process. This leads to our first research question: *How do alternative design problem representations compare to traditional, open-ended representations in terms of cognitive load or other neurocognitive effects?*

Student Motivation

Although neurocognition yields valuable insights into how students process design tasks, their motivation is equally important when determining future success [49]. One commonly used method of quantifying Student motivation is using the Motivated Strategies for Learning Questionnaire (MSLQ). More specifically, metrics to evaluate engineer's motivation have been identified as: cognitive value, the importance of students' place on a task; self-regulation, managing one's learning and problem-solving processes; intrinsic motivation, students' desire to engage in tasks for personal satisfaction; anxiety, nervousness during tasks; and self-efficacy, the belief in one's ability to succeed [50]. Previous work has also shown that cognitive value, self-regulation, intrinsic motivation, and self-efficacy are predictors of academic achievement, with anxiety being negatively correlated to self-efficacy for young students in STEM [51].

The characteristics of an open-ended design problem previously mentioned bring self-regulation to the forefront of principal factors for young designers. Without this skill, students may spend too much time on a single aspect of a design problem, causing them to get stuck or a drop in productivity. Work by Kado shows that students who are skilled in self-regulation are better equipped to manage these complexities by allocating their cognitive resources to efficiently solve the most important aspects of a design problem [15], [16], [17], [48]. Cognitive value gives insight into the effort students are inclined to invest in design problems. Students are generally more likely to contribute if there is a perception that the task is useful to their learning or future careers. Creativity and problem-solving are also linked to intrinsic motivation, inducing students to approach design tasks with interest and a drive to explore multiple possibilities. Additionally, it has been shown to correlate with increased levels of cognitive engagement, due to students being more likely to power through difficulties and maintain a positive outlook toward the design process [52]. Persistence has also been linked to high levels of self-efficacy in the face of challenge, viewing failure as a learning opportunity. However, students with low self-efficacy experience anxiety when tasks are perceived as too challenging or beyond their abilities and can become discouraged. Building self-efficacy in students is essential for ensuring they have the confidence needed in industry [48].

It is important to take motivational factors into account when developing engineering curriculum. Motivational factors are also not fixed, as they tend to vary throughout students' academic careers. This shift suggests that intervention should be adopted in engineering pedagogy to accommodate the dynamic needs of students as they transition from traditional coursework to advanced design challenges [53]. Bellad and Kim capture this by saying, "In the context of instruction, design is the translation of theories of learning and motivation to create artifacts that can solve learning or performance problems." [54], [55], [56]. This leads to our second research question. *How do alternative design problem representations compare to traditional open-ended representations in terms of student motivation?*

Experimental Methods

The authors chose the inclusion criterion that would allow for scoping of the current state of the field as well as finding and addressing research gaps. Keywords included “engineering design”, “problem representation/ structure”, “modality”, “design neurocognition”, “student motivation”, “cognitive load”, and “problem framing”, amongst others. Search and screening were done through databases, such as EBSCO, ProQuest, Wiley, and Elsevier, in addition to Google Scholar.

Inclusion Criteria

1. Must be in the context of engineering or design.
2. Must be higher education
3. Examine the impact of design problem presentation (Open-ended, closed-ended, scaffolded, or visual) on student motivation (cognitive value, self-regulation, intrinsic motivation, anxiety, and self-efficacy) **or** neurocognitive effects
   - Must use more than one problem representation.
   - Must measure student motivation or neurocognitive differences between problem representations qualitatively or quantitatively.
   - Must use a neurophysiological approach (EEG, fNIRS, and eye-tracking).

272 papers were analyzed, 63 papers were pulled aside for screening, and only 5 were eligible for this review. The papers were split into 2 categories, looking at student motivation or neurocognitive effects. No papers were found that solely compared changes in design problem representation and their effect on student motivation, while 2 papers discussed neurocognitive effects, and 3 papers discussed both. There were also 3 papers that the authors could not access. Articles were reviewed by the authors and a design expert through open multiple discussions to ensure that criteria were met.

Table 1. Inclusion and Exclusion by Number of Papers

Total Papers Pulled for Screening	n = 63
Papers Included	n = 5
Did Mot Measure Motivation or Neurophysiological effects	n = 40
Did Not Compare More Than One Problem Representation	n = 9
Not Higher Education	n = 4
No Access	n = 3
Not Engineering or Design	n = 2

Results & Discussion

Neurocognitive Impact

In 2024, Gestson [57] explored differences in problem-solving behavior using eye-tracking between 10 undergraduate engineering students and 19 engineering practitioners using multiple representations. Three problems associated with head loss were derived using an open-ended, multiple-choice, and formulaic format, alongside four problem representations regarding head loss through a pipe. This included two visuals, which contained a head loss table and chart for either representation, where the two formulaic representations provided formulas and coefficients to aid in problem solving. The problems were presented via slides on a computer screen and divided into five areas of interest (AOIs): the problem statement and four representations, where the participants solved three problems, all in the same order.

Results showed that students had a higher fixation count and total fixation duration (TFD) on formulaic representations than on visual ones, implying that students accessed information in formulaic representations more frequently and for longer average fixation durations (AFDs). However, for engineering practitioners solving the same problem, there was no observable difference for TFD, but they did have a greater AFD on visual representations. For problem 2, TFD and AFD were greater than those for visual representations for both engineering practitioners and students. Problem 3 showed greater TFD for visual representations, while AFD was higher for formulaic representations. For engineering practitioners on the same problem, TFD and AFD were both higher for the visual representation [57].

In 2025, Li [58] investigated the neurocognitive effects of students solving design problems in an open-ended, unconstrained format involving 37 subjects. Participants were assigned either a problem-solving task (PS) where the objective was to generate as many solutions as possible, or to design with a morphological table (DwMT) converging on one solution. Both groups were asked, "How to empty a glass placed in the center of a heavy table without touching it.", but the DwMT group was required to pick elements from the morphological table that consisted of mechanical components or features. The results showed a strong statistical link between Task-Related Desynchronization (TRPD), a decrease in power of brainwaves during a task, and superior design performance. Also, the left frontal region was most effective as a predictor of design clarity and detail. Li also implied that high performance was mainly associated with a drop in power of the theta band, suggesting that high performers were better at managing the high working memory demand required to tie multiple ideas into a concept. For PS, performance indicators were linked to both Task-Related Desynchronization and synchronization, depending on metrics like quantity, variety, or novelty. Unlike DwMT, the temporal channels located on the side associated with creative ideation and processing were better predictors of success. High performance was also correlated to theta Desynchronization and alpha band synchronization [58].

Neurocognitive Correlations to Student Motivation

Examining design problem representation with respect to student motivation is a novel topic that to find neurocognitive correlations. Although the study may not aim to directly address design problem representations' effect on student motivation, there is still valuable insight into how the two interact. A study in 2023 was conducted involving sophomore students in the first-semester cornerstone course, where they were introduced to the basic concepts of design. Students filled out the MSLQ and the VARK learning assessment before the study to get a baseline for motivation and learning styles. The study featured two design modalities: a written problem and a pictural or visual representation. Students were given 10 minutes to complete each design problem with a 3-minute break between them. After completion, students filled out a post survey. The author did not mention what metrics were collected or what the design tasks entailed other than problem modality.

EEG analysis indicated that the Beta Low frequency was the most significant brain wave when comparing the two design problems, with multiple regions showing statistical significance, and a general increase in brain activation for the visual problem compared to the written. The results showed that the written problem had a less positive impact on student motivation compared to the pictorial. There was also a decrease in intrinsic motivation as well as an increase in anxiety when students solved the written prompt compared to the visual. Students also showed increased solution variety and higher engagement when solving the pictorial design problem. The study also found correlations between changes in brain activation and self-reported motivation factors, where cognitive value exhibited positive correlations with brain activation in frontal/prefrontal regions, while anxiety and intrinsic motivation exhibited negative correlations in these regions. The study also revealed a significant correlation between problem modalities and changes within the beta frequency located in the right frontal cortex. This region is associated with divergent thinking or generating a multitude of solutions [59].

In 2024, a study examined perceptions of design problems that correlate with changes in design problem modality. Each participant filled out the MSLQ, with questions relevant to cognitive value, self-regulation, anxiety, intrinsic motivation, and self-efficacy, which together characterize how students value the task, manage effort, experience stress, and perceive their ability to succeed [50]. The VARK learning styles assessment was also given to subjects. The study analyzed the effects of four different problem modalities: visual, auditory, written, and kinesthetic. All problems were based on the prompt format of "Design a system to translate a box/ cylinder, horizontally/vertically." Auditory and written were represented by the same prompt, with one being read aloud. The visual modality relied on a graphic representing a box moving on a plane, and the kinesthetic representation involved a physical demonstration. Participants were divided into groups with two random modalities and given 7-10 minutes to develop as many solutions to the design problem as possible, followed by a 3-minute break. Finally, the last design problem and a post survey assessing perceived problem difficulty and satisfaction with generated solutions.

Across modality comparisons, theta frequency trends (particularly in posterior regions such as Oz and other rear regions) were indicative of significant changes, and the auditory and kinesthetic problems tended to induce increased brain activity overall compared to traditional and written problem statements. Though motivation data were limited, there was a significant negative correlation found between perceived problem difficulty and self-regulation. Simply put, as difficulty went up, self-regulation went down for the auditory representation and was perceived as more difficult than the kinesthetic. Learning styles were not found to correlate with problem difficulty. Additionally, problem order did not produce significant changes in brain activity. The study also suggests that students with lower intrinsic motivation may experience greater perceived difficulty. In the kinesthetic modality specifically, regression analysis indicated that high cognitive and self-regulation motivation correlated with higher brain activity, while lower brain activations correlated with higher intrinsic motivation. The study identified significant differences within the beta high frequency, or at the high end of the beta frequency range based on problem representation. These brain activity changes were triggered through an auditory description or a kinesthetic example. However, the Beta High deltas themselves were not found to correlate with MSLQ and VARK results, even though post-survey perceptions showed meaningful relationships with motivation factors (e.g., self-regulation and self-efficacy). [48], [52].

Research Gaps

Design problem representation and its effect on student motivation and neurocognitive activity have proven to be under-researched topics. Although the research questions in this paper yielded few but insightful results, research gaps were identified, which leaves an opportunity to address a novel topic using modern, advanced tools [35], [41], [44]. Many papers screened lacked the context needed to be included in the analysis. The frameworks and design problem representations mentioned in the introduction of this review are not often looked at in the context of allowing students to attempt design problems and measuring motivation or neurocognitive activity. Others changed aspects of the problem modality that were not problem framing or representation. For example, works by Nur Guler and Sajadi tested a scaffolded approach to sketching assignments that were given remotely versus in class. Although the results showed that students had varying levels of motivation, whether they were in class or remote, the study gave both groups the same scaffolded prompts, meaning there was no alternative problem representation to compare them to [60]. Other papers discuss how design solutions can be represented for interpretation by other entities. Although it covers alternative design representations, it does not examine students during design, nor does it measure the impact on student motivation and neurocognition [61].

Various articles were excluded because they did not contain students in higher education. However, these papers still have elements that could give insight into the neurological impact of problem representation. For example, Vieira et al. measured EEG frequency band power while professional mechanical engineers and industrial designers completed constrained versus open design tasks, and reported significant differences between constrained and open tasks in the beta bands during the earliest reaction stage, along with additional differences in alpha 2 and beta bands during open externalization, with the open design request producing higher activation in areas associated with semantic associations, planning/executive control, visual mental imagery, and searching for originality [45]. Additionally, Vieira et al. used EEG to compare problem-solving (closed) versus designing (open) in mechanical engineers and reported increased activation when designing compared to problem-solving, emphasizing that time-related neural responses connected to Brodmann-area functions can help characterize cognition in open design tasks [62].

Overall, there are indications in literature that design problem representation can shape how novices allocate cognitive resources during design tasks in addition to their motivation towards such tasks. However, there is little evidence to support this, and it will require more examination in future work. Across the screened studies, alternative representations appear capable of shifting neurocognitive activity while also influencing key motivation factors such as cognitive value, self-regulation, intrinsic motivation, and anxiety. The field lacks replication and suffers from small sample sizes as well as consistent task structures and reporting, making it difficult to isolate which representation features drive the observed effects. The author will link representation features to specific motivational constructs, and pair those constructs to neurophysiological measures under controlled, comparable design tasks to clarify when alternative representations support productive engagement, and when they have a negative impact on students.

Acknowledgments

This research is supported by the National Science Foundation CMMI-2501443

References

[1] E. W. Banios, “Teaching Engineering Practices,” *Proceedings Frontiers in Education Twenty-First Annual Conference. Engineering Education in a New World Order*, pp. 161–168, 1991.

[2] A. J. Dutson, R. H. Todd, S. P. Magleby, and C. D. Sorensen, “A Review of Literature on Teaching Engineering Design Through Project-Oriented Capstone Courses,” *Journal of Engineering Education*, vol. 86, no. 1, pp. 17–28, Jan. 1997, doi: 10.1002/j.2168-9830.1997.tb00260.x.

[3] C. L. Dym, “Design, Systems, and Engineering Education,” 2004.

[4] C. L. Dym, A. M. Agogino, O. Eris, D. D. Frey, and L. J. Leifer, “Engineering design thinking, teaching, and learning,” in *Journal of Engineering Education*, Wiley-Blackwell Publishing Ltd, 2005, pp. 103–120. doi: 10.1002/j.2168-9830.2005.tb00832.x.

[5] C. Telenko *et al.*, “Designettes: An Approach to Multidisciplinary Engineering Design Education,” *Journal of Mechanical Design*, vol. 138, no. 2, Feb. 2016, doi: 10.1115/1.4031638.

[6] K. Lulay, “Implementation of a Design Spine for a Mechanical Engineering Curriculum,” Hyster Co, 2015.

[7] ASME Board on Education, “ASME Vision 2030,” 2012.

[8] C. L. Dym and D. Brown, *Engineering Design Representation and Reasoning*, Second Edition. Cambridge University Press, 2012.

[9] H. A. Simon, “The structure of ill structured problems,” *Artif. Intell.*, vol. 4, no. 3, pp. 181–201, 1973, doi: https://doi.org/10.1016/0004-3702(73)90011-8.

[10] J. Carroll, J. Thomas, and A. Malhotra, “Presentation and Representation in Design Problem Solving,” 1978.

[11] T. A. Björklund, “Initial mental representations of design problems: Differences between experts and novices,” *Des. Stud.*, vol. 34, no. 2, pp. 135–160, Mar. 2013, doi: 10.1016/j.destud.2012.08.005.

[12] M. Kavakli and J. Gero, “STRATEGIC KNOWLEDGE DIFFERENCES BETWEEN AN EXPERT AND A NOVICE DESIGNER.”

[13] E. P. Douglas and D. J. Therriault, “MOVING BEYOND FORMULAS AND FIXATIONS: EX-PLORING APPROACHES TO SOLVING OPEN-ENDED ENGINEERING PROBLEMS Moving beyond formulas and fixations: Exploring approaches to solving open-ended engineering problems,” 2011.

[14] ABET Board of Directors, “CRITERIA FOR ACCREDITING ENGINEERING PROGRAMS Effective for Evaluations During the Accreditation Cycle Engineering Accreditation Commission,” 2009.

[15] H. Christiaans and K. Dorst, “Cognitive Models in Industrial Design Engineering: A Protocol Study,” *American Society of Mechanical Engineers*, 1992.

[16] N. Cross, H. Christiaans, and K. Dorst, “Design Expertise Amongst Student Designers,” 1994.

[17] C. J. Atman, J. R. Chimka, K. M. Bursic, and H. L. Nachtmann, “A comparison of freshman and senior engineering design processes,” *Des. Stud.*, vol. 20, no. 2, pp. 131–152, Mar. 1999, doi: 10.1016/S0142-694X(98)00031-3.

[18] J. K. Murray, J. A. Studer, S. R. Daly, S. McKilligan, and C. M. Seifert, “Design by taking perspectives: How engineers explore problems,” *Journal of Engineering Education*, vol. 108, no. 2, pp. 248–275, 2019, doi: https://doi.org/10.1002/jee.20263.

[19] E. DRINGENBERG, A. Abell, and G. Guanes, “Decision Making in Engineering Capstone Design: Participants’ Reactions to a Workshop about Diverse Types of Reasoning.”

[20] J. R. Chimka, C. J. Atman, and K. M. Bursic, “Describing Student Design Behavior.”

[21] D. H. Jonassen, “Design Problems for Secondary Students,” 2011. [Online]. Available: www.ncete.org

[22] D. H. Jonassen and W. Hung, “All Problems are Not Equal: Implications for Problem-Based Learning,” *Interdisciplinary Journal of Problem-Based Learning*, vol. 2, no. 2, Oct. 2008, doi: 10.7771/1541-5015.1080.

[23] K. Dorst, “The Problem of Design Problems.”

[24] D. Wood, J. S. Bruner, and G. Ross, “THE ROLE OF TUTORING IN PROBLEM SOLVING*,” Pergamon Press, 1976.

[25] B. J. Reiser, “Scaffolding Complex Learning: The Mechanisms of Structuring and Problematizing Student Work,” *Journal of the Learning Sciences*, vol. 13, no. 3, pp. 273–304, Jul. 2004, doi: 10.1207/s15327809jls1303_2.

[26] J. Sweller, P. A. Kirschner, and R. E. Clark, “Why Minimally Guided Teaching Techniques Do Not Work: A Reply to Commentaries,” *Educ. Psychol.*, vol. 42, no. 2, pp. 115–121, 2007.

[27] P. A. Kirschner, J. Sweller, and R. E. Clark, “Why Minimal Guidance During Instruction Does Not Work: An Analysis of the Failure of Constructivist, Discovery, Problem-Based, Experiential, and Inquiry-Based Teaching,” *Educ. Psychol.*, 2006.

[28] M. T. Tucker, M. S. Shehab, T. Tucker, S. Shehab, and E. Mercier, “The Impact of Scaffolding Prompts on the Collaborative Problem Solving of Ill-Structured Tasks by Undergraduate Engineering Student Groups,” 2020.

[29] J. H. Larkin and H. A. Simon, “Why a Diagram is (Sometimes) Worth Ten Thousand Words,” *Cogn. Sci.*, vol. 11, no. 1, pp. 65–100, 1987, doi: https://doi.org/10.1016/S0364-0213(87)80026-5.

[30] J. M. Clark and A. Paivio, "Dual Coding Theory and Education," 1991.

[31] R. E. Mayer and L. Fiorella, *Spatial Contiguity Principle*, 2nd ed. Cambridge: Cambridge University Press, 2009. doi: DOI: 10.1017/CBO9780511811678.010.

[32] R. E. Mayer and L. Fiorella, "Principles for reducing extraneous processing in multimedia learning: Coherence, signaling, redundancy, spatial contiguity, and temporal contiguity principles," in *The Cambridge Handbook of Multimedia Learning, Second Edition*, Cambridge University Press, 2014, pp. 279–315. doi: 10.1017/CBO9781139547369.015.

[33] J. Rho, M. A. Rau, and B. Van Veen, "Supporting engineering students' representational competencies in individual and collaborative learning settings," *Journal of Engineering Education*, vol. 114, no. 2, p. e20631, Apr. 2025, doi: https://doi.org/10.1002/jee.20631.

[34] N. Elizabeth and J.-G. Dissertation, "HOW VISUAL REPRESENTATIONS AFFECT UNDERGRADUATE STUDENTS' USE AND UNDERSTANDING OF ENGINEERING CONCEPTS DURING PROBLEM SOLVING," 2018.

[35] W. Srimahara, R. Chaisricharoen, S. Chaising, and P. Sittiprapaporn, *Classification of Human Brain Attention focused on Meditation, effected by L-Theanine Acid in Oolong Tea*. IEEE, 2018.

[36] J. S. Gero, "From Design Cognition to Design Neurocognition From Design Cognition to Design Neurocognition." [Online]. Available: https://escholarship.org/uc/item/6z42017c

[37] P. A. Abhang, B. W. Gawali, and S. C. Mehrotra, *Introduction to EEG-and speech-based emotion recognition*. Academic Press, 2016.

[38] S. Sierra Camp *et al.*, "EVALUATING THE POTENTIAL OF NEUROIMAGING METHODS TO STUDY ENGINEERING COGNITION AND PROJECT-LEVEL DECISION MAKING."

[39] M. Cass and R. Prabhu, "LOOKING BEYOND SELF-REPORTED COGNITIVE LOAD: INVESTIGATING THE USE OF EYE TRACKING IN THE STUDY OF DESIGN REPRESENTATIONS IN ENGINEERING DESIGN," *Proceedings of the Design Society*, vol. 3, pp. 2475–2484, 2023, doi: DOI: 10.1017/pds.2023.248.

[40] R. S. Hessels, A. Nuthmann, M. Nyström, R. Andersson, D. C. Niehorster, and I. T. C. Hooge, "The fundamentals of eye tracking part 1: The link between theory and research question," *Behav. Res. Methods*, vol. 57, no. 1, Jan. 2025, doi: 10.3758/s13428-024-02544-8.

[41] S. Cullipher, S. J. R. Hansen, and J. R. VandenPlas, "Eye Tracking as a Research Tool: An Introduction," in *Eye Tracking for the Chemistry Education Researcher*, vol. 1292, in ACS Symposium Series, vol. 1292. , American Chemical Society, 2018, ch. 1, pp. 1–9. doi: doi:10.1021/bk-2018-1292.ch001.

[42] G. J. Augustine, D. Fitzpatrick, W. Hall, A.-S. Lamantia, D. Purves, and L. White, *Neuroscience:Types of Eye Movements and Their Functions*, 2nd ed. Sinauer Associates, 2015.

[43] M. Cass and R. Prabhu, "Looking Beyond Self-Reported Cognitive Load: Comparing Pupil Diameter Against Self-Reported Cognitive Load in Design Tasks," *Journal of Mechanical Design*, vol. 147, no. 4, p. 044503, 2025.

[44] J. Klingner, "MEASURING COGNITIVE LOAD DURING VISUAL TASKS BY COMBINING PUPILLOMETRY AND EYE TRACKING A DISSERTATION SUBMITTED TO THE DEPARTMENT OF COMPUTER SCIENCE AND THE COMMITTEE ON GRADUATE STUDIES OF STANFORD UNIVERSITY IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF DOCTOR OF PHILOSOPHY," 2010.

[45] S. Vieira, M. Benedek, J. Gero, S. Li, and G. Cascini, "Design spaces and EEG frequency band power in constrained and open design," *International Journal of Design Creativity and Innovation*, vol. 10, no. 4, pp. 193–221, 2022.

[46] S. Ackerman, "Discovering the brain," 1992.

[47] The University of Queensland Australia, "Lobes of the brain."

[48] C. Kado and E. Kames, "Exploring the Impact on Neurocognitive Process and Motivation Caused by Problem Modality," in *International Design Engineering Technical Conferences and Computers and Information in Engineering Conference*, American Society of Mechanical Engineers, 2024, p. V004T04A005.

[49] A. Kirn and L. Benson, "Quantitative assessment of student motivation to characterize differences between engineering majors," in *2013 IEEE Frontiers in Education Conference (FIE)*, 2013, pp. 69–74. doi: 10.1109/FIE.2013.6684790.

[50] P. R. Pintrich, "A manual for the use of the Motivated Strategies for Learning Questionnaire (MSLQ).," 1991.

[51] P. R. Pintrich and E. V De Groot, "Motivational and self-regulated learning components of classroom academic performance.," *J. Educ. Psychol.*, vol. 82, no. 1, p. 33, 1990.

[52] C. J. Kado and E. Kames, "Neurocognitive Examination of the Impact of Design Project Representation on Student Motivation and Performance," in *2023 ASEE Annual Conference & Exposition*, 2023.

[53] E. Kames, B. Morkos, and D. Shah, "A longitudinal study exploring motivation factors in cornerstone and capstone design courses," in *2018 ASEE Annual Conference & Exposition*, 2018.

[54] B. Belland, C. Kim, and M. Hannafin, "A Framework for Designing Scaffolds That Improve Motivation and Cognition," *Educ. Psychol.*, 2013, [Online]. Available: https://doi.org/10.1080/00461520.2013.838920

[55] W. A. Sandoval, “Developing learning theory by refining conjectures embodied in educational designs,” *Educ. Psychol.*, vol. 39, no. 4, pp. 213–223, 2004.

[56] I. Tabak, “Reconstructing context: Negotiating the tension between exogenous and endogenous educational design,” *Educ. Psychol.*, vol. 39, no. 4, pp. 225–233, 2004.

[57] S. L. Gestson, S. Brown, A. Ahmed, D. Hurwitz, F. Bornasal, and R. M. Desing, “Exploring the Differences in Hydraulic Engineering Problem-Solving Behavior between Undergraduate Students and Engineering Practitioners with Multiple Representations Using Eye-Tracking Techniques,” *Journal of Civil Engineering Education*, vol. 150, no. 1, Jan. 2024, doi: 10.1061/jceecd.eieng-1872.

[58] S. Li, N. Becattini, and G. Cascini, “Neuro-Cognitive Insights Into Engineering Design: Exploring Electroencephalography Predictive Associations With Task Performance,” *Journal of Mechanical Design*, vol. 147, no. 5, May 2025, doi: 10.1115/1.4066681.

[59] C. J. Kado and E. M. Kames, “The role of design problem presentation in shaping neural activity and learning in engineering students.,” *Proceedings of the Design Society*, vol. 5, pp. 3081–3090, Aug. 2025, doi: 10.1017/pds.2025.10322.

[60] B. Nur Guler, S. Sajadi, A. Alenezi, and D. Bairaktarova, “From Doubt to Drive: How Instructional Modality and Self-Efficacy Shape Motivation in Remedial Spatial Visualization Courses.,” *International Journal of Engineering Pedagogy*, vol. 14, no. 5, 2024.

[61] D. H. Ka, S. Motamedi, F. Ahmed, F. Tehranchi, and S. Miller, “Bridging the gap in engineering creativity evaluations: Exploring novice eye-gaze behavior across design modalities,” in *Proceedings of the Design Society*, Cambridge University Press, Aug. 2025, pp. 781–790. doi: 10.1017/pds.2025.10092.

[62] S. Vieira *et al.*, “UNDERSTANDING THE DESIGN NEUROCOGNITION OF MECHANICAL ENGINEERS WHEN DESIGNING AND PROBLEM-SOLVING,” 2019. [Online]. Available: https://www.panopto.com/