Collaborative Inquiry into Students' Evidence-based Explanations: How Groups of Science Teachers Can Improve Teaching and Learning

Jessica Thompson, Melissa Braaten, and Mark Windschitl
University of Washington, Seattle Washington
Bethany Sjoberg, *Evergreen High School, Seattle, Washington*
Margaret Jones, *Rainier Beach High School, Seattle, Washington*
Kristi Martinez, *Eastlake High School, Sammamish, Washington*

Teachers in schools across the nation are gathering regularly with colleagues to examine student work and uncover how their young learners are thinking about science ideas. Such groups aim to 1) improve their practice by basing instructional decisions on evidence of student thinking and 2) improve outcomes for students. Achieving positive student learning outcomes, however, requires that teachers use principled ways of designing instruction, selecting student work, analyzing these artifacts, and making evidence-based changes to instruction (Bray, Lee, Smith & Yorks, 2000; NRC, 1996; Wood, 2007).

This article presents a model of collaborative inquiry for groups of science teachers who would like to systematically improve their practice through analyses of student work. We refer to this type of collaborative inquiry as the APEXST model (Advancing High-leverage Practices by Examining Student Thinking) (Figure 1). The APEXST model of collaborative inquiry has three important features: 1) a focus on a high-leverage practice (in this case pressing for evidence-based explanations), 2) a focus on longitudinal learning—both student and teacher learning over the course of a year, and 3) attention to students at all levels of achievement.

Critical Friends Groups

We have designed and tested the APEXST model of collaborative inquiry for Critical Friends Groups (CFGs). A CFG is a learning community of 8–12 educators who gather for about two hours a month to discuss improving their practice through collaborative learning. In collegial CFG meetings, teachers engage in a cycle of inquiry, reflection, and action to promote adult growth that is directly linked to student learning (Curry, 2008; NSRF, 2009). The APEXST model provides a structure and focus for these groups to engage in cycles of meaningful examination of student work. There are five phases of the APEXST model that support the improvement of teaching and student learning.

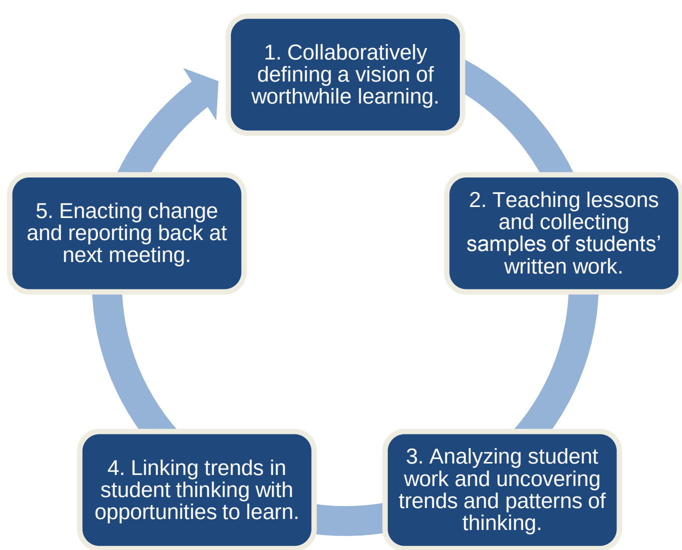


Figure 1. APEXST model of collaborative inquiry into practice

Phase 1. *Collaboratively defining a vision of worthwhile learning*.

Perhaps the most important decision that teacher groups can make is to identify some aspect of student learning that is important enough to focus on for a full academic year (Ball, Sleep, Boerst, & Bass, 2009; Curry, 2008; Windschitl, Thompson & Braaten, forthcoming). We recommend teacher groups choose a core scientific practice that can be developed over the course of a year in learners across different topics and even across different science courses. In our most recent project with teachers we chose students' "construction of evidence-based explanations." This type of scientific thinking is critical to understanding the big conceptual ideas in science and it is a valued scientific practice (NRC, 2000; Windschitl, 2008). We do *not* recommend that teacher groups choose student understanding of specific topics that change from meeting to meeting. This prevents a sustained opportunity by teacher groups to look at the development of an important scientific practice across time.

Developing lessons that press students for evidence-based explanations can be difficult work, and we have found that teachers benefit from discussing with peers what counts as a "big idea" and a rich scientific explanation. The challenge is that lessons from standard curriculum materials are often organized around topics or processes, not big ideas with rich underlying explanations. Big ideas have causal stories, composed of a web of events that help explain why observable phenomena occur. For example, one observable phenomenon could be diffusion of materials across a membrane. The causal explanation for why this occurs has to do with equilibrium, concentrations of solutions, and permeability of membranes.

Once a big idea is selected, teachers can work together to identify a lesson or series of lessons that aim to explain observable phenomena. Typically lessons that ask students to synthesize data from an investigation or information from a body of existing evidence are the most fruitful for helping students wrestle with both the use of evidence and the development of an explanation. Examples might include students making sense of data from a pulley investigation by using ideas about forces, work, and energy to explain why a single person can lift a very heavy load using simple machines. Students could also synthesize what was learned from a series of investigations that examine air pressure in order to explain why molecules behave in predictable ways, in terms of kinetic molecular theory. Alternatively students could synthesize existing bodies of evidence such as DNA, fossil records, and morphology to explain examples of natural selection and evolution.

The next step for teachers is to co-construct a full explanation for the phenomena. A full explanation is a causal story that describes *why* a phenomenon occurs. There might be a chain of "why" explanations that complete the full causal story. To connect this explanation to evidence from an investigation, it is helpful to outline or diagram what is observable or measurable and then draw in features and processes that are not observable—thus creating a scientific model for the phenomenon under study (see Windschitl, 2008 and Windschitl, Thompson & Braaten, 2008 for more information on Model-Based Inquiry).

"What-how-why" explanation

Once the *why* explanation is outlined, the team of teachers can then write a rubric that details a *how* and *what* explanation (see Row 2 in Appendix A. *Analysis of Student Understanding of Evidence-based Explanations*). Figure 2 provides an example of the *what-how-why* explanation framework that a group of teachers we worked with developed for a cellular respiration investigation in which students were asked to "Explain why you would see an increase in respiration after exercise." In the investigation students breathed into a Bromothymol Blue (BTB) solution as a direct indicator of carbon dioxide output and an indirect measure of glucose being converted to energy.

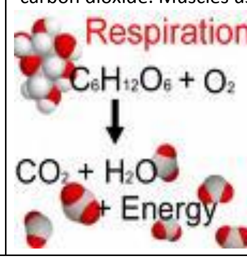
	Level 1	Level 2	Level 3
Depth of Explanation	○ Student describes *what* happened. ○ Student describes, summarizes, or restates a pattern or trend in data without making a connection to any unobservable/ theoretical components.	○ Student describes *how* or partial why something happened. ○ Student addresses unobservable/ theoretical components tangentially.	○ Student explains *why* something happened. ○ Student can trace a full causal story for why a phenomenon occurred. ○ Student uses powerful science ideas that have unobservable/theoretical components (like kinetic molecular theory) to explain observable events.
EXAMPLE explanation for cellular respiration investigation	The Bromothymol Blue changed color after exercise because the body exhaled more carbon dioxide as compared to when the body is stationary. 	When exercising the body requires more oxygen. As oxygen intake increases so does the carbon dioxide output. 	When exercising the body requires more oxygen which is taken from the lungs to muscle cells (via the circulatory system and diffusion). The cells use the oxygen to breakdown glucose into energy and carbon dioxide. Muscles use the energy to do work and the carbon dioxide diffuses into the blood and then the lungs and is exhaled. Cellular respiration happens at a faster rate when a person is exercising. 

Figure 2. Row 2 of the Rubric for Examining 3 Dimensions of Evidence-based Explanations and a sample explanation co-developed by a group of teachers.

Teachers are now ready to co-develop written and spoken prompts to guide students toward "why" explanations.

To help students attend to the use of evidence to support such explanations, teachers can use *Row 1—Degree to which the student makes comparisons among pieces of evidence* and *Row 3—Degree to which evidence and explanations are integrated in written products* in Appendix A to design questions for students as well as to evaluate students' written work.

One of the groups of teachers we worked with wanted students to use multiple forms of evidence *and* coordinate these with a scientifically rich explanation. They devised an investigation in which students collected three types of data before and after exercising: heart rate, number of breaths per minute, and amount of time in seconds it takes for BTB to change from blue to yellow. Following this investigation, students considered two additional forms of evidence: they read about how the brain controls carbon dioxide levels in the body as well as about what it means for the body to be physically fit in terms of lung capacity, blood vessels, and the heart. Students used these five "buckets of evidence" to answer: "How and why does your body return to a resting rate after being at an elevated rate in terms of gas exchange and breathing rate? How might this be different for a person in good shape versus a person out of shape?"

Phase 2. *Teaching lessons and collecting samples of students' written work*

A key feature of the APEXST model is the attention to students of all achievement levels. We recommend selecting nine students to track throughout the school year—three high achieving, three average achieving and three underserved students. The chunk of student work you analyze can be small, perhaps a 3-5 sentence response to an explanation-type question asked on a quiz, or it may be a bit longer if you choose to analyze an evidence-based claim students made following an investigation.

Many of the teachers we worked with found it helpful to also collect video samples as a way to share images of rich classroom conversations with peers. This is optional. As you might expect, recording and editing video samples is time consuming. If available, this work could be done by an additional support person—a district-level science coach, administrator, or a research partner from a university. For video segments, try to capture student-to-student talk as a way to provide insight into how students wrestle with evidence and/or scientific explanations.

Phase 3. *Analyzing student work and uncovering trends and patterns of thinking*

Most assessments will tell you *if* students have learned, however principled examinations of student work can reveal *why* some students have learned and others have been less successful. This analysis phase of the APEXST model is usually done individually by teachers. The first step is to use the specialized rubric you've developed as a reference to detect what "partial understandings" students might have of the target understandings. This provides clues about different paths to understanding, rather than simply making judgments about whether students' responses were correct or incorrect. To conclude prematurely that a student is "wrong" or "didn't get it" distracts from the possibility that there is *some* learning taking place that you can build on.

Partial understandings by students may take several forms. Perhaps a student is familiar with a scientific idea, but uses it in the wrong context. Perhaps a student understands part but not all of an idea. Perhaps they recognize when a vocabulary term should be used but do not provide evidence that they understand what it means. Perhaps they can go through the motions of a scientific practice (like interpreting data, or creating a model), but don't know when or how to apply this practice in a new situation.

Another aspect of analysis is to look carefully at the full range of students in your classroom—high performing, middle, and underperforming students. Attending to a full range of students' written work provides a foundation for teachers to address more systematically how groups of students are learning. One of the teachers working with us found that her underperforming students were having difficulty writing scientific conclusions, not because they comprehended the task differently from their peers, but because they did not know how to respond to feedback the teacher had given them on this type of writing a few weeks earlier. The teacher realized she had to help her underperforming students understand not only how to engage with scientific writing practices, but how to use her feedback more productively.

In the first pass at student work, you can use sticky notes and highlighters to mark places where students show elements of understanding the target idea. Students who have similar responses to one another can be grouped together, and you can then look for one of two types of patterns in student thinking. One pattern is an *unexpected trend*—this is where many students responded to instruction in an unpredicted way. It signals perhaps that a learning situation did not present students with an opportunity to process ideas in the way that that you thought it did. Another pattern is a *relationship*. This is where groups of students, who share similar characteristics, perform similarly on a feature of the task or question. In one of our cases, the English Language Learners in a classroom were able to draw sophisticated models of air pressure during small group work, but during whole class discussions, they were unable to verbalize their thinking to others.

If you decide to also include video as part of your analysis of student thinking, then here are some questions to ask yourself as you analyze the videotape and select a 5-7 minute segment:

- What evidence is there for partial understandings?
- If students gave incomplete or puzzling responses, what questions might you ask to clarify or stretch their thinking?
- If students did not engage in talking about explanations or only gave "what" or "how" level explanations, what prompt or scaffolding could be used?

Phase 4. *Meeting with peers to link trends in student thinking with opportunities to learn*

In the APEXST model of collaborative inquiry, the actual team meeting should be characterized by three kinds of accountability. The first type of *accountability is to peers*, which means showing respect to one another by doing the "groundwork" before the meeting. For each presenter, this means having thoughtfully collected and analyzed student work, made copies for everyone, and being ready for an in-depth discussion. For other participants, being accountable to one another means reserving the full time in your professional schedule needed to engage in this process with others (typically at least 50 minutes for each presenter). Being accountable to peers also requires the use of constructive criticism.

The *second type of accountability is to the science itself*. As part of the collaborative meeting, everyone is asked to make public a shared understanding of what a full and complete explanation is for the phenomenon that student work was collected on. This "primes" all participants to see certain clues to understanding in the student work. It also forms the basis of a common language that can be used during the session. We found that many times we were not confident of our understandings of some fundamental ideas in science, but we made these questions public because a level of trust we had developed, which ultimately helped us better understand the scientific phenomenon.

The *third type of accountability is to understanding the student work.* During the meeting, a segment of time is devoted to giving a generous review of the student artifacts, meaning that everyone looks for partial understanding as if every paper, no matter how sparse, contains important clues to the workings of a student's mind. Participants need to resist glossing over a sample of work, only to dismiss it as "wrong." Participants should look within the work of each student, but also across the samples of student work.

It is helpful to avoid "repair talk"—that is, talk of how one would fix the instructional activity. This talk can be contagious; a skilled facilitator should steer participants instead toward understanding of student thinking.

Two tools are indispensable in maintaining the three types of accountability. One is Appendix A and the specific explanation rubric teachers co-develop in Phase 1. The other is the *Critical Friends Group Protocol* (Appendix B) which is used to structure the conversation with peers. Our research has demonstrated the importance of three specialized parts of the protocol: 1) the invitation to come to a group understanding of the best possible scientific explanation of the focal phenomenon, 2) the prompt to participants to seek out evidence of partial understandings, and 3) at the end of the collaborative session, the move for everyone to imagine how particular instructional choices made by the teacher may have influenced how different groups of students responded to a question or task—thus, allowing the group to hypothesize, *based on evidence*, how changes in instruction could positively impact learning.

Materials needed for a Critical Friends Group (CFG) Meeting:

- Student work: The presenter should bring copies of 3-4 students' work (not all 9 students) that are particularly illustrative of the patterns he/she noted—circle the 1 or 2 assignment questions that were analyzed and include any notes/highlighting from the analysis. Bring one set of papers for each member of the team.
- Rubric: The presenter should bring copies of the rubric that the group co-constructed in the first meeting (based on Appendix A but specialized for the explanation at hand) and notes about all 9 students' thinking (see Appendix C).
- Patterns & Questions: The presenter should bring written reflections on their analysis, summarizing 1) the patterns they saw in the data and 2) questions they would like their peers to focus on during the session.
- Protocol: The facilitator should bring copies of the CFG protocol for all members (Appendix B).

Phase 5. *Enacting change and reporting back at the next meeting*

For the APEXST model of collaborative inquiry, you will want to leave about 30-60 minutes at the end of each CFG meeting to cycle back to Phase 1. After the presentations, the strategies employed by the featured teacher(s) are labeled and recorded on a master list. Each teacher can choose one idea or practice to try out prior to the next meeting. Teachers can then work in pairs to discuss exactly which practices might be applied to an upcoming lesson and work through the activities listed in Phase 1.

Does this form of collaborative inquiry influence practice and student learning?

We have worked with groups of teachers who meet once a month and others who have negotiated with administrators to have three full professional development days per year for this work (models are describe below). Regardless of structure, most teachers made significant gains in how they conceptualized which scientific ideas were worth teaching, how they posed why-level questions in the classroom and how they identified and responded to students' partial scientific understandings. Through collaborative inquiry, teachers were able to greatly improve students' opportunities to engage in rich forms of scientific reasoning. Moreover, over time they grew into a community of 'critical colleagues' who were willing to hold each other accountable, to take intellectual risks, and to open up windows into each other's classrooms.

APEXST Model 1- High stakes, high reward

- *Overall structure.* Teachers invest time and effort into three meetings per year. This option works well for teachers who have constraints about meeting frequently or for teachers who are devising a Professional Learning Community across multiple schools. We ran this model with a group of 11 first year science teachers.

- *Meeting structure.* For each CFG meeting teachers analyze 2-3 different assignments for each of the 9 focal students they selected. Larger groups of teachers are broken into groups of 3 or 4 so that each teacher has a full hour to present his/her analysis. At the end of the day, teachers reconvene and spend about one hour working on Phase 1.

APEXST Model 2- Regular influx of ideas and visions

- *Overall structure.* Teachers meet eight times per year. This option works well with groups of teachers who have regularly scheduled release time and/or who have the aid of a district-level science coach. The coach can pace the group by assisting teachers in designing lessons, videotaping/editing and evaluating student work for each meeting (see Nelson et al., 2008 for more information on coaching). We worked with two groups of teachers using this model: an evening video club with 11 teachers and district-level science coaches (see Sherin and van Es, 2009 for more information on video clubs) and the other group was a science department with 5 teachers plus one coach.
- *Meeting structure.* Each month one or two teacher(s) feature his or her analysis of student work (and possibly a video segment) as part of the CFG meeting. For the last 30 minutes of the meeting all teachers work in pairs to choose a strategy for an upcoming unit and commit to analyze related student work for the next CFG meeting. At the start of the next meeting teachers can report on patterns in student data according to a particular shift in practice.

NOTE: We tried an additional model in schools with small science departments (with 2 teachers) who met every two weeks during a common planning time. The benefit was that the teachers were invested in one another's teaching. However, there were two drawbacks. First, the groups were not always large enough to support critical conversations that could lead to shifts in practice. Second, in one school a teacher stopped participating and the remaining teacher was left without a partner.

Summary

The principled and collaborative analysis of one's practice for the purposes of improvement is the work of professionals. This inquiry itself is scientific, involving the generation of questions, producing and collecting evidence, and co-constructing theories about how and why students respond to instruction in particular ways. Through the APEXST model of collaborative inquiry it is entirely possible for committed groups of science educators to understand their students' thinking in new and deeper ways, and to eventually make evidence-based changes that bring science achievement within the grasp of all their students.

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For more information see: http://depts.washington.edu/mwdisc/ Or contact Dr. Jessica Thompson: jjthomps@u.washington.edu

Rubric for Examining Dimensions of Evidence-based Explanations

Dimension		Level 1	Level 2	Level 3
1. Degree to which the student makes **comparisons among pieces of evidence**.		○ Student uses only one form of evidence. ○ For example: discussion of data in a simple experiment, or discussion of an amino acid sequence in a textbook example.	○ Student <u>*reports*</u> multiple forms of evidence. ○ For example: *reports* data from a complex controlled experiment, or *reports* about human, chimp, and gorilla amino acid sequences from a textbook example.	○ Student <u>*compares*</u> multiple forms of evidence (data from one investigation or multiple investigations) in a sophisticated way and/or considers counterevidence. ○ For example: *compares* findings from complex experiment(s), or *compares* amino acids sequences from humans, chimps, and gorillas from a textbook example.
2. Degree of **depth in student's explanation**.	Explanations with Theoretical Components	○ Student describes *what* happened. ○ Student describes, summarizes, or restates a pattern or trend in data without making a connection to any unobservable/ theoretical components.	○ Student describes *how* or partial why something happened. ○ Student addresses unobservable/ theoretical components tangentially.	○ Student explains *why* something happened. ○ Student can trace a full causal story for why a phenomenon occurred. ○ Student uses powerful science ideas that have unobservable/theoretical components (like kinetic molecular theory) to explain observable events.
	Explanations with Mathematical Components	○ Student describes *what* happened. ○ Student describes, summarizes, or restates a pattern or trend in data.	○ Student describes *how* something happened. ○ Student links observations to mathematical concepts in isolation. ○ For example: correlates the number of strings supporting a load in a pulley system with the effort to lift the load.	○ Student explains *why* a mathematical model accounts for a phenomenon. ○ Student links observations to statistical or other mathematical models. ○ Student explains the links between observations and statistical or other mathematical expressions.
3. Degree to which **evidence and explanations are integrated** in written products		○ Student reports of data are sandwiched in between descriptions of what happened	○ Student begins to describe how their data are about a larger idea ○ Connections between evidence and explanations are implied but not fully described	○ Student writes about how observable/ measurable components are cases of unobservable/theoretical ideas ○ Students can identify how the specific component from the investigation(s) relates to the general case from theory or a complex mathematical relationship ○ Student explanation contains a claim that justifies the link between observable data and unobservable/ theoretical components.

This rubric was designed by Jessica Thompson, Melissa Braaten and Mark Windschitl as a part of the Tool Systems to Support Progress toward Expert-Like Teaching by Early Career Science Educators 2008-2013 Discovery K-12 Grant National Science Foundation No. DRL-0822016

Consultancy Protocol

for examining student work

Roles

Presenter – teacher bringing student work and a question for the group to discuss.
Facilitator – colleague who coordinates the group process and monitors time while participating.
Participants – teacher colleagues who collaborate in the analysis of student work.

Protocol

Step	Description	Time
1	<u>**Overview**</u> Presenter gives an overview of the student work and the central question or dilemma. Please address the following factors: ○ Summary of findings from the analysis of student work including any patterns or trends seen in the data. ○ Brief context of the lesson(s) & student(s) featured in the samples of work. ○ Central question or dilemma that emerged from the analysis and that is featured in the samples.	**5 minutes**
2	<u>**Scientific Evidence and Explanation**</u> What is a level 3 explanation for this phenomenon? What might be students' partial understandings of the phenomena?	**10 minutes**
3	<u>**Reading for Partial Understandings & Listening**</u> Group quietly reads and reviews the sections of the student work pertaining to the presenter's question, attending to students' partial understandings and patterns within and across students. OPTIONAL: Then the group watches a 5-7 minute video segment with student talk from a relevant lesson with students talking about scientific explanations.	**15 minutes**
4	<u>**Clarifying questions**</u> Participants ask clarifying questions of the presenter. Clarifying questions have brief, factual answers. Presenter responds to the clarifying questions.	**5 minutes**
5	<u>**Probing questions**</u> Participants ask probing questions of the presenter. Probing questions push the presenter to think deeply about assumptions and different perspectives. The goal is to use questions to help the presenter expand his/her thinking about the student work and the central question. Presenter responds to the probing questions, but there is no larger discussion.	**5 minutes**
6	<u>**Consultancy**</u> Presenter is a silent listener while participants engage in a larger discussion of the student work, the central question, and the information gathered from the responses to questions. Participants are encouraged to include both "warm" and "cool" feedback in the discussion. ○ *Warm feedback* – identify what you see or hear about successful first steps that students made (or that the teacher made) in these assignments. ○ *Cool feedback* – suggest an area that has some room for improvement and provide the next step that could be taken.	**10 minutes**
7	<u>**Reflection**</u> Presenter summarizes statement between student data and instructional conditions or opportunities for change. Presenter reflects on any new ideas, new perspectives, or new questions that emerged from the group discussion. Presenter also reflects on the central question in light of the discussion.	**5 minutes**
8	<u>**Debrief**</u> Facilitator leads a conversation about the overall group process reflecting on the dynamics of the group and the use of the protocol. Some ideas for debriefing include: ○ *Accountability to students' ideas*: How did group members give the student work a "generous reading" during the process? ○ *Accountability to science*: Did we reach any consensus about the science behind this activity? ○ *Accountability to one another*: Did everyone have a chance to participate? How did we use strategies like paraphrasing and "wait time" to be active listeners? ○ *Overall*- How might we change the ways we are collecting, analyzing, and discussing student work?	**5 minutes**

The Consultancy Protocol, from which this was adapted, was developed by Gene Thompson-Grove, Paula Evans and Faith Dunne as part of the Coalition of Essential Schools' National Re:Learning Faculty Program. This protocol was designed by Jessica Thompson, Melissa Braaten and Mark Windschitl as a part of the Tool Systems to Support Progress toward Expert-Like Teaching by Early Career Science Educators 2008-2013 Discovery K-12 Grant National Science Foundation No. DRL-0822016.

Appendix C. Analysis of Student Work Record Sheet

Teacher name: ___________________________________ Date: ___________________

Brief description of the student work sample____

Directions:	Level 1	Level 2	Level 3
In the columns to the right, write your specific expectations for a Level 1, Level 2, and Level 3 response for students' science work using the Evidence-Based Explanations rubric as a guide. In the spaces below, read and analyze samples of your students' work, record the Level that the work seems to be, and make some notes about why this work seems to be at this Level.			
Student Codes/ Pseudonyms	Record student data below:		
1.			
2.			
3.			

4.			
5.			
6.			
7.			
8.			
9.			

Analysis & Implications for Practice

After examining patterns in your data, answer these two questions in preparation for your Critical Friends Group Meeting.

1) Discuss patterns for students (high, middle, underserved) seen in the assignment.

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2) What student learning dilemma emerges from examining these patterns? What is something that bothers you about the data? Or what is something that you find interesting? Phrase this as a question:

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Tips for Identifying Patterns in Student Work over Time

Here are some tips for identifying patterns in your data and devising a question for a follow-up CFG meeting.

Patterns to look for (choose 1)	**Who to analyze? (choose 1)**	**Ideas for CFG Question (choose 1 or 2)**
1. Student's partial understandings stayed the same across time or across all assignments.	All students *(i.e., high, middle, underserved)* One group of students *(i.e., just the underserved students)* One student	• What might be going on here that I am not seeing? Are there some subtle changes in the student work that I am not seeing? • What could I do to challenge all of these students (or this student) even more? • What was the nature of the instruction or questions on the assignments that might have influenced my student(s) staying at the same levels?
2. Student's partial understandings changed across time or on certain assignments.	All students *(i.e., high, middle, underserved)* One group of students *(i.e., just the underserved students)* One student	• What was the nature of the assignments/questions that might have caused the levels of student work to change? • If the change was an improvement, how can I generalize this change to other assignments or to other students?
3. Student's partial understandings were not sophisticated enough for analysis.	All students *(i.e., high, middle, underserved)* One group of students *(i.e., just the underserved students)* One student	• What was the nature of the assignments/questions that might have limited the sophistication of student responses? • How can I improve the sophistication of the assignments and/or questions that I ask students in order to elicit more sophisticated student responses?

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