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To meet the immense challenges our society faces in areas such as energy, health, and environmental protection, we, as science teachers and teacher educators, need to invest in the creation of classroom cultures that turn the intellectual heavy lifting over to the students while developing students' identities as competent learners. Our vision is that classrooms are both intellectually rigorous—accountable to important ideas and practices in the discipline—and uncompromisingly responsive to students' developing scientific ideas. Problematically, this type of teaching is currently rare in science classrooms (Corcoran & Gerry, 2011; Kane & Staiger, 2012; Pasley, 2002; Roth & Garnier, 2007; Weiss, Banilower, McMahon, & Smith, 2001). Studies of novice teachers indicate that "the use of analogies, the implementation of strategic approaches to questioning, and the elicitation of student understandings remained virtually absent from their dialogue in class" (Hogan, Rabinowitz, & Craven, 2003, p. 243). Creating rigorous and responsive science learning environments that are the norm rather than the exception in the American educational system is thus a grand-scale inquiry project that will require decades of collaboration and investigation to generate a shared vision of quality teaching and learning.

The first-year teachers who co-authored this paper are leading this charge. They were one of the first cohorts to complete a teacher education program that focused on learning and inquiring into a core set of ambitious science teaching practices—practices that focus students' intellectual work on complex problems rather than the typical emphases on activities and procedural talk; are adaptive to students' needs and thinking; and maintain rigorous standards of achievement for everyone, enabling learners of all backgrounds to succeed at high-quality work (Fennema, Franke, Carpenter, & Carey, 1993; Hill, Rowan, & Ball, 2005; Lampert & Graziani, 2009; Newmann & Associates, 1996;). In science, ambitious practices engage students in generating and revising scientific models that are explanatory and predictive of natural phenomena (Windschitl & Thompson, 2006). Scientific modeling and the development of evidence-based explanations and arguments are central disciplinary practices students need to learn to participate in civic decision making and participation in the next generation of science careers (see the Next Generation Science Standards, Achieve 2012). The teacher education program also supported teachers in inquiring into their teaching practice during practicum (in preparation for the Teacher Performance Assessment, TPA, needed for state teaching certification) and during their first year of professional practice (as a part of the requirements for earning a master's degree). The teachers collected and analyzed samples of students' written attempts at scientific explanations and associated video segments of students' classroom talk. During their first year of teaching, the cohort of teachers met three times, using a Critical Friends Group (CFG) meeting format, to share their analysis of student work and make informed changes to their practice (see Thompson, Braaten, Windschitl, Sjoberg, Jones, & Martinez, 2009 and Windschitl, Thompson, &

Braaten, 2011 for a full description of these activities and tools that supported the analysis of student work).

The three novice teachers whose work is featured in this article used these opportunities for analysis and reflection to examine strategies to shift the intellectual authority in classrooms over to students in equitable ways. They all taught in urban high-needs schools where, historically, students have not had access to intellectually demanding curriculum and instruction. Ms. C. became interested in supporting students in reflecting on how and why they revise explanatory models. Ms. H. became interested in creating student-led routines that made their evolving explanations public. Ms. K. became interested in capitalizing on students' everyday language and supporting the development of their academic language. The three teachers demonstrate how their participation in collaborative inquiry was more than a series of projects scattered across practicum and their first year of teaching, but rather a stance toward teaching and learning that became a habit of mind (Cochran-Smith & Lytle, 2009). Yet they also sought to capture their knowledge of ambitious teaching practices in tools and routines that can be modified over time and shared among teachers using similar practices. Each of the following cases describes how an initial action research project fueled ongoing cycles of inquiry that generated innovative tools and routines for shifting the intellectual authority in classrooms from the teacher to students.

Supporting Students' in Revising Their Ideas: Ms. C.

Throughout my pre-service practicum and into my first year as a science teacher, I developed a theory of teaching and learning grounded in the importance of supporting students in revising their science ideas and reversing traditional teacher-student roles in order to promote engagement in the process of science. As a trained scientist and as a teacher, I was interested in the process of revising scientific models and how supporting students in doing this could inform me and my students about how and why their ideas changed over time. During my practicum in an urban high school, I investigated how students used tools to revise their scientific models and explanations. I did a systematic analysis of students' written artifacts over several assignments, comparing their pre-assessments to post-assessments, and chose to analyze one of my "revision tools" for my Teacher Performance Assessment. This particular "revision tool" took the form of a set of scaffolded prompts for sticky-notes that supported students in tracking and modifying their ideas throughout a two-week unit on sound. On Day 1 of the unit students were asked to construct an initial conceptual model to answer and explain the following essential questions: 1) how is sound created by a musical instrument; 2) how does sound travel to the listener; and 3) how do we hear sound? Toward the end of the unit students used color-coded sticky notes to reexamine their initial conceptual models. They used green to revise part of the model based on evidence, orange to add to the model based on evidence, yellow to delete or find out more based on evidence, and purple to ask additional questions (Figure 1).

My analysis demonstrated that some students were directly referencing labs and activities as they added sticky notes to their models (see Figure 2), yet most students did not reference specific changes in their understanding nor reflect on their own learning process. During this analysis, I realized that the tool employed did not directly encourage reflection and metacognition.

In response to data collected from my pre-service teaching last year, the tools I use now focus more on students' own reflections and analysis of their learning. While I previously centered my action research on *how* science ideas changed over time, I now look at *why* those ideas change over time, from the perspective of students. This analysis led me to incorporate a reflection and metacognitive component to the end of a recent unit assessment on mitosis and cancer (Figure 3). In this assessment, students were asked to compare their current ideas to their initial science ideas and identify why those ideas changed. Using these prompts, students were afforded the opportunity to identify how and why their ideas changed over time. Instead of providing students with teacher-centered feedback, I used this tool to put the role

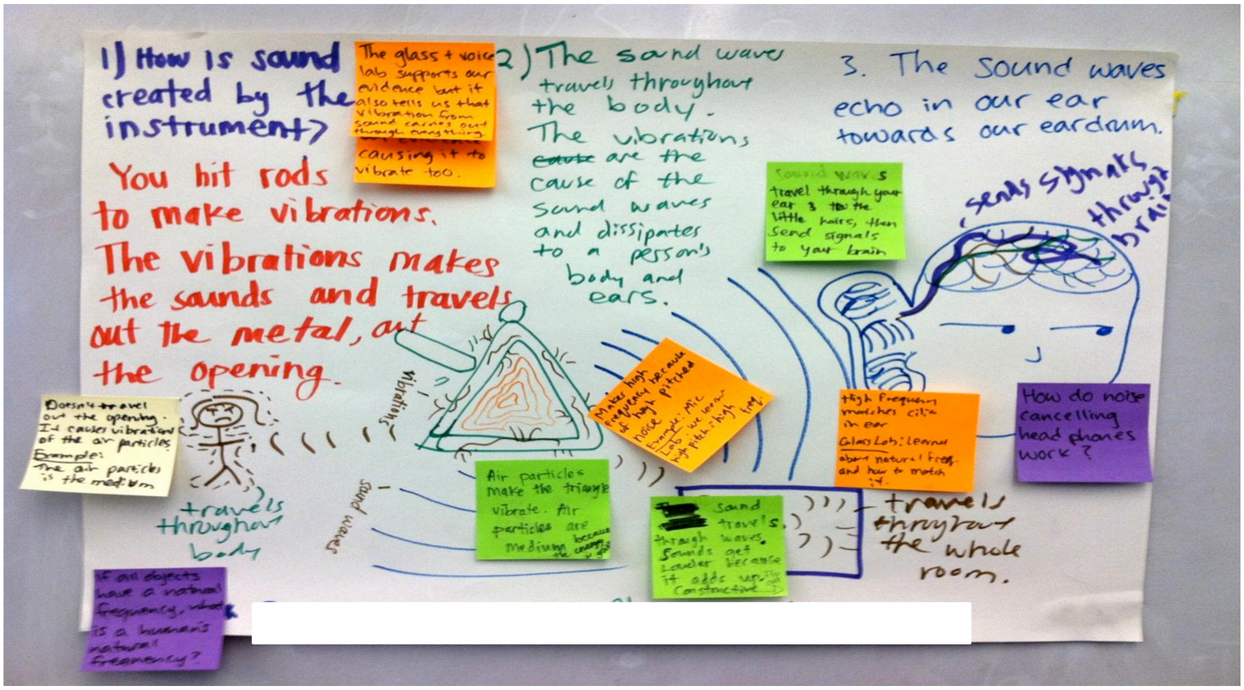


***Figure 1.* An example of student revisions to an initial model of how sound is created by an instrument.**

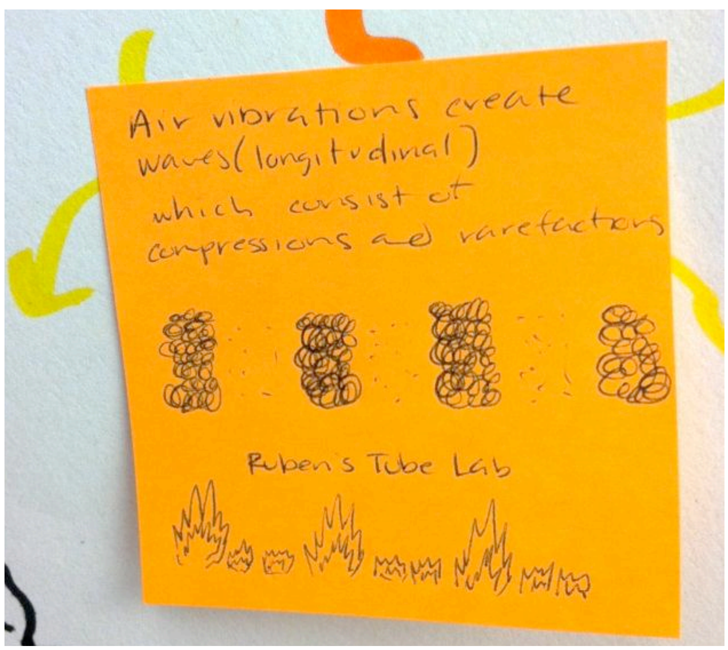
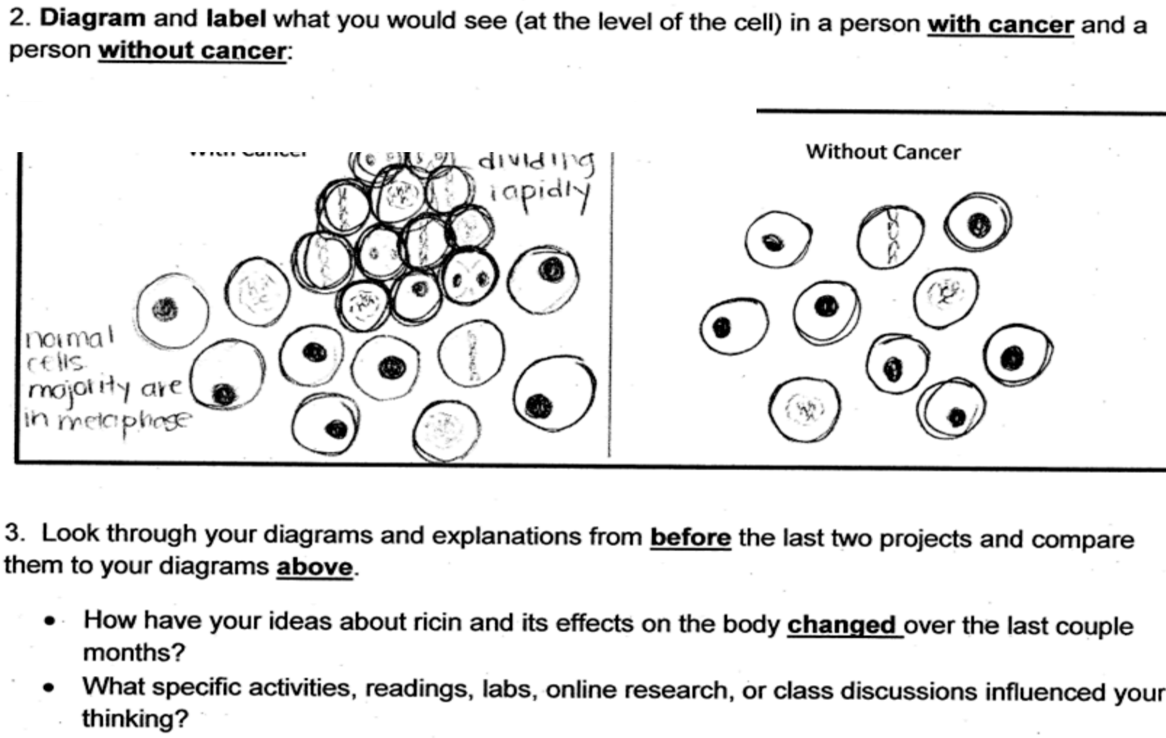


***Figure 2.* An example of a student revising his model of sound based on the Ruben's Tube lab from a few days earlier.**


2. **Diagram** and **label** what you would see (at the level of the cell) in a person **with cancer** and a person **without cancer**:

3. Look through your diagrams and explanations from **before** the last two projects and compare them to your diagrams **above**.

- How have your ideas about ricin and its effects on the body **changed** over the last couple months?
- What specific activities, readings, labs, online research, or class discussions influenced your thinking?

Figure 3. **Prompts to support student reflection on how cells divide.**

of feedback and reflection into the hands of the students. While the process was initially difficult for some, it proved to be empowering for many students who had not been asked to reflect and analyze their own ideas. Students were amazed at how much they had learned over a short time period and could identify where and when their thinking changed. This experience was particularly powerful because students were engaged in the true nature of the discipline. Science is not merely a body of knowledge, but a way of understanding, explaining, and revising ideas as new evidence comes to light. By working to help students navigate their own reflections on learning, it encouraged them to identify as scientists and in turn gain new access and open opportunities for engagement in real science.

Routines for Facilitating Conversations about Science Ideas: Ms. H.

Regular reflection was a defining characteristic of my practicum experience in an urban high-needs high school science classroom. Early in my pre-service practicum, I began to focus on the question, “How can students be encouraged to take more ownership over their science learning?” Throughout the year my cooperating teacher and I employed various tools and routines that could both provide a public record of student thinking and cultivate a sense of ownership. During a chemistry unit on atomic structure, we had student groups regularly revise a KWL-type (what do I Know, Want to know, want to Learn) poster to track how students’ initial questions were being answered over time. During several units, we had students generate questions then used large summary tables of student learning to visually show connections between their questions and class activities. At the end of each activity students were asked to fill in their own chart on which they described patterns or observations from the activity, explained the cause of the pattern/observations, and finally, described their ideas about the connection between the learning and the puzzling phenomenon/big idea of the unit (see Figure 4). We then led the students in a whole class discussion about what they had written in the charts and tried to capture the essence of the class discussion on the class summary chart.

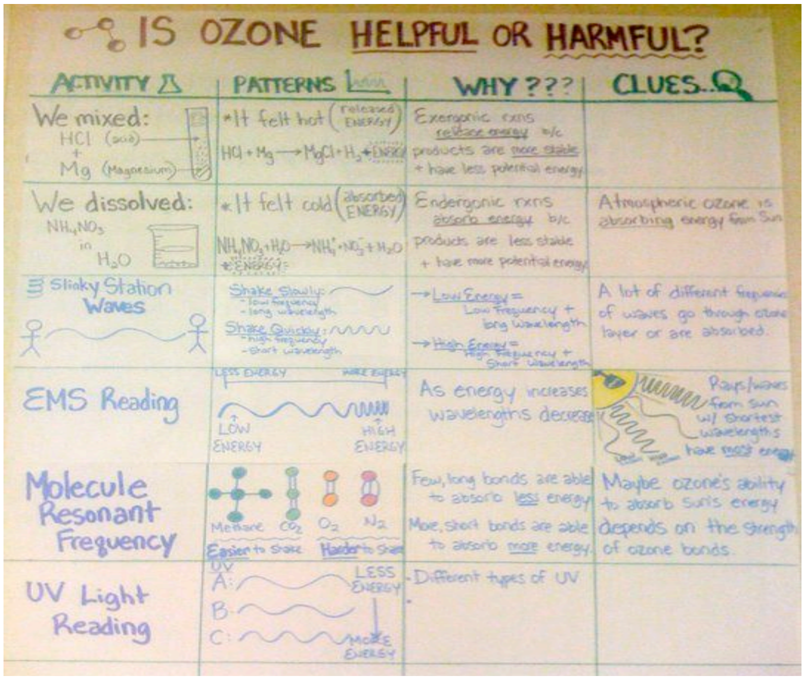


Figure 4. **Summary Chart for a chemistry unit on energy and how it affects ozone at higher and lower levels in the atmosphere.**

We found that these summary tables were successful in helping students sum up their learning from the day, keep track of the activities we had done, and see how that learning connected to the puzzling phenomenon and big ideas of the unit. Students found these charts to be useful tools when synthesizing explanations that included multiple types of evidence from throughout the unit. However, when we analyzed their individual charts it became clear that most students' charts were exactly the same; they had simply copied what the teacher had written after the class discussion. The last column of the chart was intended for students to personalize the learning and make their own connections between the activity and the big idea of the unit. Despite using strategies like think-pair-share during the class discussions, during which many students shared their own ideas, students seemed to believe that the authority for what belonged on the summary charts belonged to the teacher.

When I moved into my first year of full-time teaching, I sought to find a way to continue using tools and routines that facilitated students in reflecting on their learning and making connections to the big idea of the unit, while working to shift some of the intellectual authority to the students. I found that there was no substitute for literally putting a student into the spotlight as "the teacher." Every day, we now have student-led warm-up time for the first five minutes and cool-down time for the last five minutes and students complete the class summary chart as a part of these discussions. On a rotating basis, students lead these times in pairs, going over the warm-up questions, taking answers from the class, summarizing their answers, and generating more questions. Warm-up leaders also go over the learning target for the day and ask the class to think about why that is an appropriate learning target based on how it connects to previous lessons. In the cool-down the leaders help the class briefly reflect on how well we met the learning target and what "need-to-knows" or questions students still have in order to meet it. Students record these responses and questions on a class summary chart. Not only has the summary chart shifted, but so have discursive routines around this chart. In a recent unit, students were learning about metabolism and energy in body builders. During the cool-down, the following student-generated questions were recorded (SL1 &2 = Student Leaders, S= Student).

> SL1: So today we learned how the body builds muscle.

SL2: Our learning target was how muscle is formed. Do you know why we did this?
S1: So we know why body builders are different from us.
SL1: So does anyone still have questions?
S2: How much fat can a body hold? What is the least amount it can hold?
S3: How do muscles grow?
S4: Is too much protein bad for your body?

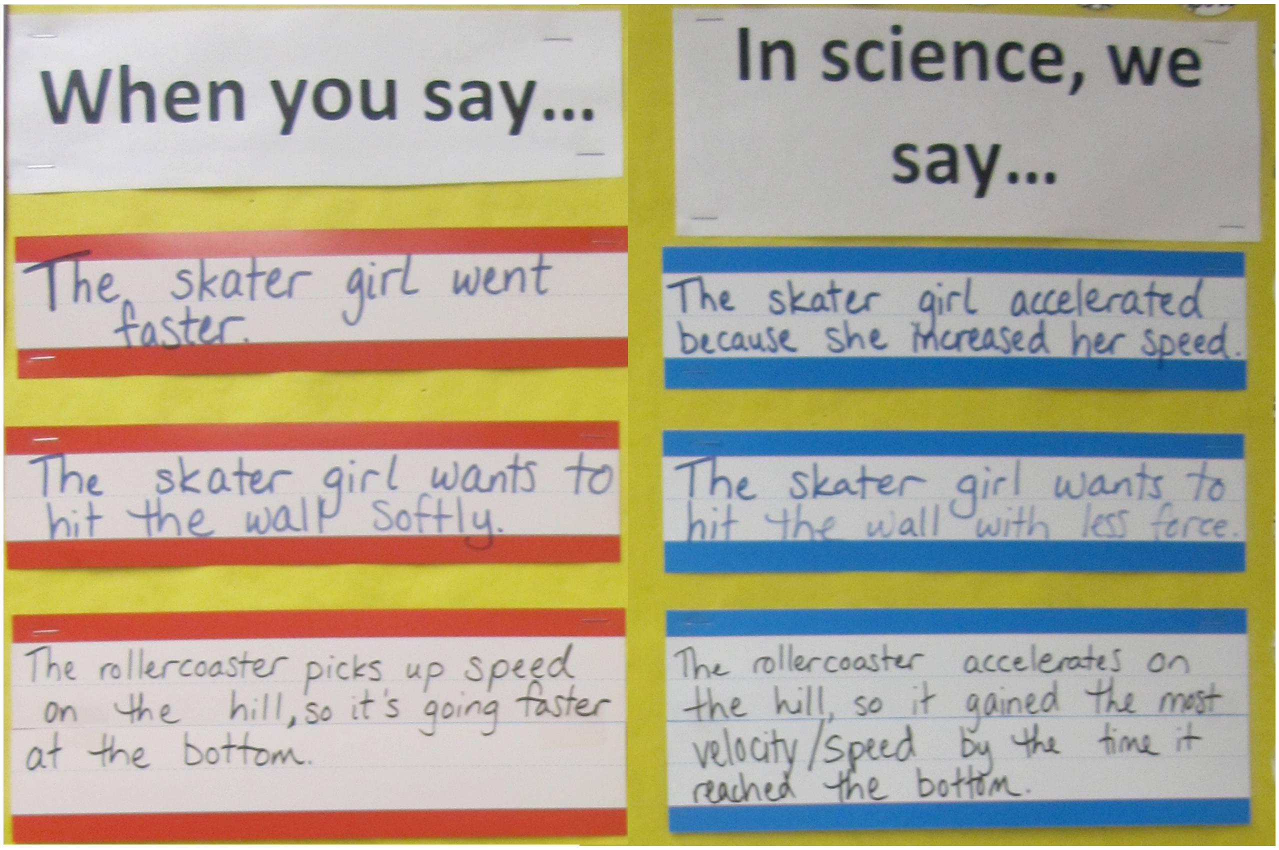
These questions helped shape our lessons and discussions over the following days. This year I videotaped warm-ups and cool-downs, and analyzed student talk for both the quality of the scientific explanations/questions as well as the degree to which students used their everyday language. By using this classroom routine, I have dramatically increased student voice in the classroom. Students are actively engaged in understanding their own and others' progress toward meeting the learning objectives and are sharing questions with others in their learning community. Additionally, I have found that students act more professionally and often demand the respect of their peers when they stand up to lead the class. In return, students are incredibly responsive toward their peer leaders and I more often hear students say, "Shh, stop talking, this is our learning!" I am encouraged by this response and continue to reflect on how to provide structured time and space within the class to more fully hand ownership of learning to students.

Bridging Student Language and Academic Language: Ms. K.

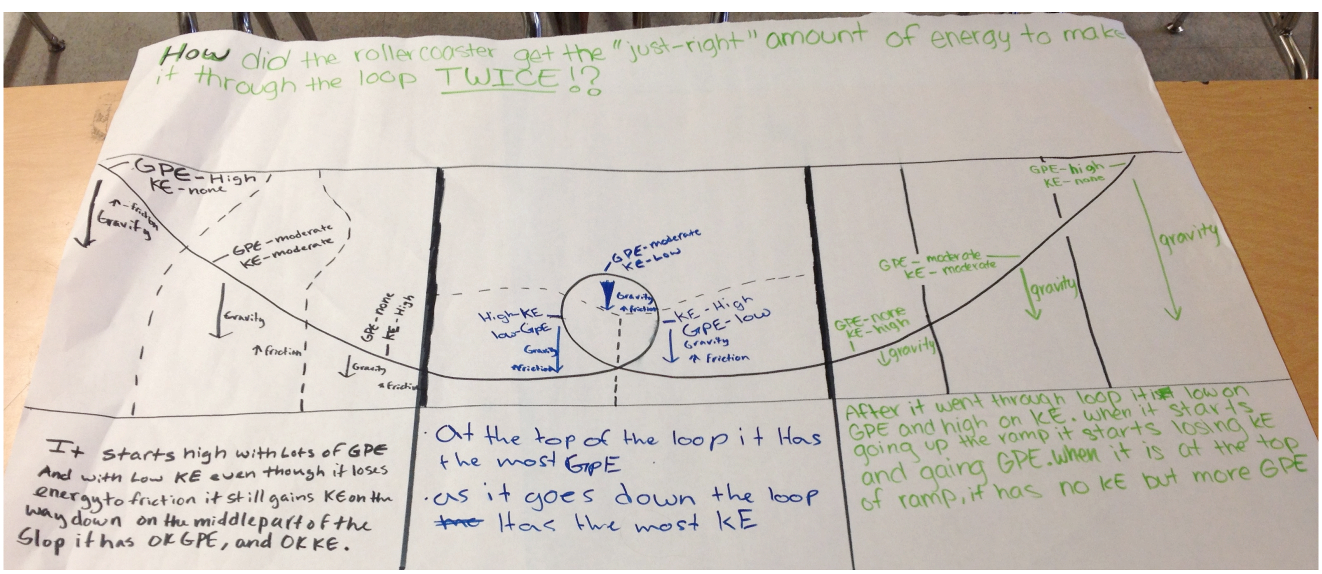
During my practicum, I found myself drawn to exploring ways to encourage and support student independence in navigating ideas. My approach was based on the idea that one of the main barriers to student independence in science is the massive amount of scientific academic language that students believe they must conquer before dealing in the ideas of science. I believed that if I could remove the intimidation factor of the academic language, students would be able to realize more easily that the ideas are already there. I approached this barrier by asking my students to keep an ongoing glossary, in which they would construct a multi-level definition for each word that I deemed important in a lesson or a unit. We made entries in our glossary when I felt they should have mastered that word or concept. For example, students may be able to enter the word "producer" (an organism that can make its own food – most often using photosynthesis) into their glossary after one lesson. However, they may need multiple lessons to fully understand the more complicated concept of a "niche" (how an organism makes a living in its ecosystem – this includes its relationships to other populations, what it eats, where it lives, etc.). The goal was to have a full working glossary by the end of the unit. Students could modify definitions and were always given class time and teacher guidance, if needed, to enter these words into their journals. This also provided me a reliable formative assessment that could be spot-checked at various times throughout a unit to gauge the students' progress.

At the end of the ecology unit, the students took a test that asked them to go beyond identifying the definition of a niche. They were asked to use the concept of a niche to explain the unit's overarching question: Why has the Lake Victoria ecosystem changed so much after the introduction of an invasive species? Students were provided with a word bank, which matched the words they had entered into their glossary. They were allowed to use their journals to complete this assessment. My quantitative analysis of this assessment showed that 56% of the students were able to meet the learning goal of "…identify[ing] and describ[ing] what an organism's general task or role is in an ecosystem." Only 14% of the students who took the assessment were able to identify and describe more than one aspect of an organism's niche.

Upon further qualitative analysis of selected students, I noticed that students were simply copying definitions from their glossary onto the paper. This was not mastery of academic language. Many students, when using the actual word "niche," tended to do so in awkward sentences that demonstrated their inability to incorporate more than an academic definition. Upon reflection, I realized that asking the students to work with the words mainly by writing or copying their definition had solidified the



***Figures 5 & 6.* Phrase wall to support students in generating explanatory models of energy transfers on a rollercoaster loop.**



academic language as nothing more than a set of definitions to memorize and recite/copy into the appropriate place – exactly what I had hoped to change by using the glossary! These ideas were backed up by the overwhelming amount of students (over half!) who failed to even attempt to use the word in their explanation of what happened and why to the Lake Victoria ecosystem. I was left with a huge question: "How can I create spaces in class for academic student discourse (oral or written) to support my students' attempts to construct full, meaningful explanations about science?"

In my first year of teaching, I have implemented a few core tools and practices in my classroom that aim to give students space to use academic language in a low-stakes setting. Instead of student glossaries, I use a word wall with pictures and written definitions so students always have a place to start if they feel they don't understand a word or concept. Next to the word wall is a phrase wall (see Figure 5), which we add to every week or two. On one side, there is a sentence that uses everyday language to explain a science concept; typically, these are explanations I have heard in class. As an entry task, students are asked to "translate the sentence into science language." We post their ideas for how the words they are already using can be easily translated into academic language. Perhaps the most important change I have made in class, though, is providing multiple times during a unit for students to pause and try to use the language/words we have been adding to our word and phrase walls. We do this in a variety of ways – during class discussion and, partner talk, in quick writes on a personal whiteboard and exit tickets, and when developing and refining scientific models (Figure 6).

I have seen an overwhelming shift in my students' ability to incorporate academic language in a meaningful way into their explanations about science. Not only are more students intertwining science words and ideas with their own, existing "layman's terms," but more students are simply trying to use the academic language. I believe this shift is due to the way I have asked students to focus on science language in class. We still have a class glossary (the word wall), but it is one of many resources, and it is only used as a starting point. Instead of placing attention on completing a glossary, I am asking students to do something that requires the glossary, but also involves them in intellectually engaging the scientific language and concepts. This has resulted in a safer place to share ideas and has helped develop a science classroom that stresses the importance of questioning, using evidence, and constructing valid explanations instead of memorization and recitation of facts. Students are starting to view their ideas as possible facts, waiting to be tested and translated – beginning to lower one of the most major, intimidating barriers to meaningful engagement in science.

Cycles of Inquiry and Innovation

Through cycles of collaborative inquiry these beginning teachers have taken on challenging questions about how to make classrooms spaces where students are sense-makers. They are conducting small tests of small changes to practice (Morris & Hiebert, 2009) and are designing innovative tools and routines to locally support their students in working with and on one another's ideas. Through this process they challenge traditional teacher-student roles that emphasize the transfer, rather than the building of knowledge. The questions they ask help improve not only their teaching in their individual classrooms, but help advance collective understanding of ambitious science teaching. Three features of their work thus appear to be critical to improving teaching and learning: 1) developing a shared vision of ambitious practices, 2) engaging in cycles of inquiry around a core set of ambitious practices, and 3) developing visible, tangible, adaptable tools that contain embedded knowledge important to learning practices in the discipline (see also Bieler & Thomas, 2009 and Hiebert & Morris, 2012). The teachers have found that their public representations of student thinking tools and the constant refinement of these tools not only support student learning, but mimic the importance of building knowledge in the discipline of science. Importantly, the teachers' cycles of inquiry and tool development are shared among a larger community of educators, thus making it possible to support the improvement of teachers, as well as ambitious teaching.

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