Cognitive Flexibility and Sense Making in High vs. Low Cognitive Closure Undergraduate Engineering Students

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ABSTRACT

Understanding how students persevere through uncertainty and ambiguity is critical for evolving engineering education that values creativity, adaptability, and open-ended problem solving. The Need for Cognitive Closure (NFCC), a cognitive construct reflecting an individual's desire for firm answers and discomfort with ambiguity or uncertainty, has been shown to shape reasoning patterns, decision-making, and problem-solving behaviors. This research investigates how engineering students with differing NFCC levels exhibit sense-making and cognitive flexibility while solving an engineering problem. This research is guided by one major research question: How do engineering students with low versus high need for cognitive closure demonstrate sense-making and cognitive flexibility during problem solving?

Eight engineering undergraduate students were purposively selected from a larger dataset of 103 based on their low and high NFCC scores as determined by a validated Need for Cognitive Closure questionnaire. Qualitative data collected through a think-aloud technique, intended to record reasoning processes in real-time, participants completed a structured problem-solving activity. Audio-recorded data by using think-aloud protocols were transcribed and analyzed by thematic analysis using an inductive coding approach.

Findings revealed that low NFCC students, when facing conceptual uncertainty, demonstrated more exploratory reasoning, frequent strategy shifts, and greater reflection. Conversely, high NFCC students exhibited decreased tolerance for ambiguity, early commitment to single-solution approaches, and rigid thinking tendencies. These findings shed light on how motivational disposition, like NFCC, influences reasoning flexibility and cognitive engagement through perseverance in engineering problem solving. This study contributes to expanding efforts in fostering epistemic openness and cognitive adaptation in engineering education.

Keywords: *Cognitive flexibility, sense making, problem solving, need for cognitive closure*

1. INTRODUCTION AND BACKGROUND

Engineering problem-solving is often characterized by the effects of ambiguity and/or certainty [1]. To address such ambiguity and uncertainty, researchers often argue that conceptual knowledge and its application skills are necessary [2] – [4], without accounting for the influence of personal factors that can drive motivation and cognition during problem solving. Problem-solving skills are essential in the engineering profession, where engineers routinely confront complex challenges. However, individual differences in terms of different motivational profiles and cognitive controls "that control the ways that individuals process and reason about information" [5], for example, cognitive flexibility, are most likely to interact with problem solving. According to Jonassen [6], both cognitive and affective factors internal to the problem solver influence the development of problem-solving skills. He emphasized both attributes of the problem as well as the problem solver. One such attribute is need for cognitive closure (NFCC), which reflects individuals' desire for certainty and their tolerance for ambiguity [7], [8]. Prior studies suggest that individuals with high NFCC tend to favor rapid resolution and stable solution paths, whereas individuals with low NFCC are more likely to tolerate uncertainty and explore alternative interpretations [9], [10]. These motivational differences suggest that cognitive flexibility is not uniformly enacted across learners but instead varies as a function of NFCC. As also argued by Stewin and Anderson [11], learners who exhibit greater cognitive flexibility and cognitive complexity tend to engage more effectively in problem solving, as they can consider multiple alternatives and engage in more analytical reasoning. This difference in cognitive flexibility necessarily leads to differences in how sense-making is enacted during problem solving. Schoenfeld [12] emphasizes that sense-making provides a critical foundation for examining how students interpret, evaluate, and adapt their reasoning during complex problem solving.

NFCC was initially conceptualized as a general individual difference reflecting variation in individuals' desire for certainty, commonly examined along a continuum from low to high need for closure. As the construct developed, Webster and Kruglanski [7] further conceptualized the NFCC construct into five subscales: preference for order, preference for predictability, decisiveness, discomfort with ambiguity, and closed-mindedness. These facets are closely related to how individuals tolerate uncertainty, revise interpretations, and explore alternative explanations. Empirically, Abideen [13] investigated that students with low NFCC were more likely to persist through uncertainty, revise interpretations, and engage in conceptual reasoning, whereas students with high NFCC tended to rely on procedural adherence, seek early validation, and limit exploratory reasoning during problem solving.

While these findings were interpreted through the lens of cognitive engagement, they suggest underlying differences in how students construct meaning and adapt their reasoning under uncertainty processes central to sense-making and cognitive flexibility. The present study also adopts a unidimensional low–high NFCC framework to examine how differences in closure motivation shape students' sense-making and cognitive flexibility in engineering problem solving; future research may further extend this work by investigating how specific NFCC facets differentially influence these processes. This research specifically focused on the motivational construct of Need for Cognitive Closure (NFCC) to examine the problem-solving behavior in terms of cognitive flexibility and sense-making of low or high NFCC participants.

2. PURPOSE OF STUDY

The purpose of this study is to investigate how differences in need for cognitive closure relate to engineering students' sense-making and cognitive flexibility during problem solving. Specifically, this study examines how students with low and high NFCC engage with uncertainty, revise interpretations, and construct meaning while solving an engineering problem. The following research question guides this study: RQ - How do engineering students with low versus high need for cognitive closure demonstrate sense-making and cognitive flexibility during problem solving?

3. METHODOLOGY

This study employed a sequential explanatory mixed-methods design consisting of a quantitative phase followed by a qualitative phase [16]. During the quantitative phase, participants completed a validated Need for Cognitive Closure Scale (NFCCS) questionnaire to identify low and high NFCC profiles. Based on these profiles, a subset of students was purposefully selected to engage in engineering problem-solving tasks. Qualitative data collected through a think-aloud technique, intended to record reasoning processes in real-time, participants completed a structured problem-solving activity. Audio-recorded data by using think-aloud protocols were transcribed and analyzed by thematic analysis using an inductive coding approach.

3.1. Participants and Data Collection

As this is a sequential design study, data were collected in two phases. In the first phase, quantitative data were collected from 103 engineering students through a self-administered questionnaire developed by Webster and Kruglanski [7], which was later updated and validated by Roets and Van Hiel [14]. Roets and Van Hiel operationalize NFCC across five facets: preference for order, preference for predictability, decisiveness, discomfort with ambiguity, and closed-mindedness. An aggregate NFCC score was computed by averaging responses across all items, reflecting participants' overall motivational orientation toward closure.

This composite score was used to classify participants into low and high NFCC groups for subsequent analyses. Students whose scores fell at least 0.5 standard deviations below the sample mean were categorized as low NFCC, whereas those whose scores fell at least 0.5 standard deviations above the mean were categorized as high NFCC. Participants with scores near the mean were excluded from the qualitative phase to ensure clear motivational contrasts. For the second phase, eight participants were selected through purposive sampling, four with low NFCC and four with high NFCC. Qualitative data were generated by engaging them in a problem-solving activity using a think-aloud protocol (TAP). The activity was audio-recorded and then transcribed and independently verified by two researchers to ensure transcription accuracy and reliability.

3.2. Data Analysis

Data collected from the NFCC survey questionnaire were analyzed for descriptive statistics. Based on those descriptives, the participants were classified into low and high NFCC participants. Qualitative data collected from the problem-solving activity were transcribed using the MAXQDA transcription services. The transcribed data were analyzed using inductive thematic analysis. Inductive coding was conducted following Saldaña's [19] approach through an iterative process of coding, categorizing, and theme development. Two researchers independently coded the data using MAXQDA and then collaboratively refined the codes and themes through analytic discussion. Inter-rater agreement exceeded 90%, established through a peer debriefing process [20].

4. FINDINGS

Data collected from the NFCC scale were used to classify participants into two groups: low and high need for cognitive closure groups. Two major themes were developed for each case of low and high NFCC participants to answer the research question.

Case 1: Low NFCC Participants

Two major themes representing cognitive flexibility and sense-making of low-NFCC participants were developed.

Theme 1: Iterative and Adaptive Regulation of Problem-Solving Strategies

Low NFCC participants demonstrated cognitive flexibility by regulating their problem-solving strategies iteratively through continuously revisiting prior steps and verifying analytically and conceptually. The participants remained flexible and open to revising their assumptions and recalculating values, treating problem-solving as an ongoing and evolving process. This flexibility was evident in students' engagement with redrawing circuits to test alternative interpretations of the problem. For example, one participant stated: "So then looking at, I'm going to redraw the circuit again …Looking at as T equals infinity.", showing an inclination to revisit earlier representation. Similarly, another participant mentioned, "I'm kind of realizing I may have made a wrong assumption, so I believe my analysis was correct, but it was at the wrong kind of time that I thought about so," which illustrates how uncertainty prompted further exploration rather than early closure. The participants persist in instances of uncertainty through explicit recognition of incorrect strategies, reinterpretation of computed results, and then reorientation.

Low NFCC participants also shifted between procedural and conceptual verification rather than privileging one mode exclusively. When students rely only on procedural verification of their solution, they may achieve correctness without understanding; when they rely only on conceptual reasoning, they may lack precision. The participants delayed closure until both procedural and conceptual coherence were achieved. For example, one participant said during problem solving, " We now have the current divider rule between the 18 ohm and the 20 ohm resistor…So looking at it that way, we can find that current again using Ohm's law." followed later by, " Because thinking about it also the 12 ohm resistor doesn't actually affect this current calculation because everything that goes in has to come out." This shows that the participant does not privilege the procedure as sufficient on its own. Instead, the participant uses conceptual reasoning to evaluate and validate the procedure, showing adaptive switching between modes rather than rigid reliance on calculation. Together, these patterns indicate that low NFCC students regulate their problem-solving flexibly by coordinating procedural and conceptual verification, revisiting interpretations, and tolerating uncertainty rather than seeking rapid closure**.** Cognitive flexibility in this group is therefore reflected not in the use of many strategies, but in the adaptive shifting and regulation of those strategies in response to evolving understanding.

Theme 2: Conceptual Meaning-Making Through Interpretation of System Behavior

Sense-making was evident in how low NFCC participants explained the circuit behavior during problem-solving, especially when reasoning about initial versus steady state conditions, current flow, and circuit components' roles. They demonstrated their sense-making by connecting procedures to the underlying principles. For example, participants reasoned about the circuit states by explicitly linking switch positions and time conditions to expected current behavior. (e.g., recognizing that at steady state an inductor behaves as a short, or that immediately after switching, current cannot change instantaneously). Low-NFCC participants took time to solve the problem as they started by first making sense of the problem through conceptual understanding. For example, one participant stated:

> *"My first instinct is to look at the way the circuit's going to look at each position of the switch. So right now, it's no current or voltage at any point. I feel like I should just draw out what those will be."*

The participant was engaged by looking closely at the circuit behavior before the mathematical analysis. Another participant also adopted the same approach as "Okay, so I'm going to actually redraw the circuit really quickly. just to take out the stuff that doesn't exist when there is uh…When the circuit is open." Both participants exhibited careful planning before engaging with the execution. This pattern showed deep sense-making as the participants were engaged in understanding the circuit behavior through intuition. But their intuition was supported by logic about the circuit behavior. Participants also challenged their intuition as "At t equals zero, it would theoretically have zero current... but I'm questioning whether that's actually true. Wait a second... I'm going to actually redraw the circuit really quickly.", through validation with reasoning.

As they progressed, participants were also engaged in reflection and explaining through reasoning as:

> *"Oh, I am also looking back at my last problem, and I, because of the direction of the voltage source, I just realized the I2 as its drawn in the diagram. The actual I2 is the opposite direction of that. So my final or my answer. That section is now negative."*

This exploration with conceptual understanding kept the low-NFCC participants engaged. Similarly, another participant also stated the same trend as: "It should be, I mean, zero plus for an inductor. That current should be like super small. Almost a zero, honestly, because it hasn't gone up to steady state.", explaining the behavior of the circuit conceptually. Besides conceptual, participants were equally engaged in analytical reasoning during the problem-solving activity for sense-making. The analytical reasoning included calculating resistances, using formulas, and breaking down complex parts into simpler ones. For example:

> *"I am just calculating the resistance. Yeah, it's just 10 and 18 in parallel and then in series with a 20 and a 12 ohm resistor. Because I have two resistors in parallel, I'm going to use the current divider rule to solve for I2."*

But this is not just the case; some participants were also engaged superficially and made sense through procedural reasoning only. They continued to rely on procedural steps despite recognizing uncertainty. Hence, low-NFCC participants demonstrated sense-making during problem-solving using both conceptual and analytical reasoning and sometimes only analytical reasoning.

Case 2: High NFCC Participants

Two major themes representing cognitive flexibility and sense-making of high-NFCC participants were developed.

Theme 1: Early Exploration Followed by Quick Cognitive Closure

High NFCC participants exhibited an initial moment of constructive engagement, followed by a rapid narrowing of cognitive flexibility as they became stuck in complexity. They initially attempted to engage by making logical connections, but failed to sustain the effort when immediate clarity was not achieved. Across participants, early flexibility was visible in initial setup and interpretation. For example, participants frequently began by reasoning about steady-state behavior and time conditions (*"We're at position one for a long time, so that means there was a steady-state response"*), or by redrawing circuits to simplify analysis (*"I'm going to redraw the circuit so that it's simpler for me to understand"*). These moments indicate early engagement with multiple representations and conditions.

However, as they progressed, cognitive flexibility narrowed. Their eagerness towards closure without embracing the ambiguity, coupled with frequent shifts in strategies without understanding, resulted in an incorrect solution. Participants relied on surface-level strategies for navigating the uncertainty, for example trial and error methods as mentioned below:

> *"And so I'm just going to test it and plug that in to my calculator to remember which One. I'm supposed to use. Whether it's one minus e to the negative t over, tau over or just e to the negative t over tau Okay. And then trying the other way."*

The participant above demonstrated a procedural-level cognitive flexibility by switching between alternative methods to resolve uncertainty. This shows flexibility within a procedure, not across representations or conceptual interpretations. Instead of freezing immediately, the participant relied on testing alternatives, indicating short-term flexibility for problem-solving. But this cognitive flexibility does not lead to exploration or meaning building. Even when the participant acknowledged uncertainty, these moments rarely led to a shift towards adaptive strategies. This behavior is evident in the excerpt below:

> *"I'm just going to call that exactly the same as what I2 is after a long time in position one… Which is 50 amps… I imagine it would be what it had been previously… Let's call those my answers, maybe I don't know if it's right, but…"*

This reflects the avoidance of assigning some previously calculated values without any calculation. Uncertainty was often followed by procedural continuation, assumption making, or a sudden move towards closure rather than conceptual framing or iterative revision. This limited cognitive flexibility was also evident in the bounded exploration with procedural adherence. The procedural adherence in terms of plug-and-play strategies keeps them from considering alternative strategies. These findings indicate that high NFCC participants demonstrated limited cognitive flexibility over time, with a commitment to alternative surface-level procedural strategies with a strong orientation towards closure. Their cognitive flexibility diminished over time as problem-solving shifted from exploration to closure-oriented convergence.

Theme 2: Sense-Making as Uncertainty Control Rather Than Meaning Expansion

High NFCC participants demonstrated short-term sense-making, shifting from conceptual to surface-level procedures, focusing on closure and confidence as problem-solving progressed. Early in problem-solving, participants articulated a conceptual interpretation of system behavior and made sense of underlying principles without just applying formulas mechanically. For example:

> *"We're at position one for a long time…So that means there was a steady state response or like a steady state our inductors are at steady state. So, it was basically a short circuit….So once it's reached steady state conditions. So first I will look at what would have been happening if it's been at steady state in position one. Which means… that the inductor will be behaving as a short circuit."*

The participant was making sense of the problem by explaining that in a steady state, an inductor behaves like a short circuit, so the inductor was replaced with a straight line. Similarly, another participant also showed conceptual understanding as, "So first I'll solve for i2. Before it is switched when it's at one to see what the kernel be like. Soon after it has switched, which means I can ignore the branch that has the 140 volts". A consistent pattern emerged across the excerpts, with both participants engaging in conceptual reasoning to determine which components of the circuit could be disregarded when finding the current at $t = 0^{+}$or $t = \infty$.

Later phases of the problem were characterized by surface-level validation of the results, focused more on conceptual correctness through analytical reasoning. They used analytical reasoning as the main phenomenon for sense-making. They were actively engaged in using known procedures like formulas without any novel interpretation. They started paying more attention to procedural recall, lacking the sense-making, as evident from the excerpt, "I guess. There's no current going through the resistor anymore. It's a 10 ohm resistor and let's see what else can I say?". The absence of conceptual connections decreases the participants' confidence. As evident in the below excerpt:

> *"Maybe I'm feeling a little bit less confident than I was when I first looked at the problem. But we're going to keep going.. So maybe while I'm looking at this problem, there are a couple of things maybe that I didn't think about…."*

This reflects sense-making among high NFCC participants as a form of reflective monitoring, where awareness of reduced confidence and potential oversights serves to regulate uncertainty and sustain task progression rather than to prompt deeper conceptual restructuring. Taken together, these patterns indicate that sense-making among high NFCC participants is primarily instrumental and closure-oriented, functioning to manage uncertainty and confirm solution adequacy rather than to sustain conceptual exploration**.** Once a viable solution path was established, sense-making shifted toward maintaining confidence and progressing to completion.

5. DISCUSSION AND CONCLUSION

This study examined how students with differing need for cognitive closure (NFCC) profiles engaged in cognitive flexibility and sense-making during engineering problem solving. The findings reveal a meaningful difference between low NFCC and high NFCC participants. Low NFCC participants exhibited a sustained cognitive flexibility by revisiting their prior steps and verifying them conceptually. Importantly, analytical verification and conceptual reasoning were coordinated rather than hierarchically ordered; procedures were used to probe understanding, and conceptual reasoning was used to evaluate whether procedural outcomes made sense. In contrast, high NFCC participants exhibited high cognitive flexibility in the early phases of problem-solving activity, followed by rapid narrowing closure. As a viable solution path was identified, cognitive flexibility faded out. Even when uncertainty arose, they managed it by making assumptions, testing different procedures, and verifying answers without relying on conceptual framing. These patterns align closely with the theoretical profiles of the NFCC [9], [10] and the argument made by Stewin and Anderson [11], [13], that the learner who exhibits greater cognitive flexibility engages with more strategies of problem solving and analytical reasoning.

An important observation here is that cognitive flexibility is not absent in high NFCC students, but is constrained in scope and duration, often confined to narrow procedural decisions rather than broad strategy revision. Spiro et al. [15] argue that cognitive flexibility involves situation-dependent schema assembly rather than retrieval of rigid, prepackaged schemas, which aligns with the sustained strategy revision observed among low NFCC participants but contrasts with the rapid convergence exhibited by high NFCC participants. In terms of sense-making, the differences among participants with different NFCC profiles were also pronounced. For low-NFCC participants, sense-making was meaning-driven, emphasizing the conceptual explanation of the system behavior. The procedures they were applying were integrated with underlying principles. The sense-making of high NFCC participants was more procedural and oriented toward quick closure. They articulated conceptual reasoning initially, but as they progressed and got into the complexity of the problem, their sense-making shifted towards procedural level testing and confirmation of the correctness. The overall analysis has shown how cognitive controls like sense-making and cognitive flexibility interact with problem-solving and differ across participants with different motivational profiles. This aligns with the prior research that motivation interacts with cognitive controls [17], [18]. This research informs instructors on how to modify their instructional strategies to address individuals with diverse cognitive and motivational profiles, thereby improving the learning environment for understanding difficult concepts. This Understanding enables targeted interventions tailored to the needs of engineering students and enhances student engagement and learning outcomes. The findings of this research suggest that instructional design should balance structure and ambiguity to support students with differing closure needs.

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