Attending to Student Perception of Agency in the Design of Science Lab Curricula

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Submitted by
Robert Hayes

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Advisor: Julia Gouvea

Abstract. In this paper, I examine a gap between *curricula positioning* students with the agency to construct knowledge (epistemic agency) and *students perceiving* themselves as enabled to exercise epistemic agency, through a case study of one student in an inquiry-based biology laboratory course. This course is designed to engage students in contributing ideas to make sense of complex biological phenomena. The focal student, Caleigh (ps), expands the kinds of explanations she provides when encountering unexpected experimental data—from seeking mistakes with how she carried out the protocol in the first two units, to providing ideas about how the biological study system might be behaving in the final unit. Drawing on interview data, I show that this expansion can be accounted for in terms of *a shift in Caleigh's perception of her own epistemic agency in the lab*. I then illustrate, using framing theory, ways in which the curriculum influenced Caleigh's perception of constrained agency in the first two lab units. Lastly I zoom out to consider how we as curriculum designers can factor student perception of agency into the design of learning spaces.

Introduction

Curricula for Doing Science

There is a push in science education to support students to be "doers of science" rather than "receivers of facts" (Miller et. al. 2018). The linguistic shift from a passive to an active role reflects a broad pedagogical interest in students taking on a more agential role in their learning. Through exercising agency over how scientific investigations are carried out educators hope students will "learn to think like a scientist, (and) find research exciting" (Auchincloss et al., 2014, p. 29).

Curriculum designers support students' exercising agency by positioning[1] students to contribute ideas and have them valued (Engle & Conant, 2002, p. 404; Ko & Krist, 2019, p. 4). Inquiry (Lehrer, et. al., 2000; Ward, 2002) and discovery (Brown & Campione, 1994; Hammer,

[1] I use positioning to refer to a curricular intention, as found in Engle & Conant, 2002, p. 404 or Ko & Krist, 2019, p. 4. This is distinct from the relational discourse analysis construct found in Davies & Harré, 1990, or Watkins, et. al., 2018.

1997) curricula, for example, position students to construct[2] questions about phenomena—an activity typically reserved for authorities such as instructors and textbooks—and to investigate answers to those questions using their existing knowledge and the knowledge of their peer community.

Building from the inquiry literature (Indorf et. al. 2019), college biology lab curriculum reform has promoted the development of authentic research experiences, most recently through initiatives intended to reach large groups of students like Course-Based Undergraduate Research Experiences (CUREs) (Ballen et. al., 2017), ALLUREs (Rowland et. al. 2016), & AIM-Bio (Hester et. al., 2018). These reformed lab curricula are viewed as extending a spectrum of traditional (or "cookbook") labs and inquiry labs, in the degree to which they position students to exercise agency in the discovery of new ideas *and* in the use of scientific practices (Auchincloss et. al., 2014, p. 32; Brownell & Kloser, 2015, p. 528).

For the last 30 years educators and researchers have grappled with a major challenge of implementing curricula for doing science—helping students to *take up* the agency to construct knowledge when, from prior schooling, they've learned that science ideas come from authorities such as the textbook (Redish, Saul, & Steinberg, 1998), and that the way to engage in problem solving is superficial and prescribed (Schoenfeld, 1988). Positioning students with agency to conduct investigations in a lab course could contrast with students' prior expectations of "doing lab" (Holmes & Bonn, 2014; Duschl, Jimenez-Aleixandre, & Rodriguez, 2000)—they might come in with the expectation that in lab there is a "right answer" that they are meant to confirm, and so

[2] I use *construct* on the recommendation of Phillips, Watkins, & Hammer (2017; 2018) to foreground the effort in generating good questions. Other researchers have likewise valued students *asking* questions (Bransford & Schwarz, 2001) and *posing* questions (Manz & Suarez, 2018; Karelina & Etkina, 2007).

tailor their experimental design and data interpretations to demonstrating that answer (Smith et. al., 2020; Holmes, 2020).

In this paper I present a case study which illustrates this challenge; in which one student saw a curriculum not as positioning her with agency to contribute new ideas about the biological systems she was studying, but instead as *limiting* the kinds of contributions she was able to make early in the course. In unpacking what happened for this student, and why, I examine how we can better structure curricula to support students taking up epistemic agency in doing science.

A Case Study in Agency

The case is situated within an inquiry-oriented, introductory-level biology lab course. A primary objective of the course was supporting students' exercising epistemic[3] agency in reasoning about biological systems—that is, contributing their own ideas about how study organisms might be behaving. One place where we positioned students to contribute to knowledge building was in accounting for unexpected experimental data. We designed experimental protocols that were not "amenable to a (simple) target conceptual interpretation" (Hardy, Dixon, & Hsi, 2020), and reinforced the expectation that students reason about the complexity of the biological system. For example, the first lab report prompted students "not to get to some particular "answer," but rather to make some sense of the data". We planned that having an unanticipated phenomenon would provide space for and motivate students to contribute ideas about the behavior of the biological systems they were studying.

Over the span of the course, the focal student of this case study, Caleigh[4], expanded the *kinds of ideas* she contributed to account for unexpected experimental data. In the first two units

[3] Epistemic meaning related to students contributes to *knowledge building* - I elaborate on this in the theory section.
[4] All research participant names are pseudonyms.

Caleigh explained unexpected data solely in terms of mistakes in how she carried out the experimental protocol. Only in the final unit did she additionally contribute ideas about how the biological system might be behaving. Interviews with Caleigh reveal that this expansion was tied to Caleigh's *perception* of her epistemic agency (Miller et. al., 2018)—that is, what kinds of explanations she saw herself enabled to contribute (or not).

In this paper I address the question of why Caleigh felt that she couldn't contribute biological explanations in the first two units of the course, and why that perceived constraint was lifted in the third unit. Through a lens of framing (Hammer & Scherr, 2009), I show that this constraint is entwined with a familiar expectation of lab courses as about confirming a predetermined target idea. I then unpack how the structure of the early curriculum stabilized this expectation *for Caleigh* even while prompts within the curriculum were explicitly messaging students to engage in sensemaking rather than to get to a "right answer." Lastly, I present specific revisions that we've made in later iterations of the curriculum which address the dynamics explored in unpacking this case.

Agency & Framing in Education Theory

In order to understand Caleigh's participation in the course, what changes for her, and how that is connected to the structure of the curriculum, we first need to unpack agency and framing in education contexts.

Agency

Epistemic Agency & Decision-making Agency

The term agency as I'm using it in this paper comes from a conception in the education literature of agency as learners' ability to contribute to the knowledge building work of the classroom

community (Stroupe, Caballero, & White, 2018; Miller et al, 2018; Scardamalia, 2002; Ko & Krist, 2019; Damşa et al., 2010). This emphasis on knowledge production (or a shared knowledge object) leads education researchers to refer to students' exercising *epistemic agency*.

Another kind of contribution that is specific to science lab courses is making decisions about how to conduct an investigation (for instance, how to design an experiment). In the paper I find it useful to distinguish *decision-making agency* (Holmes, Keep, & Wieman, 2020) for considerations of curriculum design and analysis of student activity in the lab.

"Ability to contribute" is contingent on many factors and (powered) dynamics between (and among) students, instructors, and curricula[5]. I will focus on one particular dynamic identified by Miller et. al. when they define epistemic agency as "students being positioned with, perceiving, and acting on opportunities to shape knowledge building work in their classroom community" (Miller et. al. 2018, p. 1058).

Positioning with Agency ↔ *Perceiving Agency* ↔ *Acting with Agency*

In the design of curricula for doing science—that is, from the perspective of a curriculum designer—one may think about providing students opportunities to exercise "more agency" (Scardamalia & Bereiter, 1991) over various elements of learning—for example, "the agency afforded students in how they chose to test their models was a key element of our AIM-Bio curriculum design" (Hester et al, 2018). I say that a curriculum *positions* students with agency[6] when it provides students opportunities to contribute ideas or decisions about an investigation.

[5] And beyond the context of the classroom, though my attention is restricted to the classroom here.

[6] This phrasing is something of a shorthand for "curriculum designers, through the structure of a curriculum, position students with opportunities to exercise agency." Though it's also worth noting that opportunities may arise in the implementation of curricula that were not intended in the design.

Curricula positioning students with agency is in service of students taking up, or *acting* with agency. Ko & Krist define agency as "*the way in which* [a student] acts, or refrains from acting, and the way in which her or his action contributes to the joint action of the group in which he or she is participating (Gresalfi, Martin, Hand, & Greeno, 2009)" (taken from Ko & Krist, 2019, p. 4, emphasis added). This definition does not identify whether or not students take up agency. The presumption is that students always act with some form of agency (Gresalfi, 2009; Stroupe et. al., 2018; Miller et. al., 2018), and instead puts focus on characterizing what students do with the opportunities afforded them, and how those actions contribute to knowledge building.

Miller et. al. (2018) identify students' *perception* of their own agency as an important (and underexplored) bridge between curricular intentions in positioning with agency and the ways in which students actually act. If 'positioning with agency' prompts us to ask "where in the curriculum can we provide students opportunities to contribute ideas?", and 'acting with agency' prompts us to ask "what sorts of ideational contributions do students make?", then 'perceiving agency' prompts us to ask "what sorts of ideational contributions do students *see themselves as able to make within the context of this curriculum*?"

The central focus of this paper is on unpacking one student's, Caleigh's, perception of agency, and how it was informed by the design of the curriculum. This requires examining places in the curriculum where students were positioned with the opportunity to contribute explanations[7], characterizing the types of explanations Caleigh did contribute, and identifying when she perceived herself as enabled (or not enabled) to contribute certain types of explanations. In particular, we're interested in when and why there is (mis)alignment between curriculum

[7] As noted in the introduction the curriculum positioned students to exercise epistemic agency in accounting for unexpected experimental data. The focal knowledge building contributions in this paper are Caleigh's explanations that do this accounting.

positioning with agency and student perception of agency. To understand this we first need to consider the dynamics of how students *frame* learning spaces.

Framing

Framing describes how people *interpret*, and *act* within, social contexts (Bateson, 1987/1972; Goffman, 1974; Tannen & Wallat, 1987). The central idea behind framing is that there are many ways to understand and act in a setting such as a classroom. For example, students could interpret a classroom discussion as a space for argumentation, or as a space for sharing ideas (Berland & Hammer, 2012). In a space for argumentation student action might include noticing inconsistencies in a claim and raising those to peers, while in a space for sharing ideas student action might include generating new explanations and offering those to the instructor.

Using framing we characterize this automatic interpretation of the setting as an answer to the tacit question of "what's going on here" (Scherr & Hammer, 2009, p. 149). This is important in the context of student agency because a student's sense of what's going on in the classroom—how they interpret lectures, materials, questions, assignments, feedback, discussions—will impact the contributions they will see themselves as enabled to make.

Structures of Expectation

> *"To frame an event, utterance, or situation in a particular way is to interpret it based on previous experience: to bring to bear a structure of expectations about a situation regarding what could happen, what portions of the information available to the senses require attention, and what might be appropriate action." (Scherr & Hammer, 2009, p. 149)*

In the above example, "a space for argumentation" and "idea-sharing" describe two *structures of expectation* (Tannen, 1979) that students could bring to understand and act in a classroom discussion. The term structure of expectation points our attention to a consistency in framing

carried to the present from prior experience. When education researchers refer to "confirmation" as a feature of traditional labs (Smith, Stein, & Holmes, 2020; Hester et. al., 2018; Brownell & Kloser, 2015), they are invoking a structure of expectation—that experiments yield data which illustrate a previously known concept—borne out of prior experience—having engaged in lab courses which are structured in a certain way.

The Dynamics & Stability of Framing

This begs the questions of where do structures of expectation come from, when are they applied, and how do they change? If we want to support new forms of student engagement with doing science (for example discovering new ideas rather than confirming known ideas) we need language for discussing the dynamics of framing.

Education researchers have found that framing can shift over the course of a single tutorial session (Scherr & Hammer, 2009) or classroom discussion (Berland & Hammer, 2012). Many factors can contribute to such shifts, from change in audience (see TA Frame in Scherr & Hammer, 2009; or the juggling of audience in Tannen & Wallet, 1987) to bids by classmates, instructors, and curricular materials (e.g. a worksheet prompt).

These factors are referred to in the language of dynamics (Thelen & Smith, 1994) as *perturbations* because they push on structures of expectation. In the Berland & Hammer (2012) paper students started in an idea-sharing discussion, and during that discussion one student perturbed that framing by challenging another students' idea (p. 77). This bid was *destabilizing* in that it acted to change the idea-sharing frame to something new. As the conversation evolved into one of argumentation, students made bids that *stabilized* the new frame when they directly addressed one another over the directive of the instructor to "shh" (p. 81). Perturbations of

students' expectation structures (frames) are the conceptual tools we use for understanding how students learn new ways to interpret, and act in, the classroom.

In short, framing describes a process by which students actively interpret and decide how to act in learning environments—that is, what they perceive is going on and what they should be doing in a classroom. Experience in classrooms leads students to develop structures of expectation through which they frame their participation. Designing with framing in mind requires us to consider both what structures of expectation students might bring in, and how curricula might destabilize *or reinforce* those structures of expectation.

Study Context - Designing for Agency

This case study is situated within a large—about 400 students across 14 sections—introductory biology laboratory course, taught by graduate student Teaching Assistants (TAs) paired with undergraduate student Learning Assistants (LAs). The design trajectory described in this section was our first attempt at reforming a pre-existing curriculum with the intention of positioning students with epistemic and decision-making agency in conducting biology investigations. For the former we planned that engaging with unexpected data would be a strong motivator for contributing explanations. For the latter we planned that designing experiments would be a locus of decision-making.

We anticipated that students would have previously experienced highly structured confirmatory lab courses—that is, labs in which experimentation functioned solely to generate data that demonstrated a concept previously discussed in lecture (Hardy, Dixon, & Hsi, 2020). In addition to positioning students with epistemic and decision-making agency, we saw it important to destabilize that "target idea" framing of lab courses, and set the expectation that this lab course

was a place to explore and reason about biological phenomena. This was especially important to embed within the design of the curriculum, given the large, distributed nature of the lab course.

The course design consisted of three units spanning three weeks each (Table 1), connected by a broad theme of evolutionary trade-offs. Each unit centered around a study system, chosen specifically for their complex behavior which tends to resist simple confirmatory conjectures. The enactment of the course was broken into four activity structures: Experiment, Simulation, Discussion, and Lab Report. In this section I

1. Present an overview of the biological study systems for each unit to ground our interpretation of Caleigh's reasoning in the findings and
2. Describe how and why the aforementioned activity structures were enacted in each lab unit to open space for students to exercise epistemic and decision-making agency.

Summary of Course Design

Unit	Weeks	Study System	Focal Idea	Design Emphasis[8]
1	1-3	*E. coli* Bacteria	Mutation rate	Framing : Exploratory rather than Confirmatory lab
2	4-6	C3 / C4 plants	Energy allocation	Epistemic Agency : Making sense of unexpected data
3	7-9	Bean Beetles	Oviposition behavior	Decision-making agency : Designing an Experiment

Table 1: Study systems & Design Emphases for each lab unit

Unit 1 - Mutation Rate Variability via E. coli *bacteria*

In unit 1 students investigated trade-offs of varying mutation rate through studying two strains of *E. coli* bacteria in varying growth media. One strain (E939) was a 'wild-type' bacteria strain, while

[8] Each of these design intentions is present, to varying degrees, throughout the course.

the other (E938) had a defective DNA repair mechanism, causing it to accumulate mutations at approximately ten times the rate of the E939. The focal trade-off was between the advantage conferred from more readily acquiring a "beneficial" mutation—for instance gaining resistance to a particular antibiotic—and the disadvantage of harmful mutations, such as might kill a replicate bacterium.

This tradeoff was posed as a question in the opening Discussion of the lab—"Is it better to mutate a lot or a little?" This is deliberately ambiguous. The intention was to leave space for students to locate the ambiguities themselves—for instance, in individual versus population level units of analysis, or in one environmental context versus another. In order to establish a classroom norm of students exercising epistemic agency, TA instructors were trained to attend and respond to students' reasoning in classroom discussion and in their written reports (Hill, 2018). This responsive pedagogy (Hammer, 1997) was meant to facilitate students exploring the conceptual space of the study system, rather than honing in on a single conceptual target for the unit, and valuing and critically engaging with the knowledge contributions of their peers. The weekly, facilitator led, class-wide Discussion was typically structured around orienting to the system in week 1 of a unit, and interpreting wet-lab data in weeks 2 and 3 of a unit.

In the *E. coli* bacteria unit, the Experimental Design protocols and sequencing were entirely structured a priori, leaving no room for students to exercise decision-making agency in the experimental design. This design was in part pragmatic, given the scope of the lab course (400 students across 14 sections), and also enabled us to design a protocol we knew was likely to result in multiple experimental outcomes (messy data). Having multiple experimental outcomes can resist alignment with simple confirmatory hypotheses, and provide space for students to *problematize* the system under investigation (Phillips, Watkins, & Hammer, 2018; Phillips,

Watkins, & Hammer, 2017), a point I will elaborate on below in outlining unit 2. This, we hoped, would destabilize students' expectations of confirmation.

As students were making sense of their wet-lab experimental results (Week 3) they were introduced to an agent-based computer Simulation in NetLogo (Wilensky, 1999). In this environment (see Figure 1) students could manipulate parameters inaccessible to them in the experimental design, such as the frequency of certain kinds of mutations and the mutation rates of the bacterial strains. The primary intention of introducing the simulation at this time was to further downplay the expectation of confirmation by reinforcing the *exploratory* nature of their investigations. This intention was built into the design of the simulation, which foregrounds novel patterns such as those which occur over time, and into the sequencing of the simulation, which was introduced immediately after seeing their (likely unexpected) experimental results. It was also made explicit in a handout accompanying their introduction to the simulation, which prompted that it was "meant to help you explore.... If you notice any strange or puzzling patterns be sure to make note of those here to share with your TA/LA" (Lab 1 Handout 5_Sim).

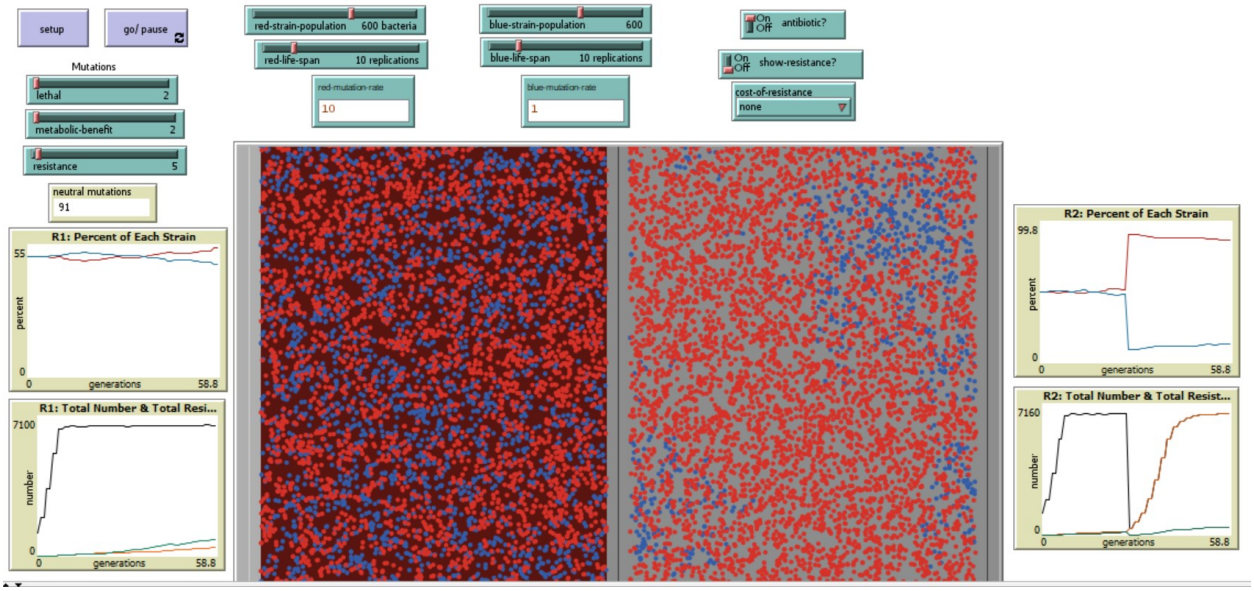

Figure 1: Screenshot of Simulation for Bacteria Lab (Unit 1)

After making sense of experimental results and exploring in the simulation, students were expected to synthesize their findings in a final Lab Report. As with the other elements of the lab this came with explicit messaging against confirmation expectations, such as "The purpose is not to get to some particular 'answer,' but rather to make some sense of the data and support your ideas with logic and evidence" (Mutation Lab Report Guidelines). At the same time it included a degree of structure, outlining expectations for what to include in an Introduction, Methods, Results, and Conclusion sections, as well as Formatting Guidelines. In each section we encouraged clarity and reasoning over conventions and jargon.

In summary, the main curricular focus of Unit 1 — the Mutation Rates or Bacteria Unit — was on disrupting students' expectations of Lab as a place to confirm a target idea, and setting up an expectation of it being a place to explore ideas about biological phenomena. This was designed through ambiguity in the orienting question of the unit, TA training in responsive pedagogy aimed at eliciting students' ideas, an experimental protocol with multiple likely outcomes to make sense of, a simulation built and sequenced to promote exploration over confirmation, and a lab report with explicit messaging to reason rather than get to a particular 'answer'. This structure, we intended, positioned students with space to exercise epistemic agency—that is, to contribute (and have valued) explanations about the biology of the study systems under investigation. Each of the following units followed a similar structure, with adjustments being made primarily to provide space for students to exercise *decision-making agency*—that is, to contribute (and have valued) ideas and actions about how to conduct the investigation.

Unit 2 - Environmental conditions for success via C3/C4 plants

In unit 2 of the course students investigated environmentally mediated trade-offs between the C3 & C4 cycles of photosynthesis. This unit aligned with a section of the lecture course on plant

physiology, and explored a similar evolutionary question to the first unit—under what conditions are certain traits favored—in a more complex organismal system. This trade-off was explicitly contextualized by global warming—what changes might we expect in relative C3 & C4 plant abundance as the atmospheric temperature, CO2 concentration, ambient humidity, and other factors change?

The primary structural difference in Unit 2 from Unit 1 was in the Experimental Design. To provide space to exercise decision-making agency, student groups[9] were given control over which of two conditions they would like to vary in their main experimental protocol—ambient CO2 concentrations, and ambient water vapor. They may adjust one or both conditions. This small change introduced students to making experimental design decisions while preserving the scalability of data collection—as with the first unit, the organisms needed to be kept in controlled conditions for extended time outside of the lab. Additionally, two measurements—plant height and plant weight—served as proxies for success, in contrast to the singular "number of colonies" from the first Unit.

This 2x2 experimental condition, with multiple metrics of success, expanded the space of possible experimental outcomes. This was intended to afford more opportunities for students to encounter messy data through *material resistance* (Manz, 2015; Pickering, 1993). Stated roughly, this framework locates the motivation for scientific investigation and innovation in the material world "pushing back" against our understandings of how things work. Notably this includes considerations of the interpretive assumptions being made, in addition to the hypotheses about the study system behavior. For example, a simple interpretive framework could be that successful plants grow taller AND heavier. Under certain conditions, like low light, this is not necessarily the

[9] Across all units of the course students work in groups of 2-4 students, depending on lab section size

case—plants starved of light will grow taller—and such resistance of the plants to conform to our expectations can direct the flow of student inquiry (Manz, 2012). In fact, we have reported (Hayes & Gouvea, 2017) on the knowledge building contributions of Alice, a contemporary of Caleigh, who encountered this exact resistance—C3 plants grew taller while C4 plants grew heavier in one condition —problematized it, researched the literature, and generated her own hypothesis as to why the two plant types were allocating their carbon differently to one another.

In short, in Unit 2 we opened some space for students to make decisions about the conditions under investigation in the Experimental Design. In order to increase the likelihood of multiple outcomes, we designed multiple measures into the protocol. This opened up the possibility for students to encounter material resistance when both measures were taken as simple proportional proxies for success. We have evidence of students in Caleigh's year responding to this resistance by contributing their own biological explanations for the observed phenomena.

Unit 3 - Behavior, synergies and trade-offs in reproductive success via bean beetles

In unit 3 of the course students investigated trade-offs in oviposition behavior and population growth of two sub-strains of *C. Maculatus*, more commonly known as bean beetles—both of which are agricultural pests which parasitize beans to grow their larvae. One strain, named SI for its original location in Southern India, grows in mung beans, and their larvae tend to fight for space in their host beans, cannibalizing competitors. The other, named BF (Burkina Faso), grows in cowpeas, and their larvae tend to share space in host beans, so that a single bean can support multiple larvae. As with the prior units, students investigated the conditions which might select for variegated oviposition strategies, though notably there was a much larger space of factors affecting oviposition presented to investigate.

The curriculum design in Unit 3 opened considerably more space for students to exercise *decision-making agency***,** through the design and execution of their own experiments. In week 1 the class collectively carried out a predetermined experimental protocol to familiarize themselves with the system (what sorts of data can one expect to collect?), and generated multiple models of beetle oviposition. They engaged with a simulation at this point (rather than at the end of the Unit) to explore the plausibility of these models being selected under a variety of conditions. In week 2 student groups generated a research question to test a model, and devised and carried out their own experimental designs using provided materials (e.g. multiple types of host bean). This structure explicitly foregrounded novel physical/material explanation (Hester et. al., 2018), and provided a new space for material resistance, in the form of limited material, space, and time. At the same time, any given class had many different experiments being run, drastically *reducing* the opportunity to see multiple outcomes from an experiment.

To summarize, Unit 3 employed student design of experiments as a means of opening space for them to exercise decision-making agency, though materials selection and study system were still chosen a priori (out of necessity, this being a large-scale lab course). How this impacted students' opportunities to exercise epistemic agency seemed much less predictable, though in principle by this point they would have had 6 weeks of practice generating biological ideas and explanations in efforts to make sense of the earlier biological systems.

Methods & Analytical Coding

Data collection

Data for this study come primarily from hour-long, semi-structured interviews, conducted at the start, middle, and end of the semester (full transcripts for the Second and Third interviews are available online). The first interview, a pre-interview, is not included in this analysis, as it does

not capture how students acted within or interpreted the lab. The second interview occurred after Unit 2 and covered student experience in Units 1 & 2. The third interview occurred after Unit 3 and covered student experience in Unit 3, as well as the class as a whole.

Each interview was one-on-one between a student and researcher, each student was interviewed by the same researcher across all three interviews. Accounts from interviews are triangulated with students' written lab reports. The interview protocol was created to get a sense of how students were experiencing doing science in the lab course. To elicit this we asked them to describe what they did in lab (general recall), to recall specific moments in lab associated with a feeling, such as "moments that were challenging" or "moments that were exciting," (stimulated recall), and to report on when in lab they most felt like they were doing science. Below I describe what we see as evidence for perceived epistemic agency, and for framing, in the interview data.

Interpretation of analytical evidence

Perceived Epistemic Agency

The central question guiding our interpretation of perceived epistemic agency is, "What kinds of explanatory contributions, both ideational and material, do students *see themselves as able to make* about the study systems they are investigating in our lab course?"

Ideally, perception of epistemic agency would be evidenced by explicit self attribution of an explanatory contribution, as in "This was *my* idea." Such attributions are rare, and usually appear as a hedge (i.e. "I'm not saying this is the right idea, it's just what I thought.").

More commonly, we mark perception of epistemic agency in students' descriptions of what they actually do, or habitually would do, or feel they cannot do in moments of uncertainty about what to contribute. For instance, when Caleigh notes "if we got, results that showed our C3 plants did better, um like, *we can't really write* a lab report saying C3 plants do better" we see this as

evidence that she did not see herself as having the agency to contribute a certain kind of explanation when interpreting her data. This evidence is elicited in our interview protocol by questions about moments which were surprising, challenging, frustrating, or uncertain.

Framing

Framing characterizes students' sense of "what's going on" in the lab—both their interpretation of what curricular elements mean, and of what actions they should take.

We mark framing in student justifications for their actions, particularly when informed explicitly by an expectation—as in "I analyzed data that would have been more, correct and (laughs) like I don't want to say/ that data is correct just like um, what the lab instructor expected us to see"—and in students' interpretations of what they should do in lab—as in "I am pretty sure that we were given the question we were supposed to answer… we weren't expected to like incorporate all the other stuff."

Findings

In this section I first describe the kinds of explanations our focal student, Caleigh, makes to account for unexpected experimental data—from attributing it to human error in carrying out the protocol, to contributing new ideas about the behavior of the biological system. Second, I provide evidence that this is best accounted for by a shift in how Caleigh *perceived* her own epistemic agency—that is, that she saw providing her own explanatory contributions about the system as not appropriate in the first two lab units, but expected in the third unit. Third, I explain this shift in terms of her framing the first two lab units as about confirming a target idea, and the destabilization of her framing lab in this way in the third lab unit. Lastly, I discuss those elements of the curriculum enactment which contribute to the stability of her confirmatory framing in units 1 & 2, and those which contribute to the destabilizing of that framing in unit 3.

Caleigh's accounting for unexpected experimental data across the lab course

Units 1 & 2 - "take into account everything that could have gone wrong"

In this paper we examine Caleigh's contributions when she accounts for unexpected data—that is, what she does when, as she puts it, "After analyzing the results from our lab section, we noticed that our results did not support our hypotheses." (Lab Report 2) In unit 2, for instance, the hypothesis was "that the C4 plants…would experience more growth than the C3 plants in environments with low carbon dioxide and low water levels." (Lab Report 2) The unexpected data was that C3 plants grew taller than C4 plants in that condition.

Caleigh recalls accounting for unexpected results in the first two units by "tak(ing) into account everything that could have gone wrong and just like lay(ing) it all out there." (I2, 41:45) That is, she "look(s) for places we made mistakes" when "our results (don't) match what we expect to happen." (I2, 35:54) This is corroborated by her lab report discussions, in one of which she notes "Our results contradict what we know about C3 and C4 photosynthesis" followed by a lengthy paragraph about "various potential sources of error that could have led to the results that we got" (Lab Report 2). For units 1 & 2, any deviation of data from expectation is characterized as a *mistake* in carrying out a protocol, a point on which she is very specific during her third interview, noting "everyone's given that same piece of paper, so our results should more or less be the same as those of our classmates. So it was really obvious if one group did something wrong." (I3, 17:20)

In short, Caleigh accounts for unexpected data in Units 1 & 2 by searching for and identifying possible errors that her group made in carrying out the experimental protocol. This contrasts with unit 3, where she additionally seeks biological mechanisms and factors which might account for generating unexpected data.

Caleigh, Unit 3 - "try to figure out what factor, was making certain beans more appealing."

In unit 3, students designed their own experiments. Caleigh's group partnered with another group and hypothesized that bean color might be an important factor determining beetle oviposition. The two groups ran identical experiments in which beetles had access to two types of beans with contrasting colors—they even set up beans in an alternating grid configuration, to control for spatial organization of the beans, and massed beans to a tight band of 0.11-0.14 grams, to control for mass preferences (Lab Report 2). Both groups found a trend of preference for the darker bean, but her group's results were not statistically significant while the other group's were (I3, 1:42). Caleigh views this ultimately as a negative result, as they were not both able to significantly support the hypothesis that color is an important factor in oviposition.

In response to this discrepant data, Caleigh notes that "with lab three… it was more of like-figuring out, what each group found from the results, like from th- *doing* the experiment, and not like whether or not each group did it correctly." (I3, 17:20) In the interview she describes *wondering* (about the biological system behavior), and "trying to figure out what *factor*, was making certain beans more appealing." (I3, 1:16, her emphasis)

This is strongly corroborated in her lab report, where she introduces the possibility of alternative factors to color—e.g. smell, and presence of previously lain eggs—which might affect beetles' egg-laying behavior. She still considers areas in which the experimental protocol could have been lacking—for instance, in small sample size undermining interpretations of statistical significance, or in potentially insufficient control for mass. Additionally, she now accounts for unexpected data with explanations *about the biological system*.

For us as curriculum designers the question is, what contributed to this expansion in Caleigh's ideational contributions in the third unit?

Perception of Epistemic Agency influences the scope of Caleigh's explanatory contributions

In the third interview, Caleigh herself presents her experience in unit 3 *in contrast to* her experience in units 1 & 2. In a summary, provided near the end of the interview, Caleigh reveals a sense of *constraint* she felt in writing her lab report in the first two units that was absent in the third.

> "So, I feel like, umm, that- at the beginning of (the course) I thought there are very specific pieces that we need to use in order for our TA to give us a good grade. But, towards the third lab I felt more like, um, they were letting us use our best judgement for what pieces we needed to include." (I3, 45:11)

Going back in the third interview we see in more detail this constraint that Caleigh felt, in her description of how she engaged with writing her earlier lab reports, and her rationale for the choices she made.

> "I feel like, like we were comparing C3 and C4 plants and like every bio textbook out there will tell you that like C4 plants, do better in hot, environments. And if we got, results that showed our C3 plants did better, um like, we can't really write a lab report saying C3 plants do better. Because like everyon- like every scientist will tell you that C4 would do better. So I feel like, because they were very specific results that, they were looking for in the first two labs, like we had to write our report and analyze our data like around those. Around what was expected." (I3, 21:10)

Caleigh says plainly that she feels she *cannot* write a lab report which validates the interpretation that the C3 plants did better. This is because the idea that C4 plants do better than C3 plants in a particular type of environment is, for her, a scientific fact backed up by textbooks—she cannot change that. In the second interview Caleigh expresses a very similar feeling in the first unit, identifying results that she is "supposed to see" because they support "an accepted fact in the field." When her experimental data doesn't align with that she figures something went wrong with how she carried out the experiment, because her "tiny little experiment probably didn't like *disprove* this whole thing that's been accepted." (I2, 24:37, her emphasis)

This evidence indicates that Caleigh perceived a constraint on the *kinds* of knowledge contributions she could make during the first two units—she did not see herself enabled to revise the biological ideas central to those units. This perceived constraint seems absent in the third unit. The question we ask ourselves is, why did Caleigh see herself as not enabled to contribute certain ideas in the first two units, and what changed in the third unit?

Caleigh's framing the lab course

Units 1 & 2 - framing lab as about confirming a target idea

In explaining why she couldn't write that C3 plants did better than C4 plants, Caleigh stated that "they were very specific results that, they were looking for in the first two labs." Across both interviews we see evidence that her perception of which kinds of knowledge contributions she can make, or not, is informed by a felt expectation of what the instructors of the course (the TAs) are looking for, which she characterizes as the correct answer for the lab.

> "I analyzed data that would have been more, correct and (laughs) like I don't want to say that data is correct just like um, what the lab instructor expected us to see… we used, data that the lab instructor told us we were *supposed* to see, just like based off of what we know in like real life situations... the results we got were definitely *not* correct. Or I don't know I am hesitant to say the word "correct" in experiments. ... Yeah so I feel like just because we did something different doesn't necessarily mean they're wrong even though like, for the purpose of *learning* from the experiment, and learning about bacteria and how they mutate, um that data would not have helped us like come to the conclusions that we came to." (I2, 23:03, her emphasis)

In this excerpt Caleigh hedges a bit when characterizing data as correct because she is trying to tease apart a subtle distinction between the behavior of the system (what the bacteria are doing)

and the learning outcomes of the lab course (the idea the bacteria are illustrating)[10]. It's not that the bacteria behave wrongly, it's that data that are worth analyzing are those which support the idea we're supposed to learn for the unit.

In other words, the point of being in this lab is learning a target idea in each unit—for example that C4 plants outperform C3 plants in hot environments. 'The thing we're doing in lab is demonstrating that we've learned that idea by generating particular data which confirm it.' At the time of the second interview (end of Unit 2), Caleigh frames the lab as about confirming these target ideas.

When I say that Caleigh frames the lab as about confirming these target ideas I mean that she *interprets* the curriculum to this purpose. So in analyzing data for her lab report she is actively "looking for ... whether or not our results match what we expect to happen," (I2, 35:54) with the understanding that "what we expect to happen" should confirm the target idea for the unit. This objective directs and constrains her attention (i.e. identifying correct data) and activity (analyzing said data). This is most clearly illustrated in her engagement with the simulation.

Confirmatory framing impacts Caleigh's interpretation and use of the simulation in lab units 1 & 2

Recall that we had students use an agent-based computer simulation in each unit with the intention of emphasizing exploration, rather than confirmation, of ideas. In units 1 & 2 Caleigh takes up the simulation, and how it fits into the broader unit, in ways coherent with the confirmatory framing of the class (and thus contrary to the design intention).

In the first unit Caleigh does describe *exploring* population growth trends using the simulation, including some which don't align with her experimental results. She then goes on to characterize this exploration as "beyond the scope" of what she's expected to analyze and write

[10] This is a sophisticated epistemological distinction. Caleigh's framing of the lab is not a naïve view of science, but a well-adapted view of doing school science.

about in her lab report, because “we were given the question we were supposed to answer and … I feel like that question was specific enough that we weren't- we weren't expected to like incorporate all the other stuff.” (I2, 32:39) In a way the simulation pushed her into an exploratory frame for a little while, but the need to write a lab report restabilized confirming an idea (from the wet-lab experiment), and the simulation data was seen as just something extra.

In the second unit, Caliegh takes up the simulation not as an exploratory tool, but as an epistemic authority against which to compare her experimental data, precisely because it is less error prone than students are.

> “at least my group we, we trusted, that we did the experiment right if that reflected what we saw in the computer simulation... Just because I feel like when we are doing something there's a lot more room for error than if a computer is doing something.” (I2, 58:24)

Caliegh’s not saying here that simulations are more real than wet-lab experiments. She’s saying that they’re more likely to reliably produce results which confirm the target idea that the lab instructors want students to learn in this unit, than are students at the bench.

Both responses to the simulation—rejecting it as beyond the scope of what’s needed to write about in the lab report and treating it as a less error prone data generator—are coherent epistemic activities when the lab course is framed as about confirming target ideas. These examples suggest that Caleigh’s confirmatory framing is stable enough not only to resist perturbation by curricular elements, but to re-interpret them through the lens of the confirmatory frame.

Unit 3 - destabilizing confirmation framing and replacing it with something new

I’ve argued that in units 1 & 2 Caleigh frames the lab as about confirming a target idea. This influences her interpretation of curricular elements like the simulation, constrains how she perceives her own epistemic agency, and so impacts the kinds of knowledge building contributions

she makes. We don't see this same interpretive lens applied to the third unit. Caleigh is very explicit on this point in the third interview, contrasting the third unit from the first two.

> I think it was our lab instructor wasn't looking for like specific results (in the third unit). It was just kind of whatever, results we got we were supposed to analyze that to the best of our ability. So it was more of like the process and the analysis, in lab three. Versus like, I feel like in labs one and two, part of doing the lab was making sure that we could follow like a procedure or protocol. (I3, 16:37)

It's difficult to characterize Caleigh's emergent framing of the lab in unit 3. In describing the process of designing her experiments, and of interpreting her data, she invokes a "path" metaphor:

> ...if we were intereste- more interested in one thing **after** realizing like we did something, then we would go down that path. Like there was just so much more, like flexibility within the third lab so, we didn't feel like we were doing anything wrong, even if like i- it deviated from our original plan. (I3, 14:40)

"Pursuing what's interesting" is maybe the simplest way to characterize Caleigh's framing of unit three. Notably, this is something she feels like she's *meant* to be doing, that the instructors "were letting us use our best judgement for what pieces we needed to include" (I3, 45:11).

For her the agency she takes up in unit 3 is an intended part of the journey, a destination after going over the basics in the first two units, "Kinda like, how, the difference between grammar and usage like once you learn proper grammar you could like kinda bend the rules a little bit to make your writing better..." (I3, 18:23). She sees this as a natural part of the progression of science education, noting that "for upper level classes like later on there's going to be more of, students using their own judgement on what's best to include (I3, 45:59).

For us as curriculum developers the question then is, what (in the enactment of the curriculum) contributed to Caleigh's shift in how she was framing the lab course (and so expanding

the kinds of explanatory contributions she saw herself as enabled to make), and why didn't it happen sooner?

Dynamic interaction between curriculum and framing

I investigated the dynamic stability of Caleigh's framing of the lab to identify how and why a shift might occur in the middle of the course. This involved characterizing elements of the curricular enactment that perturbed—that is acted to destabilize *or to stabilize*—certain ways of framing the lab, and Caleigh's response to these perturbations. For example, above I noted that using the simulation in the first unit cued Caleigh to explore ideas (i.e. destabilized confirmation), and that it was writing her lab report which seemed to pull her back into (stabilized) a confirmation framing.

I have consolidated these elements into two lists: those parts of the curricular enactment that acted to *stabilize* Caleigh's framing the lab as about confirming a target idea, and those which acted to *destabilize* this framing and contribute to her emergent "pursue what's interesting" framing. My intention in presenting these lists is in part to identify specific places in the curriculum that had an impact on Caleigh's framing (and so which might be worth revisiting in later iterations of the lab course), and in part to identify underlying factors that could inform how we restructure labs for students exercising agency.

Curricular elements which stabilized confirmation

Instructors as origin of the experimental protocol

Recall that Caleigh identified a reason for *why* it was easy to spot errors in the first two units, stating "everyone's given that same piece of paper, so our results should more or less be the same as those of our classmates. So it was really obvious if one group did something wrong." (I3, 17:20) This provision of a protocol by the lab coordinators acts as a stabilizing factor for framing lab as

about confirming a target idea, because it supports a sense that “our TAs know exactly what we did and (are) looking for very, specific, like results inside our lab re*port*." (I3, 11:41)

In short, if the instructor defines the protocol then they know what sorts of results should come out of it; this coheres strongly with there being a specific conceptual idea that those results illustrate. I’ll revisit this momentarily when investigating *destabilizing* factors.

Instructor moves stabilize the “wrong results”/“right answer” interpretation

In moments of making sense of her unexpected data, Caleigh attributes to the instructor frequent reinforcement of the ‘wrong results’ paradigm, stating “our instructor even told us (our data) was a little messy” and “we were told some of stuff we saw isn't- isn't what was expected.” (I2, 37:30) Similarly she identifies moves that reinforced the ‘right answer paradigm,’ as when her group generated a hypothesis about the bacteria system and “we were told by our instructor at that end that like we were correct.” (I2, 14:32)

Calling attention to these moves is not an indictment of the graduate TA of her lab section. The data from the labs was meant to be messy, and the latter move could even characterize the TA noticing and affirming her group’s ideas. Rather, I’m calling attention to something that *stuck* for Caleigh, in how it supported her framing the lab as about confirming a target idea.

Alignment of lab conceptual material with lecture material

Part of what sets up an expectation of a target idea for Caleigh is that the study systems chosen for the first two units line up considerably with material covered in lecture. This overlap relegates the overall role of the lab to the *application* of conceptual material—“we got like the background knowledge from our instructor and then we got to somehow apply it to, the, lab we were doing.” (I2, 21:30)

This is coupled with that sense that the instructor is the mediator of canon—"we, learn something in lecture and we expect that to happen in our labs but like when we don't- like we're not sure if our understanding is incorrect or if like the lab just didn't go as expected. So it's definitely helpful to have like, our lab instructor there telling us, or like keeping us on track." (I2, 38:44)

Curricular elements which destabilized confirmation and supported an emergent framing

Students as the origin of the experiment, and the impossibility of a checklist

Recall that the stabilizing effect of the instructor-provided protocol was that the instructor could design the protocol with a specific outcome in mind[11]—one which demonstrates the target idea for the unit. This interpretation is further corroborated by the *destabilizing* effect of a student generated protocol, because "it would be impossible (for the instructor) to have, a checklist for like what each group needs to include." (I3, 45:59) That is, the instructor couldn't have a specific experimental outcome in mind for every student designed experiment, which strongly perturbs framing lab as being about confirming a target idea.

This also appears to influence Caleigh's emergent "pursue what's interesting" framing. She sees that the instructor trusts her and her classmates to design their own experiments, and seeing this suggests to her that they're being positioned as more advanced doers of science.

Comparison of experimental results with peers - equal epistemic authority

Caleigh's framing lab in units 1 & 2 involves her comparing her results to what she expects should be the "right" results. The "right" results are inferred from various authoritative sources, such as the lecture and her lab instructor. By contrast, in unit 3 Caleigh compares her experimental

[11] We specifically did the opposite, designing in multiple outcomes, but that curricular *structure* leant itself to the familiar expectation of confirmation.

outcomes to those of her peers. This destabilizes the interpretation that she's done something wrong, because "we don't know if their results were due to chance, or our results were due to chance." (I3, 3:23) Caleigh can't immediately assume error when comparing with her peers, because "they're in the same class as us, they like in theory don't know much more than we do…" (I3, 30:57)—that is, her and her peers have *equal epistemic authority*.

Instructor feedback on prior work - destabilizing the safety impulse

The lab being a graded course has a stabilizing effect on students framing lab as about confirming ideas. Ultimately students are assessed and their grade is carried on into their broader schooling trajectory. We have evidence that this embeddedness may have encouraged Caleigh to initially play it safe when things didn't go as expected—"after the first lab when we got completely random *results*, I was like 'oh no, this lab report is going to be so bad, like our TA is going to give me such a bad grade'." (I3, 39:33) Over time, feedback from the TA seems to have had a role in destabilizing this safety impulse and making Caleigh "feel, like more comfortable taking more risks" (I3, 11:41).

Taking these stabilizing and destabilizing elements as a whole, Caleigh's framing of the lab appears intertwined with a sense of who is the epistemic authority for the unit, and an attention to the safest course of action for achieving a good grade in the course. I unpack how those factors influence our own design thinking in the discussion.

Discussion

In this paper I presented a case study examining a shift in the kinds of explanatory contributions one student, Caleigh saw herself as enabled to make in a biology lab course—from identifying where she made mistakes in carrying out a protocol, to proposing ideas about how the biological study systems might be behaving. I showed that this was connected to how she was framing the

labs, first as about confirming a target idea and later as about pursuing what's interesting. Lastly, I identified elements of the curriculum that influenced this framing shift, and noted some underlying factors that were central to the dynamics of her framing.

On the one hand, we see Caleigh's engagement throughout the course as scientific, and are happy with the shift she experiences towards the end of the course, which appears connected to her own sense of being more like a scientist. On the other hand, we would like to support such a shift in engagement earlier in the course, so that students have more time to practice the work of learning to think like a scientist. In the remainder of this section I discuss how we're reconceptualizing designing labs for students exercising agency, and present specific design revisions that we've implemented in later iterations of the course.

Design thinking with student perception of learning spaces in mind

In this paper much of the theoretical machinery was identified post hoc out of a desire to make sense of what had quite clearly changed for Caleigh, and how this intersected with the design intentions and implementation of the lab course. As such we do not have the data to confidently characterize Caleigh's emergent framing in the third unit. Is the motivation to "pursue what's interesting" aligned with the more well studied sensemaking framing (Odden & Russ, 2019, p. 192)? Is this new framing stable, as with the emergent argumentation framing in Berland & Hammer (2012)? Does it extend beyond Caleigh to other students? While I cannot answer these questions, the underlying dynamics of Caleigh's framing shift offer more traction for design of learning spaces.

Examining the factors that influenced Caleigh's framing shift, we see it involves a "'Dance' of conceptual, epistemic, social, & affective dynamics" (Conlin & Scherr, 2018). Her sense of lab having a right idea is tied up in how the curricular structure, and instructor moves,

position epistemic authority of data (including how closely the conceptual material of the lab aligns with concurrent lecture material), and in the affective sense of risk associated with being graded on performance in lab. We have attempted to incorporate these considerations into design revisions for later iterations of the lab course. I will outline the larger changes here.

Curricular enactment with student perception of learning spaces in mind

One lesson we've taken from this is that it's useful, when thinking about agency and framing, to expand the unit of analysis from curriculum-student to curriculum-student-instructor. Caleigh (and other students) attended to the (perceived) expectations of the instructor, even when curricular materials were signaling different expectations. We had trained Graduate Teaching Assistant instructors of this course with a weekly lab prep, particularly with respect to grading lab reports (Hill, 2018), and lab report feedback may have played a role in communicating to students that they could (and should) share their ideas without fear of being punished through getting points off. In future iterations of the course we expanded training to include a separate (voluntary) course on responsive teaching pedagogy, for both GTAs and Undergraduate Learning Assistants (Simon, 2018).

As noted above, Caleigh felt enabled to contribute ideas for interpreting data when those data were being compared against her peers' data rather than to expectations set by the instructor or textbooks—that is, Caleigh shared ideas when she saw herself as having epistemic authority over deciding how to interpret data. This connection between epistemic authority and perceived agency (Holmes, 2020) highlights a tension in science education between student agency and disciplinary agency (Hardy, Dixon, & Hsi, 2020). One strategy for addressing this tension has been to shift emphasis from replicating broad Disciplinary practices (i.e. those things Biologists do) to constructing locally emergent disciplinary practices (i.e. those things which help our classroom

community to do biology) (Manz, 2012; Scardamalia, 2002; Engle & Conant, 2002, Cobb et. al., 2001). In later iterations of our lab course we have attempted to enact this by 1) having students design experiments from the start of the course, to remove the possibility that data interpretations are fixed ahead of time by an authority; and 2) encouraging students to use peer and/or simulation data in constructing (and critiquing) their arguments (Gouvea & Parker, 2020).

Accompanying Caleigh's shift in perceived agency was a shift in her feeling that she could take risks without being punished (with poor grades). Researchers have discussed how students mitigate affective risk through epistemic distancing (Conlin & Scherr, 2018) and meta-affective learning (Radoff, Jaber, & Hammer, 2019). In our lab course we have sought to reduce risk by breaking up lab reports into parts that can be done across a unit. This means that any one assignment carries with it less weight, so taking risks is made easier. It also means that students receive feedback (and grades!) from instructors earlier and more often, which communicates expectations of reasoning and contributing ideas in a tangible way.

Concluding Remarks

In the context of designing educational spaces for students doing science, Caleigh's case puts a spotlight on *how* a student takes up agency when positioned with it, and foregrounds student *perception* of learning spaces as a critical consideration for how we structure and teach in those spaces. Designing learning spaces with student perception of agency in mind involves a shift from considering what students are positioned to do, to what students may think to do. This involves taking into account the structures of expectation students have for framing a learning space, and thinking carefully about the ways in which the enactment of a curriculum might push on those expectation structures (either to destabilize *or to stabilize* them).

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Appendix A: Mutation Lab Report Guidelines[12]

Mutation Lab Report Guidelines

Mutation Rates Lab Report

Grading

- Discussion Draft Write-up & Peer Review (15 pts)
- Full Lab Report (20 pts)

Purpose of Lab Report

- The primary purpose of the lab report is for you to slow down and take time to think about what we have been doing and carefully write up your thoughts
- The purpose is not to get to some particular "answer," but rather to make some sense of the data and support your ideas with logic and evidence
- We want you to improve your skill in communicating scientific ideas clearly. Clean writing and formatting will help you communicate
- We will be primarily be grading for clear expression of your ideas and evidence (not particular formatting conventions)

Purpose of Peer Review Cycle

- We want you to practice noticing good scientific arguments so that you will get better at making your own
- You will have time in lab to discuss feedback from both a peer and your TA
- You will have time to ask questions/get clarification before the final lab report is due

Structure of Lab Report

Introduction

- Introduce the problem or question you will be writing about. What is known about the problem? What is unknown? What will you be writing about in this report?
- As you are writing, ask yourself, what is the overarching "story" here? Does this make sense? Could a reader follow and understand my train of thought?

Methods

- Explain what you did in a clear and concise manner.
- You don't need to recount every single detail, but you do need to give your reader a sense for what you did that will impact how they make sense of the results. What was the experimental setup? What was the data you were collecting? How did you collect it?

Results

- Report on what you found.
- Specifically, choose how you want to represent the data. Decide what data is appropriate to include and what data it may be appropriate to leave out.
- Describe in words what you see in the data and appropriately use figures to help you communicate and summarize what the data say.
- You may add footnotes to explain or justify your choices.

Discussion

[12] Parts of this document which could serve as identifying information, such as due dates, have been removed

- Come back to the question/problem you posed in the introduction and help your reader make sense of the results. Do the results answer any of the questions posed in the introduction? Do they raise new questions? What does it all mean?

Formatting Guidelines:

- Include your name, the names of your lab group, your lab TA
- Decide on your title after the lab report is written so you can choose a title the clearly communicates to a reader what they can expect to read about (i.e. not just "Lab Report 1)
- Include page numbers and a running header that has your name
- Make section headings clear and double-space your report so it's more readable
- Include citations in your text (if appropriate) and a **References Cited** section at the end of the write-up
- Acknowledgements (if you want)

Additional Tips for Good Scientific Writing

- Use simple, precise language. If there is a vocabulary word that will help you communicate your idea, then use it. But avoid using excessive jargon (especially if you aren't sure
- what it means).
- Read your lab report aloud or to your roommates. It should flow and make logical sense.
- Revise your writing! (All writing gets better with revision)