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Work-in-Progress: FLEX Journals as a Theory-to-Practice Framework for Formative Assessment of Student Design Processes

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Introduction

This work in progress study presents preliminary results from a design-based research [1] effort examining how documentation formats influence the quality of formative assessment evidence available to instructors of project-based engineering design courses. Prior work revealed that engaging students in active reflection throughout their design process helps balance teaching and learning creative design intent and technical engineering execution [2]. This study extends that work, examining the FLEX Journal (**F**ormative **L**earning, **E**valuation, and e**X**ploration). Grounded in cognitive frameworks for Reflective Practice [3], expert-like decision-making [4], Deliberate Practice [5], and Preparation for Future Learning [6], the FLEX Journal provides weekly scaffolding for students to document progress, visualize thinking, and explore design decisions throughout their projects. It integrates intentional reflection and decision-making as deliberate course components, reinforcing their centrality in developing design practice.

Through comparative case analysis of student artifacts, we investigate how the FLEX Journal captures evidence of student thinking and decision-making. Using qualitative coding grounded in our cognitive frameworks, we compare how each documents competency development to address: (**RQ1**) What evidence of student thinking do FLEX Journals capture (Manipulation Check), and (**RQ2)** How does the breadth and quantity of evidence differ across FLEX Journals (FJ) and Photo Essays (PE) for similar student archetypes (Between-Subjects Differences)?

This work in progress paper presents our methodological framework, analytical approach, and preliminary results. Full coding results and comparative thematic analysis will follow in future work. We invite dialogue with engineering educators on how theory-informed reflective instruments like the FLEX Journal may impact student development and the challenges of both cultivating and evaluating intentional, reflective design practice in project-based learning.

Background & Theoretical Framework

This study extends a multi-year design-based research effort in an intermediate-level engineering design course focused on CNC machining. The course structure, learning objectives, and theoretical foundations are detailed in [2]. Briefly, the course prioritizes developing intentional designers capable of balancing creative design intent with technical execution through two individual CNC-machined design projects. Earlier research phases identified gaps between intended and enacted instruction, leading to curricular redesign and the Reflective Brief to develop reflective decision-making as a critical skill. Students who consistently engaged in targeted, expert-like reflections demonstrated higher project performance, validating the impacts of embedded reflective practice. Now, we examine the FLEX Journal, designed to make reflection ongoing rather than milestone-based. Below, we summarize cognitive frameworks grounding the journal's design. For comprehensive details on prior interventions, see [2].

Reflective Practice: Iterative Metacognition

Reflection enables designers to analyze decisions, consider alternatives, evaluate outcomes, and adapt strategies in response to encountered or anticipated challenges. Schön's seminal work on Reflective Practice (RP) describes design as an ongoing "reflective conversation" with and within a given situational context [7]. This iterative responsiveness is inherent to skillful design practice. With greater expertise, making novel connections and rapid decisions may appear more intuitive, requiring less conscious effort; however, learners must develop this metacognitive and contextual expertise in design decision-making which reflection helps enable.

Expert-like Questioning: Decision-making Behaviors

To operationalize reflective practices for building design competency, we looked to Price et al.'s characterization of the twenty-nine critical questions STEM experts use when problem-solving [4]. We adapted those Expert-like Questions (EQ) most applicable to engineering design contexts and mapped them to empirically-validated reflective practices from Salehi's problem-solving framework [3]. Mapped sample questions are included in Table 1.

TABLE 1

Expert-like Reflective Questions for Design Problem-Solving

Reflective Practice	Expert-like Questions
Reflection on Problem Definition and Assumptions	How am I framing the problem? Are my assumptions/simplifications appropriate? What constraints matter most?
Reflection on Knowledge	What do I know that can help me solve the problem? What additional knowledge do I need? Where can I find this information?
Reflection on Strategy	What are different approaches to solving this problem? How well is my current approach working? When should I pivot to an alternative?
Reflection on Solution	How good is my solution? What trade-offs did I make? Should I integrate or further iterate?

Deliberate Practice: Skill Development

Deliberate Practice (DP), Ericsson's seminal theory of expertise development [5], proposes that mastery of a skill is achieved not through generic repetition but through effortful, intentional practice of specific subskills under expert guidance. DP requires four essential elements: (1) decomposition of complex skills into distinct, learnable subgoals; (2) learning activities for each subgoal tailored to the learner's current level of preparation; (3) detailed, specific, and timely feedback on performance; and (4) opportunities to incorporate feedback and iteratively improve.

Preparation for Future Learning: Adaptive Transfer

Preparation for Future Learning (PFL) [6] challenges traditional paradigms of demonstrating immediate performance on well-defined tasks. PFL emphasizes developing students' capacity to learn and adapt their knowledge to different contexts. This skill is critical in engineering design, where practitioners face rapidly evolving technologies and ill-structured problems which cannot be comprehensively anticipated in learning spaces. PFL posits that learner-centered activities completed *before* direct instruction improve cognitive readiness. Students develop organizing frameworks, identify gaps, and formulate questions making subsequent instruction more meaningful and applicable. This "time for telling" suggests that instruction is most effective when students first engage in productive struggle, making them receptive to expert guidance [8].

Methods

Course Context

The study targets an intermediate-level computer-aided design and manufacturing course at a US-based R1 university. Admission is by instructor permission due to enrollment constraints, and both undergraduate and graduate students pursuing degrees in Design or Mechanical

Engineering receive priority. Students engaging in personal, research, or course-related projects requiring CNC mills in the university's student-run machine shop also must complete this course.

During the six academic terms evaluated in this study over two academic years, the course admitted 22–29 students per term. Student enrollment data is overviewed in Appendix A. Students complete two individual design projects (midterm and final), each following a four-phase design sequence (Figure 1). They develop and manufacture CNC-machined products in response to an open-ended prompt. While prompts and processes may vary across courses and institutions, this sequence aligns with ABET defined design components [9].

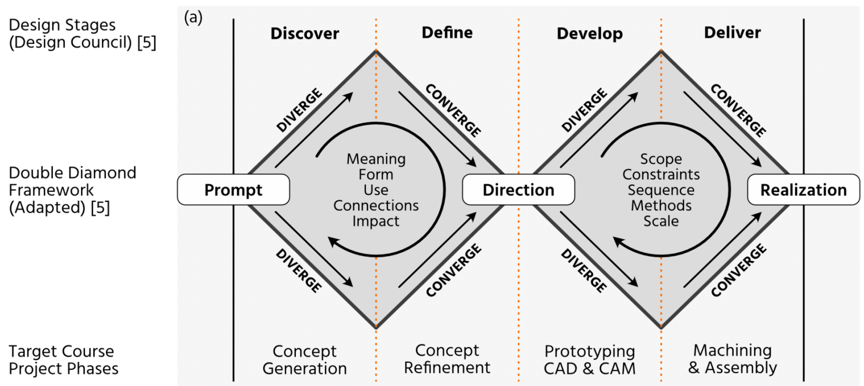

Figure 1. Double Diamond project sequence, adapted from [10]. Vertical lines indicate project milestones, with the middle three denoting one-on-one check-ins. While milestones support project progression, the dashed dividers illustrate the iterative, non-linear nature of design [2].

Study Design

The research study began in Autumn quarter 2023. This paper's primary author collaborated with the instructor as a researcher and instructional designer to help refine the course's structure and content over two academic years as described in [2]. Table II visualizes this sequence, coding each term according to the iteration of the primary reflective artifact collected from students; Photo Essay (PE1, PE2), Reflective Brief (RB1, RB2), and FLEX Journal (FJ1, FJ2).

TABLE II

Study Timeline and Intervention Artifacts

Study Phase	**Teaching Observation**			**Reframe & Redesign**	**Implementation**		
Year	2023-2024				2024-2025		
Term	Autumn 23	Winter 24	Spring 24	Summer 24	Autumn 24	Winter 25	Spring 25
Label	PE1	PE2	RB1	—	RB2	FJ1	FJ2
Role	Baseline 1	Baseline 2	α-Int. 1	—	α-Int. 2	β-Int. 1	β-Int. 2
Artifact	Photo Essay	Photo Essay	Reflective Brief	—	Reflective Brief	FLEX Journal	FLEX Journal

Data Collection

Entry Survey

Students completed an entry survey within the first three weeks of instruction to capture a preliminary snapshot of their incoming perspectives and preparation related to engineering design. The survey also requested basic demographic data to characterize the course population. Participation was voluntary with no penalty for non-participation, incentivized with extra credit.

Design Assessment
Students completed a scenario-based formative design assessment—authentic to subsequent tasks and thinking encountered in the course—in offerings RB2, FJ1, and FJ2; measuring ability to apply design practices in Discover and Define phases (Figure 1). This PFL activity and class diagnostic had students consider effective design practices before applying them to project work.

Student Artifacts
The student artifacts served dual purposes; functioning as instructional tools to support and enhance student learning while simultaneously providing rich data for this research study.

Photo Essay

The Photo Essay (PE) is a standard deliverable in prerequisite introductory courses [11] for students to collect, organize, and communicate their project work. In PE1/PE2, it consisted of a slide deck limited to three to five slides that documents highlights from students' process and the final physical product. See Appendix B for PE2's midterm project and photo essay assignment. The Photo Essay summarizes students' process and provides communication practice; however, it frames documentation as an afterthought. Students typically saved this assignment until the end of projects, reviewing work retroactively, capturing limited information, and approaching the documentation as a presentation tool rather than an intentional formative practice.

Reflective Brief

The Reflective Brief (RB), detailed in [2], was introduced in RB1 and RB2 as a milestone-based reflective tool that prepared students for instructor one-on-ones through phase-specific prompts. Students who consistently engaged with the briefs demonstrated higher project performance and received more targeted formative feedback [2]. These findings validated the pedagogical value of embedded reflective practice and directly informed the design of the FLEX Journal.

FLEX Journal

Engineering education research indicates that structured reflective activities, such as journaling or guided questioning, significantly enhances students' ability to connect theoretical knowledge with practical applications [12]. Thus, for our beta intervention, we developed the FLEX Journal (FJ) for offerings FJ1 and FJ2. The journal format provides a guided yet adaptable weekly structure for students to document their progress, visualize their thinking, and explore design pathways throughout their entire design process. Students captured their thoughts and progress through sketches, photographs, and/or writing. Appendix C provides a weekly rubric and describes how the journals fit the course grading scheme.

The FLEX Journal operationalizes our four theoretical frameworks: (1) **RP** [3]: engages students in responsive metacognitive dialogue with their design process, prompting reflection rather than mere documentation; (2) **EQ** [4]**:** scaffolds intentional decision-making via prompts that model expert considerations; (3) **DP** [5]: builds in weekly repetition and targets phase-specific subskills for reflective design practice; and (4) **PFL** [6]: sequences submissions before one-on-ones to enable targeted formative feedback. The journal's structural features (3, 4) create conditions for developing reflective and expert-like thinking (1, 2), evidence of which we assess through submitted artifacts. Appendix D shows a sample FLEX Journal assignment from FJ2.

Offering Selection
This work in progress paper compares PE2 and FJ2, because (1) each represents the most refined implementation of its artifact and (2) the five-quarter interval encompasses the complete cycle of artifact iteration and curricular redesign. Our initial work focuses on students' midterm projects to assess their earliest experiences with these intervention artifacts. Structural differences between formats, FLEX Journals' open weekly reflections versus Photo Essays' constrained retrospective summaries, are not confounds but the focus of investigation. Our interest is not whether FLEX Journals capture *more* evidence, as we expect this. Rather, we examine how redirecting student attention, from *product* documentation toward *process* reflection, changes what *kinds* of evidence become visible and whether this visibility supports formative assessment.

Participant Selection
Our sample included students who provided informed consent, completed the entry survey, and submitted the target reflection artifact. Students who declined consent, took an incomplete, or withdrew from the course were excluded. If submitted multiple times, we used the last complete survey submission. Students with complete surveys but incomplete artifact data were included only in statistical analyses. Of the 23 students enrolled in PE2, 20 have complete data for full inclusion. Of the 23 students enrolled in FJ2, 19 have complete data for full inclusion.

Analysis
Analytical Framework
We deductively coded student artifacts, applying a binary coding scheme to address our research questions. Our codebook (Appendix E) drew from theoretical frameworks of reflective practice [3] and expert-like decisions [4] to identify evidence of student thinking, as well as design process phases [10] inferred from representative design activities [2]. This framework enabled systematic examination of students' artifacts. To facilitate comparison between design decisions and reflective practices, and align with institutionally implemented frameworks [11], we collapsed a subset of the 29 problem-solving decisions [4] into four Design Decision (DD) codes that parallel Salehi's Reflective Practice (RP) structure [3]. This enabled direct comparison of student decision-making versus reflective thinking within parallel domains of design practice.

Binary coding provided a consistent, replicable method for identifying the presence of specific practices. DD and RP codes were mutually exclusive within and across their respective categories; however, either could co-occur with General Documentation codes. This allowed for comparison between PE2 and FJ2 artifacts despite differing structure and submission frequency.

Sample Selection
For intercoder agreement and refining the codebook, we selected four exemplar students—two each from PE2 and FJ2—reflecting distinct profiles along the course's dual emphases: creative design intent and technical execution [2]. We sampled using a two-dimensional scoring system based on self-assessed technical and non-technical scores, informed by incoming design ability.

Incoming Design Ability Score
The design assessment, described previously, measured students' incoming design ability. An AI-assisted scoring system adapted from [2] evaluated responses using GPT-5.2 in a secure university sandbox. Researchers directed the model to: (1) generate a three-level quality rubric

based on project discovery and definition characteristics, (2) score each response (3-1) and provide evidence-based justification. Researchers validated the AI outputs for face validity and alignment with the course before normalizing scores for a baseline measure of design ability.

Self-Assessed Technical and Non-Technical Scores

These scores identified students' incoming experience, confidence, and perceived value in technical versus non-technical skills. Each score averaged eight Likert-scale questions from the entry survey (Appendix F). Five questions (5-point scale) established a base score while three questions on perceived value of knowledge, experience, and identity (4-point scale) applied a 0.9–1.1 multiplier. Normalized scores indicated greater alignment with each skill domain.

Relationship between Scores

Table III presents summary statistics for correlation analyses, paired t-tests, and effect size on technical, non-technical, and design scores. Technical and non-technical scores showed negligible correlation (PE2: $r = 0.20$, $p = .366$; FJ2: $r = 0.13$, $p = .577$), indicating two distinct skill domains (Table IV). Students' design scores correlated positively with non-technical scores ($r = 0.46$, $p = .041$) but not with technical scores ($r = 0.18$, $p = .442$) (Table V).

This positive correlation between design and non-technical skills, combined with technical skills' independence from both measures, reveals these domains operate distinctly. It suggests students who operationalize their broader experiences, identity, and values in engineering design exhibit stronger discovery and definitional design practices while incoming technical proficiency has minimal bearing on initial design capabilities. This informed our case selection of students with similarly high non-technical but contrasting technical scores to examine whether FLEX Journals help instructors support students in translating conceptual strengths into technical executions.

TABLE III

Summary Statistics for Course Offerings PE2 and FJ2

Course Offering (n)	Technical Score Mean (SD)	Non-technical Score Mean (SD)	Design Score Mean (SD)
PE2 (n = 22)	0.76 (0.16)	0.47 (0.13)	NA
FJ2 (n = 20)	0.66 (0.17)	0.48 (0.16)	0.64 (0.14)

TABLE IV

Statistical Tests Between Self-Assessed Technical and Non-Technical Scores

Course Offering	Correlation (r) (p-value)	Paired t-test (p-value)	Cohen's d (Effect size)
PE2 (n = 22)	0.20 (0.366)	7.34 (<.001)*	1.98**
FJ2 (n = 20)	0.13 (0.577)	3.66 (0.002)*	1.08**

* significant at α = .05 | ** effect sizes > 0.8 are large

TABLE V

Statistical Tests Between Design and Technical/Non-Technical Scores for FJ2

Comparison	Correlation (r) (p-value)	Paired t-test (p-value)	Cohen's d (Effect size)
Technical & Design	0.18 (0.442)	-0.46 (0.649)	-0.13
Non-technical & Design	0.46 (0.041)*	4.49 (<.001)*	1.04**

* significant at α = .05 | ** effect sizes > 0.8 are large

Exemplar Case Selection
We plotted FJ2 students' technical scores versus non-technical scores, with design assessment scores as a color gradient (Figure 4). We selected students positioned at the outer range of at least one metric to ensure representation of diverse student profiles, yielding two exemplar cases: (1) Student FJ2S21, High Technical–High Non-technical (HT-HN), and (2) Student FJ2S02, Low Technical–High Non-technical (LT-HN). This pairing enables examination of how the FLEX Journal supports students with different technical but similar non-technical foundations.

Matched Comparison Students
We identified comparable PE2 students using Euclidean distance analysis (technical score, non-technical score). Because the design assessment was introduced in RB2, we excluded design scores from matching. For each FJ2 exemplar, we identified the three closest matches and cross-referenced with Photo Essay submission status to select the closest match who submitted an artifact, yielding two matched pairs. This 2×2 design enables comparison of metacognitive evidence across different student categories and documentation structures.

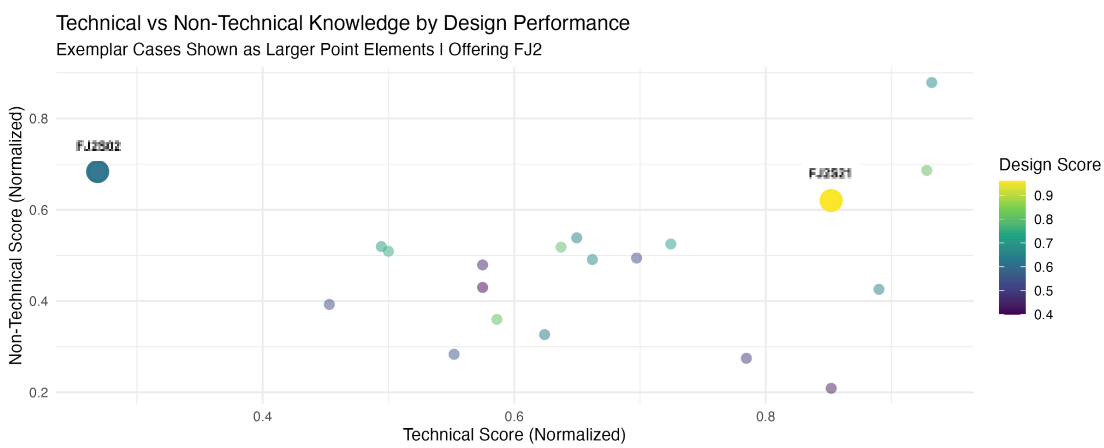

Figure 4: Normalized self-assessed non-technical vs. technical scores by design score as color.

Qualitative Coding
The lead investigator developed an initial codebook grounded in the theoretical frameworks described above. Two coders independently applied it to FLEX Journals from four students, using QualCoder. Coders identified natural sections within the FLEX Journals and compared the presence or absence of codes within each section. This approach was chosen because journal entries were organized into discrete units [13], either by instructor-required elements or by students' own organizational choices. Since each section functioned as a coherent unit of student thinking, coders checked if evidence of specific decisions or reflections was present per section.

Codebook refinement occurred over three iterations; each consisted of independent coding, comparison, discussion of discrepancies, and revision of definitions and boundaries. Iterations focused particularly on clarifying distinctions between Decision and Reflection codes to ensure mutual exclusivity. Following refinement, the coders independently coded one week's FLEX Journal submissions for the four students, compared results, and resolved disagreements through discussion. To interpret the reproducibility of the coding scheme, we calculated intercoder reliability and agreement (Table VI), incorporating reconciliation of coding discrepancies via discussion to account for differences in subject matter knowledge [13].

TABLE VI

Intercoder Reliability and Agreement

Category	Total Codes (Denominator)	Independent Agreement (ICR)	Post-Discussion Agreement (ICA)	ICR %	ICA %	Deferred to Primary Coder	Deferred to Secondary Coder	Irreconcilable
Total	**169**	**56**	**167**	**33.14%**	**98.82%**	**67.57%**	**30.63%**	**1.80%**
General Documentation	38	19	38	50.00%	100.00%	68.42%	31.58%	0.00%
Design Decisions	61	20	61	32.79%	100.00%	65.00%	35.00%	0.00%
Reflective Pratice	70	17	68	24.29%	97.14%	69.23%	26.92%	3.85%

Preliminary Results

Table VII presents a summary of coding results for the selected cases. Appendix G and H contain excerpts of comparative examples of LT-HN artifacts and HT-HN artifacts, respectively.

TABLE VII

Binary thematic coding for High Technical–High Non-technical (HT-HN) and Low Technical–High Non-technical (LT-HN) FLEX Journals and Photo Essays

	General Documentation					Design Decision				Reflective Practice				Total Codes	Total Code Categories (%)
	PD1	PC1	PD2	PC2	OKS	PFS	RII	RKA	PPM	RDA	RKN	RST	RSL		
HT-HN FLEX Journal	X	X	X		X	X	X	X	X	X	X	X	X	74	12 (92%)
HT-HN Photo Essay	X		X	X		X		X	X	X	X	X	X	38	10 (77%)
LT-HN FLEX Journal			X			X	X	X	X	X	X	X	X	27	9 (69%)
LT-HN Photo Essay	X	X	X	X						X				7	5 (38%)

RQ1: What evidence of student thinking do FLEX Journals capture?

Preliminary results indicate FLEX Journals provide richer evidence of decision-making and reflective processes compared to Photo Essays. Our codebook captured evidence of all DD and RP codes across FLEX Journal entries, demonstrating comprehensive coverage of metacognitive activity. Higher evidence-capture in FJ2 does not imply PE2 students exercised less sophisticated thinking, only that Photo Essays' retrospective, summary presentation format made this thinking less visible. The FLEX Journal's structured prompts and ongoing submission cadence make student cognition observable while instructors can still provide timely, formative intervention.

RQ2: How does the breadth and quantity of evidence differ across FLEX Journal and Photo Essay artifacts for similar student archetypes?

Despite comparing a single week's FLEX Journal against the Photo Essay's comprehensive final project documentation, FLEX Journals exhibited broader code category representation and higher total code counts. This suggests the structured weekly format captures more diverse and abundant evidence of student thinking, providing instructors with more representative visibility into students' design processes throughout development rather than only retrospectively.

Discussion

This work in progress demonstrates that theory-informed instrument design that deliberately operationalizes cognitive frameworks through structural features can make typically invisible design competencies observable and assessable. This visibility supports formative feedback that improves student learning and generates evidence of competency development. The finding that non-technical skills correlate with design performance, while technical skills do not, challenges the centering of STEM knowledge application. Students who incorporate diverse experiences and identities as design resources may enter with cognitive advantages. Cultivating cognitive awareness through reflection can help inform design decisions and complement technical skills.

Our preliminary findings suggest the FLEX Journal successfully operationalizes its four theoretical frameworks showing theory to practice alignment. The presence of all target design decision and reflective practice codes (RQ1) indicates it captures evidence of both expert-like decisions [4] and reflective practice [3]. More importantly, higher code frequency and broader category representation—even in single-week FLEX entries versus comprehensive Photo Essays—demonstrates that structured, ongoing prompts make more kinds of student thinking visible than retrospective documentation (RQ2). This visibility stems from deliberate design grounded in DP and PFL principles. Weekly submissions before one-on-ones create Schwartz and Bransford's "time for telling" [8]; students struggle productively, document thinking, then receive targeted feedback when prepared to integrate it. Phase-specific prompts decompose complex competencies into learnable subskills while weekly repetition provides iterative improvement opportunities [5].

Formative Assessment for Timely Intervention

The pedagogical value of FLEX Journals extends beyond simply capturing more evidence; the timing and specificity of evidence fundamentally changes instructors' capacity for formative intervention. Photo Essays, submitted after project completion, function as summative documentation, useful for grading and portfolio development but offering no opportunity for correction. In contrast, weekly journals reveal when students make critical decisions, encounter challenges, or demonstrate misconceptions while instructors can provide actionable guidance.

Bridging Reflective and Technical Capabilities

The positive correlation between non-technical scores and design assessment performance, combined with technical scores' independence from both measures, reveals an important pedagogical opportunity. Students who operationalize their broader life experiences, diverse knowledge, and personal values in design contexts demonstrate stronger initial abilities in the creative, problem-framing phases of design. However, this conceptual strength doesn't automatically translate to technical execution, as evidenced by the lack of correlation between technical experience and design assessment scores. Furthermore, technical experience alone is unlikely to translate into compelling and meaningful design choices. The FLEX Journal's structure may help bridge this gap. By prompting students to explicitly document not just *what* they're doing but *why* and *how* they're making decisions, the journal scaffolds connections between design intent and implementation.

For LT-HN students, articulating and reflecting on decision-making processes may help them recognize specific technical knowledge gaps and strategies for addressing them, preparing them to seek targeted guidance. For HT-HN students, the same prompts can deepen connections between technical proficiency and creative resources, enabling more conceptually ambitious project outcomes within their zone of proximal development. Future analysis will explore whether these prompts support HT-LN students in developing metacognitive awareness of how mechanical affordances can inform design exploration, preventing technically proficient but creatively shallow solutions. These interpretations align with Schön's conception of design as a reflective conversation [7]. The FLEX Journal externalizes students' internal dialogue, making it visible and evaluable. Repeated engagement in structured reflection helps students develop habits of mind that characterize expert-like design practice.

Generalizability

While this study examines a specific CNC machining course, the FLEX Journal framework transfers to project-based design contexts more broadly. The Double Diamond (Figure 1) aligns with ABET-defined design components [9], and the underlying cognitive frameworks apply across engineering disciplines. The key transferable insight is not the specific prompt language but the principle that structured, ongoing reflection that scaffolds expert-like thinking and creates formative visibility makes student development more observable and supportable. However, implementation requires careful attention to cognitive load and assessment burden. Students in FJ2 produced 2–25 page weekly submissions, substantial work that must feel meaningful rather than performative. The instructor managed this through strategic grading (completion-based weekly scores with deeper feedback cycles) and by positioning journals as student-centered learning tools first, assessment artifacts second. Educators adapting this approach must balance rigor with practical sustainability for both students and instructors.

Limitations

While the overall study includes a substantial dataset across six course offerings (n = 120), individual offering sample sizes are relatively small (n = 22-29), limiting statistical power for quantitative comparisons. However, the depth and multimodal richness of qualitative data from student artifacts provides robust material beyond this case study. This paper demonstrates the coding methodology and establishes proof of concept for the comparative framework. Despite the FLEX Journal's success in capturing more frequent and varied evidence of student thinking compared to Photo Essays, ambiguities occurred. When students' intended meaning was unclear, particularly when distinguishing between students' thinking and ideas given by the instructor, coders conservatively excluded those segments rather than risk misinterpretation. This approach may underrepresent the full extent of evidence present.

Future Work and Open Questions

We are completing coding for the full dataset which will enable statistical comparison of code patterns across student profiles and artifact formats, testing whether our preliminary qualitative observations hold at scale. A longitudinal analysis examining within-student development across project cycles is also ongoing, helping reveal whether continuous reflection supports progressive skill development differently than milestone-based documentation. Cross-offering comparison incorporating Reflective Brief data will further illuminate how instrument timing and structure independently influence what evidence students record.

Several questions remain open for community dialogue: What indicators and measures distinguish surface-level compliance from deep engagement with reflective practice? How can educators balance formative assessment value with practical grading constraints in large courses? What computational tools or approaches can help make this assessment of rich, complex datasets efficient at scale? We invite engineering educators to engage with these challenges as we collectively work toward cultivating intentional, competent, and reflective design practitioners.

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Appendix A

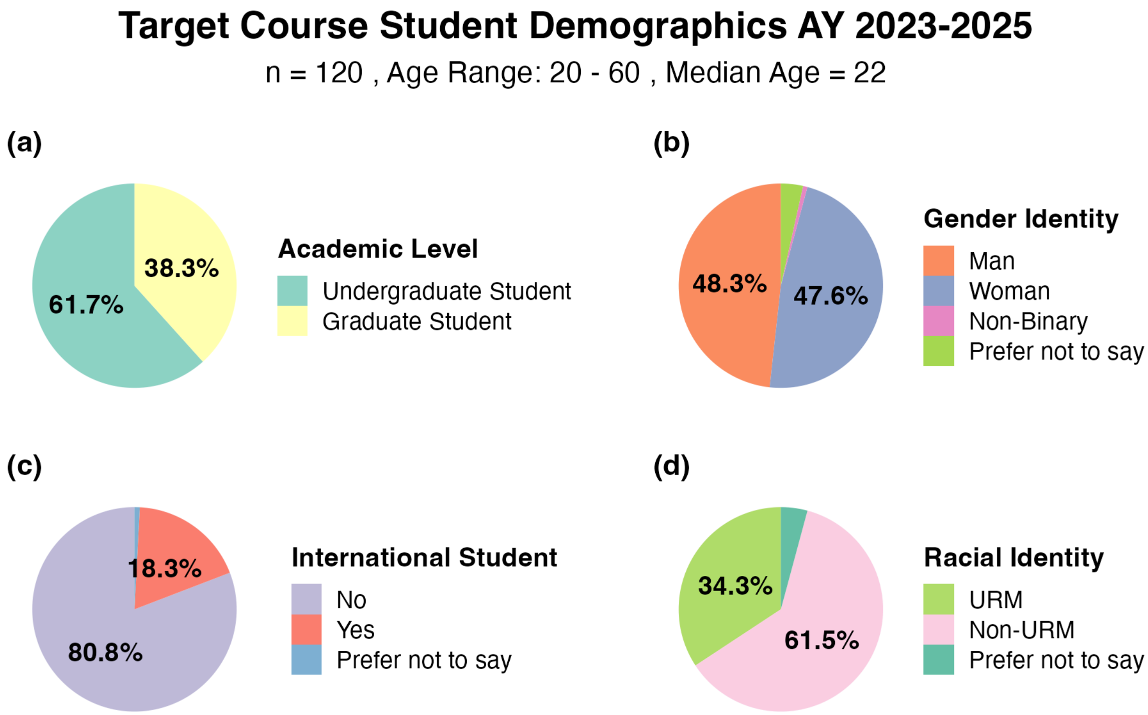


Figure 5. Target course's student demographic data during academic years 2023-2024 and 2024-2025 (n = 120). Charts show relative distributions by self-reported (a) academic level, (b) gender identity, (c) international student status, and (d) racial identity. Students' ages ranged from 20 and 60 years, with a median age of 22. [2]

Appendix B
PE2 Midterm Project Description & Deliverables (Minimaze)

Assignment
Design a miniature "maze" inspired by the following theme:

The future as you see it.

Your final design will ultimately be modeled in Fusion but should start with Lateral Thinking about the theme and hand sketches.

Constraints
Your final design needs to be machinable from the given standard aluminum stock volume, and must include:
- Stainless steel bearings to run your maze
- An acrylic lid
- At least two supplied 6-32 UNC threaded fasteners
- Matching threaded holes to accommodate these fasteners for the lid to capture your bearing(s) permanently in the maze
- Your name and date engraved on the back

Available Materials
- 1 aluminum block: 1.625" x 1.625" x 0.375"
- 1 clear acrylic sheet: 1.625" x 1.625" x 0.125"
- Stainless steel bearings to run your maze, as needed: available diameters are 0.0625, 0.125", 0.156", and 0.188"
- Two or more 6-32 UNC button head hex cap screws

Goals
This assignment will start you on a path to elevate your levels of conceptualization, design, use of materials, and introduce designing for CNC manufacturing. For the first few days stick with hand sketching. It will be great practice in fluid thinking and visualization.

Assignments Due
- Lecture, Week 2 - Maze concept sketches, .pdf uploaded to Canvas
- Sunday, Week 2 - Maze CAD
- Lab, Week 3 - Maze CAM Checkoff
- Lab, Week 4 - Final Maze + Drawing
- Lecture, Week 5 - Maze Presentations in class + Documentation detailed below

Tip: You are strongly encouraged to meet intermediate project deadlines early. Machining time is always in high demand nearing major deadlines in this course. We are always happy to review work and check CAM in advance of deadlines!

Deliverables and Documentation

1. **Minimaze** - your machined, finished, assembled minimaze. Enough said!

2. **Photo Essay:** One singular slide deck, PDF horizontal format, no more than 3 pages. The deck should consist of the following sections:
   - **Title**: your name, assignment, project name, date, and professional photo of your work.
   - **Process Story**: Show us the thinking behind your maze. What was the starting point? How did you get to this idea? What was the thematic inspiration? Any iterations? What tools did you use? (sketches, mindmap, lists, concept visualization, aha! moment, prototypes, etc.)
   - **Design Decisions**: visually explain the decisions made behind the design, driven by creativity, usability, form.
   - **Final Design**: High quality image(s) in slides highlighting the qualities of your final design and why you think it is optimal. At least one view from the engineering assembly drawing detailed below.
   - **Documentation Appendix**: Complete scans of all sketches and processes (mind map, etc.), CAD drawing, etc. (the appendix page count is not included in the 3-page maximum).

2. **Engineering Assembly Drawing**
   - Complete an engineering assembly drawing of your maze including all parts, and two views:
     i. Exploded view
     ii. Top-down view
   - Template will be provided.
   - Print your drawing and bring it to lab along with your completed maze when due.

Appendix C
Course Grading and FLEX Journal Rubric

As the instructor iteratively refined the course design, both the pedagogical approach and the grading structure evolved through the DBR process to better support students' design engineering proficiency and reflective practice. In Spring 25 (FJ2)—the primary focus of this comparative analysis—student grades were determined by attendance and participation (5%), quizzes, exams, and structured labs (25%), an intermediate design project (20%), and a final design project (50%). This ultimate grading structure positioned the FLEX journal—and thereby reflection—as an integral component of the course experience and students' project grades. Earlier offerings (A23-A24) used different grade weightings with breakdowns for all offerings shown in Table VII.

TABLE VII

Evolution of Grading Scheme Across Course Offerings

Offering	Attendance & Participation	Quizzes/ Exams/Labs[1]	Starter Project[1]	Intermediate Project[1]	Final Project[1]	Assignments (General)
A23	20%	—	—	—	—	80%[2]
W24	20%	5%†	20%†	30%†	45%†	80%
S24	20%	5%†	—	35%†	60%†	80%
A24	5%	15%	—	35%	45%	—
W25–S25 (FJ1, FJ2)	5%	25%	—	20%	50%	—

[1] † Component percentages of 80% Assignments category in offerings W24 & S24

[2] Offering A23 used a general Assignments category (80%) without specific project breakdown

Intermediate deliverables for both design projects and other necessary homework tasks were embedded within the FLEX Journal structure. This integration meant that students completed one cohesive submission per week rather than treating reflection as an additional or separate activity. Each weekly journal was assigned a point value based on expected content and evaluated using a rubric shown in Table VIII.

TABLE VIII

FLEX Journal Rubric

Criteria	Ratings		
Thoroughness and Evidence of Progress	**Full Credit** The submission includes all required components. Each component clearly demonstrates the progression of work and aligns with the weekly tasks.	**Partial Credit** Most required components are included, but some are incomplete or lack clear evidence of progress.	**No Credit** Key components are missing or fail to document progress in the weekly tasks, showing little to no evidence of effort or understanding.
Depth of Reflection	**Full Credit** Reflections provide thoughtful insights into strategies, challenges, and decisions, showing a deep understanding of the design process and engagement with the prompts. Specific examples and critical thinking are evident.	**Partial Credit** Reflections address prompts but are surface-level or lack specific examples, providing limited insights into strategies or challenges.	**No Credit** Reflections are missing or fail to provide meaningful engagement with the prompts, offering minimal or irrelevant content.
Quality and Clarity of Presentation	**Full Credit** The journal entry is well-organized, with all entries clearly labeled, dated, and legible. Visuals (sketches, photos, screenshots) are clear, appropriately annotated, and effectively communicate the process.	**Partial Credit** The journal entry is moderately organized, but some sections or visuals are unclear, incomplete, or lack proper labeling, making the work harder to interpret.	**No Credit** The journal entry is disorganized, with illegible text or visuals and insufficient labeling, resulting in a submission that is difficult to review.

Appendix D
FLEX Journal Week 2 Assignment (FJ2 Midterm Project: Whistle)

Lecture Comprehension

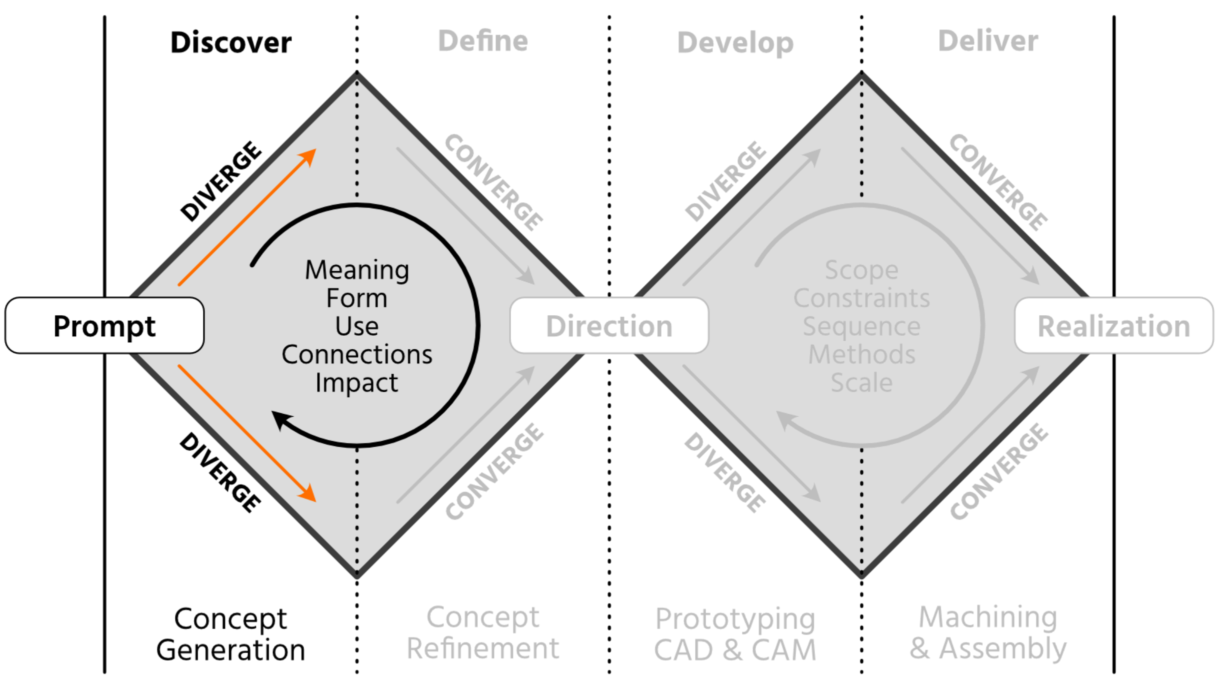
- **Spend no more than one page on this section. Be concise!**
- **Please include the three requested screenshots from the Pre-Lecture slides**
- Reflect on the concepts and approaches discussed in Week 2's lecture.
- Respond to the following prompt:
  "How might the content covered in Week 2's lecture change or inform your design process as it relates to form?"

Whistle Project

- The majority of your FLEX Journal should be devoted to the whistle project development.
- Include all concept sketches for your whistle design. After two weeks of ideating, we expect you to have multiple pages of sketches!!!
- Capture your prototyping process.
- Use the 1:1 Design Brief structure below to help you prepare to discuss your sketches, prototype, and process during your 1-1 check-in during **Lab Week 2**.

1-1 Design Brief

Before our scheduled 1-1, respond to the underlined prompt in each section below. Your response should consider **at least one** of the guiding questions provided in each section. Think about which consideration(s) have been most useful to your Whistle design process. You don't need to write a lot; bullet points are fine. **Keep it concise!!!** The idea here is to get you thinking, not to write an essay. Bring your FLEX Journal entries and Design Brief responses as a conversation guide during your 1-1 this week.



Before your 1-1: Here are some suggestions to help you prepare and get you thinking during concept generation:

Summary: Concept Generation

1. Write a concise summary of your process for concept generation & sketching.

Here are some guiding questions you might consider:

- What varied interpretations of the movie did I explore?
- What elements or aspects of the movie did I pull inspiration from and why?
- How many ideas did I generate?
- Can I categorize my concepts into common themes (iconographies, characters, settings, etc.)? How did I attempt to think outside these boxes?
- What makes my concepts unique or original?

Techniques: Discovery Process

2. Detail specific techniques or strategies you used during your discovery process

Here are some guiding questions you might consider:

- What strategies did I use to ensure I thoroughly explored possible project directions?
- What approaches did I use to uncover non-obvious design directions from my chosen film?
- What did I do when I got stuck or reached a dead end?
- How did my thinking vary in breadth versus depth?

Functional Prototyping

3. Describe your process for developing and testing your prototype

Here are some guiding questions you might consider:

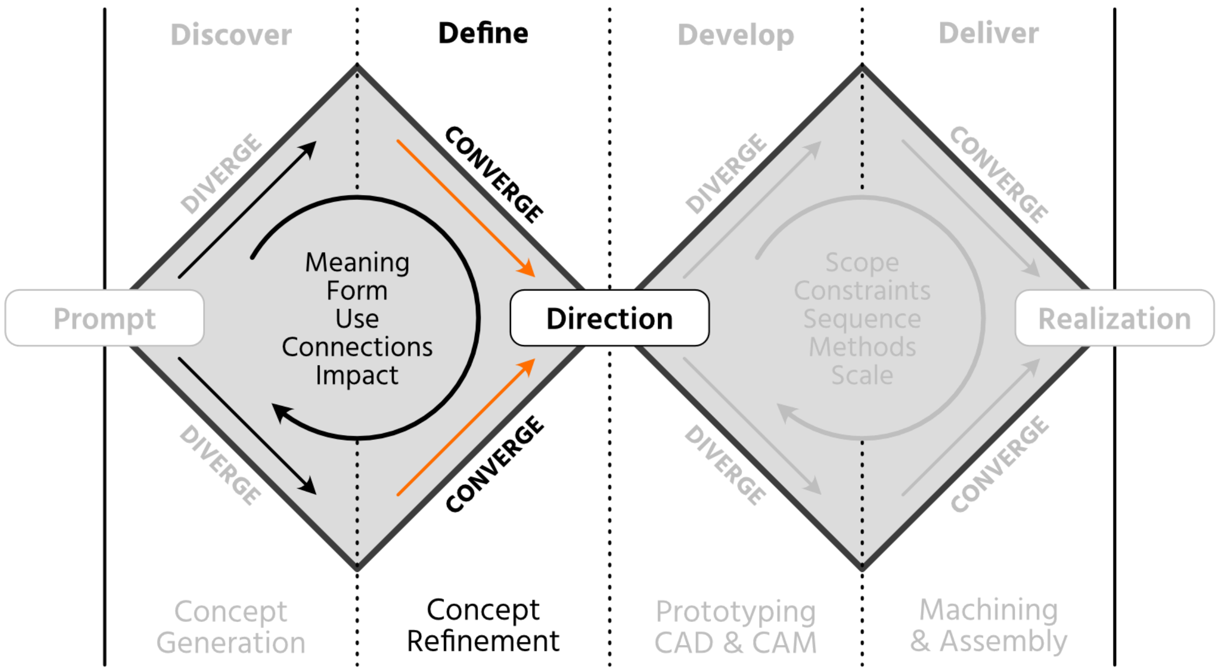
- What are my project's most critical functions, fits, or interactions?
- To what extent did I break down my project into testable sub-components (parts, features, joints/fits, processes, or other sublevels)?
- What driver questions did I try to answer with my prototype?
- What criteria did I use to determine the success or failure of my prototype?
- How many prototypes did I make? How could I optimize my process by testing multiple considerations at once?
- If successful, are there opportunities to further optimize or improve my design? If unsuccessful, how might I iterate my design based on the insights I gained?

Concerns: Top Three Pain Points

4. List your top three concerns you'd like specific help or feedback on

Here are some common issues you might consider:

- Where I'm stuck
- Strategy recommendations
- Process concerns
- Requirement clarification



After your 1:1 - Here are some suggestions to get you thinking and help you proceed as you move toward refining your concepts:

Key Takeaways

1. List your key takeaways from your one-on-one conversation

Here are some guiding questions you might consider:

- How have I interpreted and processed the feedback I received?
- What new insights, questions, or challenges were generated from the discussion?
- In what aspects of my process do I see room for improvement?
- In which areas of my process are my strengths most evident?
- How might I incorporate what we discussed in my upcoming project work?

Next Steps

2. Outline the next steps to take in your project

Here are some guiding questions you might consider:

- What progress do I want or need to make by my next 1:1?
- What should I prioritize among many competing considerations?
- How can I break down larger tasks into smaller, manageable subtasks?
- Are there any resources or knowledge I need to gather to prepare for the upcoming steps?
- What potential challenges might arise, and how can I proactively address them?

Appendix E
Codebook for Student Design Documentation

The codebook (Table IX) consists of 13 codes organized into three main categories: General Documentation (5 codes), Design Decisions (4 codes), and Reflective Practices (4 codes). Drawing from [4], Design Decision codes captured evidence of expert-like decision-making processes, including framing project scope and constraints (PFS), interpreting results and impacts (RII), aligning resources and knowledge (RKA), and planning processes and methods (PPM). From [3], Reflective Practice codes assessed students' metacognitive engagement and questioning, including reflection on their problem definitions (framing) & assumptions (RDA), access to knowledge and resources (RKN), strategic approaches (RST), and solution evaluations (RSL). Based on framing by [2], General Documentation codes identified evidence of students engaging in the four divergent and convergent design phases—Discover (PD1), Define (PC1), Develop (PD2), and Deliver (PC2)—as well as general documentation of ongoing knowledge and skill development (OKS) that did not align with the other frameworks or the specific projects being evaluated but provided other evidence of student learning.

TABLE IX

Codebook for Student Design Documentation

Categories, Codes, and Descriptions

Category	Code	Abbreviation		Description
General Documentation	Project Discovery Activity	PD1		Student shows evidence of exploring various project directions—by identifying opportunities, developing requirements, or generating potential solutions—driven by the initial instructor-provided project prompt.
General Documentation	Project Definition Activity	PC1		Student shows evidence of refining and selecting towards a singular project direction—by performing analysis and synthesis, evaluating solutions against requirements, considering risks, and making trade-offs.
General Documentation	Project Development Activity	PD2		Student shows evidence of exploring various pathways towards realizing a design—by identifying opportunities, developing requirements, or generating potential solutions—driven by their chosen design direction.
General Documentation	Project Delivery Activity	PC2		Student shows evidence of executing their chosen design direction—by performing analysis and synthesis, evaluating solutions against requirements, considering risks, and making trade-offs—to bring about a fully realized final product.
General Documentation	Ongoing Knowledge and Skill Development	OKS		General documentation that neither falls under Reflective Practice nor Design Decisions but provides evidence to the student's ongoing learning and development.
Design Decision	Project Frame & Scope	PFS		Evidence that the student came to a design decision about goals, criteria, constraints, important features, narrowing down problems, potential solutions, or simplifications.
Design Decision	Result Interpretation & Impact	RII		Evidence that the student came to a design decision about difficult/uncertain areas, comparing to predictions, identifying anomalies, drawing conclusions, evaluating solutions, or considering broader implications.
Design Decision	Resource & Knowledge Alignment	RKA		Evidence that the student came to a design decision about what is important in field, opportunities, related problems, information needed, calculations/analysis, or audience for communication.
Design Decision	Process Plan & Methods	PPM		Evidence that the student came to a design decision about design strategy, decomposing into sub-parts, priorities, specific plans for getting information, organizing information, or presentation methods.
Reflective Practice	Reflection on Definition & Assumptions	RDA		Evidence that the student is engaging in reflective thinking about how they frame or interpret the design task, validity of assumptions, goals/criteria, or alternative approaches.
Reflective Practice	Reflection on Knowledge	RKN		Evidence that the student is engaging in reflective thinking about what they know, what they can learn, sources of inspiration/feedback, and available skills/resources.
Reflective Practice	Reflection on Strategy	RST		Evidence that the student is engaging in reflective thinking about different ways to complete tasks, potential outcomes, effectiveness of techniques, or improvements to approach.
Reflective Practice	Reflection on Solution	RSL		Evidence that the student is engaging in reflective thinking about whether proposed solutions make sense, iteration decisions, integration decisions, or implications.

Appendix F
Entry Survey Questions used to Calculate Technical and Non-technical Scores

Questions used for technical score are marked with 🟢 and a 🟣for non-technical questions.

Q4.2 | RQ3-Perception | Relevant Factors

Rate the extent to which the following factors **have practical relevance** in your engineering design work.

		Not at all relevant	Slightly relevant	Moderately relevant	Very relevant	Extremely relevant
🟣	My life experiences	○	○	○	○	○
	My hobbies and interests	○	○	○	○	○
🟣	My personal or cultural identity	○	○	○	○	○
🟢	My **technical** knowledge and expertise	○	○	○	○	○
🟣	My **non-technical** knowledge and expertise	○	○	○	○	○
	External sources (online search, interpersonal sources, research, generative AI, etc.)	○	○	○	○	○

Q4.5 | RQ2-Performance | Leveraged Factors

Rate the extent to which you **leverage, as a source of guidance**, each of the following factors when little instruction is given on how to solve an engineering design problem.

		Not at all	A little	A moderate amount	A lot	A great deal
🟣	My life experiences	○	○	○	○	○
	My hobbies and interests	○	○	○	○	○
🟣	My personal or cultural identity	○	○	○	○	○
🟢	My knowledge and expertise from **technical** disciplines	○	○	○	○	○
🟣	My knowledge and expertise from **non-technical** disciplines	○	○	○	○	○
	External knowledge sources (online search, interpersonal resources, research, generative AI, etc.)	○	○	○	○	○

Q4.8 | RQ1-Population | Prior Knowledge (Pre-Undegrad Experiences)

Rate the amount of experience you possessed **prior to taking this class** in performing the following tasks:

		None at all	A little	A moderate amount	A lot	A great deal
🟢	Using **physical tools** to build or create things (considered broadly, e.g., hand tools, power tools, manufacturing equipment, etc.)	○	○	○	○	○
🟢	Using **mechanical equipment** to do work or perform a task (considered broadly, e.g. lawn mowers, sewing machines, tractors, etc.)	○	○	○	○	○
🟢	**Repairing things** in my home or job (considered broadly, e.g., plumbing, furniture, electrical wiring, etc.)	○	○	○	○	○
🟢	**Disassembling and reassembling** things (considered broadly, e.g., electronics, automobiles, appliances, etc.)	○	○	○	○	○
	Engaging in reflection *throughout* project work (considered broadly, e.g., journaling, diary, vlogging, memos, etc.)	○	○	○	○	○

Q7.12 | RQ3-Perception | Valued Identities (Self)

I value this aspect of my identity within the design and engineering field.

	Strongly disagree	Somewhat disagree	Somewhat agree	Strongly agree
Age or Generational Cohort	○	○	○	○
National or Regional Affiliations	○	○	○	○
Racial or Ethnic Background	○	○	○	○
Gender Identity	○	○	○	○
Technical Interests or Experience	○	○	○	○
Non-Techincal Interests or Experience	○	○	○	○
Other	○	○	○	○

Q7.13 | RQ3-Perception | Valued Identities (Others)

Others value this aspect of my identity within the design and engineering field.

	Strongly disagree	Somewhat disagree	Somewhat agree	Strongly agree
Age or Generational Cohort	○	○	○	○
National or Regional Affiliations	○	○	○	○
Racial or Ethnic Background	○	○	○	○
Gender Identity	○	○	○	○
Technical Interests or Experience	○	○	○	○
Non-Technical Interests or Experience	○	○	○	○
Other	○	○	○	○

Q7.14 | RQ3-Perception | Positive Influence of Identities

I can utilize this aspect of my identity to **positively impact my problem-solving process** within the design and engineering field.

	Strongly disagree	Somewhat disagree	Somewhat agree	Strongly agree
Age or Generational Cohort	○	○	○	○
National or Regional Affiliations	○	○	○	○
Racial or Ethnic Background	○	○	○	○
Gender Identity	○	○	○	○
Technical Interests or Experience	○	○	○	○
Non-Technical Interests or Experience	○	○	○	○
Other	○	○	○	○

Appendix G
Comparative Example of LT-HN Photo Essay vs FLEX Journal Samples

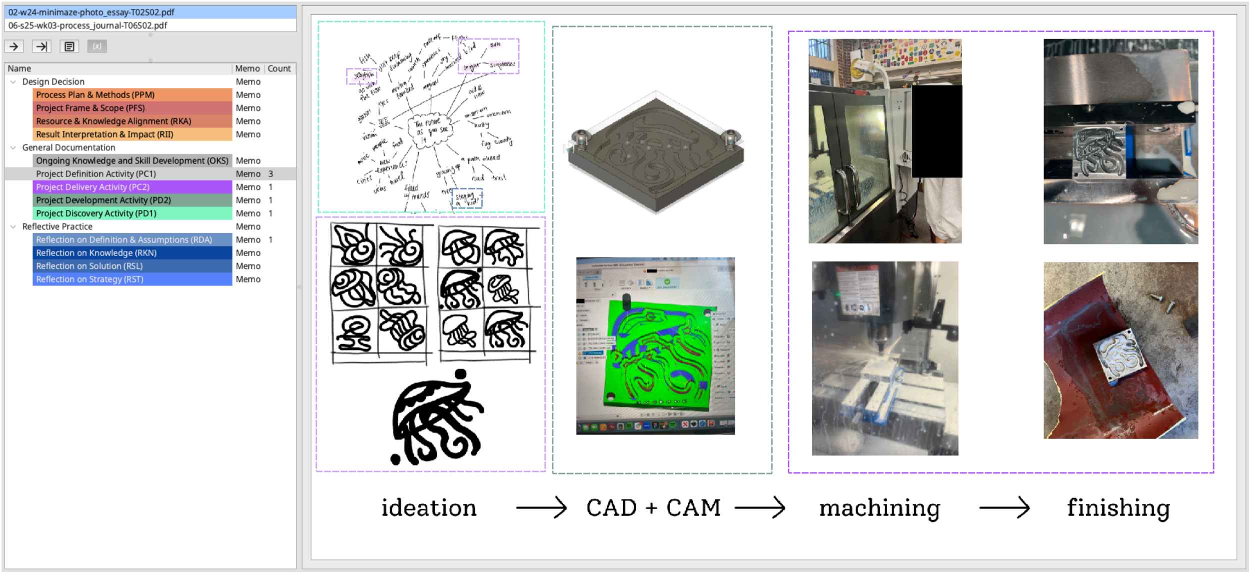


Figure 6: Participant PE2S02 Photo Essay (Page 2 of 3): Captured evidence of 7 codes across 5 thematic categories.

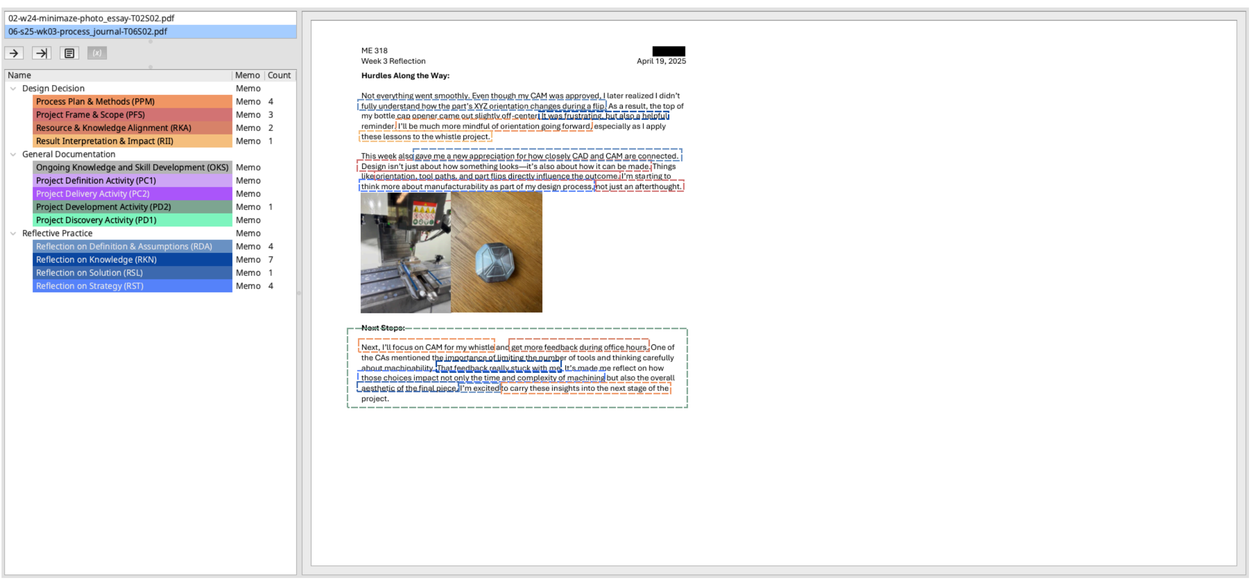


Figure 7: Participant FJ2S02 FLEX Journal (Page 1 of 3): Evidence of 27 codes across 9 thematic categories.

Appendix H
Comparative Example of HT-HN Photo Essay vs FLEX Journal Samples

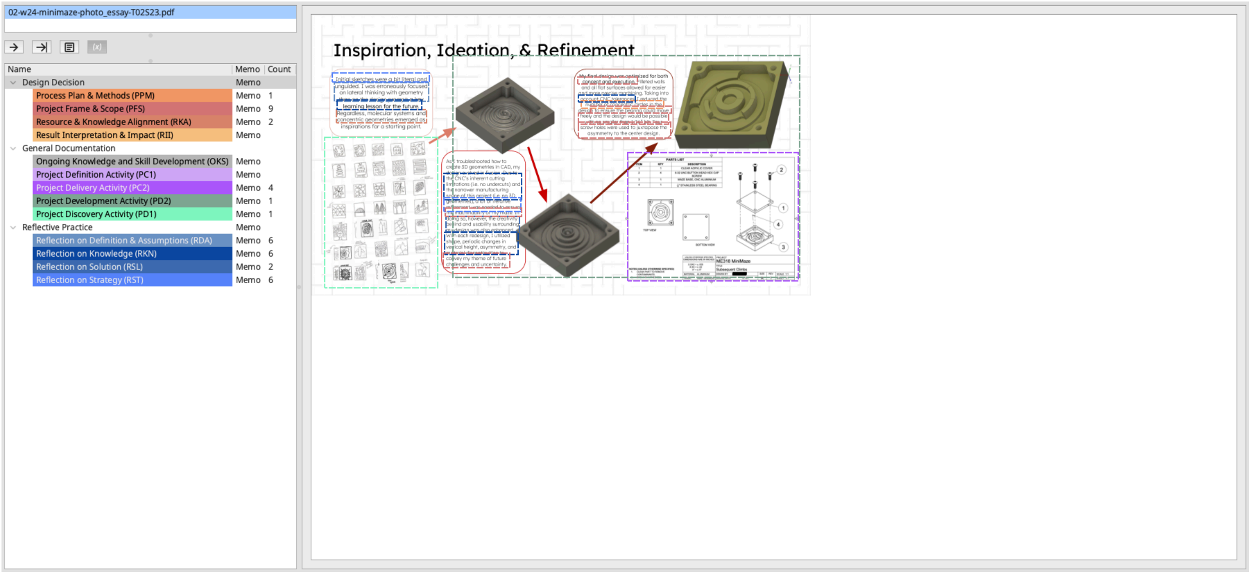


Figure 8: Participant PE2S23 Photo Essay (Page 2 of 9): Evidence of 38 codes across 10 thematic categories (pages 4-9 uncoded supplemental appendices).

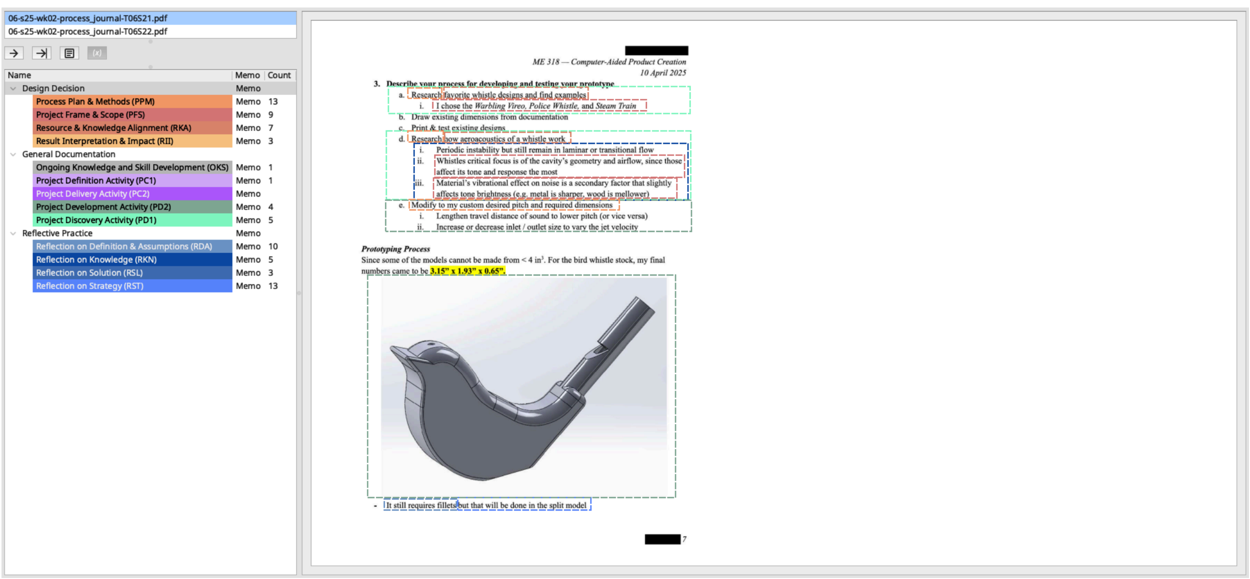


Figure 9: Participant FJ2S21 FLEX Journal (page 7 of 13): Evidence of 74 codes across 12 thematic categories.