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Exploring the Impact of Formative Assessment on Cognitive Engagement in Problem-Solving Tasks: The Role of Need for Cognitive Closure

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Abstract

This study is a theory or methods full paper that examines formative assessment, which is characterized by continuous feedback opportunities, chances for self-reflection, and ways to improve, and has been widely recognized as an instructional strategy to promote improvement in learning outcomes. However, limited research is available on how undergraduate students' motivational and cognitive dispositions, such as (high/low) Need for Cognitive Closure, may moderate the effectiveness of formative assessment in a higher education context. This study explores the effect of formative assessment on the cognitive engagement of undergraduate students, with a specific focus on how varying levels of Need for Cognitive Closure (NFCC) influence this relationship. As a part of a larger study, we used a sequential mixed-method design with a participant selection model followed by quantification of qualitative code for data analysis. The research design involved quantitative analysis of approximately 67 first-year undergraduate engineering students, while qualitative analysis was conducted on a subset of 8 students, selected according to predetermined criteria. Each student participant solved two equally difficult engineering mechanics static problems in two separate audio-recorded sessions. During problem-solving, the participants practiced the think-aloud protocol (TAP), verbalizing their thoughts and reasoning processes to capture their cognitive engagement and problem-solving strategies. The first task was conducted without the use of formative assessment, relying solely on the students' prior knowledge and individual problem-solving abilities. In contrast, the second problem-solving task incorporated formative assessment techniques to provide feedback and guide student learning throughout the process.

Narrative analysis and quantification of qualitative data analysis results indicate that formative assessment promotes cognitive engagement in students, which is reflected through encouraging reflection, strategic thinking, and a greater commitment throughout the process. However, the level of cognitive engagement related to formative assessment depends on the level of Need for Cognitive Closure (NFCC). Students with low Need for Cognitive Closure (NFCC) generally exhibit higher cognitive engagement and greater persistence when receiving feedback during problem-solving tasks, as they are more comfortable with ambiguity and reflective thinking. In contrast, students with high NFCC prefer quick and certain feedback and show lower engagement with feedback that requires extended reflection. Understanding these differences can help in designing formative assessments that effectively support diverse student engagement styles. The implications of this are that formative assessment should be adjusted with the learner profile in mind, to help students gradually require greater comfort in coping with either uncertainty or reflection. Overall, the study highlights that assessment needs to be designed in accordance with students' cognitive and motivational characteristics to develop deeper and greater learning engagement in higher education.

Keywords: Formative Assessment, Cognitive Engagement, Need for Cognitive Closure (NFCC), Engineering Education, Mixed-Method Study, Think-Aloud Protocol, ICAP

Introduction and Literature Review

Assessment in education is a process of evaluating and measuring student learning, primarily through standardized tests or classroom assignments. These assessments serve different purposes, typically categorized as assessment of learning [1]. The purpose of assessment varies based on its type, as assessment of learning, often standardized, aims to measure student knowledge and provide accountability by checking if learning standards are met [2]. This type of assessment is called a summative assessment, an approach focused on measuring what students have learned at a specific point, normally at the end of the learning period, by utilizing standardized tests [3,4]. However, the formative assessment for learning has a different purpose; it's intended to support and enhance the learning process. Through regular feedback and self-assessment, this type of assessment aims to help students feel confident, engaged, and motivated in their learning journey [5]. Formative assessment is an approach that supports the learning process. It involves providing continuous feedback that helps students to evaluate their progress, identify areas for improvement, and experience the benefits of testing without the accompanying anxiety [6]. Formative assessment aims to enhance learning by cognitively involving students, fostering confidence, and encouraging academic growth [7]. According to Shute (2008), formative assessment potentially facilitates students' cognitive engagement by encouraging active control over their learning through self-assessment, monitoring, and modifying strategies to enhance their learning [8].

Cognitive engagement is a crucial element of learning, where learning tasks can consist of easy or difficult problem-solving activities, and students overcome their uncertainties by utilizing diverse cognitive strategies [9]. Cognitive engagement pertains to the mental effort and persistence exhibited by students when facing difficult tasks that require a high level of cognitive ability to solve a problem [10]. The formative assessment can amplify cognitive engagement, subsequent metacognitive awareness, and reflection of students when they receive feedback focused on specific learning goals [11], especially when problem-solving tasks are aligned with their cognitive closure levels [12]. Formative assessment plays an important role in cognitive engagement during problem-solving activities, and consequently, developing thinking skills necessary for solving difficult technical problems, which is especially true of engineering and STEM fields [13]. Difficult problem-solving tasks require students to manage uncertainty, integrate knowledge from various domains, and persist through multiple feedback and revision cycles. The formative assessment supports students in solving difficult problems by providing timely feedback, developing self-regulation, and improving their engagement [14]. However, timely feedback should be aligned with the NFCC level of students to maximize the benefits of formative assessment practices [15]. Formative assessment plays a significant role in fostering cognitive engagement among students with different NFCC levels because it enables students to adjust their learning strategies by providing continuous feedback [8, 13, 16]. The need for cognitive closure is a psychological concept that describes an individual’s urge to reach a firm and definite answer as quickly as possible, reflecting both a dislike of ambiguity and an aversion to prolonged uncertainty. It explains their strategy to process incomplete information and decision-making, which often focuses on a quick conclusion rather than exploring all possibilities [17,18]. The need for cognitive closure (NFCC) is the individual's preference to overcome uncertainty by reaching definitive conclusions when making decisions, so as a motivational variable, NFCC may affect different cognitive and social processes, such as the process of forming judgments, decision-making, and interpersonal collaboration [19]. NFCC is a continuum-based variable, where individuals fall between poles of high need for closure and low need for closure. Rather than strictly unipolar or neatly falling into “high” or “low” categories, NFCC indicates how the desire for cognitive closure of an individual can vary, depending on the context and the demands of the situation [20]. Since NFCC is not a binary characteristic but individuals' NFCC may vary along a continuum between high and low levels. Student were grouped into high and low NFCC levels based on where they lie on that continuum for better comparison and interpretation of results. [21]. Descriptive statistics and method of distribution have been included to demonstrate that the grouping does not misrepresent the statistical interpretation of the data [44].

High NFCC has two main characteristics, urgency and permanence [22]. Urgency refers to the need for an immediate answer and entails situations wherein the individual seeks early closure and may lead to hasty decisions, even if that information would yield a sub-optimal solution. As for permanence, it refers to an unchanging form of knowledge whereby individuals who have a high need for cognitive closure would prefer answers that will give permanent closure and are less likely to be revisited or remain resistant to new information that might challenge or disrupt that sense of certainty [22]. Together, these tendencies help to explain why high-NFCC individuals often make swift, firm decisions and resist changes to their established views. The individuals with low NFCC show greater comfort with ambiguity, uncertainty, and fluidity in decision-making processes. As a result, they tend to entertain more open-ended thoughts, consider multiple perspectives, and reflect before concluding [23], such individuals prefer flexible and dynamic environments (that are less prone to fixed patterns of thought) where knowledge is not static but can evolve [24]. NFCC is not a deterministic behavior in every situation, as the context plays a significant role in shaping actions. In other words, an individual with a low need for closure may behave or think differently under time pressure, such as a tight deadline versus too much time left for deliberation. Likewise, High NFCC individuals still seek closure when the stakes are high or in a high-risk situation [25]. These subtle differences highlight the importance of the situational context in understanding how NFCC can influence cognitive engagement and decision-making processes. The NFCC is usually measured using the Need for Closure Scales (NFCS), which assesses the individual's tendency to seek cognitive closure and their capacity to handle ambiguity, especially when faced with competing or evolving explanations [17, 26]. These scales gauge how strongly individuals prefer clear, decisive answers over uncertain or complex information, as well as their resilience against ambiguity in processing new or conflicting information [27]. For example, typical items on NFCS could evaluate how much one prefers order and structure, whether one feels comfortable or distressed about ambiguity, and how quickly one would be willing to formulate a judgment [28].

Purpose of The Study and Research Question

Formative assessment enhances learning through continuous feedback and reflection, allowing students to engage actively with the learning material [29]. However, the actual effectiveness of the formative assessment practices may be influenced by differences in students' NFCC levels [18]. The purpose of this research is to delve into the intricate association between formative assessment and cognitive engagement among undergraduate engineering students who have different levels (high or low) of Need for Cognitive Closure (NFCC). The following research questions inform the study about each factor to facilitate the development of a fully articulated exploration. The following research questions inform the study about each factor to facilitate the development of a fully articulated exploration. (RQ1) *How do different levels of Need for Cognitive Closure (NFCC) moderate the relationship between formative assessment and* *cognitive engagement among undergraduate engineering students?* (RQ2) *How does formative assessment influence cognitive engagement among undergraduate engineering students?*

Research Method

This research employs a sequential mixed-methods design with a participant selection model [30,31], followed by the quantification of qualitative codes [32]; both quantitative and qualitative data are utilized to understand how formative assessment affects cognitive engagement among undergraduate engineering students with varying levels (high & low) of need for cognitive closure (NFCC). These combined approaches enable deeper insights into the research questions. Furthermore, in this research design, the initial quantitative phase identifies patterns or variables of interest, which then guide the purposeful sampling strategy [33] for the qualitative phase [34,35]. The collected qualitative data is used for narrative analysis, coding, and quantification that enables the interpretation of qualitative data through the coding process, thus ensuring reliability of integration between two forms of data: similarities and differences across each case [36, 37]. Four graduate engineering education researchers with experience in qualitative analysis independently coded the data, achieving 100% agreement to ensure consistency and trustworthiness. All coders had formal training in qualitative research methods and prior experience applying structured coding frameworks in engineering education contexts. While they were familiar with the ICAP framework and formative assessment literature, they engaged in reflexive discussions throughout the coding process to minimize potential bias and ensure analytic rigor.

Quantitative & Qualitative Data Collection and Instrument

To collect quantitative data for the study, the Need for Cognitive Closure Scale (NFCS) Survey was administered via Qualtrics (a secure online survey platform). A public (Qualtrics) survey link was provided to undergraduate engineering students at a public land-grant research university in the western part of the United States. The survey was accompanied by a detailed description of the study that included the purpose, procedure, and voluntary participation. Students were informed that the study had received Institutional Review Board (IRB) approval, as well as provided with assurances of privacy and anonymity of their data. The Need for Closure Scale (NFCS) survey uses a 6-point Likert scale, with options ranging from "Strongly Disagree" to "Strongly Agree." [38]. This survey has proven reliable and validated by Webster and Kruglanski [17] in 1994 and revised by Pierro and Kruglanski [39] in 2005, showing strong internal consistency and the ability to distinguish between groups expected to differ in NFCC levels. The qualitative phase of the study included three instruments: the think-aloud protocol, formative assessment, and problem-solving tasks. These tools were designed to capture students' real-time cognitive engagement while solving course-related problems and to examine the impact of formative feedback on their reasoning processes. The problem-solving tasks in this study were designed in collaboration with a senior course instructor to match the key concepts in the Engineering Mathematics course (Appendix A). Both problems with equal difficulty level were designed to maintain consistency among participants and allow for meaningful comparison of cognitive engagement. Each participant solved both problems individually in two separate audio-recorded sessions on the same day. During the problem-solving tasks, participants practiced the think-aloud protocol (TAP), and the session was audio-recorded. The first problem-solving task is presented without formative assessment, requiring students to work independently. However, the second problem-solving task is incorporated with formative assessment with feedback. During the second problem-solving task, participants first read the problem statement and then completed a formative assessment activity designed to develop their initial understanding. After completing the formative assessment, participants received specific feedback on their responses. After examining their feedback and reflecting on it, participants attempted to solve the second problem.

Data Analysis

In the quantitative data collection phase, to calculate each participant's NFCC score, the responses to all questions were summed to generate a total score representing their overall level of need for closure. These scores were then used to categorize participants into high and low NFCS groups for further comparison. Once these NFCC scores were computed, all participants were ordered and ranked based on their NFCC score in ascending order. To group participants into high NFCC and low NFCC subgroups, the NFCC scores, along with their mean and standard deviation (SD), were utilized as a statistical cutoff point [40]. The participants with NFCC scores above one SD above the mean score (Mean + SD), were classified in the high NFCC group [41, 42], than individuals in the low NFCC group which were represented by participants with NFCC scores below one SD from the mean (Mean – SD) [18], Using this descriptive analysis, we select a subset of eight students for the qualitative part of the research (4 high and 4 low NFCC participants).

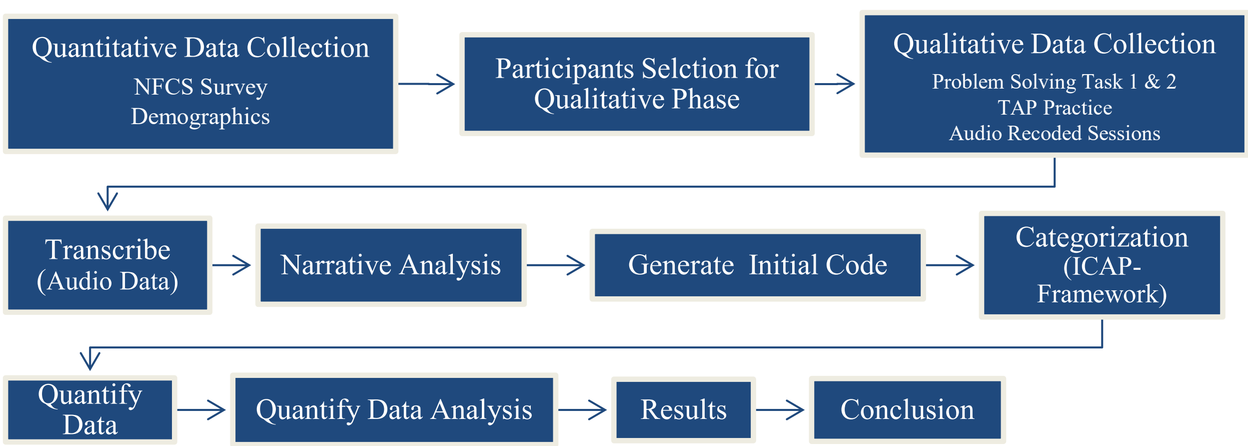

Figure 1: Procedural Flow of the Research Method

The qualitative data analysis for this study was conducted through a systematic, multi-phase process designed to ensure rigor, consistency, and meaningful interpretation of student cognitive engagement during engineering problem-solving tasks. The analysis integrated narrative methods, structured coding, and quantitative techniques to provide a comprehensive understanding of how formative assessment influenced students' engagement patterns. Both problem-solving sessions were audio recorded, and the recordings were transcribed using Trint transcription software to generate accurate textual data for analysis. These transcripts served as the foundation for the qualitative analysis. The first analytical phase employed Narrative Analysis, guided by the framework proposed by Labov and Waletzky in 1997 [43] . This framework was selected for its ability to capture the structure and meaning of participants' verbalized reasoning as coherent narratives. Narrative analysis allowed the researcher to examine how students' thinking unfolded over time and how their reasoning transitioned across different stages of problem solving. Specifically, the framework's six elements (Abstract, Orientation, Complicating Action, Evaluation, Resolution, and Coda) were applied to identify key moments in students' cognitive engagement. The next phase focused on coding for cognitive engagement, structured around the ICAP framework [9]. In this study, only Passive, Active, and Constructive engagement were analyzed, as students completed the tasks individually without peer or instructor interaction, rendering the Interactive mode inapplicable. Each transcript was segmented line by line into discrete thought units, and each unit was coded according to the ICAP categories (Appendix B). To complement the qualitative analysis, the coded data were quantified by calculating the frequency of each engagement mode for every participant and problem. By combining narrative analysis, structured coding, and quantitative measures, the analysis provided a robust and nuanced understanding of how and why formative assessment affects student cognitive engagement in engineering education contexts.

Results and Discussion

In examining how cognitive engagement unfolded across two problem-solving tasks before and after formative assessment, a clear pattern emerged that aligned closely with participants' levels of Need for Cognitive Closure (NFCC). While all participants showed some degree of engagement during the first task, the nature, depth, and trajectory of that engagement differed meaningfully between the two groups. Notably, the introduction of formative assessment acted as a pivotal turning point but its impact was shaped by each learner's underlying disposition toward ambiguity, structure, and closure. When students first faced the problem without any feedback, their thinking revealed more than just a strategy; it showed how they cope with uncertainty. Those with high Need for Cognitive Closure (NFCC) moved slowly at first. They double-checked instructions. They searched for certainty before diving in, for example high NFCC participant said "*Let me make sure I haven't missed anything….",* Another participant admitted, "*I'm not quite sure how to solve this. In the multiple-choice that I just did, it said to use graphical methods, but I'm quite sure what those are. I'm thinking if I could use triangles*". Their discomfort with open-ended tasks was clear. They weren't disengaged, just waiting for a signal that it was safe to proceed. Many re-read the problem repeatedly, comparing examples, seeking structure. Other participants expressed as, "*my mind hints are to identify what is given, what needs to be found, what theories I think I need for this, the important data and decide what formulas, theorems and problem-solving strategies apply*" and *"So I have OK. Hold on. I need to add my axis to this free body understanding diagram that's gonna help"* This reliance on step-by-step frameworks reflected a deep need for clarity. Without it, reasoning stayed shallow.

After receiving the formative assessment during the second problem-solving task, the passive and active engagement significantly reduced, and constructive engagement increased. It seemed that formative assessment empowered the High-NFCC participants to engage with greater depth and precision. *"So yeah yeah, the quiz definitely was helpful, I didn't solve the equations of sines and cosines graphically like the quiz said that I should or recommended, I suppose. So that would have been helpful to do".* Another participant try to simplify the problem before solving the question and expressed as *"I have some value that my cosine and sine theta are equal to And cosine theta, if I move back to just the sum of forces, I'll be able to determine what my D sub X force is supposed to be and that will be able to solve the cosine theta…"* this expression sheds light on a valuable perspective on how deep learning can shape the problem-solving strategy, and formative assessment always aims to understand concepts deeply. It also highlighted the importance of timely feedback in supporting meaningful engagement, particularly for learners who have high NFCC.

Low NFCC participants began the first problem-solving task with limited passive engagement, which indicated that there was a small degree of careful hesitation, possibly to think through the question or to plan an action. Participants expressed it as "*And that means since the weight pulling down isn't in the X direction, that just be horizontal components of each tension, lets read and understand question again.*" After a while, the engagement shifted to active mode and continued to develop in an increasingly constructive manner of engagement. They start identifying relevant variables, connecting with prior knowledge relevant to the topic, and explaining the rationale for each step. *"OK, so for this question, after I made the free body diagram, I noticed I had two unknowns and so I knew I couldn't just get that from one equation, but I knew that since it's a statics problem, all the forces in any direction are going to add up and equal to 0."* After receiving a formative assessment during the second problem-solving task, Low NFCC participants showed even stronger constructive engagement. The formative assessment appeared to aid deeper understanding to clarify previous strategies and to help elicit more accurate and conceptually driven responses. *" I think it's saying this angle right there is 60°, which would mean that the vertical component in this case is I think the cosine because the vertical one is adjacent to the force vector."* Low NFCC participants exhibits an engagement pattern that illustrates how individuals with a low NFCC, together with high academic ability, can work to support cognitive flexibility in thinking and applying knowledge.

The comparative analysis of participants' quantified qualitative data during problem-solving tasks (pre and post formative assessment) also aligned with the narrative analysis. This quantitative approach complements the earlier qualitative insights and explicitly clarifies which participants' characteristics (i.e., NFCC level) are associated with greater gains in constructive engagement. The high NFCC group demonstrated a constructive mode for 57.38% of their engagement. The low NFCC group demonstrated slightly less constructive engagement at 53.23%. The difference is 4.16%, with high NFCC participants taking the lead (Figure 2). Individuals with a high need for cognitive closure prefer structure and clarity; they probably pushed themselves harder to both understand and construct knowledge and further increase their clarity and independence, since with no feedback or support, they were essentially on their own. Active engagement involves doing something physically or mentally with the content, like underlining or repeating steps in a process or orienting the information in some way, but not creating new knowledge. The low NFCC group demonstrated 37.10% active engagement, and the high NFCC group demonstrated 28.69% active engagement, as shown in Figure 2.

The difference of 8.40% between active engagement of high and low NFCC group participants indicates that low NFCC participants were more active than high NFCC participants, with the negative sign showing higher engagement for the low group. However, this increased activity may reflect surface-level participation rather than deeper cognitive processing, suggesting that low NFCC participants focused more on frequency of actions than High NFCC participants and suggesting that the low NFCC participants may have engaged in the task at a surface or low level, rather than deeply questioning the information. The high NFCC group demonstrated 13.92% passive Engagement while the low NFCC group recorded a similar, yet slightly lower, rate at 9.68%. The difference between those two groups was 4.25%, with high NFCC students showing more passive behavior. Initially, this may seem incongruent; it is important to reconcile why the same group had greater constructive engagement and also had higher passive behavior as well. A possible reason is that high NFCC participants may have taken moments to pause and absorb information before making decisions (Chen et al., 2024). When the formative assessment was provided during the problem-solving activity, the two groups (high NFCC and low NFCC) reacted in distinctly different ways. The low NFCC participants engaged more constructively than did the high NFCC group. The low NFCC's average constructive engagement was 83.33%, while the high NFCC's was 75.03%, with a gap of 8.30%. At first glance, the results may be surprising, but based on the nature of high NFCC participants, perhaps formative assessment provided them with the structure they typically require, guiding their thinking and giving them the ability to take feedback to enhance their understanding. The structure of the feedback made them feel more confident, resulting in deeper thinking and reflection. The low NFCC participants tend to be organized in their thinking, so the same feedback significantly changed their cognitive engagement level.

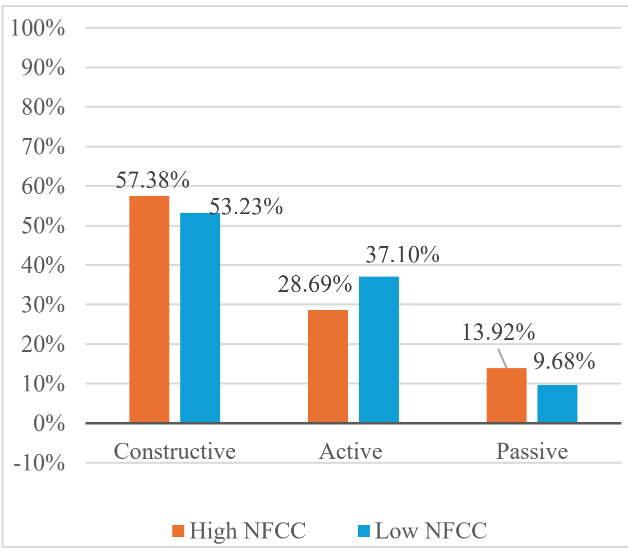

Figure 1: Pre-Formative Assessment, Cognitive Engagement Profiles Across NFCC levels (High Vs Low)

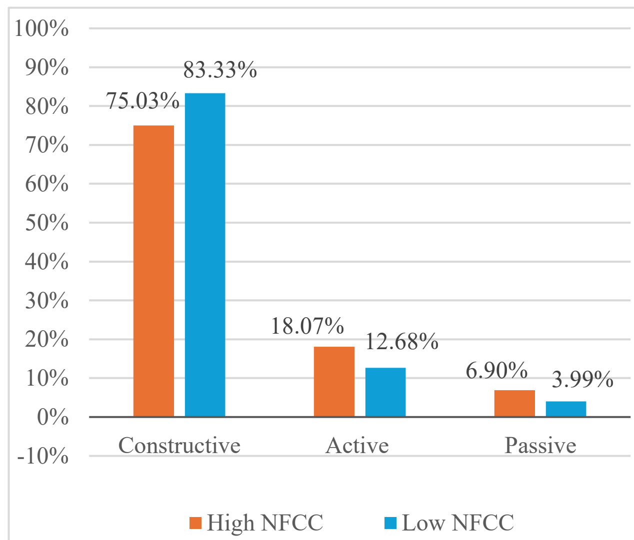

Figure 2: Post-Formative Assessment, Cognitive Engagement Profiles Across NFCC levels (High Vs Low)

The high NFCC group had 18.07% active engagement; however, the low NFCC group was only at 12.68%, which is a difference of 5.39% (Figure 3). This difference implies that high NFCC participants may have engaged in more superficial behaviors, given the internal structure, high NFCC participants made sense of the feedback and used it to confirm their existing plan or approach, rather than rethink or reconstruct it. Conversely, the low NFCC group spent more mental time trying to apply the feedback provided to not only remain active, but also constructively think about, or "become", more than just active. On passive engagement, the high NFCC group remained engaged at 6.90 %, while the low NFCC group was 3.99% engaged; the difference between the passive engagement of both groups is 2.91%, which indicates that high NFCC participants may have occasionally received information without responding actively or constructively. On the other hand, low NFCC students may have felt the need to actively engage more, and with that came less time spent as passive and less engagement in this way. The most noticeable improvement in constructive engagement was seen in participants with high NFCC. After the formative assessment, their constructive engagement increased from 57.38% (Figure 2) to 75.03% (Figure 3). This increase indicates that even students who process problems in a more structured way gain an advantage from formative assessment. Simultaneously, their active engagement dropped from 28.69% during the pre-formative assessment to 18.07% in the post-formative assessment; a change of 10.62%. When feedback was provided, these students were able to engage cognitively, instead of getting caught up in trial-and-error, surface-level engagement strategies. Their passive engagement, like active engagement, also dropped from 13.92% to 6.90%; a reduction of 7.02%. From a concept of formative assessment, this indicates that these learners took ownership and took more cognitive initiative, spending less time simply observing or rereading without further engaging, without taking any action. Reviewing the participants with low NFCC results demonstrated more pronounced changes among greater constructive engagement with the formative assessment. Constructive engagement went from 53.23% to 83.33%; an increase of 30.10% (Figure 4). This significant increase indicates that the formative assessment helped to provide structure, reducing any uncertainty they may have had, allowing them to turn their attention to organizing embedded thoughts cognitively. The low NFCC value group had a large decrease in active engagement, going from 37.10% to 12.68%. Overall, these reductions highlight the purpose of formative assessment: it encouraged students to remain meaningfully engaged while decreasing low-level or surface engagement, such as passively observing, rereading, or performing tasks without deep processing.

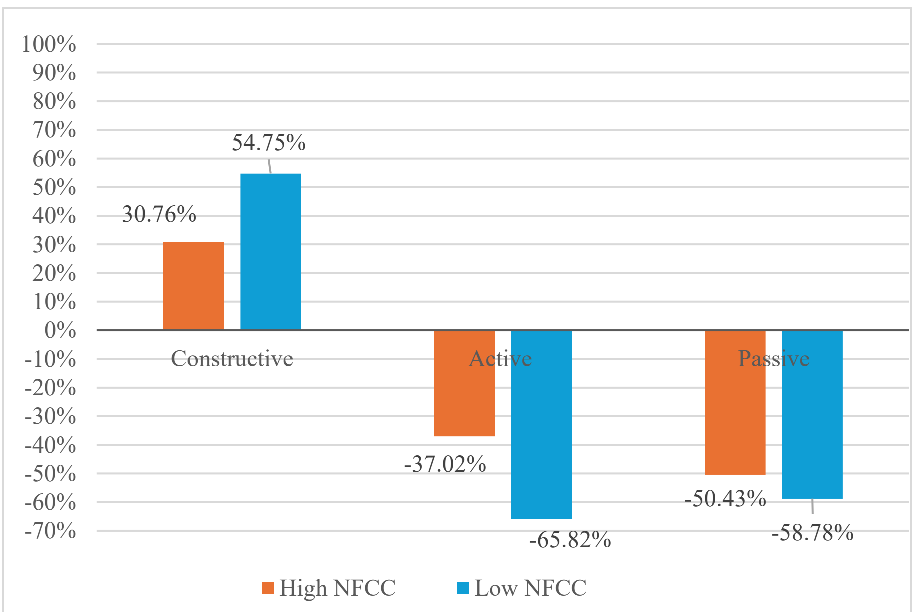

Figure 4: Percentage Change in Cognitive Engagement Modes After Formative Assessment Intervention

When looking at the *percentage change* for active engagement, the high NFCC group decreased by 37.02%, while the low NFCC group showed a higher decline at 65.82%. Meaning that both groups, after support from the guidance, tended to use fewer surface-level strategies, such as repeating the steps they had already organized, but did not think critically about them. Both groups also showed decreased decreases in passive engagement. Specifically, there was a 50.43% decline in passive engagement with the high NFCC participants and a reduction of 58.78% in passive engagement for the low NFCC group. Meaning that students were more engaged in the task, they spent less time merely observing or reading the task without acting on the task. Cohen’s effect size analysis provides further understanding of how formative assessment affected students' engagement at all NFCC levels. With constructive engagement, the low NFCC participants had a medium positive effect size of 0.65 from formative feedback to increased access to deeper cognitive engagement. High NFCC participants had a small increase in constructive engagement of 0.38, suggesting that formative assessment enhanced the activities for both groups of students; however, the improvement was greater for the low NFCC students. With active engagement, the analysis showed a negative effect size for both groups. The high NFCC group had a small effect size of -0.25, while the low NFCC group to an even greater extent had medium negative effect size of -0.58. This suggests that the low NFCC and high NFCC students moved away from surface-level engagement after receiving the feedback. Likewise, the passive engagement decreased in both groups, with a small effect size of -0.23. Consequently, the formative assessment did deliver a change in students toward a more meaningful, constructive engagement.

Conclusion

The research results highlight that formative assessment is a powerful tool to shape the students' engagement, especially when it is tailored according to the students' cognitive engagement profile. Beyond institutional implications, the outcomes of this study suggest that educators should develop flexible formative assessments that recognize student diversity in terms of learning needs. These findings indicate that formative assessment had a significant and positive influence on students' cognitive engagement. For both the high and low NFCC groups, students' constructive engagement increased while active and passive engagement declined. In the high NFCC group, there was a 30.76% increase in constructive engagement, which indicated that these students engaged in deeper thinking and building their understanding of the problem. In the low NFCC group, the increase in constructive engagement was even higher at 54.75%, suggesting that the feedback helped students organize their thoughts, which likely encouraged deeper critical engagement. Furthermore, the differences between high and low NFCC groups were significant concerning students' engagement with problem-solving activities. Participants with high NFCC tend to approach tasks with a more structured mindset in general. They showed a tendency to think deeply and systematically organize their responses when they were working in the absence of feedback. Overall, formative assessment was important to engage all participants in deeper learning. The trajectory, or pace of that change, depended primarily on their cognitive orientation in a set of learning circumstances. These results suggest that formative assessment can be further optimized by tailoring it to students' NFCC profiles. For high-NFCC students, emphasizing self-directed, structured problem-solving may strengthen deep engagement, whereas low-NFCC students benefit most from timely, guided feedback that promotes flexible thinking. Future research could investigate how different feedback types, timing, and scaffolding strategies influence engagement and learning outcomes across NFCC levels, as well as explore long-term retention and transfer in STEM learning contexts.

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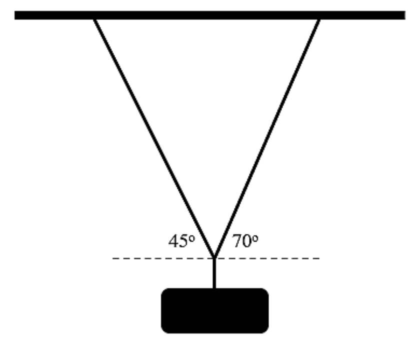
Appendix A

Selected Problems for Qualitative Data Collection

Problem 1 (Without Formative Assessment)

A 30 kN weight object is suspended by two cables

1) Create a Free-Body Diagram
2) Find Tension in each cable



Problem 2 (With Formative Assessment)

Given force at

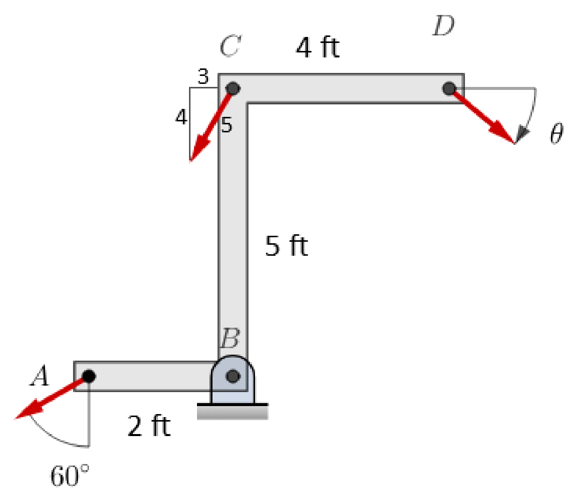
A= 250 lbs

C= 40 lbs

D= 125 lbs

and pin connection at B

Find the angle θ that will keep the bar from rotating.



Appendix B (Code Book) [9]

Mode	Definition	Rules
Interactive (I)	Interactive engagement occurs when a student engages in collaborative dialogue with a peer or tutor, where both parties contribute new ideas and build on each other's thinking beyond the given material.	Dialogue with a partner (peer/tutor)
		Both contribute new ideas
		Goes beyond given material
		Cannot occur alone unless dialogue is simulated
Constructive (C)	Constructive engagement involves generating new knowledge by going beyond what is provided. This includes self-explaining, making inferences, reflecting on strategies, or drawing connections to prior knowledge.	Self-explaining their reasoning (e.g., verbalizing why a step is needed).
		Self-questioning (e.g., verbalizing why a step is needed with or without reasoning).
		Making inferences beyond what is given (e.g., recognizing patterns, generalizing rules).
		Changing the method involves re-evaluating the current strategy, reflecting on the problem, considering alternative approaches, and generating a new path forward (e.g., recognizing patterns, generalizing rules).
		Drawing connections to previous knowledge (e.g., relating the problem to prior math concepts).
		Checking their understanding by explaining it in their own words.
Active (A)	Engaging with the material through actions, such as underlining, highlighting, repeating, or copying information.	Copying the problem statement or solution steps without modification.
		Rewriting the given equations without interpreting them.
		Underlining or highlighting key parts of the question without explaining them.
		Repeating formulas or calculations without justifying them.
Passive (P)	Passive engagement occurs when a student receives information without any observable action or response, such as simply reading, watching, or listening without	Reading the problem statement without doing anything else.
		Looking at a worked-out solution without making notes or attempting to solve the problem.

	interacting with or processing the material.	Listening to an explanation (e.g., a teacher, video, or AI tutor) but not interacting with the material.
		Watching someone else solve the problem without copying or writing anything.

Appendix C

Examples of Student Utterances Mapped to Problem-Solving Stages and ICAP Modes

Transcript (Line By Line)	Category
I'm gonna start off by writing my name and my A number.	Active (A)
Problem one is giving me umm. It says a 30 kilonewton weight object is suspended by two cables and it is asking me to create a free body diagram and find the tension in each cable. 30 kilonewton yes its 30	Passive (P)
I am given the angle of the two cables. The one on the left is 45° and the one on the right is 70° and they're both from the horizontal.	Passive (P)
I am going to get started off by drawing my free body diagram, so I'm going to start off by drawing my tension cables, and my 30 kilonewton weight. And I'm adding my angles into the horizontal so. Like I checked again the question, the left one is 45° and the right one is 70°.	Active (A)
Next, I'm just, next, I'm going to draw the tension forces. So my 30 kilonewton object is going to point downwards in the Y direction and I already have that force which is 30 kilonewtons.	Active (A)
And then on my 2 cables I have the forces of those, so I am going to call the right one tension 1 and I am going to call the left one tension 2	Constructive (C)
I'm gonna start off by doing sum of forces in the Y direction but still I feel less confident and I'm going to make the upward direction positive.	Constructive (C)
So for my problem, I have a downward force of 30 kilonewtons. And then I have an upward tension force of my T1. And that is going to be sine of 45 just based on the triangle. The Y direction is the opposite side from the 45° angle.	Active (A)
And my tension 2 is going to be sine of 70 because the sine side is opposite of the 70° angle and all that equals 0.	Constructive (C)
And so I have two unknowns and one equation, so I cannot solve but I can try.	Constructive (C)
So I'm going to set up another equation. I'm going to do the sum of forces in the X direction and I'm going to have a positive be pointing right.	Constructive (C)
And for that, I assume that I'm going to have since my tension 1 is pointing to the left that's going to be negative. Cosine of 45 because the line attached to that is the adjacent angle and my tension 2 is going to the right, so it's going to be positive and times the cosine of 70 and that all equals 0.	Constructive (C)
So now that I have set up those equations, I am going to solve. Umm for T2 in terms of T1.	Active (A)
So I'm going to add, I'm going to use the forces in the X direction and I'm going to add that to the other side. so I'm going to have T2 cosine of 70 = T1 cosine of 45.	Constructive (C)
And then I'm going to divide both sides. Both sides of my equation by cosine of 70. so Then I get T2 = T1 times cosine of 45 divided by cosine of 70.	Constructive (C)

So then using this I am going to plug it in to my sum of forces Y equation. Which equals 30 kilonewtons plus T1 sine of 45 + T2 sine of 70.	Constructive (C)
So my new equation is going to be -30 kilonewtons, plus T1 sine of 45 plus I'm going to plug in my T2 so T1 cosine of 45, divided by cosine of 70 and that is all multiplied by sine of 70 and that all equals 0 as I assumed so my method is correct so far.	Constructive (C)
Next, I am going to add my 30 kilonewtons to each side, so I have T1 sine of 45 plus in parentheses T1 cosine of 45 divided by cosine of 70 end parentheses sine of 30 = 30 kilonewtons.	Constructive (C)
Now I'm going to use my calculator and calculate sine of 45. And that equals 0.707 and that's from rounding.	Active (A)
So I'm going to multiply that by T1 and now I'm going to calculate cosine of 45. Which is the same thing as sine of 45.	Active (A)
And then I'm going to calculate cosine of 70. Which is 0.342 and that is rounding.	Active (A)
Then I am going to take cosine of 45 and divide it by cosine of 70. I typed it into my calculator wrong, so I'm redoing it real quick.	Constructive (C)
And then I get. So T1 times 2.067 and all of that is multiplied by sine of 70.	Constructive (C)
So then I'm going to take 2.067 and multiply that by sine of 70. And then I get 1.943 and that is from rounding so.	Active (A)
My equation right now is 0.707 times T1 + 1.943 times or times T1 = 30 kilonewtons.	Active (A)
So now I'm going to add my like terms so 1.943 + 0.707, and I'm plugging that into my calculator and I got 2.65 times T1 = 30 kilonewtons and I'm going to divide both sides by 2.65 so 30 / 2.65.	Active (A)
Umm equals 11.321. So my T1 is going to equal 11.321 and I'm going to round that to three significant figures. So I'd get 11.3 kilonewtons.	Constructive (C)
And now I am going to plug that back into my sum forces in the X direction Equation to recheck my answer. So I have negative T1, which I determined was 11.3 kilonewtons times cosine of 45, plus T2 times cosine of 70.	Constructive (C)
So I'm going to plug into my calculator. 11.3 times cosine of 45 and that is going to equal, yeah 7.99 but since there's a negative in front of my 11.3. My answer is going to be -7.99 kilonewtons plus T2 times cosine of 70. Not all equals 0.	Constructive (C)
So now I'm going to add 7.99 to both sides. So I get 7.99 kilonewtons equals T2 times cosine of 70.	Constructive (C)
So now I'm going to divide both sides by cosine of 70. So I'm going to take 7.99 divided by cosine of 70 in my calculator and that will give me T2 equals 23.36.	Constructive (C)
And I'm going to round that to three significant. So I have 23.4 kilonewtons equals T2.	Constructive (C)
So my final answer I have T1 = 11.3 kilonewtons. And T2 = 23.4 kilonewtons. OK, I got my answer.	Constructive (C)