Exploring Gendered Pathways: The Role of Formative Assessment in Enhancing Cognitive Engagement in Undergraduate Engineering

Dr. Talha Naqash, Dickinson State University

Dr. Talha Naqash completed his doctoral studies in Engineering Education at Utah State University. With a diverse academic foundation, he also holds a Master's degree in Telecommunication and Networking. He is currently serving as a faculty member at Dickinson State University in the School of Applied Sciences. Dr. Naqash's research focuses on cognitive engagement analysis, assessment methods in engineering education, and the role of facial expressions and emotions in the learning process. His scholarly contributions include numerous publications and presentations at prestigious venues such as IEEE, ASEE conferences, and leading Wiley and Springer journals. He is an active member of several technical committees and serves as a reviewer for reputable journals and international conferences, including the ASEE and IEEE Transactions on Education. Dr. Naqash's dedication to advancing educational research, combined with his broad academic and professional experience, underscores his commitment to fostering innovation and excellence in engineering education.

Dr. Zain ul Abideen, Utah State University

Zain ul Abideen holds a Ph.D. in Engineering Education from Utah State University, where he also served as a Graduate Researcher. He is a computer engineer and earned his bachelor's degree in computer engineering and master's degree in engineering, and brings over a decade of experience in teaching and research with undergraduate engineering students. He actively contributes to several technical committees and serves as a reviewer for leading journals and international conferences. His doctoral research focused on cognitive engagement, AI in education and engineering design, self-regulated learning, and mobile learning. His work seeks to deepen our understanding of how these elements influence learning and success in engineering education. With a strong commitment to educational advancement and a robust academic background, Zain is recognized as a dedicated and emerging scholar in the field of engineering education.

Dr. Assad Iqbal, The Ohio State University

Assad Iqbal (Sid) is a Senior Lecturer at the Department of Engineering Education in the College of Engineering, Ohio State University. Assad has been working with the National Science Foundation (NSF) funded national collaboration research project, "Engineering For Us All (e4usa) since October 2022. The core mission of this project is to increase student and teacher access to engineering with a focus on reaching traditionally underrepresented populations in this field.

With a BS in Computer Information Systems Engineering, a Master of Science in Engineering Management, and a Ph.D. in Engineering Education, Assad's long-term research goal is to converge his varied research experiences and endeavors to explore the possibilities of an inclusive instructional design to promote self-directed, self-regulated, life-long learning among pre-college and undergraduate engineering students.

Dr. Oenardi Lawanto, Utah State University

Dr. Oenardi Lawanto is an associate professor in the Department of Engineering Education at Utah State University, USA. He received his B.S.E.E. from Iowa State University, his M.S.E.E. from the University of Dayton, and his Ph.D. from the University of Illinois at Urbana-Champaign. Dr. Lawanto has a combination of expertise in engineering and education and has more than 30 and 14 years of experience teaching engineering and cognitive-related topics courses for his doctoral students, respectively. He also has extensive experience in working collaboratively with several universities in Asia, the World Bank Institute, and USAID to design and conduct workshops promoting active-learning and life-long learning that is sustainable and scalable. Dr. Lawanto's research interests include cognition, learning, and instruction, and online learning.

Dr. Angela Minichiello P.E., Utah State University

Angela (Angie) Minichiello, PhD is a military veteran, licensed mechanical engineer, and Associate Professor of Engineering Education at Utah State University.

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This study is a theory and methods full research paper that examines gender differences in learning approaches and engagement in engineering education. Gender differences in learning approaches and engagement have long been a subject of interest in engineering education research and have been widely studied. Since one of the fundamental objectives for educators is to design fair, equitable, and effective learning experiences for all students, an understanding of how male and female undergraduate engineering students react to various types of learning experiences and assessments can help contribute to these efforts. This study explores how formative assessments influence cognitive engagement during problem-solving activities among first-year undergraduate engineering students with particular attention to gender differences. Considering the growing need to account for individual differences in educational settings, this research focuses on how male and female students demonstrate distinct patterns of cognitive engagement when exposed to formative assessments during problem-solving tasks. This research is part of a larger study that utilizes a sequential exploratory mixed-method design with a participant selection model. The quantitative phase employed the Need for Closure Scale (NFCS) and demographic data from 67 students enrolled in an engineering mechanics statics course at a public land-grant research university in the western United States to identify eight participants (4 males, 4 females) for the qualitative phase of the study. In the qualitative phase, the selected participants solved two statics problems of equal difficulty, with formative assessment integrated into only one task. Using the guided Think-Aloud Protocol (TAP), students' verbalizations of their reasoning, reflections, and decision-making were recorded. The resulting qualitative data were analyzed through the ICAP framework to examine gender-based patterns of cognitive engagement and how these patterns shifted with the introduction of formative assessments during problem-solving. The findings indicated that formative assessments enhanced cognitive engagement both among males and females, but in different ways. Females were found to show improvement in reflective thinking and receptivity to feedback after the introduction of formative assessments. Male students, on the other hand, showed increases in task focus, persistence of task focus, and less modification of strategy. The findings indicate the necessity for the reframing of formative assessments and feedback, and an assessment design to incorporate gender-based differential needs of undergraduate engineering students.

Key Words: Undergraduate Engineering Students, Formative Assessment, ICAP Framework, Task Persistence, Assessment Design, Cognitive Engagement

Introduction and Literature Review

Formative assessment has gained increasing attention in educational research due to its emphasis on feedback and instructional adjustments that enhance student learning outcomes [1]. It supports teachers by providing insights into students' understanding, enabling them to adapt instruction and guide students in monitoring their own progress [2,3]. Moreover, formative assessment plays a critical role in shaping students' learning behaviors by offering timely feedback that promotes active cognitive engagement, self-reflection, and motivation [4,5,6]. Research on feedback engagement further underscores the role of formative assessments in promoting meaningful learning. Knapova et al. (2020) argue that students benefit most through active and cognitive engagement with feedback that is clear, actionable, and embedded in the ongoing instruction [7]. However, students differ in how they respond to uncertainty and evaluative information. This highlights the importance of considering individual motivational [8] and cognitive factors, such as Need for Cognitive Closure (NFCC), which shapes students' preferences for certainty, structure, and decisiveness [9]. Examining NFCC alongside formative assessment therefore provides a useful lens for understanding why some students engage deeply with feedback while others seek rapid closure and disengage from reflective learning processes. NFCC is a non-binary construct, and individuals can be found anywhere on a continuum between high and low NFCC. Higher NFCC students are characterized by a tendency to reach quick conclusions usually based on incomplete processing of information and prefer definitive answers, often seeking immediate closure in ambiguous situations. Such individuals tend not to explore problems that invite additional cognitive engagement or critical thinking. Conversely, students with low NFCC tend to engage with underlying problems, embracing uncertainty, exploring wide avenues of problem-solving, and appreciating open-ended tasks, as these activities involve a deeper cognition process [9]. Formative assessment may affect students' levels of NFCC by changing the tendency towards quick closure thus embracing and exploring ambiguity [10]. For example, high NFCC students may find feedback challenging because they are inclined towards jumping to conclusions quickly. The structured feedback, provided with formative assessment, would allow them to reconsider their conclusions and remain engaged in the learning experience by reducing their need for closure [11]. However, for students with low NFCC, who are more comfortable with ambiguity and the exploration of ideas, formative assessment can engage their propensity to spend an extended amount of time on open-ended tasks [12,13]. Some studies have established that gender differences may be associated with differences in students' responses to feedback and engagement during problem-solving [14]. For example, female students may be more engaged and more persistent in responding to formative assessment than males, who may react differently depending on their self-efficacy [15] and task-specific goal orientation [16]. According to prior research, gender and NFCC within an engineering education context is critically important because engineering problem-solving is characterized by high cognitive demand, analytical processes targeted to analyze unstructured situations, and time constraints that require sustained reasoning, tolerance for ambiguity, and iterative refinement of solutions [17]. Prior research in engineering education has demonstrated that engineering classrooms are not gender-neutral; rather, they are shaped by disciplinary norms that privilege speed, correctness, and procedural fluency [14]. These norms have been shown to differentially influence students' participation, confidence, and cognitive engagement [18]. Within this context, formative assessment functions not merely as a feedback mechanism but as a pedagogical intervention capable of either reinforcing or disrupting established participation patterns [19]. Consequently, examining how formative assessment shapes cognitive engagement across gender is essential for informing equitable instructional design in engineering education [18]. Furthermore, the NFCC construct may manifest differently in engineering compared to other academic disciplines because engineering problems are often open and ill-structured with more than one answer and multiple possible solution pathways [20]. Authentic engineering problem-solving, especially in design-oriented or open-ended contexts, requires revisiting assumptions, tolerating uncertainty, and adapting strategies in response to new information [17, 20]. Therefore, investigating the interaction between gender and NFCC within engineering education provides discipline-specific insight into cognitive engagement patterns, rather than relying solely on findings derived from general education or psychology contexts [21, 22].

Motivation and Research Question

There is a limited exploration of the relationship between binary gender (male & female), NFCC levels, and the effect of formative assessment on their cognitive engagement. Gender is recognized as an influencing factor [3] as the prior research results show that female students respond more favorably to feedback, while male students value performance outcomes more [23]. There is still limited research explaining the reasons behind these behavioral differences. Moreover, most studies related to formative assessments focused on their overall effects on student learning and performance [24] while not targeting the individual variances of cognitive profiles (e.g. NFCC), and limited research literature is available related to the NFCC interaction with gender in the context of formative assessment [25]. Based on the study's objectives and focus on gender, NFCC, and formative assessment, the following research question guides this investigation*: "How does formative feedback shape cognitive engagement among male and female undergraduate engineering students across different NFCC levels during problem-solving tasks?"*

Methods and Analysis

This study utilizes a sequential mixed-methods design with a participant selection model, followed by the quantification of qualitative codes, which involves both quantitative and qualitative phases of data collection and analysis [26, 27,28]. This design is suitable for understanding difficult and interconnected phenomena [27], such as cognitive engagement, NFCC levels, and how they are influenced by formative assessment. Using convenient sampling [29], quantitative data including demographics and NFCC, was collected from first year undergraduate engineering students enrolled in Engineering Mechanics Statics course in a public land-grant research university in the western United Sates. Demographics data included participants' gender, age, academic background, and prior academic achievement, while NFCC data was collected using Need for Closure Scale (NFCS) [30]. Quantitative data was used to select participants for qualitative phase of the study. This research approach ensures the participation of students with diverse levels of NFCC and genders in the study. Descriptive statistical techniques are used to summarize the demographic characteristics and distribution sample students based on NFCC levels. This information was also used to purposively sample participants for qualitative phase of the study. The purposeful sampling strategy [31] is used to intentionally select eight student participants to ensure a comprehensive and representative analysis of various factors, such as the NFCC and binary gender, that influence cognitive engagement during problem-solving tasks. For the qualitative data collection, each selected student participant solved two equally difficult problems related to the Engineering Mechanics Statics course (Appendix C). One of the problems incorporated formative assessment, while the other problem did not include any formative assessment. The purpose of this approach is to explore how the presence or absence of formative assessment affects students' cognitive engagement during the problem-solving activity. Selected participants practiced the Think-Aloud Protocol (TAP) while solving the problem to capture their cognitive engagement strategies. The problem-solving session was audio-recorded. The audio data captured the corpus of verbalizations of the students. Labov and Waletzky's (1997) narrative analysis framework was utilized to systematically investigate student participants' verbalized thoughts during the assigned problem-solving tasks [32].

The study analyzed the transcripts to highlight how student participants worked through complex problems, how they organized their reasoning, and how the nature and level of cognitive engagement varied with and without formative assessment. This form of analysis established a rich understanding of participants' thought processes, identified as narrative thinking, which could later be coded according to the ICAP framework for cognitive engagement levels (Appendix E). The qualitative data is coded using a cognitive engagement framework- ICAP, which categorizes cognitive engagement into four overlapping levels: Interactive, Constructive, Active, and Passive [33]. This ICAP framework helps to identify and classify student participants' cognitive engagement levels during the problem-solving tasks. Specifically, this analysis examines patterns of cognitive engagement with respect to the provision of formative assessment, considering variation in participants' levels of NFCC and binary gender. Moreover, the formative assessment employed in this study was designed to help and measure cognitive engagement in students' problem-solving activities without being overly prescriptive. The formative assessment (Appendix D) was developed in concert with the problem content and incorporated six multiple-choice conceptual questions, followed by qualitative feedback. When developing the formative assessment, special care was taken not to act to guide (step-by-step) or suggest a single path to a solution, as developing a singular solution path would result in a lack of deeper engagement opportunities. Each participant's think-aloud data was coded by three researchers independently using the ICAP framework and quantified to calculate the frequency of each cognitive engagement mode (Appendix F). These frequencies were then used to determine the percentage change and Cohen's *h* effect size between the problem-solving tasks completed with and without the formative assessment. Effect size values (Cohen's *h*) are reported in this study solely as descriptive indicators to illustrate trends in cognitive engagement. These values complement the qualitative analysis and do not replace the interpretive insights derived from the narrative and thematic data. This study helps to deepen the understanding of how formative assessment, cognitive closure, and individual differences interact to shape students' cognitive engagement.

Results

In this study, there were 103 students invited to participate, and 67 out of 103 completed the full survey. Among 67 students, 80.60% identified as male and 19.40% identified as female; this is also consistent with national findings regarding gender distribution in participants enrolled in engineering programs [34,35]. Data is rearranged in ascending order according to the NFCC score. Participants were divided into two groups: high NFCC (Mean + SD) and low NFCC (Mean -SD). To create balanced representation and improve the credibility of the qualitative analysis, two males and two females were selected from each NFCC group to participate in the qualitative analysis. Within engineering education, research indicates that males and females may have different experiences and will engage cognitively differently due to their previous experiences, classroom dynamics, and socialization within STEM areas. Including multiple participants form each gender ensures that multiple perspectives are reflected in this study and allows researchers to identify commonalities among groups of individuals who attend classes at the same NFCC level.

Narrative Analysis Results

A detailed Narrative analysis of cognitive engagement categorized by both gender and NFCC levels during two engineering statics tasks (solved without formative assessment and solved with formative assessment) illustrates the complexity of these relationships. Additionally, the verbal protocols indicated differing degrees of reasoning depth as well as how learners engaged with feedback, which were explicitly related to both NFCC level and binary gender.

Male participants with high NFCC levels appeared to be significantly more hesitant to engage initially, relying heavily on their procedural certainty. One participant, when initially solving the first task, noted, *"Let me make sure I haven't missed anything,"* indicating a surface-level processing of the problem consistent with someone very uncomfortable with ambiguity. The other participant stated, *"I have a difficult time recalling trigonometry identities from memory,"* indicating their reliance on external references rather than attempting to discover a conceptual understanding of the material. Their subsequent engagement with the task post-formative assessment was enhanced, though largely the result of increased focus and persistence rather than a more strategic revision of their ideas. As the second participant stated, *"The quiz helped me a lot… it provided me with a warning about solving for theta, which helped me."* and *"I merely used the procedure the assessment indicated, it was successful immediately, yet I never paused to ask if the fundamental ideas behind it were pertinent to this study."* He also mentioned that he used the recommended approach without thinking critically about the assumptions that he was making in carrying out that process. Although his thinking was faster, it did not seem to be more reflective.

Male participants with low NFCC showed high levels of cognitive engagement right from the beginning, establishing their reasoning on basic principles such as: *"Since the forces are in a state of static equilibrium, and thus both X and Y forces must equal zero; because of this, I can write down two equations immediately"*. After the formative assessment, they did not change their knowledge base (conceptually). Rather, they improved their ability to execute (precision in executing a reason) based on what the quiz reminded them of: *"The quiz was not new information for me, but it reminded me that I should always check to see if there is a moment (torque) around the pivot when a force is applied to an object"*. The improvement came in the ability to execute correctly by reducing errors, rather than rethinking their understanding. In contrast, high NFCC males started with uncertainties, and repeatedly re-read the problem to avoid committing to a solution: *"I keep going back (looking) at the problem statement to ensure I am interpreting the angles correctly…"* and *"I am just not sure that I remember how to break the components apart without looking them up."* High NFCC males showed less overall cognitive engagement due to a lack of sustained reasoning (fragmented reasoning). Low NFCC males used feedback to refine their already good framework to a higher level of execution, whereas high NFCC males used feedback to enable them to overcome their initial paralysis.

Female participants with high NFCC approached the first problem-solving task with a high level of caution as well as the beginning of a self-explanatory approach. For example, one female stated: *"I am going to draw the free body diagram carefully so I can get the angles correct before I write any equations."* Her reasoning was systematic but did not demonstrate much confidence as she continuously reread her instructions, saying the following: *"Let me read the problem again. I don't want to make an assumption that isn't there."* Even though both females were engaged in the activity, the level of engagement was limited by both of their need to be certain of their understanding. During the second problem-solving task, when formative assessment occurred, the High NFCC females engaged in more reflective thinking and asked themselves, *"The quiz indicated to check whether forces produce moments - does this apply in this case since the forces appear to be acting in unison?"* The answer to this question resulted in one female changing her problem-solving strategy, saying the following: *"At 1st I thought I must solve both components first, but now I can use moments about B to create equations that allow me to eliminate the unknowns; this seems a better approach.*" Formative assessment provided calm confidence and encouragement toward rethinking the approach taken when trying to assign numerical values to the unknown. Low NFCC females entered Task 1 with great confidence to explore. One female stated, *"My first thought was if I didn't know how to solve, I know the equilibrium of the sum of forces = 0 to determine equilibrium."*

Female participants with low NFCC expressed doubt even about their initial conclusions, asking out loud, *"This tension appears to be too big but given the steep angle of the rope, I may be correct; the solution will be determined using the Y equation."* The effects of formative assessment on the metacognitive level of low NFCC females were significant. One female, after completing the formative assessment, stated, *"After taking the quiz, I recognized that I left out the pin at B, this means that different forces would be producing rotation, therefore it is important that I check the lines of action of each force before calculating the moment on B"*. After formative assessment, both groups of female participants demonstrated a significant increase in their ability for reflective thinking; however, they began their journeys from different starting points. High NFCC females adapted from a cautious approach of verification to a more tactical approach for rethinking, and low NFCC females developed from an exploratory approach with confidence to a disciplined method of self-monitoring.

Secondary Data Analysis of Qualitative Data Results

A secondary quantitative analysis of qualitative data, in conjunction with the narrative analysis, was conducted to compare changes in cognitive engagement of the participants preceding and subsequent to receiving formative assessment. This analysis examined the patterns of cognitive engagement by identifying and comparing the frequencies of passive, active, and constructive engagement modes coded for each of the two problem-solving tasks performed by each participant group. By quantifying qualitative data, patterns of cognitive engagement can be identified and calculated with the magnitude and direction of change upon formative assessment. During the first problem-solving task, male and female participants in both high and low NFCC groups acted differently within the problem-solving task. Exploring the association of gender and NFCC provides insights into the manner in which gender may mediate the impact of formative assessment on cognitive engagement. High NFCC group's male participants showed 14% passive engagement, which is more than the low NFCC group participants, who showed 11% passive engagement.

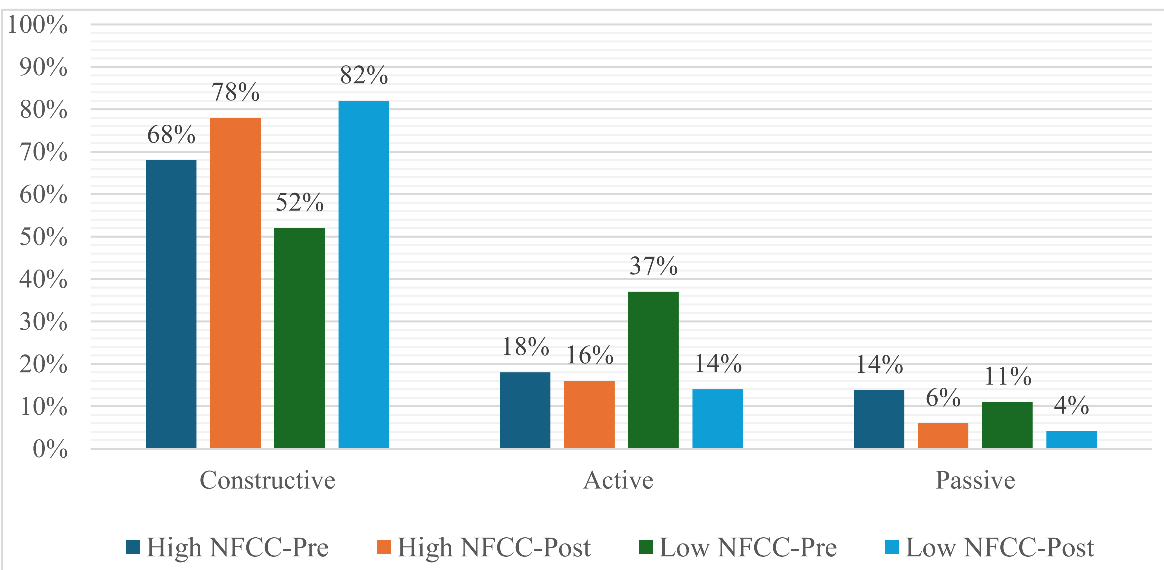


Figure 1: Male Participants' Pre and Post Formative Assessment, Cognitive Engagement Profiles Across NFCC Levels (High Vs Low)

This observation suggests that the two high NFCC males were more likely to absorb or review information without taking active steps. Alternatively, low NFCC males seem to have mentally participated more because they perhaps were less resistant to exploring uncertainty and were not waiting for “right” information to proceed there, as their active engagement is higher than that of high NFCC males. High NFCC males engaged in a more constructive engagement rate (68%) than the low NFCC males (52%). This difference indicates that high NFCC males engaged in a deeper level of independent reasoning and idea generation, likely facilitated by the high NFCC males' reliance on an internal focus to construct the task accurately. By looking at the male participants from a pairwise comparison, the same pattern may not hold for offers; rather, a different pattern of low NFCC females had lower passive engagement at 8% than high NFCC females at 14%. Therefore, it appears that low NFCC female participants were more likely to remain cognitively active, rather than receiving the information from passive engagement. With regards to constructive engagement, low NFCC females had greater levels of engagement at (55%) than high NFCC female participants (47%).

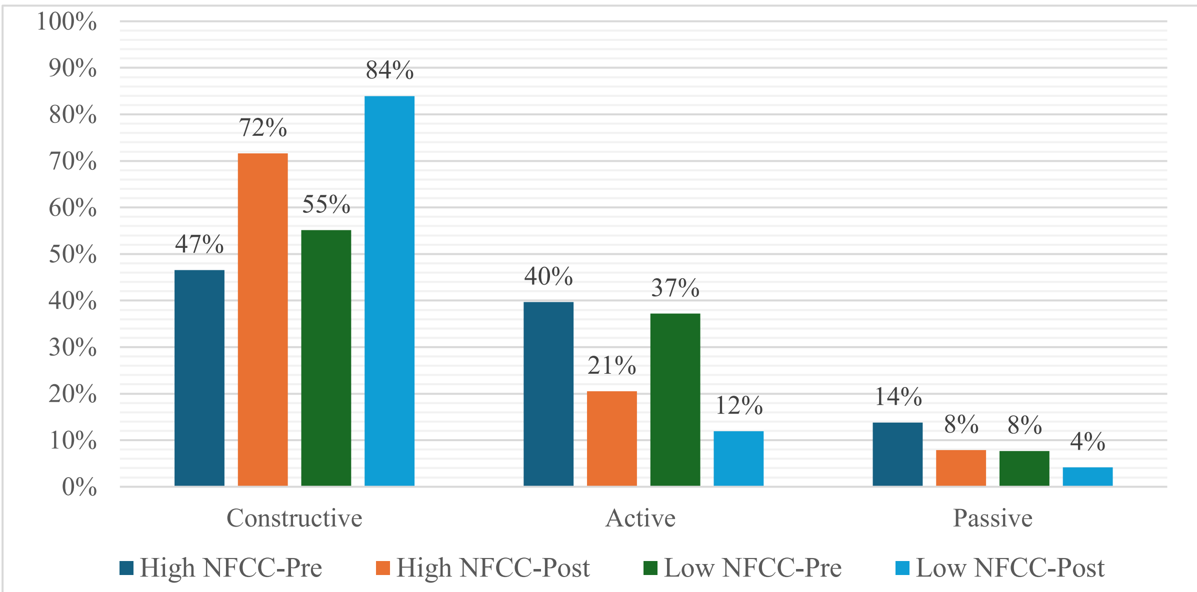


Figure 2: Female Participants’ Pre- and Post-Formative Assessment, Cognitive Engagement Profiles Across NFCC Levels (High Vs Low)

After receiving formative assessment during the second problem-solving task, male and female participants from high and low NFCC groups experienced notable differences in their engagement patterns with the task. For the male participants, the low NFCC group had the lowest passive engagement (4%) after the formative assessment, as compared to high NFCC males (6%), which means that the low NFCC males were less inert and more engaged in responding to the feedback.

The low NFCC group also showed a higher increase in constructive engagement (82%) as compared to their high NFCC counterparts (78%), as shown in Figure 1. Male participants in both groups experienced a growth trajectory in Deeper engagement; however, low NFCC males appeared to benefit the most, perhaps because the formative assessment helped them to engage their thoughts in a more processed way. Interestingly, active engagement was a measure that saw a more pronounced drop for low NFCC males (14%) than high NFCC males (16%); demonstrating that low group males reduced their focus from surface activity on the task more towards meaningful reflection. For female participants, a similar pattern of deeper engagement after feedback was evident; however, some differences were present. Low NFCC females had the lowest passive engagement (4%) after assessment, while high NFCC females recorded a somewhat higher level of passive engagement

(8%), which implies that low NFCC females became more cognitively active after support from the formative assessment. Low NFCC females also captured the greatest constructive engagement of all female participants (84%), whereas high NFCC females recorded 72%. The difference suggests that formative feedback supported low NFCC females in processing their new thoughts and helped them to build their understanding. However, a drop in active engagement was more marked for low NFCC females (12%) as compared to high NFCC (21%). In this way, the varieties of change demonstrate a considerable shift toward deeper engagement for the low NFCC females. The impact of formative assessment on male participants with varying levels of NFCC appears to show substantial differences in how these students reacted to their respective feedback during problem-solving. Modification of cognitive engagement has occurred at both the NFCC levels and by gender after formative evaluation. Males with high NFCC experienced a 58% decrease in their passive engagement (which dropped from 14% to 6%) at an effect size of Cohen's h = -0.28, and males with low NFCC experienced a 68% decrease (the decrease being from 11% to 4%) at an effect size of Cohen's h = -0.30, respectively.

Table 1: Percentage Change and Cohen's Effect Size in Cognitive Engagement Modes Post Formative Assessment by Gender Across NFCC Level (High Vs Low)

Metric	High NFCC Males	High NFCC-Females	Low NFCC-Males	Low NFCC-Females
Passive Engagement Change (%)	-58%	-43%	-68%	-46%
Effect Size (Passive)	-0.28	-0.19	-0.30	-0.15
Active Engagement Change (%)	-14%	-48%	-61%	-68%
Effect Size (Active)	-0.07	-0.42	-0.53	-0.61
Constructive Engagement Change (%)	16%	54%	58%	52%
Effect Size (Constructive)	0.24	0.52	0.66	0.64

Females with high NFCC had a 43% decrease in their passive engagement (the decrease was from 14% to 8%) with an effect size of Cohen's h = -0.19 and females with low NFCC had a 46% decrease (the decrease being from 8% to 4%) with an effect size of Cohen's h = -0.15, respectively. High NFCC males had an active engagement decrease from 18% to 16%, a 14% decrease (Cohen's h = -0.07). The low NFCC males showed a significant decline in their active engagement from 37% to 14%, which represents a 61% overall decrease (effect size = -0.53). High NFCC females saw their active engagement decline from 40% to 21%, again being a 48% decrease (Cohen's h = -0.42), and low NFCC females had an overall active engagement decline from 37% to 12%, documenting a decrease of 68% (effect size = -0.61). In addition to the noted declines in passive and active cognitions due to the implementation of formative assessment, all groups noted increases in constructive engagement. High NFCC males' constructive engagement score increased from 68% to 78% for a total increase of 16% (Cohen's h = 0.24); low NFCC males' constructive engagement score increased from 52% to 82%, yielding an increase of 58% (effect size = 0.66); high NFCC females' constructive engagement score increased from 47% to 72% resulting in a total increase of 54% (effect size = 0.52); low NFCC females' constructive engagement score increased from 55% to 84%, yielding a total increase of 52% (effect size = 0.64).

Discussion

This study has investigated the effect of formative assessment on cognitive engagement of engineering students, including gender differences and NFCC. Results indicate that formative assessment can assist students in transitioning from passive and active engagement to constructive engagement; however, the extent of each individual's shift differs due to both their cognitive preferences (i.e., NFCC) and the contextual influences of engineering tasks (i.e., gender). This finding aligns with prior research suggesting that formative assessment promotes deeper cognitive processing through structured feedback and opportunities for revision [4, 5], particularly when students are required to articulate reasoning rather than merely produce correct answers.

For males, students with a low NFCC experienced the greatest increases in constructive engagement (52% to 82%). Participants with a high NFCC experienced a more moderate increase in constructive engagement (68% to 78%). Narrative data indicated that higher NFCC males relied on procedural certainty early in the process (i.e., rereading problem steps) and were hesitant to revise their strategies, whereas lower NFCC males used an exploratory approach. This pattern is consistent with NFCC theory, which posits that individuals high in NFCC prefer decisiveness and rapid closure, often avoiding extended cognitive exploration in ambiguous contexts [7, 8]. Formative assessment provided scaffolding that supported persistence among higher NFCC males; thus, these students were able to accelerate their development of systematic reasoning skills through engagement with feedback. Such scaffolding reflects the instructional adjustment function of formative assessment described in the literature, whereby feedback reduces premature closure and encourages reconsideration of initial judgments [10, 11]. In contrast, due to their greater tolerance for ambiguity, lower NFCC males were able to utilize formative assessment with greater effectiveness than higher NFCC males. This aligns with findings that individuals low in NFCC are more inclined to engage in elaborative processing and open-ended problem exploration [9, 12, 13], behaviors closely associated with constructive engagement within the ICAP framework [5].

For females, there were also gender-related patterns of engagement. Lower NFCC females demonstrated the greatest levels of constructive engagement (55% to 84%); this increase represented a combination of exploratory and responsive behaviors to structured feedback. Higher NFCC females also approximately doubled their constructive engagement from baseline levels (47% to 72%), due to reflective thinking enhanced by formative assessments without reducing procedural caution. These findings resonate with prior studies indicating that female students often respond more favorably to feedback processes and demonstrate persistence in reflective academic tasks [14, 15]. Both groups of females demonstrated a greater decrease in active engagement than males, indicating a transition in cognitive processing from task-related processing to increased metacognitive engagement. Such a transition is theoretically meaningful because cognitive engagement literature emphasizes that movement from active to constructive engagement reflects deeper knowledge integration and self-regulated learning processes [5, 6]. Narrative observations support this transition: lower NFCC females demonstrated disciplined self-monitoring, while higher NFCC females gained confidence in revising their strategies. While there was a significant reduction in passive engagement for both males and females, the greatest reduction occurred in lower NFCC participants. This finding suggests that formative assessment not only provides useful information about progress but also assists students in developing autonomy and reflective, iterative reasoning skills, both critical in engineering problem solving, where ambiguity must be tolerated and assumptions revisited [17]. Given that engineering classrooms often privilege speed and procedural correctness [14], the observed reduction in passive engagement suggests that formative assessment may disrupt traditional participation norms and encourage more equitable cognitive involvement [19]. The study findings have several implications for theory and practice. The results suggest that NFCC moderates students' responses to formative assessment in engineering contexts, where structured tasks reward procedural correctness, yet authentic problem solving requires flexibility and adaptation. This moderation effect contributes to the limited but emerging literature examining NFCC in discipline-specific contexts [21], extending prior work by situating NFCC within engineering problem-solving environments rather than general educational settings. Gender differences demonstrate that formative assessment can assist in narrowing gaps in cognitive engagement between male and female students by guiding deeper reflection and strategy revision. Given evidence that engineering environments are not gender-neutral and may differentially shape engagement patterns [18], these findings highlight formative assessment as a potential equity-oriented pedagogical intervention. From a practical standpoint, educators can utilize formative assessment to design scaffolded assessments incorporating reflective prompts, targeted feedback, and iterative problem-solving opportunities tailored to students' NFCC profiles. Such differentiation is consistent with literature emphasizing that feedback effectiveness depends on alignment between instructional design and learners' cognitive dispositions [3]. Future studies should examine larger samples across engineering disciplines, assess the persistence of constructive engagement over time, and investigate how shifts in cognitive engagement relate to academic performance. By using NFCC and gender as analytical lenses, this study provides a more nuanced framework for optimizing formative assessment strategies to enhance engagement in engineering education.

Conclusion

In this study, we used a sequential mixed-methods design with a participant selection model, followed by the quantification of qualitative codes, which involves both quantitative and qualitative phases of data collection and analysis to explore how (binary) gender influences the effect of formative assessment on undergraduate engineering students' cognitive engagement with different NFCC levels. The analysis provided clear engagement patterns along genders and NFCC levels. This would indicate that the structure and direction afforded by formative assessment would be crucial for learners who would typically engage under an open-ended cognitive style or operate with a less structured thinking approach. In particular, the decline in surface engagement modes suggests that formative assessment would not only reduce cognitive load but also assist in focusing their engagement on meaningful learning activities. Post-assessment performances suggest that formative support allowed learners to explore targeted knowledge-building behaviors. The data analysis indicates that formative assessment had a positive effect for all groups, highlighting its role as a mechanism to support diverse cognitive styles and gender differences in engineering education. The comparative behavior of male and female participants at low NFCC levels underscores the complex interplay of cognitive style and gender. Male participants, particularly those at low NFCC, appeared more responsive to the structured content and progressed more effectively through the instructional support compared to their female counterparts. The low NFCC female participants also demonstrated strong gains, reflecting a shift in engagement from disorganized learning behaviors toward purposeful and more effective learning strategies. These findings imply that instructors can leverage formative assessments to scaffold learning, encourage reflective thinking, and promote equitable engagement across students with varying cognitive approaches. Furthermore, the study contributes to engineering education by providing evidence that targeted formative feedback not only improves individual learning outcomes but also supports inclusive pedagogical strategies that account for both gender and cognitive style differences.

References

[1] A. Orozco, “Formative assessment practices and student engagement in higher education,” *Assessment & Evaluation in Higher Education*, 2024.

[2] E. F. Prastikawati *et al.*, “Formative feedback and self-regulated learning in university students,” *Education Sciences*, vol. 14, no. 2, 2024.

[3] C. Grimalt-Alvaro and M. Usart, “Student engagement and formative assessment in blended learning,” *Computers & Education*, 2024.

[4] S. Wilkinson, “Assessment literacy and feedback effectiveness,” *Higher Education Research & Development*, 2024.

[5] P. Wallin and T. Adawi, “The reflective diary as a tool for formative assessment,” *European Journal of Engineering Education*, vol. 43, no. 4, pp. 507–521, 2018.

[6] M. Leenknecht *et al.*, “Formative assessment as practice,” *Assessment in Education*, vol. 28, no. 3, pp. 324–343, 2021.

[7] L. Knapova *et al.*, “Feedback engagement and student learning,” *Studies in Higher Education*, vol. 45, no. 9, pp. 1882–1896, 2020.

[8] Y. Liu *et al.*, “Student motivation and feedback use,” *Journal of Educational Psychology*, vol. 99, no. 4, pp. 856–867, 2007.

[9] B. M. Schumpe *et al.*, “Cognitive closure and information processing,” *Current Psychology*, vol. 42, no. 11, pp. 9324–9338, 2023.

[10] K. Wilson, “Reconceptualising student engagement,” *Higher Education Research & Development*, vol. 36, no. 4, pp. 725–738, 2017.

[11] V. Viola *et al.*, “NFCC modulates perceptual decisions,” *PLOS ONE*, vol. 10, no. 12, e0146002, 2015.

[12] N. T. Brewster, *Perceptual Confirmation in the Employment Interview*, Ph.D. dissertation, Central Michigan Univ., 2005.

[13] H. Torrance, “Formative assessment at the crossroads,” *Assessment in Education*, vol. 19, no. 2, pp. 323–336, 2012.

[14] A. L. Duckworth and M. E. P. Seligman, “Self-discipline outdoes IQ,” *Psychological Science*, vol. 16, no. 12, pp. 939–944, 2006.

[15] M. Malespina and S. Singh, “Student motivation and feedback,” *International Journal of Educational Research*, vol. 113, 2022.

[16] F. Pajares and D. H. Schunk, “Self-efficacy beliefs,” *Review of Educational Research*, vol. 72, no. 2, pp. 219–246, 2002.

[17] S. A. Ambrose, M. W. Bridges, M. DiPietro, M. C. Lovett, and M. K. Norman, “How learning works: Seven research-based principles for smart teaching,” *J. Eng. Educ.*, vol. 100, no. 2, pp. 333–335, 2011.

[18] E. Seymour and A.-B. Hunter, Eds., *Talking about Leaving Revisited*. Cham: Springer International Publishing, 2019.

[19] D. Sanchez *et al.*, "Academic motivation and assessment," *Educational Psychology*, vol. 43, no. 5, pp. 589–607, 2023.

[20] R. A. Streveler, T. A. Litzinger, R. L. Miller, and P. S. Steif, "Learning Conceptual Knowledge in the Engineering Sciences: Overview and Future Research Directions," *Journal of Engineering Education*, vol. 97, no. 3, pp. 279–294, Jul. 2008

[21] J. S. Eccles and A. Wigfield, "Motivational beliefs," *Annual Review of Psychology*, vol. 53, pp. 109–132, 2002.

[22] M. Yorke, "Formative assessment in higher education," *Studies in Higher Education*, vol. 28, no. 4, pp. 477–490, 2003.

[23] K. Asare, "Assessment feedback and student learning," *Journal of University Teaching & Learning Practice*, vol. 18, no. 4, 2021.

[24] P. Karaman, "Self-regulation and feedback," *Educational Research Review*, vol. 33, 2021.

[25] R. Morris, E. Perry, and J. Wardle, "Academic motivation and engagement," *Higher Education*, vol. 82, no. 3, pp. 527–545, 2021.

[26] J. W. Creswell, *Research Design*, 4th ed. Thousand Oaks, CA, USA: Sage, 2014.

[27] J. W. Creswell and V. L. P. Clark, *Designing and Conducting Mixed Methods Research*. Thousand Oaks, CA, USA: Sage, 2018.

[28] D. L. Driscoll *et al.*, "Merging qualitative and quantitative data," *Journal of Ecological and Environmental Anthropology*, vol. 3, no. 1, 2007.

[29] S. Gulzar *et al.*, "Student engagement and assessment," *Frontiers in Psychology*, vol. 13, 2022.

[30] A. Pierro and A. W. Kruglanski, "Revised NFCC scale," Univ. of Rome, unpublished manuscript, 2005.

[31] L. A. Palinkas *et al.*, "Purposeful sampling," *Administration and Policy in Mental Health*, vol. 42, no. 5, pp. 533–544, 2015.

[32] W. Labov and J. Waletzky, "Narrative analysis," *Journal of Narrative and Life History*, vol. 7, no. 1–4, 1997.

[33] M. T. Chi and R. Wylie, "The ICAP framework," *Educational Psychologist*, vol. 49, no. 4, pp. 219–243, 2014.

[34] National Center for Education Statistics, *Status and Trends in the Education of Racial and Ethnic Groups 2022*. Washington, DC, USA: U.S. Dept. of Education, 2022. [Online]. Available: https://nces.ed.gov/pubs2022/2022144.pdf. Accessed: Nov. 15, 2024

APPENDIX A

Demographic Question

1. What is your gender?
   a. Man
   b. Woman
   c. Do not want to disclose
   d. Other _______

2. What is your race?
   a. White
   b. Hispanic / Latino
   c. Black or African American
   d. American Indian or Alaska Native
   e. Asian
   f. Other _________

3. What is your year in school?
   a. First Year
   b. Second Year
   c. Third Year
   d. Fourth Year
   e. Fifth Year or More

4. What is your cumulative grade point average (CGPA)?
   a. 3.51-4.0
   b. 3.0-3.50
   c. 2.51-2.99
   d. 2.0-2.50
   e. 1.51-1.99
   f. Below 1.50

5. What is your grade in the following Engineering Mechanics Statics (ENGR 2010) prerequisite courses?
   a. MATH 1210 __________ %
   b. MATH 1220 __________ %
   c. PHYS 2210 __________ %

APPENDIX B

NFCS Survey

Read each of the following statements and decide how much you agree with each according to your beliefs and experiences. Please respond according to the following scale:

1= Strongly disagree 4 = Slightly agree

2= Moderately disagree 5 = Moderately agree

3= Slightly disagree 6 = Strongly agree

Sr #	Question	Scale					
1	I don't like situations that are uncertain.	1	2	3	4	5	6
2	I dislike questions which could be answered in many different ways.	1	2	3	4	5	6
3	I find that a well-ordered life with regular hours suits my temperament.	1	2	3	4	5	6
4	I feel uncomfortable when I don't understand the reason why an event occurred in my life.	1	2	3	4	5	6
5	I feel irritated when one person disagrees with what everyone else in a group believes.	1	2	3	4	5	6
6	I don't like to go into a situation without knowing what I can expect from it.	1	2	3	4	5	6
7	When I have made a decision, I feel relieved	1	2	3	4	5	6
8	When I am confronted with a problem, I'm dying to reach a solution very quickly.	1	2	3	4	5	6
9	I would quickly become impatient and irritated if I would not find a solution to a problem immediately.	1	2	3	4	5	6
10	I don't like to be with people who are capable of unexpected actions.	1	2	3	4	5	6
11	I dislike it when a person's statement could mean many different things.	1	2	3	4	5	6
12	I find that establishing a consistent routine enables me to enjoy life more.	1	2	3	4	5	6
13	I enjoy having a clear and structured mode of life.	1	2	3	4	5	6
14	I do not usually consult many different opinions before forming my own view.	1	2	3	4	5	6
15	I dislike unpredictable situations.	1	2	3	4	5	6

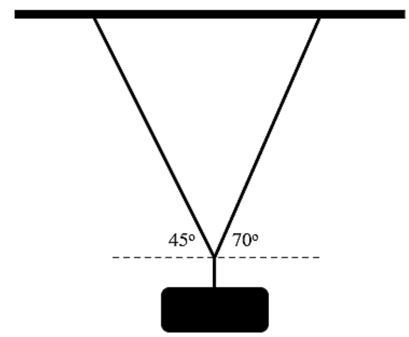
APPENDIX C

Selected Problems for Qualitative Data Collection

Problem 1 (Without Formative Assessment)

A 30 kN weight object is suspended by two cables

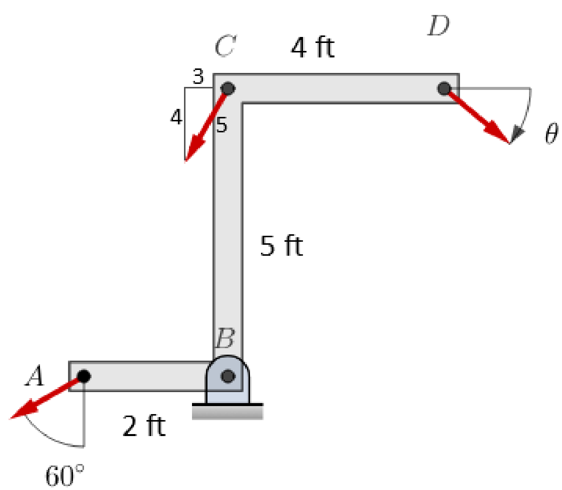
1) Create a Free-Body Diagram
2) Find Tension in each cable



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 D

Formative Assessment (for Problem 2)

1. What condition must be true for the bar to remain in rotational equilibrium?
A. The sum of the vertical forces must equal zero.
B. The sum of the horizontal forces must equal zero.
C. The largest force must act at the center of the bar.
D. The sum of the moments about any point must equal zero.

2. When resolving force A=250 into components, which of the following is true?
A. The horizontal component is A sin (*60*), and the vertical component is A cos (60)
B. The horizontal component is A cos (60), and the vertical component is A sin(60).
C. The force does not need to be resolved in this case.
D. The force components depend on the distances AB, BC, and CD.

3. If the pin connection were moved from point B to point C, how would this change the solution for the angle θ?
A. The solution for θ would remain the same because the forces and distances have not changed.
B. The solution for θ would change because the forces at A and D would need to balance each other.
C. The bar would no longer remain in equilibrium since the pin connection is not at B.
D. The angle θ would become irrelevant because the system would be in equilibrium regardless of the bar's orientation.

4. When solving for θ in an equation where both sin(θ) and cos(θ) appear, which of the following is a valid strategy?
A. Use the Pythagorean identity $\sin^2(\theta) + \cos^2(\theta) = 1$ to directly eliminate cos(θ).
B. B. Express the equation as a product of tan (θ) and sin(θ).
C. Solve for θ graphically
D. Multiply both sides of the equation by cos(θ) to simplify.

5. If force A were doubled while keeping all other forces and distances constant, what would happen to the angle θ?
A. It would increase.
B. It would decrease.
C. It would remain unchanged.
D. The bar could no longer achieve equilibrium.

6. Imagine you are solving the following equation, Which of the following best describes how you could explain your solution to someone else?
A. Simply state the final answer without showing any steps.
B. Show the steps in writing but do not explain them verbally or visually.
C. Explain each step verbally or with visuals, such as a diagram or number line, to make the solution process clear.
D. Use a calculator to find the answer and avoid any further explanation.

Appendix E
(ICAP Framework-Based Code Book) [33]

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	Reading the problem statement without doing anything else.

	information without any observable action or response, such as simply reading, watching, or listening without interacting with or processing the material.	Looking at a worked-out solution without making notes or attempting to solve the problem.
		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 F

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

Transcript (Line by Line)	Category
So I'll start writing my name and A number.	Passive (P)
And next a 30 kilonewton weight is suspended by two cables.	Passive (P)
First one is out of 45° and the second is at a 70° angle and I need to make a free body diagram and find the tension in each cable.	Passive (P)
Have you encountered this problem? Yes, I've had similar ones and I'm very confident in being able to solve it correctly.	Constructive (C)
So, to analyze it I guess I already I need to find the tension in each cable. So that's what's given let read again.	Active (A)
To the I guess what's given is 30 kilonewton weight.	Active (A)
Which means that's the force pointing downwards due to gravity.	Active (A)
And then I know that the first cable is at a 45° angle and then the second is that a 70° angle.	Passive (P)
What theories allows your? Well, I only know that it is suspended so.	Active (A)
It is at equilibrium, which means that the forces in X&Y are both equal to 0 Or the sum of the forces.	Constructive (C)
So I'm forces X = 0 and sum of forces y = 0.	Constructive (C)
And then from there, I will just add up all the forces.	Constructive (C)
And so moving on to actually solving it but how I don't know yet.	Passive (P)
I'll make my free body diagram.	Constructive (C)
I have my mind box That has 30 kilonewtons Coming down let check the question again.	Passive (P)
And then At a 45° angle. I have. The cable and then at a 70° angle.	Active (A)
Which means that I have a little bit from both of these that goes up.	Active (A)
And a little bit from both that goes to the side to balance it out.	Constructive (C)
And then I'll use Sohcahtoa to find out that for my sum of forces In the X direction which equal 0.	Constructive (C)
I have to the left so minus Cosine of 45 Degrees.	Active (A)
And then plus or yes Sorry Minus T1 for the tension and cable one Time to the cosine of 45 and then plus tension cable 2, Times the cosine of 70° let check question again.	Constructive (C)
Then some forces Y is also equal to 0 and I have -30 kilonewtons.	Active (A)
And then plus T1 times sine of 45.	Constructive (C)
And then plus the tension and cable two times the sine of 70°.	Active (A)
Because of this I can solve for T1 From my first equation.	Constructive (C)
So I'll have T1 equal to T2 Cosine of 70 Divided by cosine of 45.	Active (A)
And then I'll plug that in for my T1 value and the second equation for forces Y.	Constructive (C)
So I have. Someone forces Y again equals 0 = -30 kilonewtons, Plus then I have T2.	Constructive (C)
This is what I solve for T1. So I have T2, cosine Of 70°.	Constructive (C)
Over cosine of 45° Times the sine of 45° And then plus T2, Sine 70.	Constructive (C)
And then using this I can solve for T2 with my calculator.	Active (A)

So I'll move 30 kilonewtons over to the other side.	Active (A)
And so I have 30 kilonewtons is equal to T2 Cosine 70 over cosine of 45. Sine of 45 Plus.	Constructive (C)
And actually I can take the T2 out of there Then I'll just put it outside of the parentheses and I'll add sine of 70 On the inside.	Constructive (C)
So solving for that in my calculator I have.	Active (A)
I'll just solve for the right side and then I'll divide that from the 30 kilonewtons.	Constructive (C)
So I have cosine of 70. And divided by the cosine of 45 times the sine of 45 plus sine of 70 And I get 1.28 roughly.	Active (A)
So I have 30 kilonewtons Equals 1.28 T 2 So then 30 / 1.28 and I get T2 Is equal to 23 Kilonewtons.	Constructive (C)
Now I can solve again for T1 Because I know that T1 cosine Of 45 Is equal to T2 cosine of 70.	Constructive (C)
So I will plug in this value that I got and then times that by Cosine of 70 and then divide by the cosine of 45 and I get that T1 is equal to 11 Kilonewtons And then just to double check..	Constructive (C)
I guess Yeah, that works.	Passive (P)
So then I'll write my name up at the top of This paper too And my A number..	Passive (P)
So yes, final answers are T1 is equal to 11 kilonewtons and T2 is 23 kilonewtons.	Active (A)

Male Low NFCC-Problem 1		
ICAP	Frequency	Percentage of each mode
Passive	8	19%
Active	15	35%
Constructive	20	47%
Interactive	0	0.00%