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Cultivating Feedback Literacy through Biomedical Engineering Capstone Design

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Abstract

We redesigned a yearlong biomedical engineering (BME) senior design course to make feedback literacy (i.e., seeking, appraising, and acting on feedback) an explicit learning outcome. The course adds role-based Student Advisory Boards (technical, clinical, regulatory, IP, business) with required "response-to-advice" replies and structured stakeholder interviewing.

This study analyzes two artifact sets from semester one: (a) end-of-term "memos to future students" (n=43) and (b) brief survey of usefulness ratings for advisory boards and stakeholder interviews. Using a feedback literacy capabilities lens (appreciation of purposes/sources, evaluative judgment, elicitation, enactment, affect management), we coded evidence of feedback literacy within the memos and cross-tabbed capacities by feedback source.

In memos, prevalence was: appreciation 27/43 (62.8%), judgment 15/43 (34.9%), elicitation 8/43 (18.6%), enactment 5/43 (11.6%), affect 1/43 (2.3%); among writers showing any capacity (n=38), mean capacities per student = 1.47 (SD=0.92). External stakeholders dominated narratives of consequential movement (scoping, pivots, constraints). In the survey, stakeholder interviews were widely rated useful; advisory boards clustered from "a little useful" to "useful."

Ultimately, this work contributes (1) a scalable model (role-based advisory boards, response-to-advice, stakeholder interviewing) for cultivating feedback literacy in BME capstones; and (2) an artifact-based approach instructors can use to monitor how students understand, seek, judge, and use feedback. Future work will link memo themes to team artifacts and compare patterns across engineering disciplines.

Index Terms

biomedical engineering design, capstone design, feedback, stakeholders

I. Introduction

Feedback only improves learning and design when students can seek it, evaluate it, regulate its emotional impact, and translate it into action [1]–[3]. In biomedical engineering (BME), these capabilities are especially critical as students must reconcile inputs from technical, clinical, regulatory, intellectual property, and business stakeholders under safety, compliance, and commercialization constraints [4]–[6]. We redesigned a yearlong BME senior design sequence to name feedback literacy as a course outcome and to embed authentic opportunities for students to both give and use feedback, including a role-based Student Advisory Board (AB) review process and structured stakeholder engagement.

This paper reports students' perceived feedback literacy [7], [8] development via two sources that received research consent: (1) qualitative analysis of end-of-term "Memos to Future Designers" and (2) a post-course survey on feedback practices and beliefs. We coded memos inductively, using established feedback-literacy constructs, while being open to emergent codes to surface how students describe what feedback they sought, how they judged it, how they managed affect, and what they say they enacted in a BME capstone context. More specifically, we aim to answer the following two research questions:

RQ1: Which *sources* of feedback do students credit in retrospective memos, and what *functions* do they perceive that feedback serves in their design process?

RQ2: How do students characterize their *engagement* with feedback, including feedback literacy *capacities* and reported *barriers*, and how do these themes align with post-course *usefulness ratings*?

Our contribution is twofold: (i) a memo-based, student-voiced account of feedback literacy situated in BME design, and (ii) a mixed evidence base, with emergent qualitative themes triangulated with brief survey responses addressing a need for discipline-specific feedback literacies and authentic assessment in engineering.

II. Background and Conceptual Framework

A. History of Feedback Literacy in Education Research

Classroom feedback has been theorized for decades, initially as information designed to close gaps between current and desired performance [1], [9]. Meta-analyses made it clear that effects are heterogeneous and depend less on what teachers *say* than on what learners *do* with input [1], [10]. This recognition reoriented scholarship toward feedback as a learner-mediated, social, and dialogic process in which purposes, strategies, standards, and emotions shape uptake [2], [3], [11]–[14].

Within this turn, widely used feedback literacy "capabilities" have been defined: recognizing the value and sources of feedback, exercising evaluative judgment, managing affect, and enacting improvements [7]. Subsequent syntheses elaborated on concrete practices such as proactively eliciting feedback, using criteria and exemplars to compare options, selectively accepting or rejecting advice, planning small tests of change, and monitoring results over time [8], [15], [16].

Across this literature, several themes emerge. First, these capabilities are interdependent rather than separable: appreciation, judgment, affect regulation, and enactment tend to co-occur in productive episodes, with elicitation cutting across them as learners cause feedback to happen at the right time and from the right source [7], [15]. Second, judgment and subsequent action are strengthened when learners have access to explicit criteria, exemplars, or standards; in their absence, students report difficulty triaging contradictory advice and justifying selective uptake [3], [13], [14], [16]. Third, because much feedback exchange is oral and situated, the enactment of feedback is often under-documented unless courses prompt brief justificatory records (e.g., response-to-advice notes or decision logs) that link selective uptake to criteria and next steps [2], [11].

This historical framing guides our analysis of students' own accounts of how they sought, judged, regulated, and enacted feedback in the study context.

B. From classroom exchanges to stakeholder feedback

Much of the feedback literacy literature has examined exchanges inside the classroom—students receiving (and, increasingly, giving) feedback with instructors and peers, rather than feedback from external parties such as users, clients, clinicians, or regulators [2], [3], [7], [11], [14]. Yet in engineering design and entrepreneurship, external stakeholder feedback is essential: designers must elicit perspectives beyond the course community, weigh conflicting claims, and translate them into requirements, verification plans, and documented changes [4], [5]. Programs like the U.S. National Science Foundation's I-Corps explicitly normalize this stance through customer discovery expectations (100+ stakeholder interviews to test assumptions and refine value propositions).

Empirically, Mohedas et al. (2020) offer a detailed window into how student teams experience stakeholder engagement in a capstone setting [6]. In a study of seven teams and 110 stakeholder interactions, stakeholder type was the only factor consistently associated with perceived usefulness and conversations with “expert end-users” were more often described as helpful than exchanges with sponsors, general end-users, or other stakeholders. Inductive analysis further showed that usefulness tended to rise when teams articulated clear goals before an interaction and when a stakeholder’s expertise closely matched the design problem. It fell when messages from different stakeholders conflicted or when input was hard to apply to the decision at hand. The authors also noted that some teams ceded decision-making responsibility to stakeholders (especially sponsors) rather than synthesizing across sources themselves. Together, these patterns depict novices who value stakeholder conversations but prefer directly applicable guidance, struggle to reconcile contradictions, and underuse input that must be translated into criteria or specifications [6].

Biomedical engineering (BME) heightens these dynamics. Even the category of an “expert end-user” is multi-stranded in BME: it may mean the clinician who deploys a device (e.g., surgeon, clinician), the professionals who interface with it daily (e.g., nurses, technicians), or patient/caregiver experts with deep lived experience. Equally consequential are non-users whose judgments gate adoption (e.g., regulatory reviewers, IRBs, insurance providers who determine coverage and reimbursement). As a result, feedback routinely flows through clinical, regulatory, intellectual property, and market-access channels, and uptake must be selective, criteria-referenced, and safety-aware. Because “expertise” and “use” can be decoupled across these roles, alignment is multidimensional (clinical domain, workflow context, standards/verification, reimbursement pathways), and teams can misidentify which stakeholder is “expert” for a given decision if they equate expertise only with technical authority.

Despite this centrality, BME-specific accounts that operationalize feedback literacy capabilities (appreciation, elicitation, evaluative judgment, affect regulation, enactment) in authentic capstone artifacts remain comparatively limited. The present study addresses this gap by analyzing student-authored memos alongside brief survey evidence to characterize whom BME seniors credit as feedback sources, what functions they ascribe to that feedback (e.g., scoping, pivoting, constraints awareness), which feedback literacy capacities are visible in their writing, and how these qualitative traces align with simple usefulness ratings for advisory boards and stakeholder interviews.

III. Course Context and the Student Advisory Board Mechanism

The study site is a yearlong senior design sequence enrolling 62 students organized into 11 teams of 5-6 students. Projects were student proposed and teams were organized based on interest. Students were expected to develop a working prototype, present a pitch to the class and develop a design history file by the end of their spring semester. The broader course transformation emphasized early and frequent stakeholder engagement. Within this course, two complementary structures created repeated, documentable feedback cycles: (a) role-based Student Advisory Boards (ABs) that simulate design reviews, and (b) individual stakeholder interviews that bring external voices into early-stage decision making.

A. Student Advisory Boards (Peer Feedback)

Composition and cadence. Each AB comprises current students from other teams (not alumni) assigned to one of five roles that mirror industry review perspectives: Technical (engineering soundness, feasibility, trade-offs), Clinical (patient/user needs, safety, context of use), Regulatory (device class, standards, compliance), intellectual property (novelty, prior art, freedom-to-operate), and Business (market need, value proposition, scalability). Boards meet once in fall and twice in spring, providing three iterative review points across the project lifecycle.

Advisors receive one-page role briefs (provided in the appendix) and teams deliver a ∼30-minute design briefing (need, concept, evidence, risks, questions). Advisors independently file Individual Advisory Board Reports structured as: (a) executive summary, (b) achievements, (c) risks, including technical, logistical, or team-related challenges with examples, and (d) 3–4 actionable recommendations. Informal meeting notes are appended to the report as an evidence trail. The instructional team grades these advisory reports for feedback quality and may provide oversight to sustain feedback norms without overshadowing the peer advising process [17]–[19].

Teams then produce an Advisory Board Reply that addresses feedback from advisory board reports, questions raised during the session, and instructor notes. Teams may consolidate similar feedback, but for each major comment they are asked to explain their interpretation of the feedback, describe whether and how the team will respond, and justify any decision not to make changes. Replies are expected to draw on literature, stakeholder information, calculations, or other evidence as needed, and to reflect the team's discussion. In parallel, teams submit an Advisory Board Team Recap synthesizing lessons from other groups' ABs and specifying how those insights will be applied locally. Together, these artifacts operationalize feedback literacy by making students' interpretation, evaluation, and selective uptake of feedback visible in course documentation [7]. From receiving feedback to deciding what to act on, the process of design decision-making is made explicit through course artifacts [7].

B. Individual Stakeholder Interviews (External Feedback)

In addition to ABs, each student completed multiple individual stakeholder interviews per semester ($\approx$4 per student in the first term, yielding $\sim$20–24 interviews per team). Weekly checkpoints supported steady progress where students were required to submit a one-page write-up (stakeholder background, rationale for selection, key insights, and expected design impact) plus a transcript or detailed notes (recordings only with permission; tools such as built-in Zoom transcription were allowed).

Additionally, in a flipped micro-lecture, "Talking to Stakeholders," instructors discussed the many types of stakeholders in BME, drafting professional outreach emails, researching stakeholder backgrounds to target questions, and conducting interviews, and following up with stakeholders after interviews.

C. Retrospective "Memos to Future Designers" (End-of-Term Reflection Assignment)

At the end of the fall semester, each student authors a 1–2 page "Memo to Future Designers," a reflective letter addressed to the next cohort. The memo's purpose is twofold: (i) to strengthen a program culture of collective learning by passing forward candid, practical guidance about succeeding in senior design, and (ii) to surface students' own feedback-literacy strategies and beliefs after a full cycle of advisory boards and stakeholder engagement.

Students are asked to (i) situate their project and constraints, (ii) summarize what they did and learned, (iii) offer specific advice for navigating common challenges, and (iv) flag pitfalls to avoid. In the specific advice section, students are explicitly asked to comment on "integrating and triaging feedback from advisory boards and external stakeholders." Memos are planned to be shared with the following cohort.

IV. METHODS

A. Approach and Data Sources

We set out to understand two things: (a) how students talk about feedback in their own words, and (b) how useful they perceive key feedback structures to be. To do that, we analyzed two individual-level sources:

1) **End-of-term "Memo to Future Designers."** Each student writes a 1–2 page reflective letter to the next cohort (see Sec. III-C). Prompts ask students to describe what they learned, offer advice, and specifically comment on integrating and triaging feedback from advisory boards and external stakeholders.
2) **Post-course survey.** A short questionnaire in the final week of the term (instrument items listed below) capturing usefulness ratings for advisory boards, stakeholder interviews, and other course elements, plus open-ended comments. This paper will use only the findings from the post-course usefulness ratings.

These are individual artifacts (not team deliverables), so they do not require whole-team consent.

B. Participants, Consent, and Ethics

Sixty-two students were enrolled in the yearlong BME senior design sequence. At the start of the survey, students were asked whether their course artifacts (including the memo and the survey) could be used for research. Of the students who completed the survey, 44 students consented (71% of those enrolled in the course). One of the consenting students did not complete the memo assignment, so a total of 43 memos and 44 surveys were analyzed for this study.

Because we did not obtain consent from entire teams, we did not analyze team-level deliverables (e.g., advisory-board team responses, shared design files). Advisory Boards and stakeholder interviews remain essential course context (Sec. III), but the research dataset here is limited to consenting students' memos and surveys.

The Cornell University IRB determined the study exempt (Protocol #148499).

C. Positionality

The first author was one of the course instructors and helped design the advisory board, memo, and survey activities analyzed in this study. The first author also reviewed all memo assignments, identified feedback-related passages, and developed the a priori codebook. Memo passages were coded by the second author, a BME graduate student studying engineering education research who was not part of the course instructional team. The first and second authors then discussed code applications and resolved coding decisions through consensus.

The third author, a former BME undergraduate at Cornell who had taken a previous version of senior design, contributed to the course transformation and served as a teaching assistant for the course. The fourth author was also a course instructor and helped design the broader course, including the advisory board, memo, and survey activities analyzed in this study.

D. Survey Measures Used in This Study

From the full survey, we focus on items that speak directly to feedback channels and roles: (1) perceived usefulness of course elements (5-point scale; Not useful at all to Very useful), including Advisory Board meetings/reports and serving as an Advisory Board advisor, and (2) perceived usefulness of feedback-related assignments (5-point scale; Strongly disagree to Strongly agree), including stakeholder interviews and write-ups.

E. Analysis of Data

First, Author 1, one of the course instructors, read all memos and pulled every passage that mentioned feedback (any source, positive or negative, process or outcome). Author 2, not affiliated with the class but does have experience in senior design research, then coded each passage along four dimensions: (1) Context / Source (where the feedback came from), (2) How feedback helped (what function it served), (3) Feedback-literacy capability demonstrated (what students did with it), and (4) Challenges with feedback (barriers, breakdowns, or negative experiences). Multiple codes were allowed per passage (e.g., a single segment could be "External stakeholders," "Pivot," "Evaluative judgment," and "Challenges managing affect").

Once coded, we produced three types of tallies. First, we computed the *prevalence* of each feedback source as the number of memos that referenced that source at least once, divided by the total number of memos analyzed ($N_{\text{all}} = 43$). Second, for memos that referenced a given source, we summarized which feedback *functions* were co-coded with that source and reported conditional proportions using N_{source} as the denominator (i.e., the number of memos that mentioned that source; e.g., $13/36$ of memos that mentioned external stakeholders also linked that feedback to *Brainstorm*). Third, we summarized the presence of feedback-literacy capabilities and challenges using the same conditional approach when examining patterns by source. However, we note that these within-source patterns should be interpreted as descriptive: some sources have small N for co-coded instances, limiting comparisons across sources and generalizations.

To avoid inflating counts from verbose writers, we treated each code as binary at the memo level: within a memo, each source, function, capability, or challenge was counted at most once (presence/absence), regardless of how many times it appeared in the text. Throughout, we use "memo" as the unit of analysis; because each memo is authored by a single student, these counts can be interpreted as student-level prevalence among memo writers.

Co-coding was defined as the presence of both a source code and a function (or capability/challenge) code within the same memo, with each source–code pair counted at most once per memo.

For the survey data, Likert responses were coded 1–5 in item order. Missing responses were handled with pairwise deletion. No team-level data were included.

F. Limitations

These findings are based on self-report data from a single course and therefore reflect students' perceptions and narrated practices rather than causal effects. Because access to non–self-report course artifacts (e.g., design history files, stakeholder interview transcripts, advisory board reports, and other team-based project deliverables) was outside the scope of consent, we cannot triangulate memo themes against students' documented design work. Response bias is also possible, as only 44 of the 62 enrolled students consented to participate.

V. Results

A. Who Students Credited as Shaping Their Design Process

To address **RQ1** (which *sources* of feedback students credit, and what *functions* they describe that feedback serving), we analyzed 43 retrospective memos (one per participating student). Students most often credited *external stakeholders* as shaping their design work, while advisory boards, the instructional team, and within-team feedback were mentioned less consistently (Table I). A small subset did not describe engaging with feedback at all. Notably, none of the memos explicitly described students *giving* feedback, despite every student serving on two advisory boards, suggesting that feedback was framed primarily as something students receive rather than something they also provide. When students did describe impactful feedback, they most often pointed to external stakeholders as shaping early decisions and refining what "mattered" for the design.

Students also emphasized the scale of stakeholder influence on early design direction: *"Stakeholder engagement was also far more influential than we expected … reshaped our assumptions about what was actually useful and what would realistically be adopted."*

TABLE I
Prevalence of feedback sources and related memo characteristics for each participating student wrote a memo ($N = 43$). n is the number of memos that mentioned each source at least once; **%** is $n/43$; and 95% CI is the Wilson score confidence interval.

Category	n	**%**	**95% CI**
Feedback sources referenced			
External stakeholders	36	83.7	70.0–91.9
Advisory board (peers)	15	34.9	22.4–49.8
Instructional team	12	27.9	16.7–42.7
Own team	9	20.9	11.4–35.2
Relevant memo characteristics			
No feedback sources mentioned	5	11.6	5.1–24.5
Gave feedback (any)	0	0.0	0.0–8.2

Beyond who was credited, we also coded what students said feedback did in their projects (i.e., its perceived design function). Functions, derived from course objectives, captured whether feedback helped teams broaden or narrow scope, prompted pivots, surfaced constraints, improved communication practices, supported decision-making, encouraged openness to critique and alternatives, raised meta-awareness of limits or assumptions, or informed prototyping and iteration. Fig. 1 summarizes how students described feedback functioning within each source (composition of student–function co-codes within source).

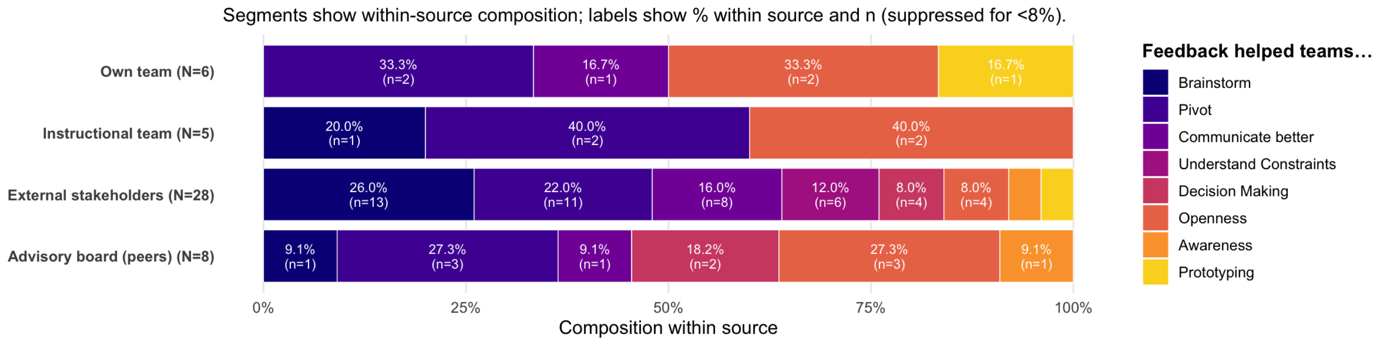

Fig. 1. Compositions of feedback functions co-coded by source. For each source, N is the number of students who referenced that source *and* described at least one function (e.g., Brainstorm, Pivot). Segments show the within-source composition of unique student–function co-codes; a memo can include multiple functions for a single source.

Students frequently linked stakeholder feedback to rapid prototyping and iteration in ways that moved the design forward:

> *"Our design process emphasized fast prototyping, testing, and learning from failure ... and evaluated designs in consultation with stakeholders."*

To make these patterns concrete, the excerpt below illustrates how students credited stakeholders as shaping early design direction:

> *"We also learned that rapid iteration, informed by both literature and stakeholder input, is essential for refining a solution that is not only functional but also safe and clinically relevant. Importantly, we discovered that focusing on the problem first and ensuring we truly understood the challenges of skin grafting was far more valuable than becoming overly attached to any particular solution. In short, stakeholder input is critical, conversations with surgeons and researchers shaped almost every early design decision we made."*

In our coding, this passage was tagged as crediting *external stakeholders* and linking their input to *prototyping* ("rapid iteration") and *understanding constraints* (emphasizing "safe and clinically relevant"), alongside *openness* (prioritizing the problem before becoming attached to a solution).

While external stakeholders dominated students' accounts overall (Table I), a smaller set of memos also emphasized peers and the team as important drivers of openness, especially the willingness to share feedback and let go of favored ideas:

> *"Teamwork is essential in senior design, it is impossible to complete everything this class entails alone, so it's critical to actively support each other, share feedback openly, and be willing to let go of ideas when necessary. Don't underestimate the impact peers can have on you and how much they can help, this is a class built entirely on teamwork."*

Together with Table I, these excerpts show that students most often positioned feedback as coming from outside the team, but when peers and teammates were foregrounded, they were commonly described as enabling openness and follow-through in the work.

B. How Students Characterized Their Engagement with Feedback

To address **RQ2** (How do students characterize their *engagement* with feedback, including feedback literacy *capacities* and reported *barriers*, and how do these themes align with post-course usefulness ratings?), we coded the 43 memos for evidence of five feedback literacy capacities (appreciation, evaluative judgment, elicitation, enactment, and affect management) and for barriers students described while engaging feedback. We then interpret these patterns alongside students' post-course usefulness ratings of feedback-related course elements and assignments (Advisory Boards as recipients and as advisors; stakeholder interviews and write-ups), using the ratings as a coarse-grained check on how students appraised the same channels they narrated in writing.

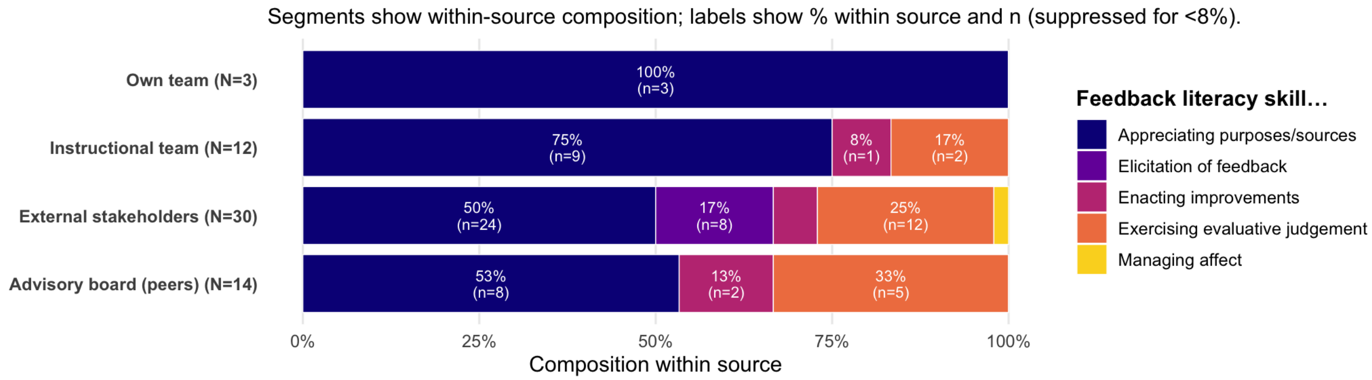

Fig. 2. Compositions of feedback literacy capacities co-coded by source. For each source, N is the number of students who referenced that source *and* demonstrated at least one feedback literacy capacity in relation to it. Segments show the within-source composition of unique student–literacy co-codes; a memo can include multiple feedback literacy capacities for a single source.

Across memos, students most often demonstrated *appreciating purposes and sources of feedback*, followed by *evaluative judgment*, *elicitation*, *enactment*, and, far less frequently, *affect management*. Five memos contained no evidence of any feedback literacy capacity, so among the 38 students who demonstrated at least one capacity, the mean number of distinct capacities evident was 1.47 (SD = 0.92). Table II reports counts, percentages, and 95% Wilson score confidence intervals (Fig. 2 visualizes the distribution).

TABLE II

PREVALENCE OF FEEDBACK LITERACY CONSTRUCTS FOR EACH PARTICIPATING STUDENT WHO WROTE A MEMO ($N = 43$). n IS THE NUMBER OF MEMOS THAT MENTIONED EACH CONSTRUCT AT LEAST ONCE; **%** IS $n/43$; AND 95% CI IS THE WILSON SCORE CONFIDENCE INTERVAL.

Feedback literacy construct	**N**	**%**	**95% CI**
Appreciating purposes/sources	27	62.8	47.9–75.6
Evaluative judgment	15	34.9	22.4–49.8
Elicitation	8	18.6	9.7–32.6
Enactment	5	11.6	5.1–24.5
Affect	1	2.3	0.4–12.1

Two patterns stand out, and they also varied by feedback source (Fig. 2). First, students frequently wrote about who to listen to and why feedback matters. Second, fewer memos made the downstream work visible: actively seeking feedback (*elicitation*), deciding what to prioritize or reject (*evaluative judgment*), and documenting how input translated into concrete action (*enactment*). When students did narrate higher-engagement moves, they tended to emphasize justified selectivity and actionability, for example: *"Your job is not to satisfy everyone, but to synthesize feedback and justify why you chose one path over another."* Affect regulation was rarely named explicitly; when it did appear, it was framed as separating critique of the work from critique of the person (e.g., *Feedback is about the design, not you."*).

To examine where different facets of feedback literacy were most visible, we also re-tagged each capacity instance by the feedback source students referenced (external stakeholders, advisory boards, instructional team, and their own team), see Fig. 2. Although students often blended sources within a single narrative, consistent patterns emerged. Stakeholder interactions most often cued appreciation, elicitation, and evaluative judgment, with students describing stakeholder interviews as high-stakes moments for deciding what counts as a meaningful constraint and which suggestions should drive the next design move. Advisory boards were more often described as perspective-broadening checkpoints that helped teams surface blind spots and work through conflicting advice. Instructional team references more often reflected clarification of expectations (appreciation), typically anchored in course norms and assessments. Mentions of the team itself were less frequent and typically emphasized norms and routines that make uptake possible—supporting each other, sharing feedback openly, and letting go of favored ideas when necessary (e.g., *"Be honest with your team if you fall behind, and be willing to give and receive constructive feedback."*).

Students also reported practical challenges that constrained feedback engagement. The most frequent difficulty was eliciting feedback from external stakeholders, especially recruiting and scheduling interviews. Students emphasized starting outreach earlier than feels necessary, broadening the pool of contacts, and leveraging local networks (e.g., faculty connections) to reduce friction (e.g., *"out of 20 people I emailed, I was ghosted by 19"*). Stakeholder feedback was also described as time-intensive and sometimes emotionally uncomfortable:

> *"Recruiting stakeholders takes more time than you think, and their feedback can be uncomfortable . . . Learning to integrate that feedback without losing momentum is one of the hardest but most valuable skills you will practice in this course."*

Accordingly, several students advised widening outreach beyond the "most obvious" contacts:

> *"It takes a lot of time to get stakeholders—start earlier than you think, and include people even if you think they aren't the most relevant . . . since they still might have insight."*

Others described evaluative judgment as difficult in the face of contradictory advice, reframing success as the ability to triage input using explicit criteria and constraints, convert suggestions into small experiments, and justify selective uptake (e.g., *"a thoughtful 'we're not doing that, and here's why' is totally valid"*).

One excerpt illustrates how students described these engagement moves as a coherent set of practices rather than isolated skills. The student acknowledges the volume of feedback as a barrier, then describes how to respond: listen for meaning, ask follow-up questions, translate suggestions into testable changes, and make a decision that can be justified. The passage also frames pivots and negative feedback as expected features of good design work rather than signs of failure:

> *"You'll also get a lot of feedback from advisory boards and stakeholders, and it can be overwhelming. The goal isn't to implement every suggestion. It is more to listen carefully, ask follow-up questions, translate feedback into testable changes, and then make a decision you can justify. A thoughtful 'we're not doing that, and here's why' is totally valid. Pivoting is valid too because honestly, it can be a sign you're doing design correctly. It is just a step in the design process and you won't always hear what you want about your project from the stakeholders but you need to remember your passion for it and look at it as a puzzle you are trying to solve. You want your device to be useful and serve a need and the passion you bring to it will definitely get you there. Everyone is there to support you, and sometimes negative feedback is what you need to push your design forward."*

In our coding, this excerpt captured multiple feedback literacy capacities at once: *appreciation* (recognizing the value of advisory boards and stakeholders), *elicitation* ("ask follow-up questions"), *evaluative judgment* (explicitly rejecting the idea of implementing every suggestion and legitimizing "we're not doing that, and here's why"), *enactment* ("translate feedback into testable changes"), and *affect management* (naming feedback as "overwhelming" and reframing negative feedback as productive).

The excerpt also makes the central barrier legible: students can be inundated by advice and must develop strategies for triage and follow-through. This interpretation is consistent with post-course usefulness ratings (Table III). Stakeholder interviews and write-ups received the strongest endorsements ($M = 4.00$, $SD = 0.91$; 72.7% rated 4–5), aligning with memo narratives that framed stakeholder engagement as consequential rather than procedural (e.g., *"Take stakeholder meetings seriously . . . they are what shapes your final product. Stakeholder interviews are the most important research you will do—make sure you treat them as such."*). Advisory board meetings and reports were rated more moderately ($M = 3.20$, $SD = 1.02$; 47.7% rated 4–5), mirroring how students often described advisory boards as useful for perspective-taking and trade-off deliberation, but less frequently as direct triggers for concrete project changes.

Notably, serving as an advisory board advisor was rated least useful ($M = 2.86$, $SD = 1.05$; 29.5% rated 4–5). Taken together with the memos' near-absence of explicit accounts of giving feedback, this pattern suggests that students may have operationalized "usefulness" primarily as immediate benefit to their own project progression, rather than as professional formation in a role where providing critique,

TABLE III
POST-COURSE USEFULNESS RATINGS FOR FEEDBACK-RELATED COMPONENTS (SURVEY $N = 44$)

Item	**Mean (SD)**†	**% rated 4–5**	**95% CI**
Advisory board meetings/reports	3.20 (1.02)	47.7	33.8–62.1
Serving as an advisory board advisor	2.86 (1.05)	29.5	18.2–44.2
Stakeholder interviews & write-ups	4.00 (0.91)	72.7	58.2–83.7

†For Advisory Board items: 1=Not useful at all, 5=Very useful. For Stakeholder interviews/write-ups: 1=Strongly disagree, 5=Strongly agree.

mentorship, and evaluative guidance is a routine expectation. This mismatch is important for interpretation: the advisory role may have supported longer-term capacities that students did not readily recognize as instrumental to their current design outcomes, even though those capacities are central to professional engineering practice.

VI. Retrospective Instructor Reflections

To contextualize the results and translate them into concrete instructional implications, we include brief instructor reflections compiled during manuscript preparation. These notes synthesize observations from teaching conversations and debriefs and are intended to align the memo/survey patterns with practical course design choices. In addition, instructor reflections help depict student perceived barriers towards RQ 2.

Mid-semester, students raised two concerns about the feedback assignments: some characterized the AB cycle as "busywork," and several viewed stakeholder interviewing as unfair because grades seemed to hinge on whether external contacts replied—students reported being "ghosted" despite repeated outreach. In response, we piloted a policy change for late stakeholder interviews; instead of point deductions, students completed one additional interview for each week overdue, preserving standards while emphasizing engagement over punishment. By term's end, however, in sharp contrast to these mid-semester perceptions, end-of-term memos cast stakeholder input as central to progress, frequently naming it as the catalyst for scope refinement, pivots, and constraints awareness. This shift from in-the-moment frustration to retrospective value aligns with prior work showing that feedback's impact turns on learner action, access to criteria, and time to use it, rather than delivery alone [2], [11], [14].

Affect management, from the instructors' perspective, emerged most visibly around AB critique. A subset of teams initially took peer comments personally; instructors observed defensiveness and frustration in several meetings. Notably, memos also contained advice to future students that directly counters this tendency (e.g., "Feedback is about the design, not you."), suggesting recognition of the issue by term's end. This trajectory aligns with work showing that emotion regulation is integral to productive uptake [7], [14].

The AB structure required each team to articulate a potential pivot or mitigation plan and then respond to advisors' recommendations. Even when written advisor reports were uneven, the response-to-advice requirement forced teams to justify selective uptake, record deferrals, and outline next tests. Although memos did not frequently narrate AB-driven pivots explicitly, instructors anecdotally observed several decisions to pivot shortly after AB rounds, likely influenced by multiple inputs (stakeholders, instructors, and AB). We view this "closed-loop" traceability as educationally valuable in its own right, independent of the absolute quality of peer commentary.

As a side note, in prior semesters, class-wide design critiques with 50–70 students (10–14 teams) afforded only 10–15 minutes per team for presentation and Q&A. "Listening" students were required to post in a Canvas discussion. However, the course instructors observed that most responses were superficial or uniformly positive rather than substantive. This aligns with prior research that untrained student peer feedback often lacks specificity and actionability [17], [18]. The pivot to concurrently run AB sessions gave each team ∼30 minutes to present and field questions, and assigned AB members explicit responsibility to deliver criterion-referenced critiques for two teams. The instructors felt that this structure increased accountability and depth, yielding more targeted questions, clearer rationales, and concrete next tests, consistent with evidence that role clarity and responsibility improve feedback quality [17].

Finally, messaging and workload likely shaped how students engaged with the written artifacts. Despite repeated emphasis on early stakeholder engagement, criteria-aligned decisions, and the normalcy of pivots, some students appeared unconvinced during the busiest weeks. We suspect (but cannot confirm) that a fraction used generative AI or produced superficial AB write-ups when the purpose felt unclear. Time-pressure effects on depth of engagement are well documented [20], [21]. In future offerings we plan to make expectations more concrete (brief exemplars of high-quality responses, rubrics keyed to criteria and enactment) and we will also provide future cohorts with exemplar memos from this semester so that guidance comes not only from instructors but from prior students themselves (advice that may carry stronger influence).

VII. Discussion and Future Work

Across data sources, external stakeholders dominated narratives of consequential movement in teams' designs. In memos, stakeholder input most often precipitated scope refinement and pivots and surfaced constraints that make designs adoptable (Fig. 1); survey ratings likewise marked stakeholders as useful. This pattern coheres with accounts of engineering design in which progress depends on reconciling heterogeneous inputs under standards, verification, and risk [4], and with evidence that students judge stakeholder interactions as most useful when goals are clear and expertise aligns with the decision at hand [6].

Advisory Boards (ABs) were named less often than stakeholders but were linked to openness, re-framing, and decision-making under conflicting advice. The required response-to-advice cycle made justification and next tests visible, echoing feedback-literacy work showing that dialogic structures, explicit criteria, and learner justifications are key levers for uptake [2], [11], [16]. The survey–memo tension (ABs rated only "a little useful" to "useful" even as memos credit perspective shifts) potentially reflects their perception of the long writing assignment as busy work, or that the benefits arrive late (i.e., keeping a paper trail helped decisions later, even if it did not feel helpful while students were doing it).

With respect to capabilities, most students articulated *appreciation* (why feedback matters and whom to ask). By contrast, *elicitation* and *affect management* were frequently framed as challenges and passed forward as cautions to "future designers" rather than as confidently gained skills. This aligns with work on proactive recipience—moving beyond passive receipt toward actively seeking, sense-making, and using feedback—which often lags without explicit scaffolds [3], [7], [14]. Our cross-tabulation (Fig. 2) reinforces that appreciation, elicitation, and judgment most often co-occurred with stakeholder interactions, while enactment was more distributed across stakeholders, ABs, and instructors.

We also note a measurement limitation that can be explored in future work: enactment tended to be under-documented in memos even when course artifacts (e.g., response-to-advice write-ups, verification plans) required teams to close the loop. Where structures forced a brief "what we did because of this" statement, enactment (or justified rejection) became visible, consistent with recommendations to anchor judgment and action in criteria, exemplars, and decision logs [11], [16].

Finally, in future work, we plan to unpack BME-specific features of stakeholder ecosystems and compare them with other engineering capstones. In BME, the "expert end-user" often spans clinicians, technicians, patients/caregivers, regulators, value-analysis committees, and payers; this breadth may place extra demands on elicitation (who to ask and when), affect management (handling conflicting/high-stakes advice), and decision ownership/traceability. Comparative studies (e.g., BME vs. MechE/EE) could test whether these demands are larger in BME and whether scaffolds like decision logs and criteria-anchored advisory boards mitigate them, extending stakeholder-engagement findings in capstones [6] and connecting capability-based models of feedback literacy to discipline context [7], [11].

VIII. Conclusions

In a BME capstone redesigned to surface feedback literacy, students' own accounts credited external stakeholders as primary drivers of consequential change (scoping, pivots, constraints) and located ABs and instructors as supports for reframing and decision-making under conflict. In reflective writing, most students demonstrated *appreciation* of feedback's value and sources; fewer narrated *elicitation*, *judgment*, *enactment*, or *affect regulation*. Provider roles were largely invisible in memos despite universal participation as advisors (i.e., givers of feedback). Taken together with survey patterns, the evidence situates feedback literacy as a multi-source, criteria-referenced practice that students recognize most clearly when stakeholder engagement is authentic and when decision rationales are made auditable.

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IX. Appendix: Relevant Course Assignments

A. Advisory Board Slides

This slide presentation should be a condensed version of your project justification and plan. This is a presentable form that conveys sufficient information to field live questions and address the major concerns of your project by asking for feedback from your peers and instructors before you dive into making the project a reality. You should anticipate 15 minutes for presenting and 15 minutes for Q&A, but questions can be asked anytime during the presentation; thus, consider a flexible slide deck that you can jump around on. Each team member should have an active role in preparation and presentation of these materials.

For your presentation, consider including a slide for each of the following (and additional slides when necessary). Feel free to adjust the order to present your project in a logical manner:

- **"Prior Art"** (existing solutions to the problem)
  - Current state-of-the-art solutions
  - Patents, companies, or research addressing the same problem
  - Conclusions drawn from prior art such as limitations in technology
- **Stakeholder Feedback**
  - Summarize feedback noting positive responses, concerns, or suggestions
- **Problem statement**
  - Definition of the core problem your project addresses
  - Motivation of the project, including impact and scale
- **Design Objectives + Product Design Specifications**
  - Diagrams of design objectives and PDS with measurable goals
- **Final design choice including description, block diagram, and/or sketches**
  - Clear statement of chosen design solution
  - Summary of how it works and why it is the best choice
  - Alignment of objectives and specifications within design choice
- **Plans for prototyping**
  - Outline major tasks and milestones for rest of this and next semester
  - Describe how you will proceed with development, testing, and validation
  - Clarify roles/responsibilities of members if applicable
  - Emphasize any remaining concerns, challenges, or barriers to success
  - Clear roadmap to bring project to reality such as a Gantt chart
- **Clinical workflow**
- **Regulatory, intellectual property, and business considerations**
  - Utilize the advisory board prompt questions in the Week 8 Individual Assignment to guide your research

Optional Slides: Optional slides you may want to consider including are:

- Outline (table of contents for presentation)
- Introduce your team (include names, concentrations, roles, aspirations, etc.)
- Patent analysis (overview of relevant patents and relation to project)
- Summary of Success Criteria (how you will measure success)

Other Guidelines:

- Every team member is required to participate.
- Creativity always adds value.
- Make slides polished and comprehensible.

B. Advisory Board Role Guiding Questions

This is not a graded assignment. However, it will be helpful for your advisory board report and for your in-person advisory board interactions to consider the questions below. These prompts will help you get into the mindset of your advisory board role and be ready to engage with teams as they present.

General considerations (all advisors):

- What assumptions is the team making that could derail the project?
- How well have they balanced innovation with feasibility?
- What is the riskiest part of their plan, and how could they mitigate it?
- If you had to invest your own money, what would you need to see first?

Technical advisor:

- Does the proposed solution clearly address the identified technical challenge?
- Is the technology feasible given current scientific knowledge?
- Does the team have a plan to validate core functions?
- Are there potential failure points in the design?
- Are materials, manufacturing methods, or performance specifications realistic?
- Has the team considered alternative technical approaches and justified their choice?
- What technical milestones should be prioritized next?
- How could the design be made more robust or scalable?

Clinical advisor:

- Is the clinical need well-defined and evidence-based?
- Does the solution fit naturally into current clinical workflows?
- Is it appropriate for the intended patient population?
- Are there safety or usability risks for patients or clinicians?
- Have the team's assumptions about clinical use been validated by stakeholders?
- Are there competing clinical priorities or barriers to adoption?
- What kind of pilot testing or clinical feedback should be gathered next?
- Are there clinical contexts where this solution might have greater impact?

Regulatory advisor:

- What are the broad safety and efficiency considerations of this project?
- Is it necessary to go through the FDA?
- What regulatory barriers are there for commercialization?
- What is the likely device classification or regulatory pathway?
- Are they aware of the timelines and costs associated with approval?
- Have they identified key safety, efficacy, and labeling requirements?
- Are there predicate devices they can leverage for a 510(k)?
- What regulatory milestones should be integrated into the project timeline now?
- Should they seek early interaction with regulators (e.g., pre-submission meetings)?

IP advisor:

- Is this project novel?
- Does the solution contain unique and protectable elements?
- Has the team considered freedom-to-operate issues?
- Are they aware of major players with potentially conflicting IP?
- What specific aspects of the design could be claimed in a patent?
- Have they documented the inventive steps clearly?
- Are there open-source or public-domain elements they need to acknowledge?
- Should they file a provisional patent now or wait?
- How might they strengthen IP through design modifications?

Business advisor:

- Is there a clearly defined market with sufficient size and need?
- What is the likelihood of adoption of this solution in this market?
- Does the solution offer a compelling value proposition?
- Have they identified the primary customers and decision-makers?
- Is their estimated cost-to-produce competitive with alternatives?
- Are there distribution or reimbursement challenges they have not addressed?
- Who are the top competitors, and how does their product compare?
- What partnerships or funding sources should they explore?
- How can they refine their business model for early adoption?

C. Advisory Board Report

Please submit the report as **SEPARATE, INDIVIDUAL** documents on Canvas. You will need to turn in **TWO** reports, one for each team you are advising.

Assignment 1: Individual Advisory Board Reports

As an advisory board member, your role is to independently assess team progress and deliver a report that provides constructive feedback, identifies risks or gaps, and suggests improvements in your assigned advisory board stakeholder role. This exercise will develop your skills in technical evaluation, professional communication, and strategic planning.

The report should be **1–2 pages** and include the following sections:

1) **Executive Summary** — Provide a concise overview of the team's progress, strengths, and areas for improvement.
2) **Achievements** — Detail the team's accomplishments relative to their objectives. What has the team done well? Describe significant successes, innovative approaches, or notable outcomes.
3) **Risks** — Discuss current "risks" or challenges the team faces, including technical, logistical, or team dynamics issues. Use specific examples to substantiate your points.
4) **Recommendations** — Offer actionable suggestions to help the team address challenges or refine their approach. You should provide **3–4** concrete recommendations per team. You may suggest possible synergies/collaboration opportunities with other teams or helpful stakeholder connections (e.g., if you know someone who would be good for the team to connect with). Additionally, propose next steps and strategies to help the team meet their remaining objectives.

In addition to the 1–2 page report, also include your meeting notes as an appendix. These do not need to be formal; they can be bullet-point notes that summarize the advisory board meeting and provide detailed feedback on the presentation. Feedback on the presentation can address both the content and depth (substantive) and the way it is delivered and presented (stylistic).

Other key notes:

- Write the name of the team you are providing feedback for at the top of the advisory report and in the name of the document.
- Be sure to include your name as well so that the team can follow up as needed.

Advisory Board Team Recap

One of the goals of the advisory boards is to have the opportunity to learn from your peers in BME. Therefore, among the team members, you all should have attended the advisory boards of all the other projects, except the ones that presented in the same time slot as you.

In this assignment, recap the projects of your peers by describing what each project is, its strengths, weaknesses, and any lessons learned that could be applied to your team's project. Consider technical, clinical, regulatory, IP, and business questions that were brought up during the advisory boards, and comment on whether they are relevant.

Summarize your discussions for each of the advisory boards that all team members attended, making sure to write **a paragraph or more** about how that information will be used by the team moving forward.

D. Advisory Board Reply

Address the feedback your team received from the advisory board. This should include feedback from advisory board reports, questions raised during the session, and notes from instructors. Similar feedback may be consolidated. For each comment, you should:

1) Provide a few sentences of commentary on the feedback received and your team's impressions (e.g., already considered by the team, a new consideration, etc.).
2) Explain what changes will be made in response to the feedback, or justify why changes will not be made.
3) Use literature, stakeholder information, or calculations to support your reply as needed.

Responses should be well thought out and should reflect the team's discussion.

E. Email Stakeholders

Identify and email **10 real stakeholders**. They can range from professors to industry professionals to graduate students. Refer to the flipped lecture for more detail.

Create a generic template that can be used in all emails and write it below. Tabulate the stakeholder information in the spreadsheet found in your team drive, and include a screenshot here showing your emails in the spreadsheet.

Important: Emailed stakeholders cannot overlap between team members (e.g., 5 members = 50 unique emails).

Email Template: Dear Professor __________________,

My name is __________________ and my project is __________________________. Your experience in ____________________ would provide great insight for our project. Would we be able to set up a time to chat? Thank you for your time!

Best,

____

F. Stakeholder Interview and Write-up

Stakeholder opinion is a core component of a successful engineering project. Individually, you will be required to contact **5 stakeholders** over the course of the semester, with checkpoints each week in the individual assignment.

After reviewing the *"Talking to Stakeholders"* flipped lecture, contact and meet with a stakeholder. Following your meeting, write a **1-page report** describing:

- the stakeholder's background,
- why you selected them to talk to,
- the insights you gained from the meeting, and
- how those insights will impact the direction of the team.

In addition to the one-page summary, include a **transcript** of the meeting. You may:

- record the conversation (with the stakeholder's permission),
- take live notes during the interview (ideally assigning a team member to handle transcription so you can stay fully engaged), or
- use built-in audio transcription features such as those available in Zoom.