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Research as Teaching: On Student Mindset and Voice in a Sustained Collaborative AutoEthnography on Mathematical Modeling

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Abstract

In this complete research paper, we advocate for a methodology with unique research affordances that also serve student mindset development. Mindset is an important element of student development; in particular, metacognition helps students learn more effectively and is a key component of lifelong learning. Theory on reflective practice suggests that key elements of metacognition are best developed through coaching. However, we find that students can develop similar skills through participation in research. We report on student mindset development from a sustained collaborative autoethnographic (CAE) study of student culture and mathematical modeling. Our results suggest two benefits: 1. Engaging in reflective practice through CAE can lead to both enhanced metacognition and advanced learning (benefiting students), 2. Engaging in sustained CAE creates ample opportunities to represent student voices, sharpening our understanding of the research object (benefiting researchers). Our results are of interest to engineering educators seeking research methods that simultaneously promote student mindset development and authentically represent student voices.

Keywords: mindset, classroom strategies, research methods, qualitative methods, mathematical modeling, sustained collaborative autoethnography

Introduction

Mindset is an important element of learning. For instance, metacognition—thinking about thinking—is an important aspect of mindset that promotes deeper and more transferable learning [1]. A review of teaching approaches found that metacognitive approaches are very effective, second only to classroom management techniques [2]. Another metaanalysis found that metacognitive strategies have a high effect size, relative to other teaching interventions (ranked 46 out of 195 factors) [3].

There are specific approaches to promote student metacognition. Journaling involves keeping and reviewing records, both of which have large effects on learning outcomes [4]. Schön's theory of reflective practice is closely related to metacognition [5]: Self-evaluation and Self-monitoring are common between reflective practice and metacognition, and both have large effects on learning outcomes [4].

This complete research paper is from a study of engineering student culture around mathematical modeling—but the study serendipitously led to findings about student mindset development. Namely, we find that students who participated in this research project experienced surprising learning mindset benefits. We attribute these benefits to the qualitative methodology used in the project—*sustained collaborative autoethnography*. This report argues that there is a dual benefit to this methodology: 1. To directly benefit the mindset development of student participant-researchers, and 2. To center student voices in a way that benefits research.

Study Framing

In this section we review the theoretical constructs that frame this study [6].

Reflective practice as a framing of student mindset

Schön advanced the metacognitive idea of *reflection-in-action* as an ideal for practitioners [5]. Reflection-in-action is a kind of self-evaluation and self-monitoring that triggers when one encounters a "surprise" in practice. Schön wrote,

> "Reflection-in-action has a critical function, questioning the assumptional structure of knowing-in-action. We think critically about the thinking that got us into this fix or this opportunity; and we may, in the process, restructure strategies of action, understanding of phenomena, or ways of framing problems." [5, p. 28]

Schön's work suggests that reflection-*on*-action—reflection after the surprising incident has passed—can help students develop their capacity for reflection-*in*-action [5, p. 31]. Therefore, in this study, our data collection emphasizes these elements of reflective practice: both reflection-*in*- and reflection-*on*-action. This also informs our data analysis, where we were on alert for potential episodes of reflection.

While reflective practice is our framing of *methods*, we have a separate framing for the *research object* of the study: mathematical modeling.

Assumptions and limitations as a framing of mathematical modeling

This framing draws inspiration from the statistical adage "all models are wrong, some are useful" [7]: The framing positions assumptions ("wrong"ness) and limitations ("useful"ness) as defining features of a model. In this framing, assumptions and limitations constitute directed relationships between the model and an object in the real world—a *referent*. Figure 1 illustrates the concept.

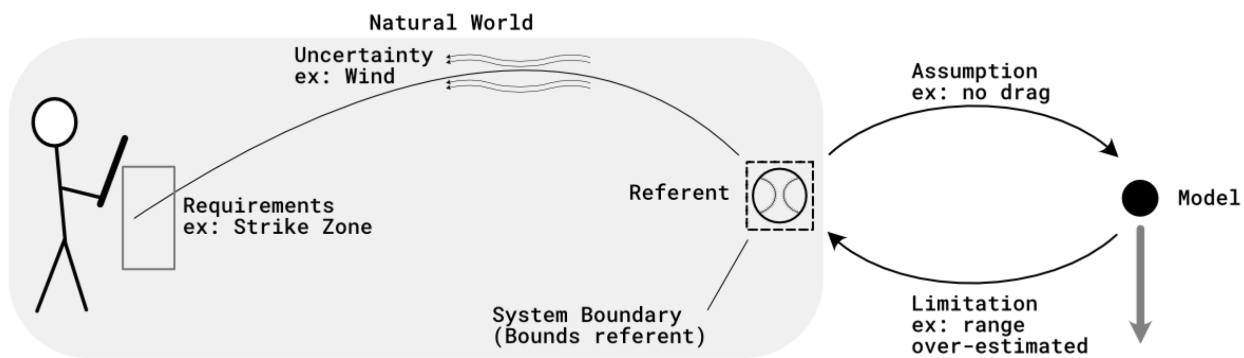

Figure 1. Initial diagram illustrating the assumptions and limitations of a model.

Figure 1 considers a baseball hit by a batter. The referent (a baseball) exists in the natural world, while the model exists outside the natural world. The diagram contains examples of assumptions (ex: no drag) and limitations (ex: range over-estimated). The diagram also contains other features for things that are not assumptions or limitations: requirements and uncertainties.

Figure 1 constitutes an *initial* framing of mathematical models. This initial framing was confusing for research participants: An important goal of this study was to improve this framing to achieve a shared language for the research object. A final theoretical piece frames our understanding of shared language.

Communicative validation as a framing of shared language

Shared language is important for maintaining the focus of a research project. Through the course of this project it became clear that members of the research team were using the *same words* to refer to *distinct concepts*. This kind of miscommunication is a serious threat to the validity of a qualitative study, which is addressed by attention to communicative validation.

Communicative validation is a facet of research quality regarding issues of consensus in communication. Communicative validation should be sought with the "relevant" community [8]. Relevant communities for qualitative research include research participants, the internal research team, and the external research audience [9].

Achieving communicative validation is difficult. Qualitative researchers have the opportunity to impose their own beliefs at any stage of research [10], [11]. Various techniques have been developed to promote communicative validation, such as *member checking* to confirm data or interpretations with research participants [12]. In our project, we sought techniques that naturally fit our chosen methodology and context—that emphasized a flat power hierarchy to avoid any single researcher from imposing their beliefs [13].

Methodology and Context

This research followed a human subjects protection protocol approved by the Brandeis IRB (#23232R-E). This work is part of an ongoing project studying engineering student culture around mathematical modelling, conducted at a small liberal-arts style engineering program.

The backbone of this work is Collaborative AutoEthnography (CAE)—a qualitative methodology synthesized from multiple traditions. Autoethnography (AE) combines autobiography and ethnography—reflection on the self to understand a culture [14]. Collaborative AE (CAE) involves multiple AE researchers in a collaborative setting, working together to enhance meaning-making [15].

Our overall approach to CAE is described in [13], but summarized here: Participants in our sustained CAE are participant-researchers—involved in both data collection, data analysis, and manuscript preparation. Participant-researchers collect field notes while participating in a technical engineering course. All members of the research group attend weekly reflection meetings, where members share and discuss findings documented in their field notes.

A contribution of this work is advocacy for *sustained* CAE: We regard a CAE as sustained not based on a specific length of time; but rather, as a period long enough to observe change *within* a person. The following participant-researchers attended meetings during the specified times (*denotes active field notes collection).

- Alex: Summer 2023*, Fall 2023*, Spring 2024*, Fall 2024*, Spring 2025*
- Leslie: Summer 2023*, Fall 2023, Spring 2024*, Fall 2024*, Spring 2025*
- Audrey: Spring 2024*, Fall 2024
- Emily: Fall 2024, Spring 2025*

The present work was inspired by two "inciting incidents", each tied to a research question (RQ):

- **Self-starting reflection:** During Fall 2024, Zach noticed that Alex and Leslie had started taking field notes on their own, before research "officially" resumed from a summer break. This suggested benefits of sustained CAE to promote reflective practice. (RQ1)
- **Miscommunication:** We noticed that members of the team were using terms to mean very different things. This suggested that specific methodological attention was needed to solve a quality issue of communicative validation. (RQ2)

A key aim of our approach is to mitigate the power hierarchy between professor and students. In discussions, Zach prioritized student voices in dialogue: he offered his opinions sparingly, and focused on asking questions and inviting contributions from other (student) members of the research team. We also followed a strict ongoing informed consent process [13]—all participant-researchers reviewed and approved this manuscript before its submission.

Key Episode: Achieving a flat power structure

Inspired by [16], we present one key episode that illustrates our approach to mitigating issues of research quality. Achieving a flat power structure is key to our research approach: this is a necessary condition for participant-researchers to express their authentic thoughts, and not just state what they believe their professor expects to hear.

Late in this project, Zach drafted Tables 1 and 2 with the goal of minimizing the required elements. Two students pushed back on excluding Usage and Engineering Requirements from the "required" Table 1. Audrey felt that these elements particularly clarified the idea of a model. Humorously, Emily pulled up materials from Zach's course on mathematical modeling,

> "Keep in mind that a cool model without an interesting modeling question is a bad choice for [this class]!"

The team had a good laugh at Zach's inconsistency; elsewhere, he had argued that Usage and (Engineering) Requirements are key to modeling. This episode illustrates the flat power structure that our approach achieved: Students felt comfortable challenging decisions their professor made, building confidence that their statements in this manuscript reflect their true thoughts.

Research questions

Given our framing, methodology, and context, we investigated the following research questions:

RQ 1. What effect does CAE have on reflection-*on*-, or even reflection-*in*-action?
RQ 2. How can CAE be modified to promote communicative validation when discussing mathematical models?

Results

RQ 1: Reflective practice with a framing

Inciting Incident—Self-starting reflection

In the Fall of 2024, as we resumed group meetings from a summer hiatus, Alex and Leslie mentioned they had already started taking field notes.[1] This was surprising to Zach, as it suggested the work Alex and Leslie had done in previous semesters had built productive habits they exercised outside the context of this research project. The sustained nature of our CAE created the opportunity to observe this kind of change in a participant-researcher.

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[1] Note that, while Alex and Leslie had been working on the project for over a year, Audrey and Emily had just started. Therefore, we did not observe—nor expect—similar self-starting reflection behavior from them.

Zach asked both Alex and Leslie to write a reflection about this self-starting. He then analyzed the reflections using process and in-vivo coding [17], and asked clarifying questions.

Student reflections

In their meta-reflection, Alex described their "everyday note-taking" practice,

> Alex: I'm more likely to call out what I don't understand or other relevant thoughts I have while taking notes instead of just writing down equations/the lecture notes. This makes it easier for me when I'm going back through my notes because I already know the points that I need to focus on/get outside help on.

Here, Alex describes a tactical reflection-in-action that uses jotting [18] to capture salient thoughts and questions in a fast-paced lecture environment, enabling later reflection-on-action. This constitutes evidence of sound and ongoing reflective practice.

Alex also described their evolving understanding of assumptions in mathematical models, specifically in the context of working as a teaching assistant for a thermodynamics course,

> Alex: I used to think of assumptions as something to just list, but now I connect them to the problem. Assuming something is an ideal gas means that we can use the ideal gas law and still have an accurate model. It doesn't mean we can just use an easier equation (although it means that too). I connect assumptions more to the output of the model now, and think of assumptions as a sort of metric to help us identify how useful our model is.

This passage provides a window into Alex's conception of assumptions and limitations. Alex is now aware that assumptions are connected to a model's use ("I connect assumptions more to the output of the model"). Furthermore, Alex is aware of their progress in learning, and has identified practical reasons to engage with assumptions. This is strong evidence of reflection-on-action on mathematical models.

In her meta-reflection, Leslie described how she incorporated the research framing into her developing professional identity,

> Leslie: I started to notice that just by nature of how our research was, and I have taken it upon my values… that limitations and assumptions are really important… to my work as an engineer.

Leslie has started to connect the research framing of assumptions and limitations to her professional identity, both in her stated values and in her "work as an engineer." This is evidence that persistent reflection-on-action with the framing has led to an increased *awareness* of the research framing—a necessary condition for unprompted reflection using the framing. Beyond this, Leslie's reflection also evidences practical learning outcomes,

> Leslie: And that is something that I've noticed in the engineering curriculum, especially in mechanical engineering, is we make a lot of assumptions, but it's not always explained *why* we make those assumptions, and it's especially when you're learning the material of like statics, when everything is equilibrium. A lot of things are assumed, but you need a completely different, complex model if you're not making that assumption.

This reflection is in reference to Leslie's first time taking a statics course, and shows that she has already developed a sophisticated conceptualization that mirrors professional practice: Gainsburg [19] found that "... structural engineers' mathematical point of view appears to be one of *skeptical reverence*—mathematics is a powerful and necessary tool that must be used judiciously and skeptically." In later work, Gainsburg [20] found that engineering students do not typically develop skeptical reverence. Through reflection-on-action with the framing of assumptions and limitations, Leslie now notices that "a lot of things are assumed," exercising skepticism even as she uses the mathematical tools of static analysis.

These data show that reflective practice with the framing of assumptions and limitations led to a variety of benefits. However, developing this framing into a truly shared language took several iterations and methods innovations.

RQ 2: CAE with diagrams

Inciting Incident—Miscommunication

In the course of this project, we noticed that team members used words to mean different things:

- Audrey described a "limitation" of a certain design project as having to fit within an area. However, Zach was inclined to call this a "requirement."
- Leslie described an "assumption" necessitated by a lack of information. However, Zach felt that the term "assumption" was more related to a model's definition.

These miscommunications illustrate the difficulties in discussing the research object—mathematical models. Further, these miscommunications arose through written reflections—the typical method of CAE. The method innovation we found necessary to address this miscommunication was to communicate not with writing, but with a collaboratively determined approach to technical drawing.

A possible alternative to addressing this miscommunication would be for the project lead (Zach) to impose strict definitions for terms such as "assumption" or "limitation". However, this would present a method misalignment with our CAE approach, which holds a flat power hierarchy as key to the research approach. Instead, we emphasized the collaborative nature of CAE to represent student voices.

An initial diagram

In response to Inciting Incident—Miscommunication, the research team sought a shared *visual* language the team could use to describe the research object (mathematical models). To begin this process, Zach developed an initial framing of the research object—Figure 1 presented in the Study Framing section.

Response diagram #1

To test whether the initial diagram (Fig. 1) clarified the framing of assumptions and limitations, Zach asked Audrey to draw her own diagram, but to reflect on a system she knew well. She diagramed an ultrasonically welded tab, a system she worked on as an intern. Note, in this response diagram (Fig. 2), the referent is connected by assumptions and limitations to a car—an object that would arguably exist in the Natural World (hence not a model). This suggests that the initial diagram missed context that may be important to an engineering student.

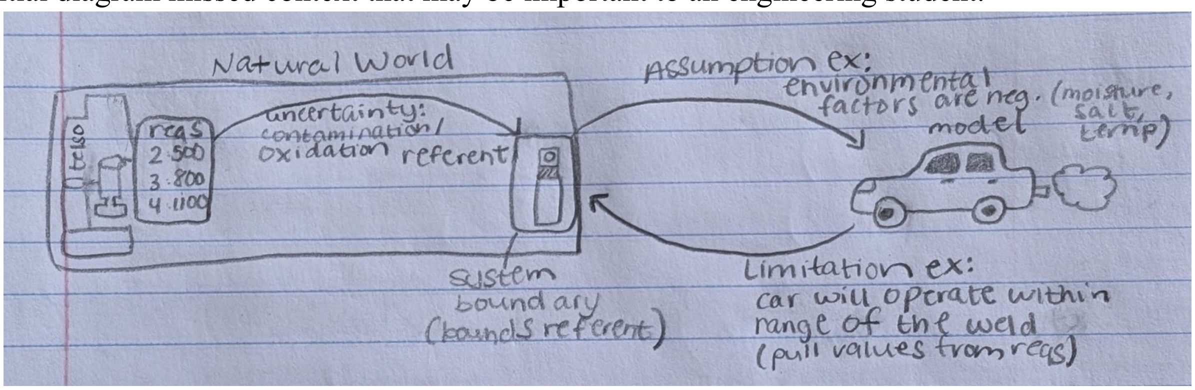

Figure 2. Audrey's Diagram #1 of an ultrasonically welded tab (referent).

Revised (*tenchi*) diagram

Zach noticed that Audrey's diagram focused on putting the referent in a natural world context, rather than posing an abstracted model. He hypothesized that two changes may clarify the visual language: 1. Providing an "outlet" in the diagram for placing the referent in a natural world context, and 2. Drawing a sharp distinction between the natural world and a "model world." Zach incorporated both features in a revised diagram (Figure 3). For its spatial layout, we call this a *tenchi* diagram—a Japanese word meaning "above and below."

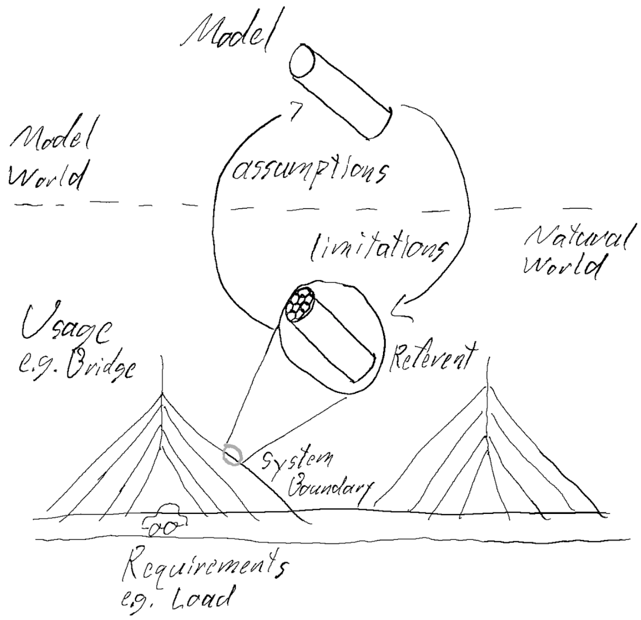

Figure 3. Zach's revised (*tenchi*) diagram to describe assumptions and limitations of a model.

Response diagram #2

In response to the revised diagram (Fig. 3), Audrey drew Figure 4. This diagram clearly separates a referent in the natural world from a model in the model world. Audrey's usage (in a car breakpad) is now situated in the natural world. This demonstrates that the hypothesized features (usage and a model-nature dividing line) clarify the shared visual language.

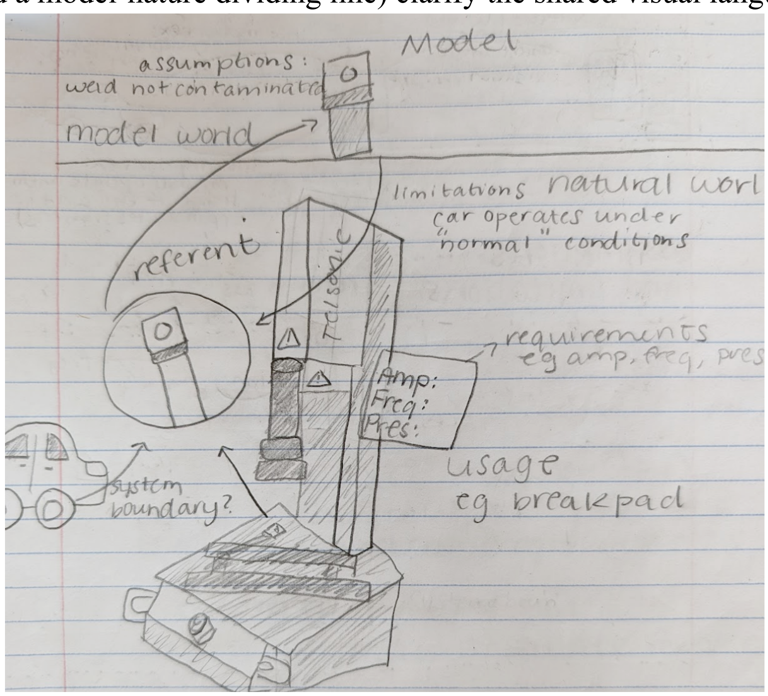

Figure 4. Audrey's Diagram #2 of an ultrasonically welded tab.

This alignment between two participants' diagrams (Figs. 3 & 4) suggests a convergence of meaning between two participants. To seek stronger communicative validation, more diagrams should be drawn by more participants. Luckily, a new member of our team decided to use the tenchi diagram concept on her own.

Emily's improvised diagram

As part of this research project, Emily drew multiple tenchi diagrams in response to Figure 4. However, she also independently decided to draw a diagram in the same style for a class project. This helped her make sense of building a model in an open-ended team project.

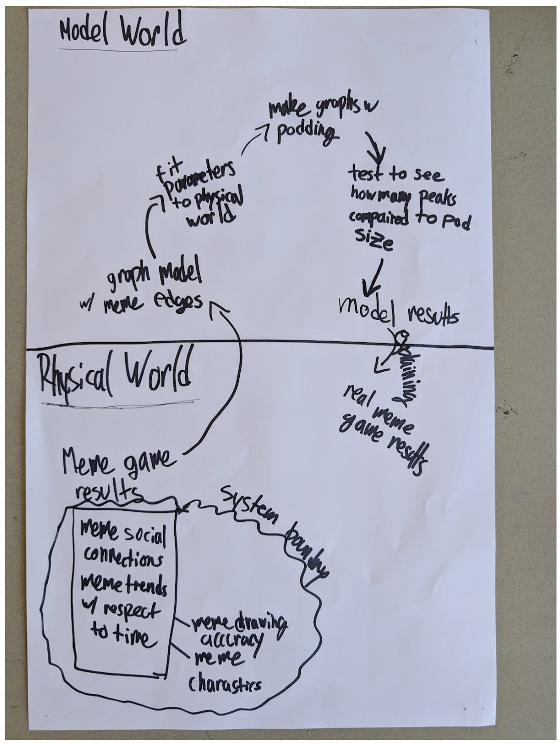

Figure 5. Emily's *tenchi* diagram for a class project.

Note that Figure 5 has neglected elements of the natural ("physical") world inside the system boundary (e.g., "meme drawing accuracy"). This would be a contradiction under the proposed visual language. However, the students were able to clarify this language for each other,

> Emily: I'm confused about the system boundary versus the referent.
> Audrey: The system boundary bounds the referent.
> Emily: Ah, that makes sense.

This is evidence that the language has become shared among the team, rather than externally imposed: Here Audrey has clarified the meaning for Emily. In editing this manuscript, and by Emily's suggestion, we added to the description of the referent the clarification, "The referent is everything inside the system boundary."

Table 1. Key (required) elements of a tenchi diagram.

Element	Description	Rules
Natural World	The home of physical objects, a subset of which are modeled.	The natural world and model world are fully separated by a boundary (distinct from the system boundary).
Model World	An imaginary home for models.	
Referent	A subset of the natural world that is represented by the model. The referent is everything inside the system boundary.	Must be in the natural world, fully contained in the system boundary.
System boundary	A boundary whose interior defines the referent. Things in the natural world that lie outside the system boundary are not in the model.	Fully contained in the natural world.
Model	A representation of the referent, defined by assumptions and possessing limitations.	Fully contained in the model world. Can be represented using equations, diagrams, and/or text.
Assumptions	Differences from the referent that define the model. e.g., idealization of the referent [21], neglect of natural phenomena outside the system boundary.	Represented as a directed connection from the referent to the model. All assumptions lead to some limitation(s).
Limitations	Aspects of the referent that cannot be represented by the model.	Represented as a directed connection from the model to the referent. All limitations arise from some assumption(s).
Usage	A broader context for the referent in the natural world. The system boundary separates the referent from the broader context of its usage.	Fully contained in the natural world.
Engineering Requirements	Rules for judging success of the engineering task, in the context of the usage. Requirements are not the same as limitations. However, limitations may require one to exercise care when using the model to judge whether the requirements are met.	Fully contained in the natural world. Distinct from "success" of the model.

Tenchi Diagram Elements

Studying this progression of diagrams (Fig. 1—5), we find that certain elements are required to define the model (Table 1), while optional elements help clarify the model (Table 2). Tables 1 and 2 represent a consensus among the authors.

For both the referent (in natural world) and model (in model world), we recommend using pictures to represent these elements. This is intended to focus the diagram on tangible, experience-near elements, rather than experience-distant concepts [22]. Figures 1—4 illustrate this heuristic, while Figure 5 provides a counterexample—a word-heavy diagram that was useful for communication within a project partnership with a lot of shared context.

Table 2. Clarifying (optional) elements of a tenchi diagram.

Element	**Description**	**Rules**
Uncertainty	Any lack of perfect information [23].	(See Real / Erroneous Uncertainty.)
Real Uncertainty	Uncertainty that can affect the usage.	Fully contained in the natural world.
Erroneous Uncertainty	Uncertainty that cannot directly affect the usage, except through decisions based on the model.	Fully contained in the model world.

Discussion

Limitations

Due to the qualitative methods employed, we cannot make statements about how frequently students may experience the benefits identified above. Similarly, we cannot be certain that our study identified all possible benefits to students. Questions about statistical generalization would only be addressable using quantitative methods, including survey item development and statistical sampling.

Furthermore, we cannot make definitive statements about how the specific approaches used in this work may (or may not) generalize to other contexts. This is due to both the small sample size of the study, and the particularities of the research context. Namely, since our engineering program is small and faculty tend to be on a first-name basis with students, this creates an environment that naturally promotes a flat power hierarchy. Given the centrality of a flat power hierarchy to the methodology, additional strategies may be necessary to achieve a similar working relationship at other institutions. This is not without precedent; for instance, Bryan Dewsbury [24] employs a *deep teaching* model that emphasizes building meaningful relationships with students while teaching at a public research institution.

Conclusions

We summarize by returning to the research questions.

RQ 1: What effect does CAE have on reflection-*on*-, or even reflection-*in*-action?

We found that CAE can have a variety of benefits for reflective practice—our framing of mindset in this work. Alex's reflection showed that practicing the elements of reflection (e.g., taking field notes, returning to previous confusions) can build productive habits that extend beyond the research context into a student's other learning efforts.

We found that further benefits accrue when pairing a specific framing with CAE; in our case, framing mathematical models in terms of assumptions and limitations. Both Alex and Leslie showed evidence of adopting this framing into their regular learning practice, modulating their reflection-on-action with mathematical models. Leslie's case showed that reflective practice with a framing can lead to surprising benefits, such as adopting a framing into one's professional identity, and exhibiting learning outcomes that are uncommon for undergraduate students but mirror professional practices [20].

RQ 2. How can CAE be modified to promote communicative validation when discussing mathematical models?

We found that sustained CAE provides ample opportunity to identify and address issues of communicative validation—ensuring shared meaning of terms. We define a CAE to be "sustained" when it is carried out long enough to observe changes in the participant-researchers. For addressing RQ 2, the change we sought was a convergence in meaning of the terms and representations our team used to represent the research object (mathematical models).

In our context, using rich representations (e.g., drawn diagrams)—rather than text—in a CAE helped overcome confusing terminology. This approach was sufficiently accessible that a new member of the team (Emily) was able to quickly adopt and adapt the diagramming approach for a novel use (in a class project).

More generally, we found that it is possible to clarify shared language using collaboration (not a top-down approach), promoting a flat power hierarchy. This was a key design consideration of our CAE approach that emphasized student voice.

Future work

Our primary hope is that researchers consider using CAE in their own work. We have found that CAE has unique benefits, both for research practice (promoting communicative validation) and student learning (reflective practice). However, instructors can also use CAE methods outside a research context as a classroom strategy to promote reflective practice. There is precedent for such a "methods as teaching" approach; Groth et al. [25] taught a group of students clinical interviewing as a means to improve their teaching practice. Features of our CAE approach that go beyond typical journaling include: small cohort discussion, encouraging reflection-in-action (e.g., through field notes), and positioning reflection as an integral part of a meaningful project (producing research results).

As noted in the Limitations section, there are potential challenges to using sustained CAE in other contexts. Our approach emphasizes a flat power hierarchy, which can be difficult to achieve due to a variety of factors; for instance, norms of student-faculty interactions or large class sizes that hinder individual connections. There are possible adaptations that may overcome these challenges. For example, near-peer mentorships have been shown to promote student belonging and connections [26], [27]; having near-peers (graduate students or advanced undergraduates) could promote a flat power hierarchy.

Given the exploratory nature of this study—discovering benefits of a research methodology—qualitative methods are appropriate. However, it is important to note that these methods do not guarantee generalizability to other study contexts. Qualitative studies on their own can 'ring true' for other contexts, but require more work from the reader to judge suitability to their own context [28]. More firmly establishing generalizability, in a statistical sense, would require quantitative methods. Future work in this area would require both (survey) instrument development and statistical sampling.

Acknowledgements

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