Supplemental Material

CBE—Life Sciences Education

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Supplemental Figures and Tables

1. What are your general goals or intentions for students during the ***[model creation or experimental design or model revision]*** activity for this unit?
Play audio episode for instructor (1-2 episodes) 2. What do you remember were your general intentions for this episode? *Answer (2-4) episode specific questions about instructor supports.* ***Possible example questions:*** *3.* In the beginning of this episode, you tell the students that they have 3 different ideas and list them out for the students. What were your intentions in doing this? *4.* Next you go on to talk with the group about limitations with their controls and encourage them to then think about what they will measure and how. What are your intentions behind this discussion? *5.* In this episode you ask the students about what evidence supports their new model or caused them to change it. What were your intentions for this?

Supplemental Table 1: General format of instructor intention interviews. This format was used for all interviews and each interview included 3 sections of this for the 3 parts of the modeling cycle.

Intention Themes	***Intention Subcodes***	***Description***	***Example***
Encourage modeling as a cognitive tool	Explanation/ mechanistic reasoning	Challenging students to explain ideas, reasoning or parts of models.	"I know I was trying really hard to push people to actually do explanatory models because in this lab there is a tendency for students to kind of recapitulate the data. . ."
	Multilevel reasoning/ systems	Challenging students to think about multiple levels of a biological system- navigating multi-level mechanisms	". . .for this unit we are trying to get them to think about kind of a system that has more than one thing going on. . ."
Check alignment of model and data	Alignment	Alignment of data/evidence to model or test to model, or hypothesis to model	". . .what data did you have available to build that initial model" ". . . making sure they are being clear about what the thing they want to test it but that, is, has connection to the model and is not just some random prediction that they can test." ". . . kind of consider interesting data that they can use um, for those models and to kind of again, articulate and think about how the data really align with their models. . ."
Supportive Classroom Culture	Agency	Encourage student agency, ownership, authentic science	". . . help them to kind of realize and help them feel like they do have ideas for how this works even if they may feel like oh its obvious or whatever, that they actually are doing a real thing."
	Data in room accessible	Encourage students to use other groups data or share data	"And then I mean they just finished a day full of collecting results, so I actually wanted to encourage them to draw on the different pieces of data that were available."

	Encourage Ideas	Encourage students to have tentative ideas	". . . potentially a frustrating task and so there was a little bit of like trying to again, cheerlead-" ". . . making sure that they understand that they should just feel comfortable to put ideas out there."
	Classroom management	General instructor moves that assist in the activities and class running smoothly, such as equal student participation, time management	"certain amount of management in trying to get groups who were going more with the more complicated tools or more time-consuming tools really, to try and make that decision quickly enough that they actually have time. . ."
Support productive efforts	Redirecting/ Intervening	Redirecting students to the task or intervening when going down unproductive or untestable path	"Like just redirecting what the task is, you are drawing an idea about your explanation of this thing remember what the thing was, kind of directing them to the puzzling parts of it if they aren't already self-directed there. . ."
	Encourage model diversity	Classroom goal of model diversity- pushing for diversity of data to be available in future weeks	". . . steer them in diverse directions, at least cause the goal is it with the data in the room, they don't have to come up with the answer but that there is actually there is going to be enough there that students can work with. . ."
Navigate practices of experimental design	Understanding tools	Assisting students in understanding what tools are available, parameters of tools, or purpose of tool	". . .making sure they understand all the tools. . ."
	Assisting with controls	Emphasizing controls or guiding students through thinking through controls	". . .I did this time that we hadn't done as much was leaned on controls a little bit more. . ."

	Thinking forward	Assisting students in thinking ahead to what data they will get	". . . to help students think about how they are going to interpret the data that they get. . ." ". . . to think forward, we have been talking about this, to think forward about like what they are going to be able to say when they get their data."

Supplemental Table 2: Coding guide for instructor intentions. All themes were coded across each of the 3 model cycle tasks, except for “Navigate practice of experimental design” which only occurred during the experimental design task.

Scientific Practice	***Description***
Model Creation	Students create a model to explain the problem or phenomena presented in class.
Hypothesizing/ Predicting	Students make hypothesis and/or predictions about phenomena or experiment.
Experimental Design	Students design an experiment using tools available to test the model they created.
Data Analysis	Students use data collected to make sense of what happened during the experiment and how it relates to their model.
Model Revision	Students revise their original model using results from experiments.

Supplemental Table 3: Scientific Practices Coding Guide.

Instructor Support Code	*Description*	*Example*
Multiple plausible ideas	Remind students that there are multiple answers, many options, and the general openness of the questions.	". . .I don't know- we just want you to come up with some ideas, there are many ideas. And next we are going to test them. . ."
Focus on explanations	Push students to fully explain ideas, often by asking follow-up questions to clarify ideas. 1)Encourage explanations 2)Push for mechanism	"So I want to you explain not just that it moves to the light but how you think that happens? What might be involved? What processes? What molecules? What mechanisms?"
Push to visualize	Encourage students to visually represent there thinking in a model explanation.	"I want you to try and draw some aspect of it, you can have words but you know there are cells, you know how to draw a cell, draw something cause, the reason for that is that it helps you to start to visualize what could be happening. . ."
Model as thinking or communication tool	Instructor explicitly directs students to use their model as a way to make sense of their ideas or help others to make sense of those ideas.	". . .I am looking at this I'm going to make sure you didn't already put it on here, just since we are going to next week be giving this to someone else to have to interpret, if you could maybe make a note that that's what's going on. . ."
Encourage emerging ideas	Encourage student thinking and initial formation of ideas by providing encouragement when students trying to form initial ideas, affirming that is okay that model/idea may be incorrect or pointing out productive idea when multiple ideas discussed (differentiate and distinguish ideas)).	"Okay so you just said 3 ideas, right. So, one is they are physically interacting, one is that bacteria need certain things to grow. . . you are on the right track in terms of they need something to grow. . ." "So there is not one right answer we just want you to figure out what is AN explanation that you can draw in your model for why this is happening, why we saw all of these things, okay?"
Plausibility filter	Assess student ideas and redirect ideas that are	"I'm not aware of that but I mean you can hypo- that's probably not

	unproductive.	going to be it. But that doesn't mean that they couldn't- you are on the right track in terms of they need something to grow. . ."

Supplemental Table 4: Coding guide for instructor supports in the model creation task.

Instructor Support Code	***Description***	***Example***
Focus on Explanations	Push (lightly) on students to	". . .Okay, so how are we

	fully explain ideas, often by asking follow-up questions to clarify ideas. 1)Encourage explanations 2)Push for mechanism	thinking about testing it has a byproduct? What do you mean by byproduct?”
Encourage emerging ideas	Encourage student thinking and initial formation of ideas by providing encouragement when students trying to form initial ideas, affirming that is okay that model/idea may be incorrect or pointing out productive idea when multiple ideas discussed (differentiate and distinguish ideas)).	“. . .And I think it's interesting because you both had really cool general ideas. . .”
Reasoning about alternatives	Support students in reasoning of alternative experimental outcomes or explanations about interpreting results.	“. . .I'm just thinking hypothetically, where you would go in different places. So, if you see what you expect to see, then it straight up supports this. But if you see a mix of the opposite. . .What if neither of these grow without [it]-- what would that tell you?”
Refine the hypothesis	Support students in articulating their current hypothesis: Is the hypothesis explanatory? Clearly stated? Multiple ideas (within their hypothesis) are distinguished?	“So is your hypothesis that A did something permanent to E? . . . So what is the thing that you think it did?” “Right so they are like part A and B right? Because it sounds like your general hypothesis in that A is doing something, making something that affects E right? That is probably sends out of itself somehow, right? So it is either changing the media or changing E permanently, right? And those are the 2- so I guess they are competing hypotheses but they both stem from your general hypothesis. . .”

Evaluate alignment between hypothesis and test	Check for a match between the tool being proposed and the students' current hypothesis. To code: -Hypothesis must be clearly stated by student or instructor -Clear language from instructor that it is or is not aligned	". . . So you are thinking [of] adding the acid to the ATCC media? (student confirm) Okay. That makes sense to me. Cause your hypothesis is that A is, that the acid is what is causing the problem for E? Okay."
Support understanding of tools	Instructor explain tool options that can be used to test their hypothesis or how tool works.	". . .And so your options would be you could literally put the full culture to test, which includes the cells and the media, or you could just spin the cells out and just test the media. Or you could actually test, you could take some of those cells that you have leftover that you spun out. . ." "So what it does is it breaks those bonds in between. But it's really just testing, is there something that breaks the bonds between those molecules."
Reasoning forward to results	Support students in thinking about the <u>possible results</u> they may get when they conduct an experiment: -Will the results be meaningful? Can also include the instructors modeling this way of thinking for their students.	"It's just kind of fun to start thinking about what could those proteins be doing? And if they are doing what you think, what might you see when you do your experiments?"
Encourage Expansion/Reduction of Test	Assess time management of tests proposed. Includes suggestion to add or limit tests being proposed.	"Although, I will say that the colominic acid breaker test is really fast, so you could probably test both hypotheses actually, which would be kind of cool because the more data, the merrier. . ."
Apply use of model	Instructor refers to student	"Got it. So I'm going to back up

	model drawing. This could be understand or discuss their possible hypotheses or to use the model as a reasoning tool to help transition to the experimental design phase of the modeling cycle (or for some other reason).	a little bit and look at your models so I kind of-- so if you could kind of draw the connection for me?”
Support thinking about controls	Instructors guide students in thinking about controls needed for proposed experimental design.	“. . . your hypothesis is that A is making this protective ability, right? So would this actually be a negative control? Would you expect E to, what is your control. . .” “But you might want to have the comparison where you know E is likely to grow. . . So that's what I was saying about how you have to have an internal positive control . . .”

Supplemental Table 5: Coding guide for instructor supports in the experimental design task.

Instructor Support Code	***Description***	***Example***
Multiple plausible ideas	Remind students that there are multiple answers, many	“Well, it could be. I don't know, that's why I am asking is for you

	options, and the general openness of the questions.	to articulate what you actually think. Cause there are multiple possible-. . .”
Focus on explanations	Push students to fully explain ideas, often by asking follow-up questions to clarify ideas. 1)Encourage explanations 2)Push for mechanism	“So it is making some protein and what do you think E does with the protein? What does the protein do?”
Push to visualize	Encourage students to visually represent there thinking in a model explanation.	“. . .So can you maybe draw that? Because I don't get that from like, seeing this.”
Encourage emerging ideas	Encourage student thinking and initial formation of ideas by providing encouragement when students trying to form initial ideas, affirming that is okay that model/idea may be incorrect or pointing out productive idea when multiple ideas discussed (differentiate and distinguish ideas)).	“They could be, they could be. I mean they are not cells they are proteins, but yeah they could be, they could be receptors.” “. . .But it does have these and it responds to light which supports your idea that like these proteins might be responding to light. . .”
Reasoning about alternatives	Support students in thinking of alternative outcomes or explanations about their results.	“. . . So I think your model's good, I just want you to think about, is there any other way you could interpret that result.”
Connect evidence to model	Support students in connecting their own data or data in room to their model. Often includes helping students to reason through their data with the purpose of revising their current model.	“So how does your model explain these results? That when you take the acid out it still doesn't grow?”
Make ideas in room accessible	Encourage students to share their ideas with other groups and inquire about findings from others.	“I encourage you to look at other people's results as well as your own just because they might have ideas you want to include in your model.”
Check back to prior model or hypothesis	Instructor brings student attention back to the students' original model or hypothesis.	“So this is a different model then what you had before, because you were thinking that. . .”

Supplemental Table 6: Coding guide for instructor supports in the model revision task.