Work in Progress: Evaluating the impact of student cognitive and emotional responses to real-time feedback on student engagement in engineering design studios

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Introduction. The Department of Biomedical Engineering (BME) at Cornell University is incorporating studios featuring iterative design exploration within the core courses of the major. The goals of these studios are to (i) enhance their understanding of human biology at the quantitative system level and (ii) to foster more consistent and purposeful BME engineering thinking. Given that studio-based learning is rich with real-time feedback due to its inherent dialogic nature, students' achievement of these goals becomes heavily influenced by students' experiences with feedback [1]. This work in progress paper describes the use of an observational tool in an upper-level biomedical engineering course aiming to address the following research questions: (1) What type of feedback are students receiving during studios? (2) What are students' emotional and cognitive responses (ECR) to this feedback? And (3) how do these real-time feedback exchanges impact student engagement in the studios? We demonstrate the tool can be used to characterize feedback interactions and propose how these interactions play a role in observed fluctuations of engagement from the students. By observing how students invite, respond to, and integrate real-time feedback into their work, we seek to elucidate what encourages students to engage in the exploration of creatively unique solution spaces in engineering contexts.

Background. High-quality feedback can significantly impact a student's academic success [2]. Despite acknowledging its value, students often feel dissatisfied with the feedback they receive, leading to minimal engagement with the feedback [3]. Consequently, there has been growing interest in understanding student's interactions with feedback and developing evidence-based pedagogical practices in providing feedback to students [4]. Course design aspects, such as including spaces to discuss feedback quality, enhancing students' self-assessment abilities, fostering goal-setting skills, and providing multiple opportunities to apply given feedback have been shown to support effective feedback [5]. Studios, which encourage informal and ongoing dialogue, embody effective feedback pedagogy by providing multiple feedback sources [1], teaching real-world problem-solving [6], fostering teamwork and objective setting [7], and encouraging iterative design practices [8]. At the same time, since students are exposed to various (at times conflicting) perspectives from both instructors and peers, it can be quite challenging for them to discern which feedback to incorporate in their designs [9]. To this end, studying how students engage with real-time feedback can provide critical insights into their broader engagement and success in these learning settings.

Course Context. BME Analysis of Metabolic and Structural Systems (BME 4010) is a required course for seniors, offered once per year during the fall semester. The fall 2023 semester was the first iteration in which studio sessions were incorporated in the department. Totaling five studios per semester, each three-hour studio emphasized quantitative physiology taught in lecture, with students working in groups to address the engineering challenge presented. Appendix A describes the design challenge presented while data was collected for this research. The goal of the studios is for students to develop the *design thinking process*, consisting of identifying and ranking engineering and design goals/constraints; developing solutions that address these constraints; conceptualizing a technology that combines these solution elements; summarizing the technology into an engineering model; and communicating the technology. Students receive real-time feedback in three studio phases: *desk visits* where instructors offer informal suggestions to

individual teams, *pin up stage(s)* where students present to their peers to allow the class to collectively explore and critique their work-in-progress, and a *formal review* where groups upload their work for a final critique. All three phases occur during a single, three-hour studio period.

Observational Tool. Building on the formative feedback guidelines developed by Kluger and DeNisi [10, 11], Hattie and Timperley [2], and Shute [12], an observational tool was developed and used to characterize feedback exchanges in BME 4010 studios (Appendix B). Divided into two components, the framework focuses on the feedback itself and the immediate ECR to that feedback by student teams. Data presented in the manuscript was recorded from one team of five students during studio three of the course. In conjunction, the engagement of the five students, measured via attention and commitment, was recorded, and ranked using a modified Schlechty Framework [13] (Appendix C). To collect the data, an independent observer (neither a member of the teaching team nor a student in the group) was assigned to observe the team throughout the studio, using the tool (Appendix B) as a checkmark to record interactions. Simultaneously, an audio recording of the group was taken to use as a time mark reference for recorded interactions. This research has received Institutional Review Board Approval (IRB 014842).

Results. Broadly speaking, a variety of different approaches to giving feedback were observed, with the majority (90%) prompted by the instructional staff rather than from students (Appendix D). Interestingly, in certain cases the same types of feedback (e.g., nature and focus) elicited very different ECRs from the students (Appendix D). To highlight the use of the tool, we call attention to two feedback interactions that elicited strong emotional responses from the students. Notably, there were fluctuations in student engagement around the occurrence of these interactions (Figure 1).

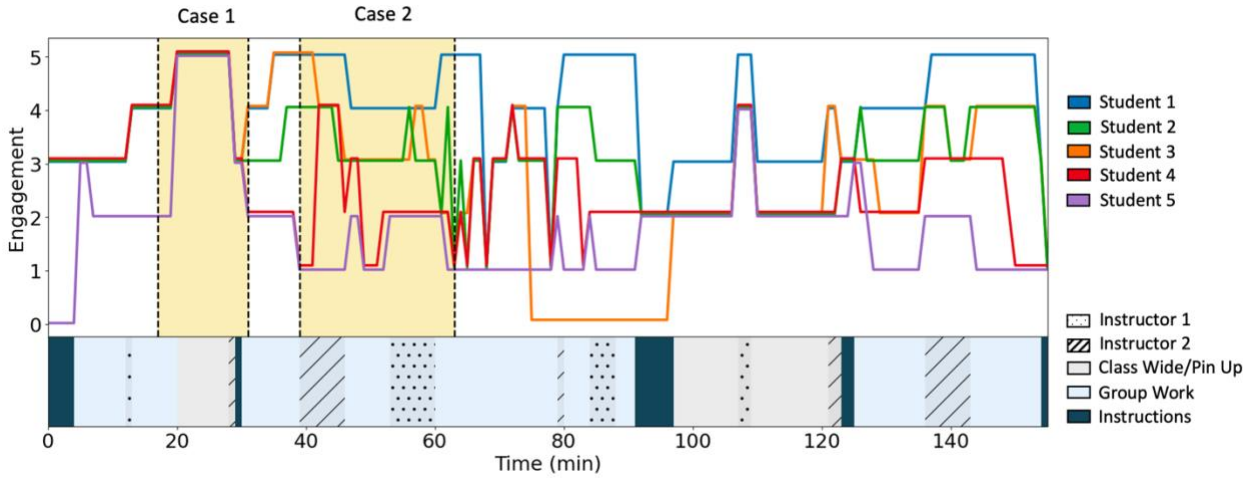

Figure 1. Engagement chart of students in the studio. The top highlights the engagement of each of the five observed students, ranked from a scale of 0 to 5 across the duration of the studio. Below, we detail what activities students were participating in the studios, ranging from receiving instructions (dark blue), to working with their group (light blue), to a class-wide discussion (light grey). Striated sections highlight when the team received feedback from the instructional team, with different patterns corresponding to the two different instructors. Yellow highlighted sections indicate the two cases we discuss in further detail.

Case 1. Students has been working with their teams to create a ranked list of the physiological and environmental design considerations of a breath-hold free dive. Now, the entire class was engaged in a game-like (i.e., family feud) discussion, comparing their ranked design constraint list with the instructors' ranking. The feedback was both directive and facilitative, focused mainly on providing information to help students develop a comprehensive list for their subsequent work. Concurrently, while other teams were sharing their ideas, the observed team was dynamically adjusting their list, revisiting their priority rankings, and incorporating new design constraints they had not considered before. This highlighted that even indirect forms of intergroup feedback effectively kept the students highly engaged. Generally, this exchange generated significant engagement from students, possibly from the pride, happiness, and satisfaction of having their design considerations, and the manner of how they assigned value to each, validated by the instructional team.

Case 2. Students were working on a block diagram for a breath hold free dive when an instructional team member suggested they were missing a force in their diagram, causing confusion among the students. They attempted to incorporate this advice, although they did not fully understand how. A few minutes later, a different instructor suggested simplifying their block diagrams, which was well-received. However, when one student sought clarification about the previously mentioned force, the second instructor said it was not necessary to be included. This conflicting feedback led to immense frustration within the team, causing most students to stop working on the assignment and rather focus on the lack of congruence between instructors. This highlights the importance of aligning guidance, fostering critical thinking skills to handle conflicting feedback, and helping students develop comfort with the lack of a "right answer" such that they are better equipped to handle situations with multiple feasible design paths.

Discussion and Future Work. The goal of this work was to develop a tool to analyze real-time feedback interactions in studios, addressing research questions on feedback's impact on student engagement. To answer research question one, we used the observational tool to examine and characterize the nature and focus of each feedback interaction (Appendix D). From these, we noted a variety of approaches taken by the instructional team (Appendix D). Concurrently, to answer research question two, the observational tool allowed us to determine how the interaction affected the ECR of the students. For research question three, we used a modified Schlechty Framework to observe student engagement and witnessed different feedback exchanges impacting students' engagement quite differently, with corresponding ECRs following similar trends to engagement level. Engagement in the classroom, however, is a deeply personal and subjective experience, shaped by the unique identities that each student brings to the table [14]. We recognize that attempting to quantify student engagement through a standardized, simplistic scale overlooks the nuanced nature of student engagement. However, more broadly observing fluctuations in engagement for individual students and moments of congruency (or incongruence) between students in teams can help pinpoint areas of focus to evaluate the impact of different pedagogical strategies within studios. In considering the scale-up use of this tool, using both visual and audio recordings of student teams could help expand the number of observed teams within a single studio while decreasing the need of having multiple independent observers conduct the observations. The next stage of this research will be to use this tool as a guide to investigate the correlation between feedback pedagogies, student engagement levels, and subsequent achievement of learning goals. With this, we aim to provide comprehensive insights into effective teaching practices that promote engagement and deeper learning experiences in BME studios.

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Appendix A: BME 4010 Studio Design Prompt

Breath Hold Free Dive: This studio focused on integrating concepts learned in the respiratory system unit by modeling a breath hold free dive scenario. The studio was broken up into three sections: first, students were asked to list and rank physiological/environmental conditions of the dive, taking into consideration the distinct phases of the dive, what is happening in the circulatory/respiratory system with depth, and what is happening to move with depth; then, students engineered a diagram to represent physical, physiological, and molecular phenomenon of the free dive; before finally, applying equations to the engineering diagram.

Appendix B: Feedback Observational Framework

Context			Feedback			Response to Feedback		
Time	Activity	Prompted by	The feedback was	Nature	Focus Level	Cognitive	Emotional	
		Group	Directive	Gaps in status	Task	Increased Efforts	Surprise	Relaxed/Calm
		Instructors	Facilitative	Provides Information	Process	Lower Expectations/Standards	Frustration	Excited
		Peers (not in group)	Other	Reduces Misconceptions	Self-Group Regulation	Reject the Feedback	Satisfaction	Disappointed
				Other	Self/Group-	Abandon efforts to achieve the goal	Indifference	Reassurance
						Other	Acceptance	Pride

Context: First, notes are taken regarding when and during which studio activity (e.g., design constraints, mathematical modeling, etc.) the feedback took place. Given the structure of the studio, the feedback can be prompted by the 'Group,' meaning the student-team are themselves requesting input on their work, by 'Instructors' during *desk visits, pin ups,* or *formal reviews,* or by peers (students not working within the student team) at random times.

Feedback: Feedback is then characterized as either 'Directive' if the feedback gave instructions or highlighted areas for improvement or was characterized as 'Facilitative' if the feedback offered comments/suggestions to assist students in making their own adjustments or comprehend concepts more effectively. 'Nature of the feedback' refers to interaction's objective, which includes: 'Gaps in status,' helps student-groups bridge the gap between their current level of performance and their desired standard; "Provides Information" lessens student's cognitive load by providing needed information; and "Reduces Misconceptions" corrects misunderstandings by offering clarity and correct information. These feedback aims can be extended across four task levels: "The Task," how well the design task is understood/performed; "The Process Level," the processes the group utilizes/engages in to successfully execute the task; "Self/Group-regulation," concerning goal setting, planning, and monitoring progress; and "Self/Group," which focus on personal evaluations and affect (usually positive) about the learners.

Response to Feedback: Student response to feedback is divided into both cognitive and affective domains. Drawing from Feedback Intervention Theory [10, 11], students, when responding to feedback, can cognitively opt to: "Increase Efforts" meaning enhance work towards meeting studio objectives; "Lower Expectations/Standards" or lessen their output; "Reject the Feedback" by not integrating it into their work; or "Abandon Efforts to Achieve the Goal" by ceasing work on given tasks. Affective reactions to feedback (not all are listed) were drawn from The Control-Value Theory of Achievement Emotions [15]. Overall emotional responses were then selected as positive, neutral, or negative based on the connotation of the observed emotions.

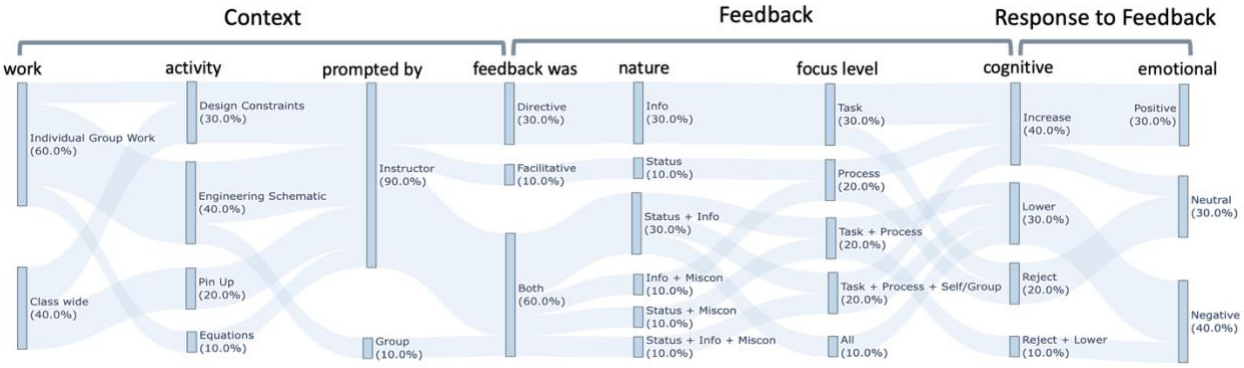
Appendix C: Studio Engagement Scale

Assigned Value	Engagement Level	Attention	Commitment	Characteristics
1	Rebellion	Diverted	None	Student is not working on the task, is disruptive, and/or is working on other material
2	Retreatism	None	None	Student is disengaged, not or very minimally contributing to the group discussion
3	Ritual Compliance	Low	None	Contributes to the group discussion, completes assignments without enthusiasm, might need pushing to complete assignments
4	Strategic Commitment	High	Low	Consistently contributes to group work, actively engaged in discussions, work may have little value, but they are engaged
5	Active Engagement	High	High	Leads discussions, drives progress with ideas and efforts, motivates others, ensures completion of tasks

The following scale was used to evaluate student engagement in the studios. Based on Schlechty's Engagement Framework [13], students were scored on a scale of 1-5, with different characteristics of 'engagement' denoted in the table above. Given the duration of the studio (3 hours), students were permitted to exit the classroom as needed contingent that not the entire group leave at the same time. Students who stepped out of the classroom were given a zero for the duration of the time they were not present with the group.

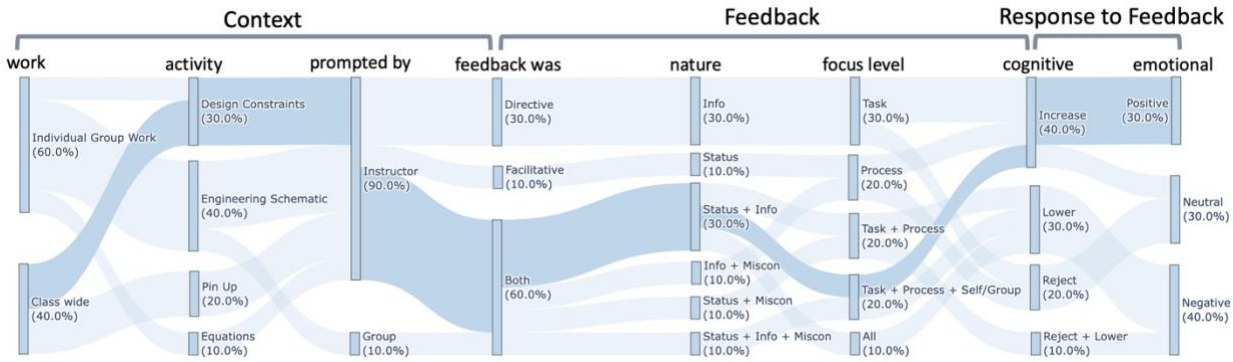
Appendix D: Feedback Interactions in the studio

The following Sankey Diagram summarizes the ten instances where the observed students were given feedback, highlighting the kind of feedback given to the team and the affective and cognitive impact of that feedback on the students. Appendix B provides details for the definitions of each column.



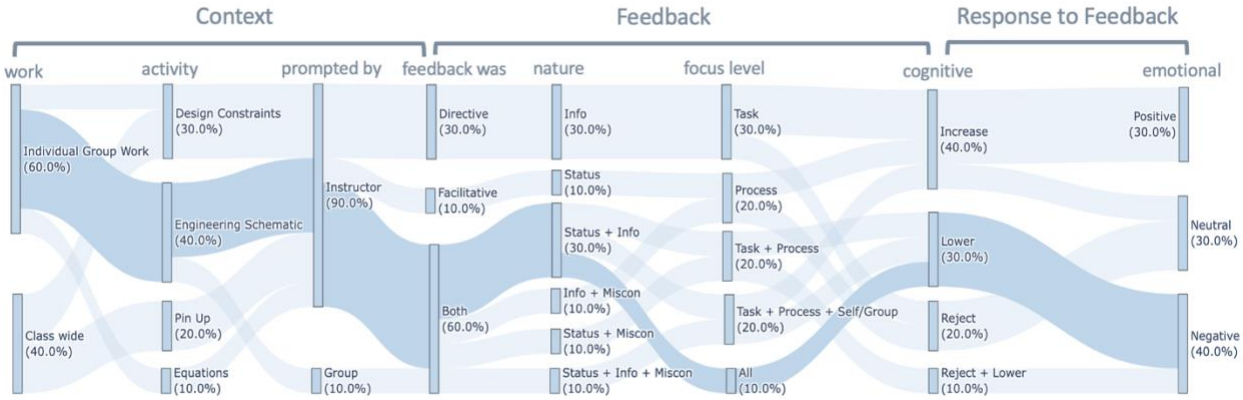
Appendix E: Case Background Information

Case 1: Class-Wide Feedback



The following Sankey diagram highlights the feedback observed during case 1 (darkened path). In this example, the students were engaged in a class-wide discussion on design constraints that was prompted by the instructional staff. The feedback was both directive and facilitative, focusing on providing students information as to how to better improve their design list. This led to an increased cognitive output and a positive emotional response from students.

Case 2: Conflicting Feedback



The following Sankey diagram highlights the feedback observed during case 2 (darkened path). In this example, students are working within their teams to create an engineering schematic of a breath hold free dive. Feedback is given by the instructors that is both facilitative and directive, focusing on providing the students information to help them progress on their task. In response to this feedback, students decreased their work output and generally had a negative emotional response, as the feedback offered contradicted previous feedback they had just received.