# From “Sharing Out” to “Working Through Ideas:” Helping Teachers Transition to More Productive Science Talk

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From "Sharing Out" to "Working Through Ideas:" Helping Teachers Transition to More Productive Science Talk

This paper presents key research findings from the *Talk Science* project, a project aimed at helping teachers promote students' scientific reasoning through discussions. The findings shed light on how teachers learn to build a culture of classroom talk that makes students active agents of their own learning (Alexander 2006). Specifically, the findings describe changes in teachers' knowledge, perspectives, and practice as they learn to facilitate classroom science discussions.

*Talk Science* is an approximately 10 week web-based teacher professional development (PD) program aligned with the web-based Inquiry Project curriculum for Grade 3-5, both the curriculum and PD are available at (http://inquiryproject.terc.edu). *Talk Science* blends independent web-based learning with classroom trials and school-based study groups where teachers discuss with grade level colleagues the successes and challenges of supporting classroom science discussions. Consistent with the emphasis on situating teachers' professional learning in their actual practice (e.g., Ball & Cohen, 1996; Ball & Forzani, 2011), the PD is designed to help teachers lead productive discussions as they teach the Inquiry Project curriculum.

To help teachers foster students' science learning through discussions, the PD provides video-rich cases on (i) scientists' reasoning about key science ideas within the curriculum; (ii) the focus and structure of effective science discussions; and (iii) discourse strategies. Teachers' independent web study begins with three *Talking Point Cases* that help them become familiar with the rationale for classroom talk and for establishing shared classroom norms. The *Scientist Video Cases* help teachers to deepen their understanding of key curriculum concepts and scientific practices; the *Classroom Video Cases* help teachers develop a vision of effective science discussions, and how teachers and students co-construct understandings by engaging in scientific practices within a classroom community. Finally, *Talk Strategies* introduce nine specific talk moves to help teachers maintain rigorous, coherent, and equitable discussions (Michaels & O'Connor 2012) where students reason and co-construct understandings with their peers. The full collection of resources is embedded within an eight step program of study referred to as the *Talk Science* Pathway.

## *Rationale*

Research from the learning sciences, science education, and the National Research Council's reports on teaching and learning science all agree that *talk is central to doing and learning science well*. Discussion is key to science inquiry, enabling students to make meaning of their investigation experiences by comparing and evaluating observations and data, generating questions, developing hypotheses and explanations, and exploring alternative interpretations (Duschl, Schweingruber, & Shouse., 2007; Mercer, 2002; Michaels, Shouse, & Schweingruber. 2008).

However, effective science discussions have been mostly absent in classrooms (Stigler & Hiebert, 2004). The discussions that do happen are often characterized by *sharing out* findings from individual or group investigations and question-answer recitation, rather than an *inter-*

*animated* process where students co-construct and critique ideas and deal with uncertainty as scientists do (Alexander, 2001 2008; Ford & Forman, 2011; Mortimer & Scott, 2003; Nystrand, Gamoran, Prachur, & Pendergast, 1997).

The Inquiry Project curriculum for Grades 3 to 5 addresses a key part of this problem by providing a conceptually-based, coherent, and challenging curriculum. Its goal is to help students build a foundational understanding of the nature of matter and material over an integrated three-year course of study. A central characteristic of the curriculum is its focus on evidence-based reasoning. It is a *discourse-intensive curriculum* in which structured discussions are part of students' investigations and essential to advancing learning.

Yet, conventional patterns of classroom discourse are resistant to change (Ogborn, Cress, Martins, & McGillicuddy, 1996), and teachers need support in orchestrating science discussions in which students think together, co-construct and critique ideas, and make scientific progress in their understanding. In the fast pace of the classroom, effective facilitation requires the ability to improvise and facilitate dialogue on-the-spot in the unpredictable flow of the discussion, to know how to make disciplined in-the-moment decisions and quickly understand a situation and respond (Ball & Cohen, 1999; Sawyer, 2004). It requires being able to reflect on and analyze when and how students' ideas are moving forward and decide how to support students in constructing deeper meaning. It is a balanced process in which the teacher continually asks—*What are students thinking? How can I help them to improve their reasoning?*—while keeping in mind the scientific ideas and practices toward which students are moving (Ball & Cohen, 1999; Hogan, Nastasi, & Pressley, 1999).

Work referred to as *Academically Productive Talk* (Resnick, Michaels, & O'Connor, 2010; Chapin, Anderson, & O'Connor, 2009; Michaels, O'Connor, Hall, & Resnick, 2002) identifies three dimensions of accountability related to talk: 1) *Talk must be accountable to knowledge*, that is, it must be purposeful, it must lead to deeper understanding of the discipline. In the case of science, this includes understanding of key ideas, practices, and core concepts of science (NRC, 2012). *Talk must be accountable to standards of reasoning*. In the case of science, reasoning is a dual process of constructing and critiquing ideas. This means, holding observations, measurable data, and models in high regard while maintaining a tentative stance toward all answers (Ford & Forman, 2011). *Talk must be accountable to the learning community*, that is, learners are responsible to each other. They listen to each other, share ideas, and build understanding together. Accountability to community is central to science as its fundamental purpose is to contribute to public knowledge (Ziman, 1968)

Within the PD program, the first two dimensions, accountability *to knowledge and accountability standards of reasoning*, pertain to building ideas into coherent lines of thinking. To be accountable to knowledge, a classroom discussion must be purposeful. It's important for teachers to view discussion as essential to learning, and to plan discussions with the same care that they plan the rest of their teaching. Specifically, teachers need a firm understanding of the important science ideas framing the instructional goals of the discussion; they need to know how students' ideas relate to the canonical science, and how the class discussion might move collective understanding forward. Teachers also need to be able to use the practices of science to support scientific thinking and talk, thereby embodying broader science practices into their classroom discourse (e.g., McNeill & Krajcik, 2008).

In *Talk Science*, teachers study video-rich cases showing how scientists reason about core ideas within the curriculum to strengthen their understanding of the science and develop facility with scientific practices. They also study video cases depicting real classroom discussions to understand the purposes and structure of different types of science discussions, and how to embody scientific ideas and practices in classroom discourse. For example, discussion types include eliciting students' preliminary ideas and predictions; encouraging students to examine data from their investigations; and helping students generate explanations using data and scientific models. The program helps teachers to plan purposeful discussions by providing clear learning goals and an overarching discussion question for each lesson of the curriculum.

The *Talk Science* program also supports accountability to community. Science learning is promoted when teachers and students co-construct understandings by sharing, critiquing, and improving ideas. Classroom research advocates engaging students in communities of inquiry (Brown & Campione, 1992; Wells & Arauz, 2006), where they are guided by shared norms of disciplinary participation (Engle & Conant, 2002; Herrenkohl & Guerra, 1998), and where they participate in discussion and argumentation with peers to advance the collective knowledge of the classroom (Driver, Newton, & Osborne, 2000; Scardamalia & Bereiter, 2006). Within classroom communities, students' discourse with peers is critical for developing robust scientific understandings because it allows them to compare multiple perspectives and revise their thinking (Bell & Linn, 2000); engage in scientific practices of constructing and critiquing claims and generating explanations (Ford & Forman, 2011; Woodruff & Meyer, 1997), and develop normative understandings of science concepts (Roschelle, 1992; Roth, 2005).

*Talk Science* introduces four goals for supporting accountability to community that in turn contribute to knowledge and reasoning (Michaels & O'Connor, 2011). These goals are to: 1) help students share, expand, and clarify their *own* ideas; 2) help students listen carefully to their peers; 3) help students dig deeper into the data, evidence and reasoning; and 4) help students engage with the ideas of their peers. To support the goals, the pathway provides multimedia cases depicting nine talk strategies, called *Academically Productive Talk Moves* (APT Moves). The APT moves serve as concrete tools for teachers to guide students' reasoning, and are based on the sociocultural premise that language, or more specifically, talk is an important cultural tool mediating individuals' cognitive development (Michaels & O'Connor, 2011).

The work on talk moves resonates with research in science education on authoritative and dialogic discourses. To help students learn science meaningfully, teachers need to navigate *authoritative* and *dialogic* discourses skillfully, both of which are critical for students' mastery of science (Scott, Ametller, Dawes, Staarman, & Mercer, 2007; Scott, Mortimer, & Aguiar, 2006; Tabak & Baumgartner, 2004). In authoritative discourse, teachers introduce and focus on the canonical scientific perspective through question and answer sequences to help students understand established scientific knowledge. In contrast, in dialogic discourse, teachers encourage students to share and engage with diverse perspectives, identifying how different ideas relate to one another and to the scientific understandings. The two kinds of discourse exist in tension in classroom science discussions, and teachers need to make purposeful shifts between the discourses to guide students' understandings. In this regard, teachers can use talk moves to foster meaningful student learning. When used strategically, talk moves can serve as a tool to help teachers bring about both authoritative and dialogic discourses in the classroom (Michaels & O'Connor, 2011).

*Research Focus and Questions*

On the *Talk Science* project, the development and research teams worked separately but in parallel to design and investigate the PD program respectively. The research component of the project began in 2010-2011 with a sample of eleven teachers from Grade 4 across five schools in the Northeastern United States.

The 2010-2011 research provided opportunity to pilot the research design and analysis instruments, and informed the research for the following year, namely the refinement of instruments like interviews and coding rubrics. In the following year, 2011-2012, the research team concentrated on a sample of Grade 5 teachers. This paper reports findings and insights from research with the Grade 5 teachers. The authors of this paper were involved mainly with the research component of the project.

The goal of the research with Grade 5 teachers was to study the teachers' professional learning as they participated in the *Talk Science* program while implementing the Inquiry Project curriculum for the first time. Specifically, the goal was to understand how teachers learn to orchestrate science discussions to support students' scientific reasoning. Toward this end, the research examined teachers' participation in the program; and changes in their understanding of the role of classroom discussions in students' learning; in their understanding of the core ideas from the curriculum; and in their practice at facilitating discussions. The research conducted was of an exploratory nature. The following questions guided the research:

1. How do teachers' understanding of the core science concepts in the Inquiry Project curriculum change as they participate in the *Talk Science* PD while implementing the curriculum?
2. How do teachers' understandings of the nature and importance of science talk and their skills at orchestrating it change as they participate in the *Talk Science* PD while implementing the Inquiry Curriculum?
3. How does student talk (amount and quality of scientific reasoning and co-construction with peers) change from early to late as their teachers participate in *Talk Science* PD while implementing the Inquiry Curriculum?
4. How do classroom discourse patterns change as a result of changes in the teachers' actions? That is, do we see less I-R-E recitation and more evidence-based reasoning and argument?

## Method

### *Participants*

The research sample for the 2011-12 year consisted of 11 teachers from Grade 5 across five schools distributed over urban, rural, and suburban settings in the Northeastern United States. These were the same schools where the *Talk Science* materials were piloted previously. The teachers varied in their teaching experience, ranging from two years to 24 years. One of the teachers had taught Grade 4 during the previous year, and had worked with the project to pilot the Grade 4 materials. As part of the *Talk Science* program, the Grade 5 teachers participated in the PD pathway described earlier, where they attended study group meetings and engaged in independent web-study of the various materials in the program, and applied their learning within their own classrooms as they taught the Inquiry Project curriculum. Of the 11 teachers in this sample, five teachers taught multiple science classes. We gathered data from a total of 14 science classrooms.

### *Data Sources*

To address our research questions, we drew on the following data sources.

#### *Science Interviews*

To examine changes in teachers' understandings of the core ideas from the curriculum, pre-post interviews were conducted on teachers' ability to draw on the curriculum while reasoning about the science. We interviewed each teacher twice, once before they taught the curriculum, and once after they completed the curriculum and the *Talk Science* pathway. A total of 11 pre-post interviews were audio-recorded and transcribed. The data contained approximately 14 hours of audio.

There were 41 questions, of which 31 probed teachers' understanding of the content, and 10 probed their thinking about particular student ideas and how they might follow up with students' ideas. The questions addressed six content areas from the curriculum: measurement and margin of error; properties of air; phase change; dissolving; condensation, and evaporation.

#### *Talk Interviews*

To examine changes in teachers' understandings on nature and importance of science talk for students' learning, interviews were conducted with the teachers, once prior to and once after the *Talk Science* program. There were a total of 10 pre-post interviews: nine teachers were interviewed individually, and two of the teachers were interviewed jointly because they co-taught their science classes. The interviews contained open-ended questions on teachers' reported use of whole class science discussions, and the nature of their discussions. All interviews were audio-recorded and transcribed. The data contained approximately 12 hours of audio.

*Classroom Discourse*

To examine changes in teachers' facilitation of science discussions and changes in students' participation during the discussions, we recorded two types of whole class discussions. First, audio-recordings from 14 classrooms were collected of teachers conducting pre- and post-concept cartoon discussions. The concept cartoons were designed to stimulate students' thinking about core ideas from the Inquiry Project curriculum. The audio data consisted of approximately 7 hours and 50 minutes of audio. All audio data were transcribed.

Second, with a subset of three teachers from the sample, video recordings of their whole class discussions were gathered as the teachers taught the Inquiry Project curriculum. For each teacher, we videotaped two discussions occurring early in the curriculum and two discussions occurring later in the curriculum, resulting in a total data set of 12 discussions. These discussions were guided by the teacher after students completed science investigations from the curriculum. The purpose of the discussions varied according to the learning goals of the lesson. The first two discussions focused respectively on engaging students to reason about phenomena with the help of data and observations, and engaging them to generate preliminary ideas about a phenomenon. The remaining two discussions involved students respectively in using observations and a scientific model to generate explanations for a phenomenon, and consolidating their understandings across numerous investigations and findings. All relevant video data were transcribed. The final data set consisted of approximately three hours of video.

*Study-group Meetings*

We recorded teachers' study group meetings to examine their participation in the *Talk Science* program. Teachers met in school-based study groups to discuss their learning, and to reflect on and plan for their teaching. The meetings took place at three school sites within urban, rural, and suburban settings, starting at Step 2 of the pathway and ending at Step 7 of the pathway.

In the suburban and urban study groups, the school science supervisors were designated moderators for the meetings. For the rural study group, the school curriculum director was present at some of their meetings but was not the designated moderator.

A study guide was provided for each meeting. The guide suggested topics for the meeting and guidelines for the independent study of the web-based materials prior to the meeting. The guide generally recommended that teachers share reflections from their study, and generate plans for incorporating what they learnt from the resources into their teaching.

All study group meetings were audio-recorded. The data set consisted of two meetings of the urban study group, five meetings of the rural study group, and five meetings of the suburban study group. All audio-recordings were initially summarized, and the summaries were used to identify relevant portions for transcription. The transcribed portions comprised segments of teachers' conversations referring to the *Talk Science* web-based materials. The portions excluded from transcription but included in the summaries pertained to logistics of enacting the Inquiry

Project curriculum, curricular materials and supplies, scheduling study group meetings, social chitchat, etc. The final data set transcribed contained approximately five hours of audio.

### *Data Analysis*

The data sources generated qualitative verbal data. Data analysis involved a qualitative and quantitative approach. In general, we followed an inductive approach to code the data (Patton, 1990). Further, we undertook a *verbal analysis* with most of the data, conducting qualitative-based quantitative analyses of the data (Chi, 1997). This section presents separately the analysis for each data source: science interviews, talk interviews, classroom discourse (concept cartoons and videotaped class discussions from the curriculum,) and the study group meetings.

#### *Science Interviews*

To identify changes in teachers' understandings of core ideas from the Inquiry Project curriculum, a coding rubric was developed inductively after initially examining teachers' responses. The rubric involved three levels to score understanding and elaboration in teachers' responses. Each response by each teacher was coded separately on the pre- and post-interviews. A score of 0 was assigned to incorrect, equivocal, and/or uncertain responses (e.g. "I don't know"; "An inflated soccer ball would be lighter because there's a lightness to air, so you are increasing the lightness"). A score of 1 was assigned to responses that were correct, descriptive of phenomena but did *not* provide explicit, scientific explanation (e.g. "Yes, freezing is an example of a phase change because it goes from a liquid to a solid"). Finally, a score of 2 was assigned to responses that were correct *and* contained scientific explanations consistent with core ideas within the curriculum (e.g., "The particles of salt were being suspended in the water without being close to one another so that you don't see them."). This coding scheme helped identify whether teachers had accurate understanding of the concepts, and whether they could provide explicit and accurate scientific reasoning, i.e., they could identify appropriate evidence, or refer to core ideas from the curriculum to justify their response.

Two of the authors coded independently a 10% randomly selected subset of responses from the entire data set, and obtained an inter-coder agreement of approximately 75%. The authors clarified the codes, and resolved disagreements mutually. One of the authors subsequently coded the remainder of the responses.

All coded responses of each teacher on the pre- and post-interviews were quantified. For each teacher, quantification generated overall scores on the pre- and post-interviews; the total number of level 2 responses on the pre- and post-interviews; the total score for each of the six content areas on the pre- and post-interviews; and the total number of level 2 responses for each content area on the pre- and post-interviews.

#### *Talk Interviews*

For analyzing talk interviews, we coded the transcripts inductively to capture main themes in the data. After a preliminary study of the transcripts, we examined two main themes:

teachers' perspectives on the benefits of whole class discussions for science, and their reported use of whole class discussions. These themes helped identify shifts in teachers' understandings of the nature and importance of science discussions.

*Classroom Discourse*

Transcripts of whole class science discussions were analyzed to study teachers' facilitation of and students' participation during the discussions. For both pre- and post-concept cartoon discussions and discussions during curriculum lessons, a set of codes was developed to explore teachers' and students' talk. Here we first describe separately our coding rubric for teachers' and students' talk, followed by a description of the coding procedure.

*Coding rubric*

To develop a coding rubric for teacher talk, we drew on research from *Accountable Talk* (Michaels, et al., 2002; Michaels, O'Connor, & Resnick, 2008; Resnick et al., 2010) and *Academically Productive Talk* (Chapin, O'Connor, & Anderson, 2009). This body of work has identified a small number of productive talk moves, and has increasingly produced evidence for linking the use of these moves to robust achievement gains (O'Connor & Michaels, in press).

We coded for nine academically productive talk moves (APT moves) based on the four goals of productive talk. That is, productive talk is accountability to knowledge, disciplinary practices, and community (see Table 1). The nine moves were introduced as part of teachers' web-based study.

Table 1

*Codes for Teachers' Facilitation of Discussions*

| **Goals and APT moves** | **Description** | **Example** |
|---|---|---|
| Goal: Help individual students share, expand and clarify their own thinking<br>APT Moves: Time to think, Say more; So, are you saying; | This set of moves prompts individual students to explicate their thinking | "Okay. Can you say a little more about that?"<br><br>"What do mean by that?" |
| Goal: Help students listen carefully to one another<br>APT Moves: Who can rephrase or repeat? | This set of moves prompts students to listen carefully to their peers' ideas | "Ok, is there anyone who understands what Jasmine is saying and might want to maybe say it a different way to help the rest of us understand?" |
| Goal: Help students deepen their reasoning<br>APT Moves: Ask for evidence and reasoning | This set of moves encourages students to push their reasoning, and justify their ideas with evidence | "Why? What is it about container A or the liquid in A that makes you think there's not a lot in there?"<br>"How do you know it didn't rise? Did you measure it?" |

| | | |
|---|---|---|
| Goal: Help students think with others ideas<br>APT Moves: Agree/Disagree; Add on; Explain what someone else means | This set of moves encourages students to engage with their peers' ideas for building on, critiquing, and improving the collective science knowledge of the classroom community | "Anyone want to, maybe want to revise Mario's idea, maybe change it, add to it?" |

To analyze students' participation during science discussions, a set of codes was developed inductively from a preliminary study of the transcripts. Specifically, we studied the transcripts for linguistic markers of reasoning, like *because, that's why, so* and examined what followed the markers. The transcripts revealed various student attempts to reason with ideas from within and outside the curriculum (see Table 2).

Table 2

*Coding Rubric for Students' Reasoning during Science Discussions*

| Students' reasoning | Explanation | Example |
|---|---|---|
| **Reasoning With Ideas from Curriculum** | | |
| 1. Classroom Science Investigations; Data / Observations | Students draw on observations or data from the Inquiry curriculum investigations in reasoning about a phenomenon | "Yeah. And they weighed the same, but then we kept one of the balloons not inflated and then we blew up the other one. And when we put it on that side was a little farther down, so that means it was heavier when it had air in it" |
| 2. Scientific Principles and Models from Curriculum | Students draw on scientific principles and the particle model from the curriculum in reasoning about a phenomenon | "I respectively disagree with Kiaja because I do think air has weight and that I agree with Layla and that the inflated soccer ball weighs more than the flat one." |
| **Reasoning With Ideas from Outside Curriculum** | | |
| 1. Everyday Experiences | Students refer to their everyday experiences | "I think that Tomas is right, because it's the same. I don't have a soccer ball, but I do have a football. And, when the football gets flat, it is heavier. But, um, but when, um, air goes into the soccer ball, um, it makes it lighter because of all the gravity around." |
| 2. Unsubstantiated Assertions/Opinions | Students assert unjustified claims or opinions | "Well, Claire is the most right, but the soccer ball would probably be a little heavier, because air is like .000000000001 more heavier, and the flat ball is the same exact thing as the actual soccer ball, but it just doesn't have any air in it, so it's pretty much the same." |
| 3. Analogies | Students generate analogies or similarities to hypothetical situations | "I have something- I agree with Ryan because if you take an air mattress out it would feel heavy and then when you blow it up it would feel easier to carry and lighter." |
| 4. If…then Axiomatic Reasoning | Students engage in chains of *if…then*, often counterfactual, thinking | "But if you think that the air has weight, like if it adds weight to it, then if you put a scale in the middle of the room right here there would probably be at least a pound showing on it. |

We also identified linguistic markers of co-construction (e.g., I agree/ I disagree/Ask for clarification), and generated the following set of codes to capture co-construction (see Table 3).

Table 3

*Codes for Students' Co-construction Attempts during Science Discussions*

| Co-construction Attempt | Explanation | Example |
|---|---|---|
| Agree | Explicit marker of agreement with a peer's idea | "I agree with Jasmine." |
| Disagree | Explicit marker of disagreement with a peer's idea | "Well I kind of disagree". |
| Ask | Requesting clarification of a peer's idea | "What do you mean when you say..?". |
| Clarify | Offer clarification of someone else's idea | "I think what she means is that when the temperature gets to like negative then things start to get cold […]and it gets hard and then it just breaks like ice." |
| Add - on | Student adds on to a peer's idea, without an overt marker of agreeing, disagreeing, clarifying, or challenging | "Um I also wanted to add on to Louie's..." |
| Challenge / What If | Student challenges a peer's idea without an overt marker of disagreement, for example, with a thought experiment or hypothetical data | "I have a question for you, Frank, What if the eraser had, like, buoyancy?" |
| Restate | Student repeats peer's idea | "She said there's more space in the air particles. I mean when the particles are pushed like – yeah, pushed." |

*Coding procedure*

Transcripts were segmented into teacher and student turns as the grain size for analysis. Analyzing turns at talk allowed us to examine: 1) the nature and extent of teachers' use of APT moves to support students' learning, and 2) examine the nature and frequency of student attempts at reasoning about the science, and co-constructing scientific knowledge with peers.

In coding classroom talk, we assigned a code, or multiple codes wherever appropriate, to each turn at talk. For teacher talk, codes for multiple talk moves were assigned within single turns only when there was a change of addressee. For student talk, multiple codes or a particular code was assigned multiple times within single turns when multiple codable units (utterances/phrases) with different content appeared within a turn.

To calculate the proportion of teacher talk in each category, we considered the total number of teacher turns in each transcript. Similarly for calculating student talk, we considered the total number of student turns in each transcript. All teacher and student turns were included in the final computation even those that were not assigned a code.

*Study Group Meetings*

We analyzed teachers' study group meetings to examine their professional learning in terms of their participation in the *Talk Science* program. For this purpose, a coding rubric was developed inductively after preliminary examination of the transcripts. The coding rubric captured two dimensions of teachers' conversations: the different *Talk Science* Professional Development (PD) resources that teachers talked about in the meetings; and the nature of their engagement with the resources, i.e. how they talked about the resources. The rubric was refined iteratively through discussions and coding trials with the project team, resulting in a set of nine *Talk Science* PD resources discussed during the study group meetings, and five categories describing teachers' engagement with the resources.

The PD resources consisted of the web-based resources provided through the *Talk Science* professional development pathway. The resources were as follows: scientist video cases; classroom video cases; talking points and strategies video cases; scientists' essays presenting the scientific perspective on core ideas from the curriculum; essays of children's perspectives on the concepts from the curriculum; reflection tool serving as a checklist to help teachers track the culture of productive talk in their classrooms; a primer on academically productive talk; In Your Classroom Sheet to help teachers plan for using productive talk strategies in their discussions; and finally, the Inquiry curriculum.

For each PD resource, the nature of teachers' engagement was coded according to one or multiple categories as described in Table 4.

Table 4

*Coding Rubric for Teachers' Study Group Meetings*

| **Nature of engagement** | **Explanation** | **Example** |
|---|---|---|
| Describe | This code captures teachers' observations, reactions to the resources (e.g. what they observed in the resource; what they liked/did not like about it, etc.) | "The only thing I liked about the science [video] that [the teacher]said, "I record my data in the table and then I analyze my data with the graph." I thought that was good for students to kind of get that differentiation." |
| Connect | This code captures statements about teachers' classroom context in comparison to a PD resource. Teachers debrief events from their classrooms in connection with a PD resource or compare what they or their students currently do with respect to a PD resource. | "And to piggyback that, I was also thinking about how the wait time is so important and sometimes like, I just get so excited I want to call on them [because I just want to move it along . . . [I]t's just remembering that wait time is so important." |
| Plan | This code captures teachers' statements expressing plans of action: e.g. goal setting, brainstorming: identifying what they would like to see happen in their | "I might go with the thinking, listening carefully to peers, I'll go with that [talk move]. I think that's kind of neat in terms of trying to restate what another student has said to prove that they heard it correctly" |

| | | |
|---|---|---|
| | classrooms. | |
| Report Transfer | This code captures teachers' statements that indicate reasonable evidence of transfer; i.e. that teachers attempted to use the PD resource to support students. Teachers' statements may also point clearly to a change in classroom culture or practice with respect to the PD resource. | "We've been utilizing (the norms) more in other subject areas as well, so now they know to come in to the circle and to follow the norms . . . so the discussions are a bit more rich and powerful as a result." |
| Analyze | This code captures teachers' statements about their own knowledge or practice; i.e. an analytic stance where teachers raise questions, issues, and dilemmas about their own teaching. | "One of the challenges . . . is how to have discussion flowing while still calling on children. . . .[A]re we calling on people, are we trying to have a discussion where people are jumping in on each other's ideas. . . We have run into the issue where someone has their hand up and I was trying to keep a speaking order, but then sometimes we get 3 or 4 people down and they'd say, well, I was responding to this comment 3 up and meanwhile they are holding in their head what they wanted to say. So, they're missing what's going on in between. . . .What happens when the conversation moves past that point? I don't know. |

*Coding procedure*

We coded each turn at talk simultaneously for the PD resource it referred to (e.g., scientist video case, classroom video case, Talking Point) *and* the nature of teachers' engagement with the resource (e.g., Describe, Plan, Analyze.) Multiple codes for a turn were assigned wherever appropriate. Coding focused on only the teachers' turns at talk. Turns taken by the science supervisors and curriculum director were excluded from the coding. Transcripts of each study group meeting were coded separately for each of the three school-based sites.

Two of the authors coded independently a subset of 10% randomly selected data from each of three transcripts in the initial stage of developing the rubric. There was 76% agreement on the first trial with one of the transcripts, and approximately 85% on subsequent trials with the remaining two transcripts. The authors discussed their coding and refined the codes accordingly. After resolving discrepancies mutually, one of the authors coded the remaining dataset.

Finally, we quantified the coding to determine percentage of turns coded for each PD resource and nature of engagement category. The coding was quantified separately for each study group meeting held in each of the three school sites.

## Results

Teachers participating in the approximately 10 week *Talk Science* program developed various aspects of their knowledge, understandings, and practice. In particular, teachers drew increasingly on the language and core ideas from the curriculum in articulating their reasoning, and made greater use of talk strategies for promoting productive talk and guiding students' reasoning. There were shifts also in their understandings of the nature and value of classroom discussions, and in their reported use of discussions for students' science learning.

We present key findings from our analyses of the multiple data sources described before. Teacher names appearing in this paper are pseudonyms to maintain anonymity of the participants. The section is organized as follows:

- Teachers' science interviews
- Teachers' talk interviews
- Classroom discourse
- Study group meetings

*Teachers' Science Interviews*

The analysis of science interviews showed that teachers provided explicit, scientific explanations and reasoned about phenomena on the basis of core ideas from the Inquiry Project curriculum more often in the post-interviews than the pre-interviews. This shift toward greater understanding, and reasoning by invoking core concepts and principles from the curriculum was evidenced by two findings: an increase in the total score combining all content areas for the teachers; and an increase in the frequency of level 2 responses combining all content areas (see Figures 1 and 2). Furthermore, Figures 1 and 2 show that *each* teacher made this shift toward a higher total score and a higher frequency of level 2 responses.

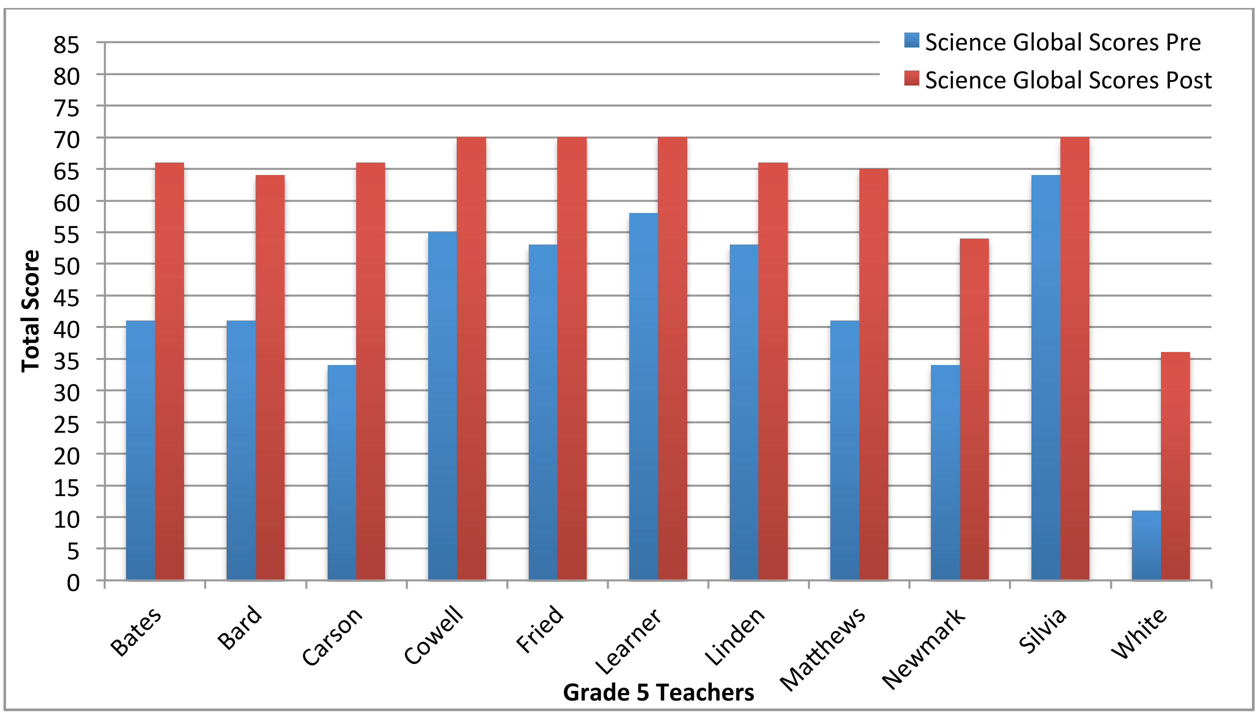


*Figure 1.* Total score on pre- and post- science interview.

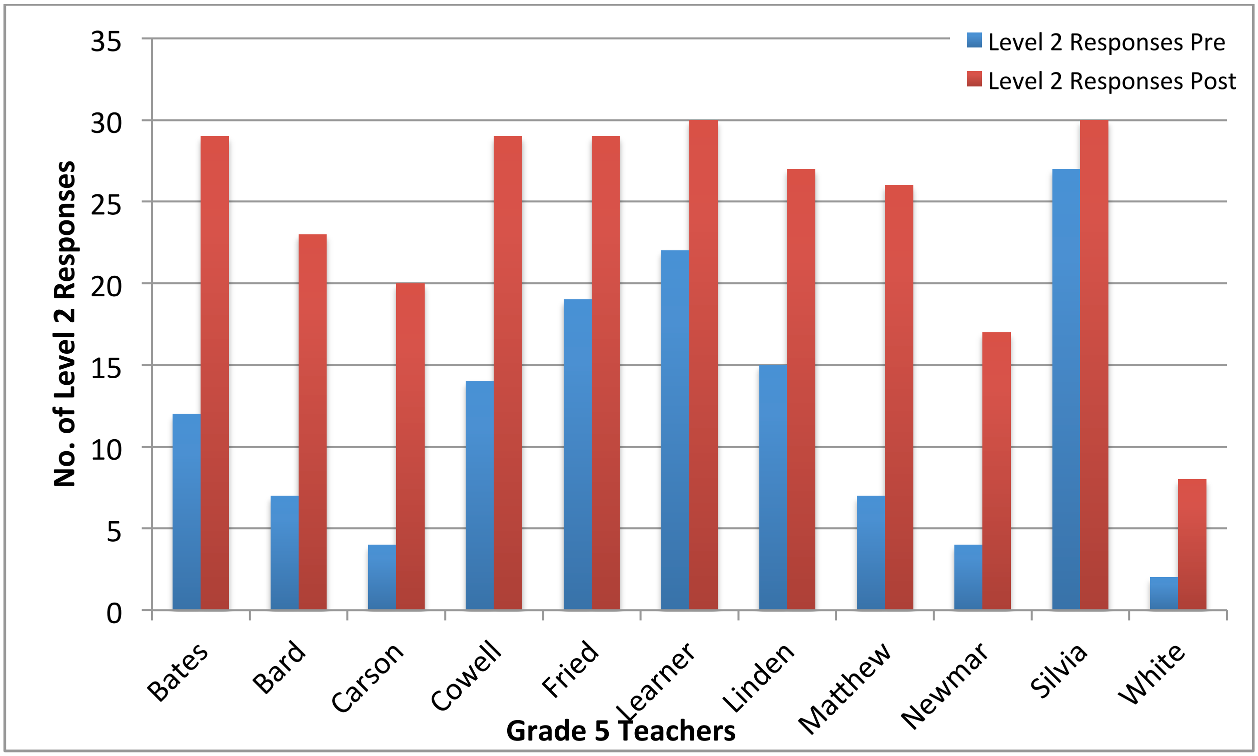


*Figure 2.* Number of level 2 responses in pre- and post- science interviews.

A careful examination of teachers' responses in individual content areas showed that more teachers drew on the particle model of matter presented in the curriculum to explain processes of dissolving, evaporation and condensation in the post-interviews than the pre-interviews. In the post-interviews, more teachers included in their responses the following core ideas from the curriculum: matter is made of tiny particles that have weight and take up space; weight is a more reliable measure of the amount of matter than volume; air is matter; and weight of a substance is conserved during phase change, although its volume may also change.

In thinking about particular student-generated ideas and how they would respond, teachers generally commented on the *accuracy* of the ideas. They were less likely to wonder *why* students might think in a particular way about a phenomenon, or describe how they might probe the student's reasoning. Few teachers offered elaborate responses such as the following:

> *[Lila] is thinking that the water is leaking somewhere, and she's thinking about water inside the glass only. She's not thinking about water outside the glass, and so therefore she's feeling like the only place where there is water is from the glass.*

*Teachers' Talk Interviews*

Teacher understanding of the benefits of whole class discussion changed. In the pre-interviews teachers identified benefits mainly in terms of participation. A key benefit often sited was opportunity for students to share what they knew about a topic, hear different perspectives, and have their ideas heard by others. The response below reflects this perception:

> *"Well they get to hear things that they might not have come up with, or they may get validated if they have -- maybe in their smaller group they were the only ones who were kind of thinking this, but now, oh, there's someone else who's thinking along my same lines."*

In the post-interviews, teachers began to recognize discussions as opportunities for students to *develop ideas together*. After the *Talk Science* program, they started perceiving whole class discussions as opportunities not simply to hear ideas and wrap up lessons, but also to help students think and learn together.

> *"[A whole group discussion] allows kids to work through ideas they have or misconceptions that they might have, things that they're wondering about, stoking their curiosity . . ."*

Teachers *reported that* whole class discussions were part of their instructional routine in science class. They would bring students together at the start of a lesson to brainstorm ideas and to identify students' initial ideas. They would close the lesson with a discussion to review the main ideas in the lesson, and to allow students to share their individual or small group experiences. The response below illustrates this trend:

> *"I mean [science lessons] almost always have to start out [with a whole group discussion] because . . . just to understand what's going on or . . .what's the purpose. And they have to end that way or at least have the next day some sort of a wrap up. . . It's the "here's what we're going to do." If we don't do the "well what did we discover, what did we find out, why did we do that, did it work", then you're kind of missing something."*

Two teachers reported not having discussions due to difficulties with ensuring adequate participation from all students and because their current science curricula did not support discussions explicitly.

By contrast, the post-interviews revealed greater willingness to incorporate discussions into science lessons, and to make discussions a more integral part of their instruction.

> *"You know, there are many science discussions every day, because we just can't really have a science class without meeting at the rug and either predicting or talking about something we did. So sometimes they're real in depth, when I'm introducing a new concept, or midway through, or we just did an experiment. But typically it's every day. There's no "just do worksheets" and it's over. It's "they have their journals." We have the experiences and then talk about them."*

Moreover, teachers now reported doing discussions not simply for closing lessons but as a way for students to *continue their learning*.

> *"[A discussion] is not just the conclusion anymore. Typically it was "we did all these activities and had a conclusion." But midway, just stopping, asking questions, kind of checking in, the whole data conversation, having discussions, the data discussions."*

Overall, teachers reported devoting time for discussions at the beginning and end of lessons, but did not always describe how they planned to *facilitate* the discussions or address student ideas during discussions. Teachers rarely reflected critically on *their role* in facilitating discussions, that is, how they were listening to students' ideas, and what they needed to learn to orchestrate more rigorous science discussions and deepen students' scientific reasoning.

*Classroom Discourse*

This analysis focuses on teachers' talk and students' talk 1) in pre- and post-concept cartoon discussions, and 2) in discussions from Inquiry Project curriculum. The analyses reveal:

- increases in teachers' use of some Academically Productive Talk moves
- a shift in teachers' use of strategies to guide students' reasoning,
- a shift in students' attempts to co-construct scientific knowledge with their peers,
- increases reasoning with investigations and principles from the curriculum.

With respect to shifts in facilitation, teachers used various academically productive talk moves (APT moves) in their turns at talk. The analysis of pre- and post-concept cartoon discussions combining all 14 classes showed that teachers used APT moves more often in their turns at talk in post-discussions than pre-discussions (see Figure 3).

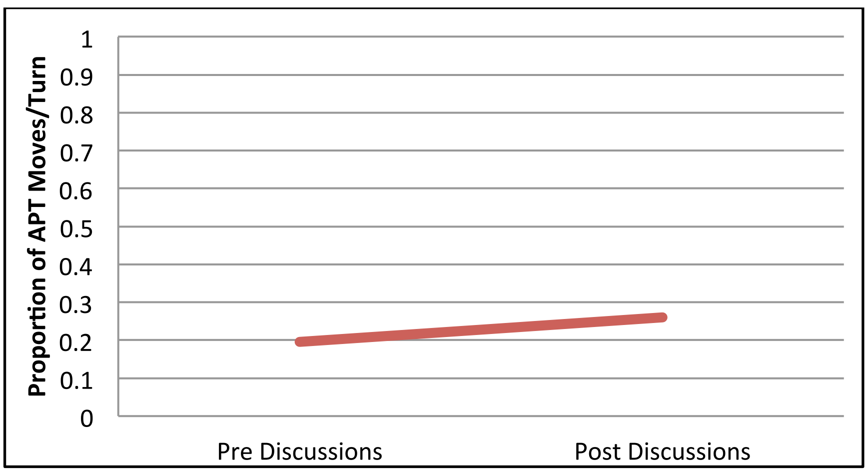


*Figure 3.* Teachers' use of APT moves / turn.

Seven of the ten teachers in the sample made a greater use of APT moves in the post-discussions than pre-discussions (see Figure 4).

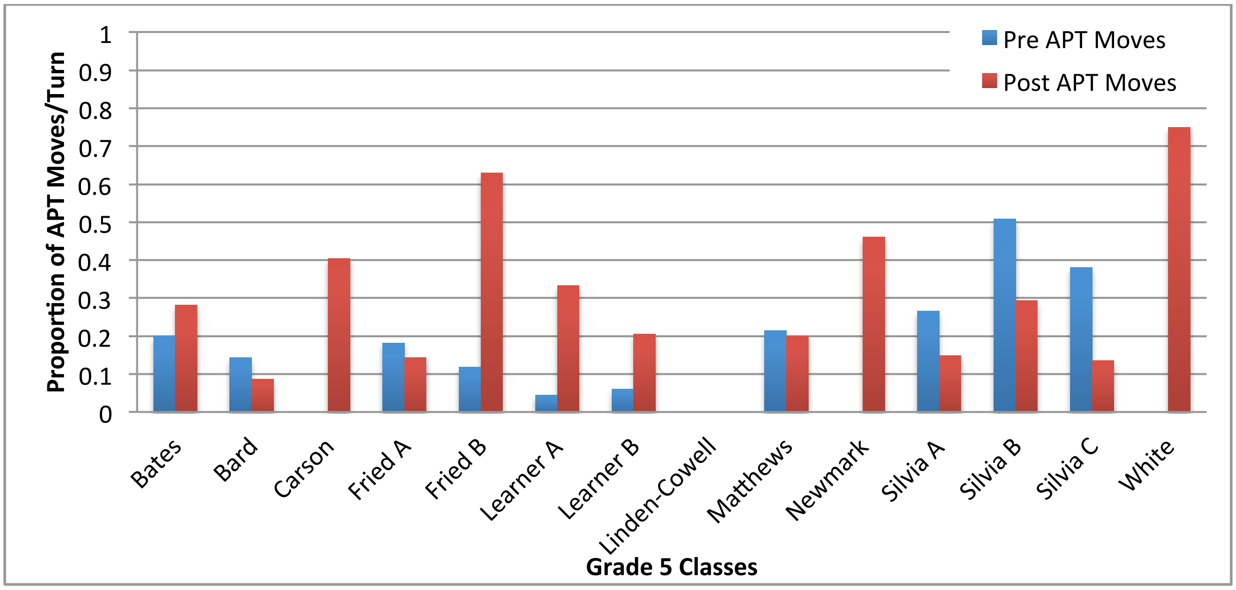


*Figure 4.* Teachers' use of APT moves in pre- and post-discussions.

The analysis identified patterns in teachers' use of four types of APT moves (see Figure 5). In the **pre concept cartoon discussions**, teachers commonly used the "Expand" talk moves (that is, strategies that help individual students share and elaborate their thinking.) By contrast, they less often used talk moves that encourage students to think with and build on their peers' ideas (Think With Others); to dig deeper into their reasoning (Dig Deeper); and to listen carefully to their peers (Listening).

A similar pattern characterized teacher facilitation in the post-discussions with the exception of an increase in the use of the Dig Deeper moves to probe students' reasoning.

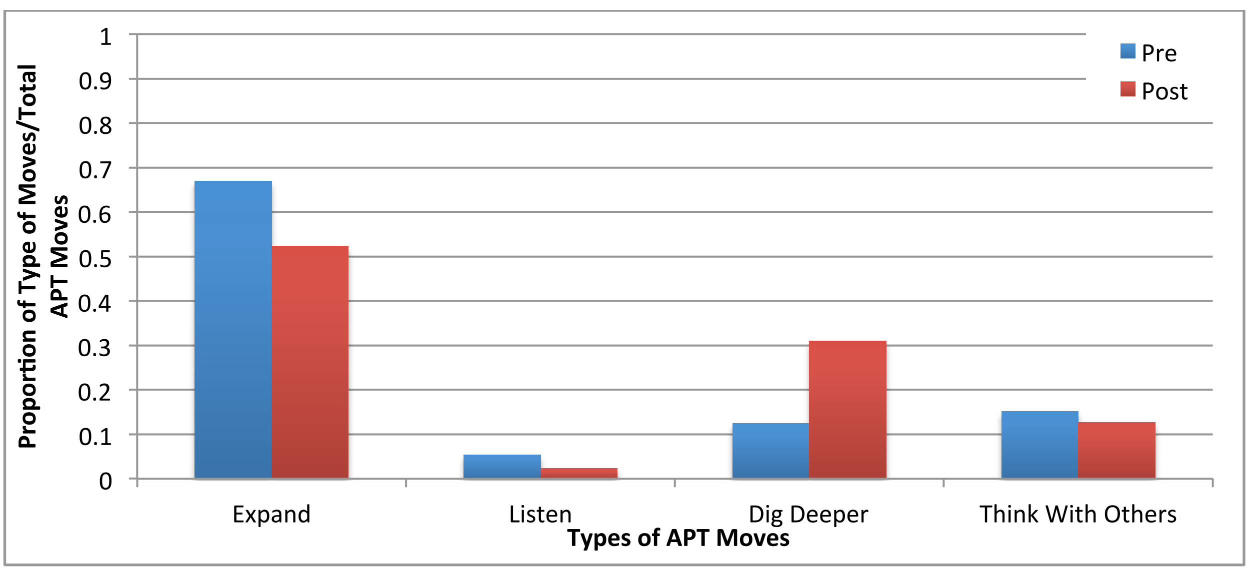


*Figure 5.* Teachers' use of different types of APT moves.

A trend in the video-taped **discussions from Inquiry Project curriculum** and consistent with pre- and post- concept cartoon discussions was the increase in use of the Expand and Dig

Deeper talk moves to encourage students to explicate their thinking and deepen their reasoning with evidence. By contrast, they less often used the Think With Others and Listen moves, designed to foster active listening and co-construction of ideas (see Figure 6).

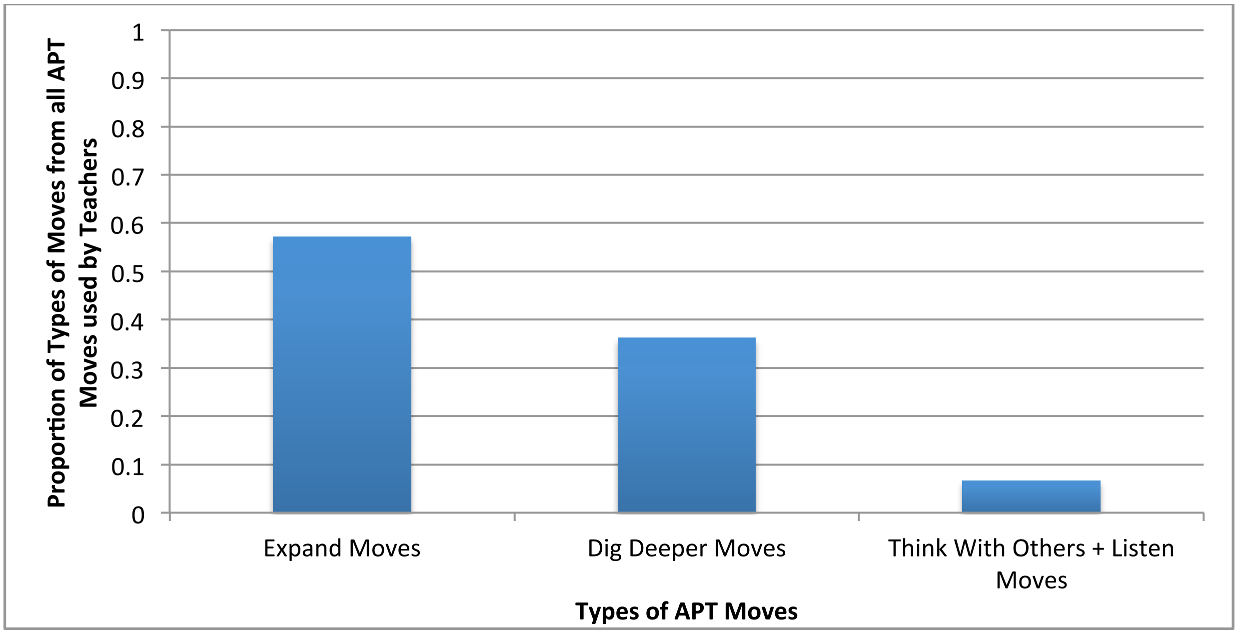


*Figure 6.* Variations in types of APT moves across three teachers.

We found that the use of Expand and Dig Deeper talk moves aligned with the underlying purpose of the discussions and types of discussions. The four videotaped discussions each had a different purpose defined by the investigation and learning goals underlying the lessons. When the purpose of the discussion was to elicit students' initial ideas, teachers made greater use of the Expand talk moves, and used fewer Dig Deeper moves. However, when the aim was to support students to construct formal scientific explanations, the teachers made considerable use of Dig Deeper moves to support students' reasoning.

The analysis also examined the nature of students' participation in the discussions. Students attempted to co-construct science knowledge with their peers, i.e., agreeing/disagreeing, restating peers' ideas, asking for or offering clarifications of peers' ideas, and adding on to or challenging their ideas. Students increased their co-construction of ideas in the post-discussions. In the post-discussions, co-construction attempts accounted for 17.34% percent of students' talk, as compared to 13.42% percent of their talk in the pre-discussions (see Figure 7).

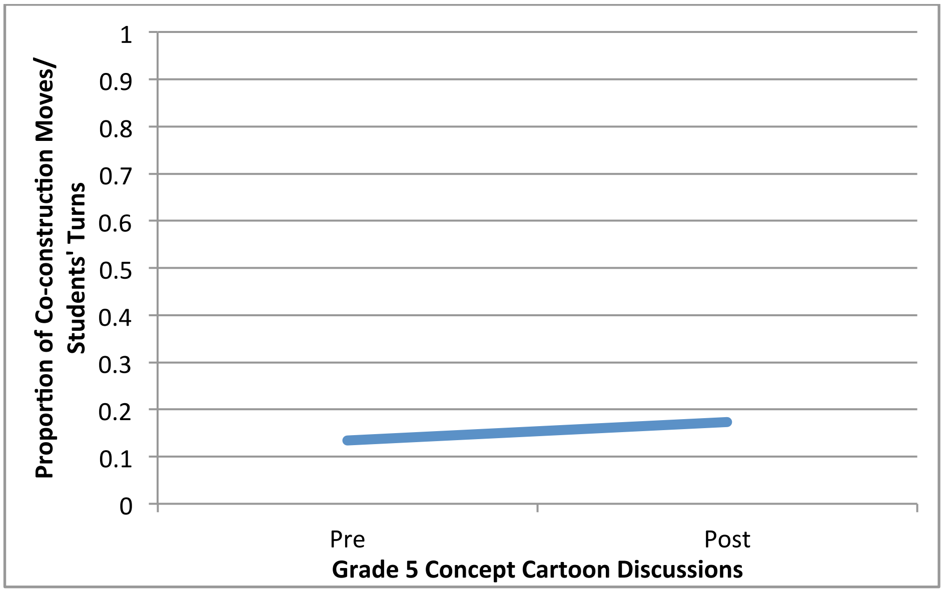


*Figure 7.* Students' use of co-construction moves.

Finally, there were changes in the extent to which students drew on observation and evidence while explicating their reasoning (see Figure 8). In the pre-discussions, students commonly referred to everyday experiences, asserting facts/opinion, etc. In the post-discussions, students made greater reference to scientific principles, evidence and their curriculum experiences to reason

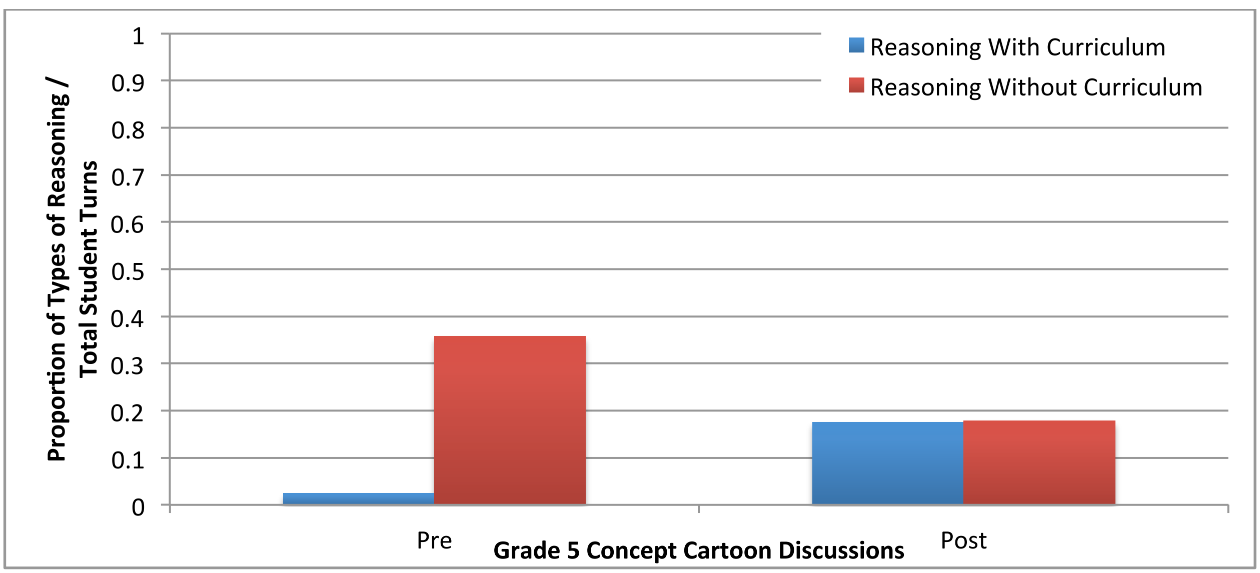


*Figure 8.* Students' reasoning with and without curriculum.

*Study Group Meetings*

Our analysis revealed that teachers across the three school-based sites utilized study group meetings for various purposes, and their conversations were fairly consistent with the objectives of the meetings and the accompanying study guide. In this section, we report results by first describing the PD resources teachers discussed in the meetings, and then describing the nature of teachers' engagement with the resources.

The study groups discussed frequently content on Classroom Cases and Talking Points/Strategy cases. Specifically, the rural and urban study groups focused most on classroom video cases and their classroom discussions. By contrast, the suburban study group discussed most often content on Talking Points/ Strategies, and discussed productive talk, norms, talk goals and talk moves in relation to this resource. Furthermore, a common finding across the three groups was that teachers talked less about the scientist cases, accounting for 21.7% of the talk combining all meetings in the rural study group; 7.48% of the talk from all meetings in the urban study group; and 4.47% of the talk from all meetings in the suburban study group (see Table 5).

Table 5

*Teachers' Talk about PD Resources in Rural, Urban, and Suburban Meetings*

| **Study Group** | **Most Frequently Discussed Professional Development Resource & Content** | **% Talk of the Most Frequently Discussed PD Resource** | **% Talk pertaining to Scientist Cases** |
|---|---|---|---|
| Rural (5 meetings) | Classroom Cases and Discussions | 47.41% | 21.7% |
| Urban (2 meetings) | Classroom Cases and Discussions | 57.01% | 7.48% |
| Suburban (5 meetings) | Talking Points/Strategies, Productive Talk norms, goals, moves | 53.07% | 4.47% |

With respect to the nature of engagement, teachers commonly utilized study group time to make connections to their own classroom context and practice, debriefing events from their classroom in relation to the PD resources. They also described their observations of and reactions to the PD resources, and made plans for their classrooms.

Specifically, teachers in the suburban and urban study groups engaged most with the PD resources by debriefing how things were going in their classrooms, and commenting on their present practice and their students' participation and science understandings. By contrast, these teachers devoted less time to generate ideas and formulate plans for their practice (see Table 6).

In the rural study group teachers mainly described their observations of and response to the PD resources, and generated ideas for what they might want to incorporate in their teaching. In comparison to this focus, they talked less often about their classroom events and experiences.

Table 6

*Nature of Teachers' Engagement in Suburban, Urban, and Rural Meetings*

| **Study Group** | **Most Frequent Nature of Engagement** | **Percentage of Talk with the Most Frequent Nature of Engagement** | **Percentage of Talk reflecting PLAN** |
|---|---|---|---|
| Suburban | Making connections between own | 50.56% | 18.72% |

| | | | |
|---|---|---|---|
| (5 meetings) | classroom and content of professional development resources | | |
| Urban (2 meetings) | Making connections between own classroom and content of professional development resources | 67.29% | 7.48% |
| Rural (5 meetings) | Sharing observations of and reactions to the content of professional development resources | 36.79% | 36.08% |

Additionally, we found that teachers made attempts to transfer their learning to the classroom, and they identified changes taking place in their classroom culture. Across the three study groups, teachers devoted some time to report their experiences with using specific PD resources to inform their teaching (see Table 7). There were also a few instances of teachers analyzing and raising issues and questions about their own teaching. Similar to reporting transfer to the classroom, this type of talk was less common in the three study group meetings.

Table 7

*Teachers' Talk about Reporting Transfer and Analyzing Practice*

| **Study Group** | **Percentage of Talk reflecting REPORT TRANSFER** | **Percentage of Talk reflecting ANALYZE** |
|---|---|---|
| Rural (5 meetings) | 9.2% | 2.12% |
| Urban (2 meetings) | < 1% | 1.87% |
| Suburban (5 meetings) | 8.66% | 4.47% |

## Discussion

This paper presents key findings from research on teachers' learning as they participated in a professional development program. The purpose of this research was to gain insight into how teachers can learn to orchestrate science discussions that support students' scientific reasoning. As teachers progressed through the program, we observed several shifts in teachers' knowledge, perspectives, and practice. In this section we review the key findings and discuss these in the following order: First, we describe what teachers learnt from the program, and what might continue to be challenging for them. Next, we identify implications for analyzing classroom interactions. We then conclude with implications for designing programs for teachers' professional learning.

## *Impact of Professional Development Program*

### *Changes in Teachers' Knowledge and Perspectives*

The blended PD model combining independent web study, school-based study groups, and classroom trials allowed teachers to participate actively in their own learning, and to develop various aspects of their knowledge, understandings and practice. Teachers engaged in learning from the PD resources, as evidenced in their study groups in which they shared observations and insights, debriefed classroom experiences, and generated plans for teaching. As teachers implemented the curriculum and participated in the PD program aligned with it, they developed more accurate understanding of the science in the curriculum.

When teachers started the program, they described their discussions and the benefits of the discussions in terms of a *share-out* model, students could share initial ideas about a topic at the start of a lesson, and teachers could identify their students' preliminary understandings; likewise, at the end of a lesson, teachers could recap key ideas and students could share and hear one another's results and understandings from classroom experiments. As the program progressed, teachers were more willing to conduct discussions, and began to recognize the value of discussions not only for externalizing individual student thinking, but also for thinking collectively and making meaning together. This shift was reflected in their descriptions of discussions as opportunities for students to *build meaning* and continue learning together.

### *Changes in Teachers' Classroom Practice*

Along with changes in underlying knowledge and perspectives, there were changes in teachers' practice in facilitating science discussions. In the PD program, teachers were presented with nine talk strategies aligned with four goals of productive talk to help students develop scientific understandings through disciplinary practices of evidence-based reasoning and collective improvement of ideas. Teachers frequently used two specific sets of talk strategies, the Expand and Dig Deeper sets, to promote students' explication of ideas about the science, and to push students to reason with the help of data and models.

Furthermore, the teachers whose discussions were video-recorded used these sets of strategies consistent with the learning goals framing the discussions. Particularly, the teachers pressed increasingly for scientific explanations when lessons contained relevant experiences with data and models that students could utilize, and when the learning goals for discussion involved formulating explanations using data and models. However, they pressed for scientific explanations less often but used more strategies to elicit students' initial ideas when the learning goals involved proposing preliminary ideas in the absence of data and explanatory models.

Overall, teachers' discursive efforts at encouraging students to generate evidence-based explanations resonate with current reform emphasis on learning core scientific ideas and practices (McNeill & Krajcik, 2008; NRC, 2012). Such instructional efforts can promote *productive disciplinary engagement* among students (Engle & Conant, 2002) by fostering accountability to disciplinary norms and to making advances in science knowledge (Michaels & O'Connor, 2011; Resnick et al., 2001)

The shifts we saw in teachers' knowledge and instruction also support the argument for connecting teachers' professional learning with their actual practice (e.g., Ball & Cohen, 1996; Ball & Forzani, 2011). Research on teachers' professional learning argues that teachers learn in the context of their daily classroom teaching. Therefore, programs for improving teachers' instructional capacities need to be aligned with their enactment of curricula, helping teachers develop subject matter knowledge and instructional practice together. Consistent with these notions, the *Talk Science* program was integrated with the Inquiry Project curriculum, providing teachers with materials to deepen their understanding of key scientific principles and practices in the curriculum, and to guide their orchestration of discussions during curriculum lessons.

### *Challenges in Teachers' Professional Learning*

As teachers participated in the PD program and implemented the curriculum, they used talk strategies to deepen students' reasoning with data and models, seen in the increased use of Dig Deeper talk moves that were designed to push students' evidence-based reasoning. Further, as students undertook investigations and were introduced to data and particle model through the curriculum, they began to draw on the core ideas from the curriculum to make meaning of the science.

With the help of talk strategies, teachers may then have attempted to lead the discussion toward an *authoritative* mode to guide students' thinking. In authoritative discourse, teachers introduce discipline-consistent meanings into the discussion, often recast students' thinking to emphasize canonical understandings, and lead students through question-answer sequences toward canonical meanings (Scott, Ametller, Dawes, Staarman, & Mercer, 2007; Scott, Mortimer, & Aguiar, 2006 ). This kind of discourse is important because with its inherent emphasis on disciplinary knowledge, it can help promote students' conceptual development and engagement with scientific practices (Scott et al., 2006; Tabak & Baumgartner, 2004).

On the other hand, teachers' less frequent utilization of two sets of talk strategies, the Think With Others and Listen talk moves, indicates they prompted students less often to attend to and respond to their peers' thinking. These strategies encourage students to critique and build on peers' ideas to improve the shared knowledge of the classroom. This kind of instructional effort can not only support accountability to knowledge and disciplinary reasoning, but can also support more explicitly accountability to the learning community, which is also fundamental to academically productive talk (Resnick et al., 2001), and for students' engagement with the science (Engle & Conant, 2002). Indeed, efforts to advance knowledge by engaging in disciplinary standards of reasoning are themselves situated within communities of inquiry. Together with the Expand and Dig Deeper moves described earlier, the latter two sets of moves can enable teachers to foster complementary, core scientific practices of constructing and critiquing claims to refine a community's collective knowledge (Ford, 2008).

The teachers' limited use of strategies to support active listening and collective thinking points to an aspect of classroom discourse that may be more challenging for teachers to develop. Although promoting accountability to peers in the classroom community is critical for developing students' scientific reasoning, it represents perhaps a greater departure for teachers from the type of discussion practices with which they are more familiar. Teachers may find it easier to incorporate strategies like Expand and Dig Deeper moves that can allow them to probe and elicit *individual* students' thinking, because the strategies may be consistent with a *share out* model of discussion that appears to characterize their reported practice. However, using the Listen and Think with Others strategies to engage students in science discussions may require teachers themselves to be more skilled at listening carefully and connecting students' ideas. These strategies can generate a dialogic discourse where students make meaning together and develop their knowledge collectively. Whereas teachers begin to recognize the value of classroom discussions for dialogic meaning making, they may need more explicit support in using strategies to *enact* such discussions.

Teachers' less frequent prompting for students' co-construction may explain in part why students showed an overall low responsiveness to their peers' ideas. Although students increased their co-construction attempts in the post-discussions, these still accounted for less than a quarter of their talk. Similarly, a closer examination of video-recorded lessons showed that students engaged in co-construction mainly during discussions where teachers prompted students to listen carefully and respond to their peers' thinking. Taken together, the findings suggest that explicit teacher prompting may be needed to foster a more communal exchange of ideas among students. A communal knowledge construction is critical for students' learning because students' discourse with peers within classroom communities allows them to learn disciplinary practices (Ford & Forman, 2011; Herrenkohl & Guerra, 1998), advance collective knowledge (Scardamalia & Bereiter, 2006), and develop robust scientific conceptions (Bell & Linn, 2000).

From a standpoint of discourse-intensive pedagogy embodied in the present curriculum and PD program, we posit that the Think With Others and Listen talk strategies are important because they can enable teachers to introduce explicitly a more *dialogic discourse* in the classroom (Michaels & O'Connor, 2011). In a dialogic discourse, teachers stress on multiple perspectives offered by students in addition to the canonical scientific perspective (Scott et al., 2007; Scott, Mortimer, & Aguiar, 2006). Classroom studies show that both authoritative and dialogic discourses are needed to promote meaningful learning of science in the classroom. Indeed, in any classroom discussion, the two kinds of discourse are not dichotomous but co-exist, with differing emphasis given to each in any actual discussion (Scott et al., 2006; Tabak & Baumgartner, 2004). Whereas authoritative discourse focuses on canonical scientific knowledge, dialogic discourse allows students to invoke and engage with multiple everyday perspectives, and compare these with the normative scientific perspective. Skillful instruction involves a balance between the two kinds of discourse, accomplished through purposeful alternations in the teachers' communicative approaches (Scott et al, 2007; Scott et al., 2006). However, and consistent with research reported previously on the tension between authoritative and dialogic discourses in science instruction, teachers in this program may have experienced a similar dilemma between deepening students' scientific reasoning as an instructional goal, and allowing multiple perspectives to seed the discussion. While pushing students toward developing normative understandings with the help of data and scientific principles, teachers may have struggled to create a dialogic exchange of ideas among students.

### *Implications for Analyzing Classroom Interactions*

The findings reported in this paper reveal patterns in how teachers attempted to facilitate discussions to guide students' thinking. Teachers in this sample were participating in the professional development program for the first time. The findings presented here are of an exploratory nature, and generate insights into aspects of teachers' practice that need more detailed study. The findings identify a need for more careful analyses to confirm our impressions and enhance our understandings of teachers' professional learning. Specifically, classroom interactions need to be analyzed not only for the frequency of various talk strategies in teachers' practice, as in the present research, but also for sequential patterns to explore how teachers actually use talk strategies to shift between authoritative and dialogic discourses. For example, do teachers solicit ideas from several students, asking them to elaborate and respond to others ideas before probing deeper into specific ideas? Or do they solicit ideas from students in rapid succession with few attempts to juxtapose ideas? And how do teachers' talk strategies influence student talk, allowing for the emergence and inter-animation of multiple perspectives, coupled with a focus on constructing normative understandings?

Further analyses could shed light on other nuances of the discourse, enabling us to understand how teachers develop their practice at facilitating classroom discourse. For example, a follow-up examination of the depth of teacher-student and student-student turns is needed to determine how sustained the conversational exchanges were and how complex the reasoning was as the classroom community wrestled with different ideas. Further, although teachers used Dig Deeper and Expand moves frequently, it is important to know how teachers used the moves to work with emerging student ideas. For instance, did teachers use the moves to produce sustained exchanges with few students to develop pertinent ideas, or did they use the moves in quick succession to let several students externalize their thinking?

### *Implications for Designing Professional Development Programs*

The present research contributes to our understanding of how teachers learn to shift the culture of talk in science classrooms, and identifies also particular challenges in teachers' learning. Overall, the findings show that to shift the culture of classroom talk, teachers begin to not only change their instructional facilitation, but also to develop their understandings of the science underlying the discussions, and their perspectives on the role of discussions in students' learning. We surmise that changes in all three areas are important in sustaining teachers' learning and development. To promote teachers' learning, professional development programs may need to guide teachers explicitly in these three areas: knowledge of the discipline, underlying models of classroom discourse, and actual classroom practice at leading discussions.

The findings imply also that there are certain aspects of teachers' learning where they may need more explicit guidance. Specifically, teachers may need more support in understanding how science discussions can be planned to deepen students' reasoning by engaging students with data and evidence-based explanations. Teachers' post-interviews suggest that although they devote time to do discussions at the beginning and end of lessons, they may not always plan their facilitation of the discussions and how they might respond to particular student ideas to promote students' thinking. Furthermore, teachers may need help with orchestrating dialogic exchanges in the classroom, and for identifying how various discursive strategies can be utilized more purposefully to foster students' science learning.

Overall, the research calls for also supporting teachers to adopt an *analytic stance* in their professional learning. Analysis of the study group meetings shows that teachers seldom examined their own practice carefully. They rarely analyzed their growth and challenges with using specific PD resources. Further, whereas teachers commented broadly on how lessons were going in their classrooms and how students were participating, they did not always examine their own role in the context of their students' learning. The less frequently adopted analytic stance in study groups is consistent with some of the other findings in this research, namely that teachers did not always discuss their own role in facilitating discussions during talk interviews, nor did they always puzzle during science interviews about why students might have particular ideas and how they might respond to the ideas. Therefore, teachers may need help (i.e. actual evidence from their own classroom) in attending more carefully to their own role in supporting their students. Guiding teachers to analyze their practice may help them identify what they need to do to support their students better.

Finally, the findings inform design of future programs for teachers' professional learning. Teachers in the present PD program met in study groups to discuss and plan for their teaching, but they did not have ongoing evidence from their own real-time lessons to use for sustained reflection and planning, and to share with colleagues in the study groups. We surmise that teachers may have found it difficult to examine and plan for their instruction in the absence of such sustained, objective bases for reflection. Therefore, in future studies, we intend to present teachers with objective feedback from their own classrooms for their reflection and planning. Specifically, we will provide them with video records of their own classroom interactions. This kind of feedback is critical for teachers' learning, as found in research advocating the use of video records from teachers' own classrooms to develop their teaching (e.g. Van Es & Sherin, 2010). Video offers teachers with objective, verifiable evidence of their classroom discourse, capturing permanently the otherwise ephemeral talk in the classrooms. Using videos of their own classrooms, teachers may be able to reflect on their classroom discourse and examine the extent to which the discourse promotes accountability to knowledge, discipline and community. Enabling teachers to take stock of their classroom interactions may also help them plan for their discussions by examining students' emergent ideas, and considering how they might use talk to guide students toward robust scientific understandings through reasoning and co-constructing knowledge with peers.

## Conclusion

The *Talk Science* web-based model of professional development was designed to improve teachers' capacity to facilitate science discussions. The research reported here has generated insights into how this professional development approach can make a difference. Our findings point to the promise of the *Talk Science* model, both with its web-based structure and its resource-rich content that blends science knowledge, scientific reasoning, and discourse practices. Through participation in the program, teachers began to re-conceptualize discussions as places for students to build science ideas together, and they began to incorporate discursive strategies that shifted more of the intellectual responsibility to the students.

Yet, challenges remain for both design of and research on teachers' professional development. Whereas teachers could incorporate more talk strategies in their discussions, they may still need guidance in how to support more dialogic discussions. To improve professional development for teachers and further our understanding of how teachers can support students' learning through science discussions, we need to understand better the *relationships* among teachers' knowledge of the science, their understanding of scientific reasoning, their understanding of their role in supporting talk, and their ability to use a range of discursive strategies purposefully to guide students' learning.

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