Talk Science Research Findings

Published by TERC on the Talk Science Website
http://inquiryproject.terc.edu/research/talk_science/

The *Talk Science* research investigates how teachers develop their capacity at leading productive science discussions to foster students' scientific reasoning. The research examines changes in teachers' attitudes, knowledge, and practice as they participate in a sustained professional development program.

Overview

Talk Science is a NSF funded research and development project to enhance elementary science teachers' facilitation of productive science discussions in classrooms to promote students' scientific reasoning. The project is based on the premise that aligning teachers' professional learning with a conceptually-driven curriculum (*The Inquiry Project*) by providing teachers with resources to deepen their understanding of core disciplinary ideas in science, and to develop their skills at orchestrating productive discussions will change the culture of classroom talk.

The *Talk Science* research investigates how teachers develop their practice at facilitating productive science discussions to promote students' scientific reasoning. In our research, we focus on identifying how teachers participate in the *Talk Science* professional development program, and on examining the changes in teachers' understandings of the nature and importance of science discussions in the classroom; changes in teachers' understanding of the core scientific ideas in the curriculum; and changes in teachers' practice at implementing science discussions in their classroom. To study the various aspects of teachers' professional learning, we draw on multiple sources of data: teachers' study group meetings to understand how teachers engage with the professional development resources; interviews to examine the changes in teachers' attitudes towards classroom discussions, and in their understanding of core disciplinary ideas from the curriculum; and recordings of classroom discussions to identify the changes in teachers' facilitation of and students' participation in classroom talk.

We addresses the following questions in our research:

- 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 Professional Pathway while implementing the Inquiry Curriculum?
- How do teachers' understanding of the core science concepts in the Inquiry Curriculum change as they participate in the Talk Science Professional Pathway while implementing the Inquiry Curriculum?
- How does student talk (amount and quality of scientific reasoning and co-construction with peers) change from early to late as their teachers

This research was funded by the National Science Foundation (NSF) under grant number DRK12-0918435 awarded to TERC. The opinions expressed here are those of the authors and do not necessarily reflect those of NSF.

participate in Talk Science Professional Pathway while implementing the Inquiry Curriculum?

- 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?

Our work draws on a body of research on promoting academically productive, accountable talk in the classroom (Chapin, Anderson, & O'Connor, 2009; Michaels, O'Connor, & Resnick, 2002; Resnick, Michaels, & O'Connor, 2011). The *Talk Science* program presents teachers with a web-enabled collection of multimedia resources focused on promoting productive, teacher-guided science discussions. The web resources are aligned with the *Inquiry Project* curriculum units for Grades 4 and 5. The resources consist of a series of videos of scientists reasoning and talking about the scientific phenomena that students investigate through the curriculum; of classroom cases to provide teachers with opportunities to see productive science discussions in action in another teacher's classroom; and of cases providing teachers with the background needed to understand the nature and importance of productive classroom science talk, and a collection of strategies to support productive talk in their classroom. In the *Talk Science* program, teachers study the web resources independently, and meet in face-to-face study groups with grade-level colleagues to discuss the web resources, and to plan for and reflect on their classroom practice.

Here we present briefly our findings from our research on how teachers participate in the *Talk Science* program, and how they develop their understandings and practice at supporting productive science discussions.

References

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Michaels, S. & O'Connor, M.C., with L. Resnick. (2002). <u>Accountable Talk: Classroom Conversation that Works</u>. Electronic Book on CD-ROM published by the Institute for Learning, LRDC, University of Pittsburgh.

Resnick, L.B., Michaels, S., & O'Connor, C. (2011). How (well structured) talk builds the mind. In R. Sternberg & D. Preiss (Eds.), *From Genes to Context: New Discoveries about Learning from Educational Research and Their Applications,* pp. 163-194. New York: Springer.

Methods

Participants

In the second year of the *Talk Science* research (2010-2011), we worked with eleven teachers from Grade 4, who participated in the professional development program and implemented the Inquiry Project curriculum for Grade 4 for the first time. We recruited the teachers from five schools distributed among suburban, inner-city, and rural areas in Massachusetts and Vermont.

In the third year of our research (2011-2012), we worked with nine Grade 4 teachers, eight of whom had participated in the Talk Science program previously. In this year, we also worked with eleven teachers from Grade 5 from the afore mentioned schools, who participated in the *Talk Science* program and implemented the *Inquiry Project* curriculum for the first time.

Data Sources

We collected various kinds of information to address our research questions. During the second year of the *Talk Science* research (2010-2011), we interviewed the Grade 4 teachers prior to and upon the completion of the curriculum to explore their understandings of and strategies for supporting classroom talk, and their understandings of the science concepts in the curriculum. We gathered audio recordings of a 15-minute pre- and post- concept cartoon discussion from each teacher's classroom, and video recordings of two sets of early and late lesson discussions from three teachers to explore patterns in teachers' facilitation of and students' participation in classroom interactions. We also audio recorded the teachers' study group meetings that took place in their respective schools.

During the third year of our research (2011-2012), we continued to collect data from the Grade 4 teachers, who were now implementing the Inquiry Project curriculum and participating in the Talk Science program for the second time. During this year, we interviewed the teachers again regarding their perspectives on and strategies for supporting classroom discussions, and collected audio recordings of 15-minute pre- and post-concept cartoon discussions in their classrooms. We collected these data to draw comparisons and track teachers' progress over the two years of their participation in the professional development program.

We also collected multiple data in the third year of our research from Grade 5 teachers pertaining to their understandings, perspectives, practice, and participation in the program. We interviewed the Grade 5 teachers prior to and upon completion of the curriculum regarding their perspectives on the role of classroom discussions in students' science learning, strategies for facilitating classroom discussions, and their understanding of the core ideas in the curriculum. We also audio recorded 15-minute pre- and post-concept cartoon discussions from all teachers, and video recorded two sets of early and late lesson discussions from three teachers to examine patterns in classroom talk. Finally, we audio recorded the teachers’ study group meetings that were held in their respective schools.

Teachers' Knowledge of Science Concepts

During the third year of the *Talk Science* research (2011-2012), we interviewed eleven teachers from Grade 5, who were teaching the *Inquiry Project* curriculum for the first time. Each teacher was interviewed twice in a pre-post manner, once before teaching the curriculum and once after teaching the curriculum. The interview probed teachers' understandings of core disciplinary science ideas regarding matter, and examined specifically the development in their ability to draw on the science concepts and principles from the *Inquiry Project* curriculum in articulating their understandings.

We interviewed the teachers in person or by phone. The pre-interviews took place prior to the teachers' participation in an implementation workshop organized to help teachers become familiar with the *Inquiry Project* curriculum. We conducted the post-interviews at the end of the teachers' participation in the *Talk Science* program, which included implementing the curriculum in their classrooms.

Interview Design

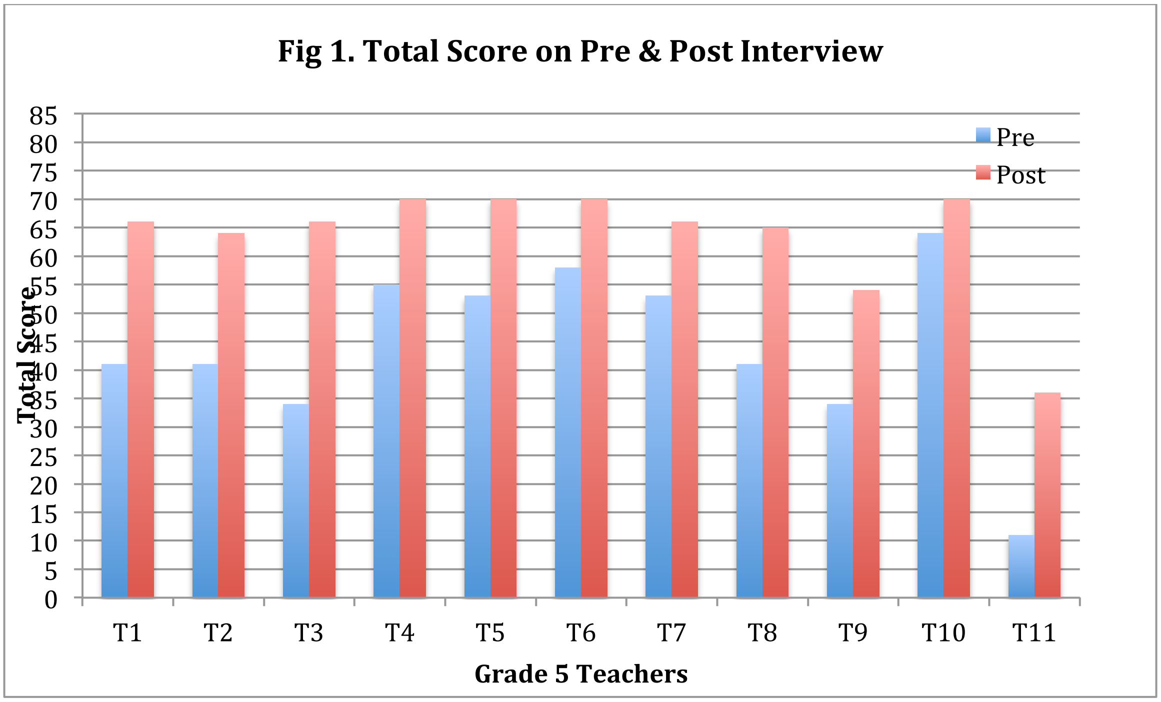
The science interview consisted of 41 questions, of which 31 questions examined teachers' content knowledge of the science concepts and principles, and 10 questions examined teachers' pedagogical content knowledge - their interpretation of and how they would follow up on students' thinking. The interview questions addressed six content areas included in the Inquiry Project curriculum: (i) measurement and margin of error; (ii) properties of air; (iii) phase change; (iv) dissolving; (v) condensation; and (vi) evaporation.

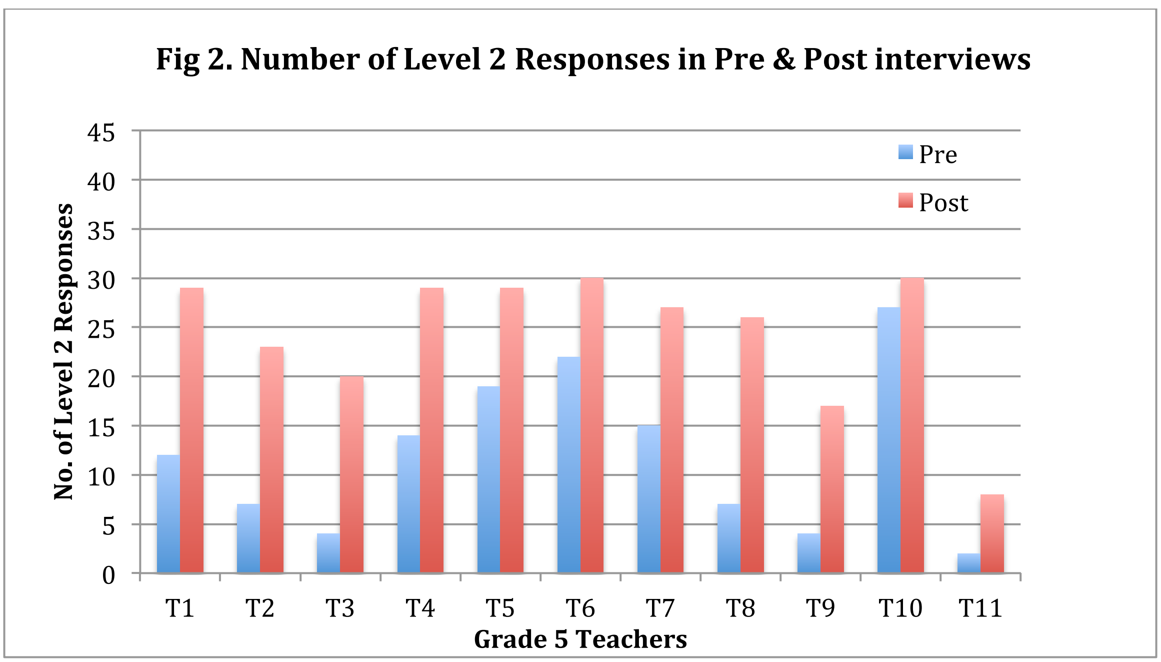
Interview Scoring

We developed a three level scoring scheme to score the depth of teachers' responses. Teachers' responses were given a score of 0 if teachers provided incorrect or equivocal responses; a score of 1 if teachers provided correct, seemingly intuitive responses, but without an accurate, complete scientific explanation; and finally, a score of 2 if teachers provided correct responses along with a scientific explanation drawn from the core ideas in the curriculum.

Using this scoring scheme, we calculated the total pre- and post-interview score for each teacher; the total number of pre- and post-interview level 2 responses for each teacher; the pre- and post-interview scores for each teacher in each of the six content areas; and the number of pre- and post-interview level 2 responses for each teacher in each of the six content areas.

Our findings suggest that after implementing the curriculum as part of the *Talk Science* program, teachers articulated their understandings about the nature of matter by drawing increasingly on the concepts and principles from the curriculum. They showed greater facility in explaining processes such as evaporation, condensation, and dissolving of salt in water with the help of the particle model from the curriculum, and understood that matter is made of particles that have weight and take up space. On the post-interview, all teachers obtained a higher total score (see Figure 1), and provided more responses that were assigned a score of 2 (see Figure 2; indicating their ability to provide elaborate scientific explanations on the basis of the core science concepts and ideas from the curriculum).





In the following section, we provide details on the changes in teachers' understandings within each of the six content areas that were examined through the interview.

Interview Findings

Measurement and Margin of Error

This content area contained a set of five questions of which three questions asked teachers to explain the notions of rounding and margin of error in the context of a fictitious scenario in which three groups of students weigh three different size blocks. The remaining two questions in this set addressed teachers' understandings regarding the difference between volume and weight as a measure of the amount of matter by asking teachers to explain how different volumes of sand from three cylinders could weigh the same.

On the post-interview, teachers improved their ability to articulate a margin of error argument to account for the differences in weight between the sum of the individual weights of three blocks and the weight of the blocks when the three blocks are weighed together. Teachers identified that the difference in these two measurements of weight could be due to the fractional weights of the individual blocks. Furthermore, teachers also articulated the notion of rounding in measurement and added that errors in rounding could occur because the scale measured only to the closest whole gram.

With respect to teachers' thinking regarding weight v/s volume as a measure of the amount of matter, most teachers identified correctly on the post-interview that weight was a more accurate measure of the amount of matter (in this case, of the amount of sand packed in a cylinder). The teachers attributed differences in volume to the way the sand might be packed in the cylinder, and the air spaces between the sand particles.

We found that nine of the eleven teachers obtained a higher score on this content area on the post-interview than the pre-interview (see Figure 1). Two of the teachers obtained the maximum score for this content area on both pre- and post-interviews.

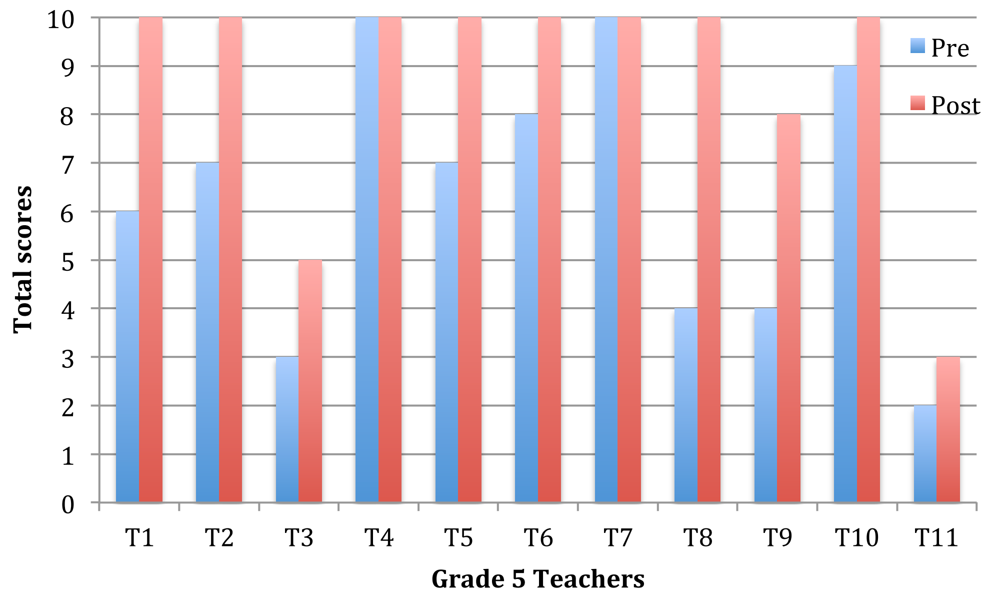


Figure 1. Scores for questions 1-5: Measurement

Further, eight teachers provided more level 2 responses on the post-interview than the pre-interview; two teachers provided level 2 responses to all five questions on both pre- and post-interviews; and one teacher did not provide any level 2 response on either the pre-interview or the post-interview (see Figure 2).

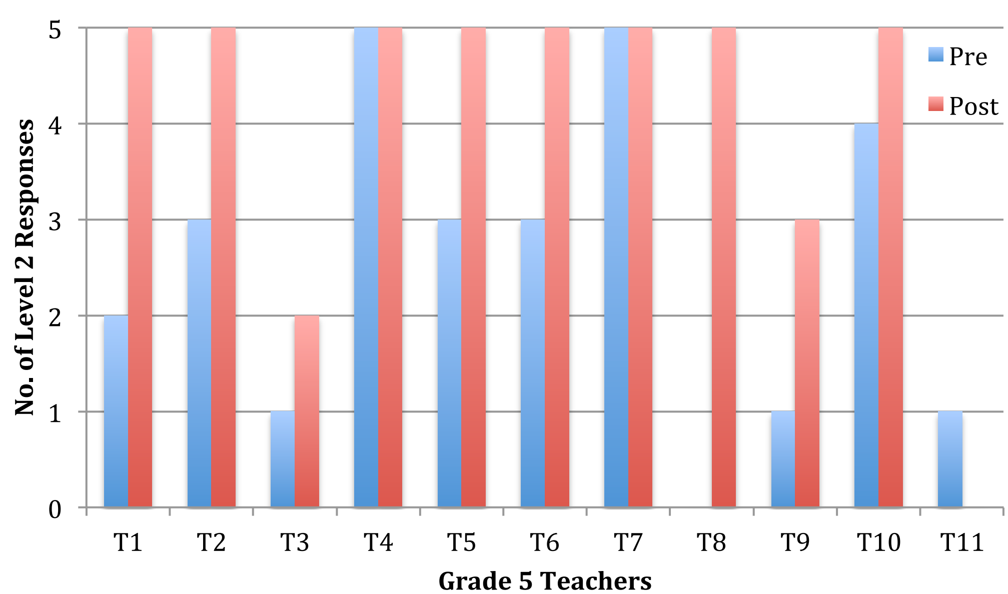


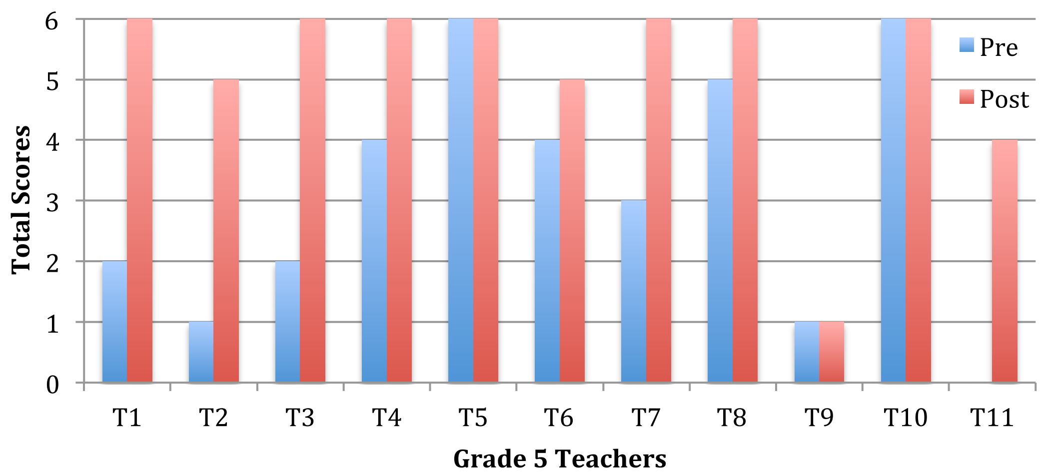
Figure 2. Number of Level 2 Responses: Measurement

Properties of Air

This content area contained a set of three questions addressing the key properties of air as discussed in the Inquiry Project curriculum: air is matter because it has weight and takes up space. The first question asked teachers to explain why they thought air was or was not matter; the second question asked teachers to consider a fictitious scenario in which they are presented with two soccer balls that are initially balanced on the scale, and explain whether the balls would weigh the same or different if one of the balls has more air pumped into it; and finally, the third question served to examine if teachers could transfer their understanding of the properties of air to a different context by explaining why air was thinner at higher altitudes.

We found that eight of the eleven teachers improved their score for this content area on the post-interview. Two of the teachers obtained the maximum score for this content area on both pre- and post-interviews, and one teacher did not show any difference in her scores (see Figure 3).

Figure 3. Scores for Properties of Air

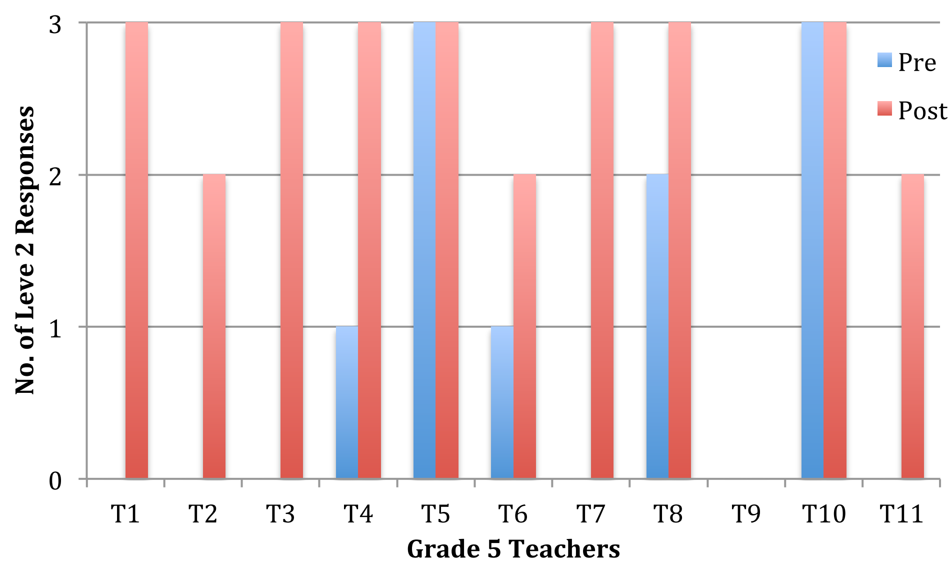


In the pre-interview, all but one of the teachers identified that air was matter but only five teachers added that air has weight and takes up space. Five teachers said it was matter but gave less specific reasons, such as air has "properties"; air is made of molecules; air is made of atoms; and gases are matter. Responses of this nature were assigned a score of 1. Of these five teachers, one said air was weightless, one thought air could not be weighed, and one did not know if air had weight. One teacher did not know if air was matter and said air did not have weight.

On the post interview, most of the teachers identified correctly that air was matter and that it was made of particles that had weight and took up space. Seven of the eleven teachers provided level 2 responses to all three questions on the post-interview (see Figure 4). These teachers identified correctly that air is matter because it has weight and takes up space. Further, these teachers also articulated that adding air to an already inflated soccer ball would make the ball heavier.

Furthermore, in answering the transfer question on the post-interview, seven of the eleven teachers drew on the particle model developed in the curriculum to suggest that the air particles were likely further apart at higher altitudes.

Figure 4. Number of Level 2 Responses: Properties of Air



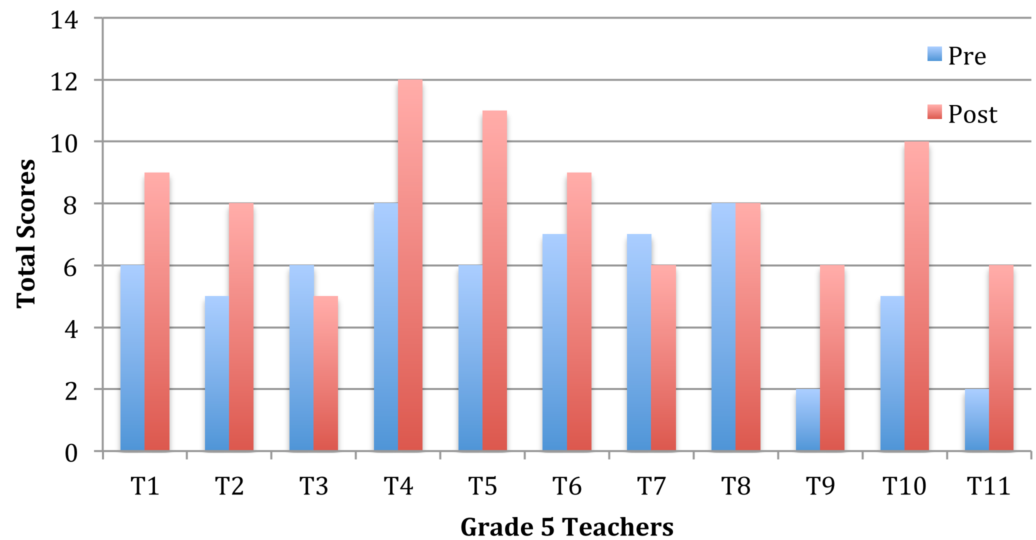
Characteristics of Phase Change

This content area contained a set of seven questions addressing the characteristics of phase change and the conservation of matter.

On the post-interview, the teachers improved in their understanding of phase change and conservation of matter. The teachers identified that phase change referred to a substance moving between a solid, liquid, and gas. They also articulated the key characteristic of phase change emphasized in the curriculum: weight stays the same even though volume can change. The teachers' improvement in their understanding of phase change is evidenced in both their improved scores for this content area, and the greater number of level 2 responses for this content area on the post-interview than the pre-interview.

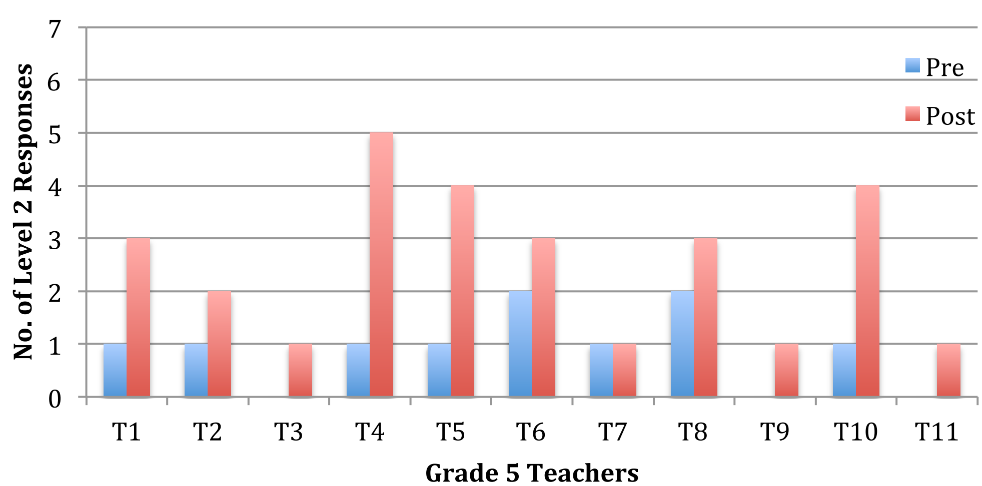
On the post-interview, eight of the eleven teachers had higher scores for this content area than the pre-interview; two teachers had lower score than the pre-interview; and one teacher's score was the same on the pre- and post-interview (see Figure 5).

Figure 5. Scores for Phase Change



Furthermore, ten of the eleven teachers provided more level 2 responses on the post-interview than the pre-interview (see Figure 6).

Figure 6. Number of Level 2 Responses: Phase change



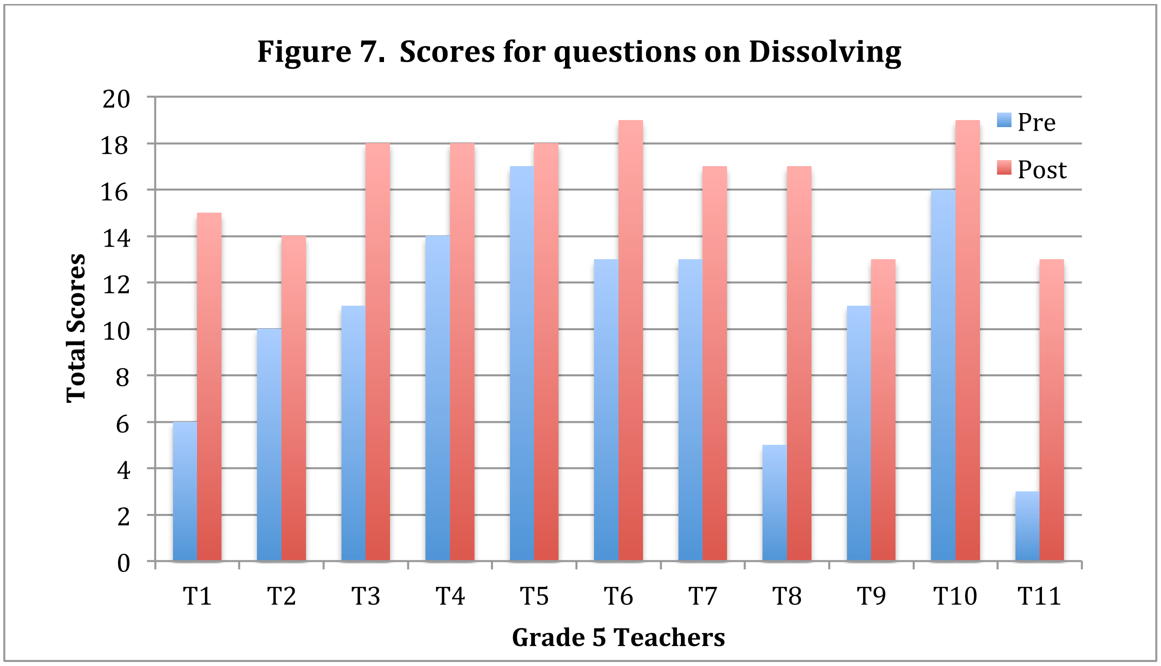
Teachers' responses also revealed that there were certain aspects of phase change they did not always articulate clearly. For example, in answering the question "What is phase change”, ten of the eleven teachers in the post-interview stated only that phase change involved a material changing states, but did not include the key features of phase change in their response: material stays the same; weight stays the same; reversibility; the particle movement is different in the different phases. Please refer to the NSF research report for more details.

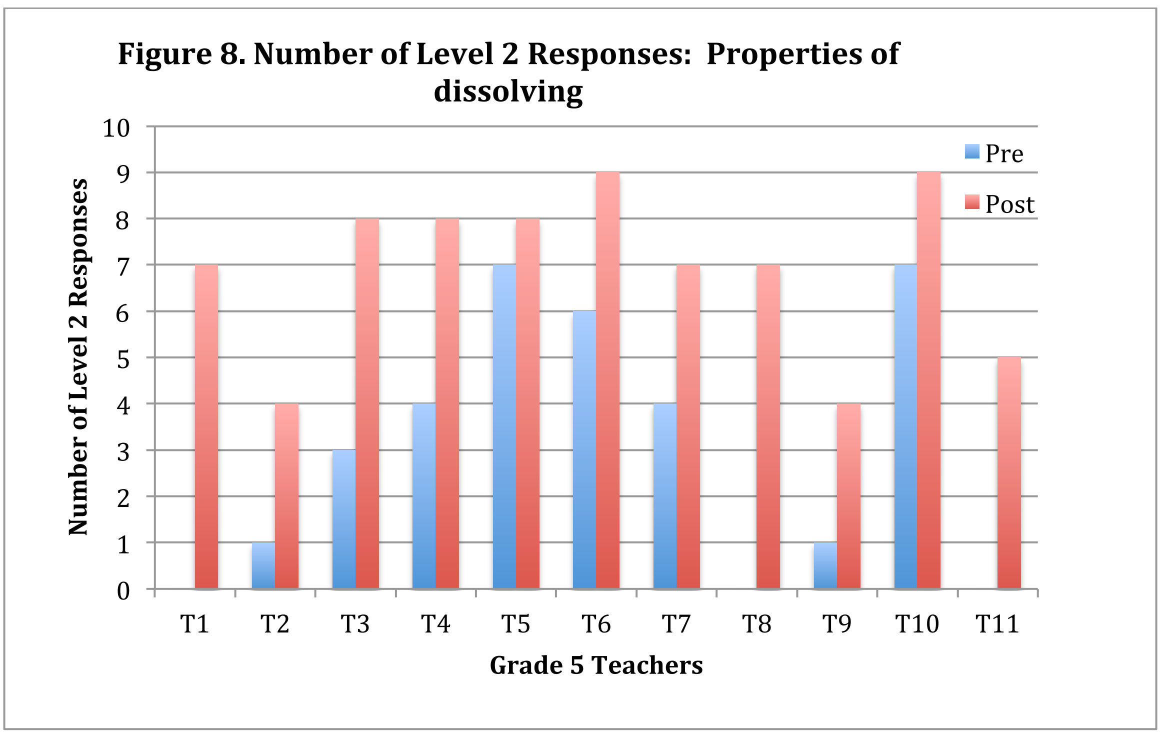
Dissolving

This content area contained ten questions asking teachers to consider what happens when salt dissolves in water. Six of the questions inquired into teachers’ content knowledge pertaining to the particle model of matter described in the curriculum, and four questions inquired into teachers’ pedagogical content knowledge: their understanding of students’ thinking, and how they would respond to students’ ideas. The pedagogical questions asked teachers to consider a fictitious classroom scenario in which two students discuss whether or not the volume increased when salt was added to water, and if their finding would provide evidence of whether or not the salt remained in the water.

All teachers in the post-interview improved in their understanding of this content area. Most teachers drew on a particle model in the post-interview to describe the process of dissolving: Eight of the eleven teachers identified that salt particles break apart and are too small to be seen when salt is dissolved in water. On the post-interview, teachers also identified weight as a measure of the amount of salt in the water. When asked for ways to test the presence of dissolved salt in the water, nine of the eleven teachers described the method emphasized in the curriculum: weigh the salt and water separately, and then weigh the water and salt together.

Teachers’ improved understandings are evidenced in the increase in their scores for this content area on the post-interview, and in the increase in the number of level 2 responses on the post-interview (see Figures 7 and 8).





Condensation

This content area contained eight questions asking teachers to consider a concept cartoon that showed condensation on a glass of water with ice cubes, and no condensation on a glass of water without ice cubes. Of these eight questions, five questions examined teachers' understanding of condensation in terms of the particle model, whereas three questions were pedagogical questions asking teachers to consider the three conflicting student perspectives presented in the concept cartoon.

In this content area, teachers showed overall improvement on the post-interview in responding to the concept cartoon. Eight of the eleven teachers had higher scores on the post-interview (see Figure 9), and seven of the eleven teachers provided more level 2 responses on the post-interview (see Figure 10).

Figure 9. Scores for Condensation

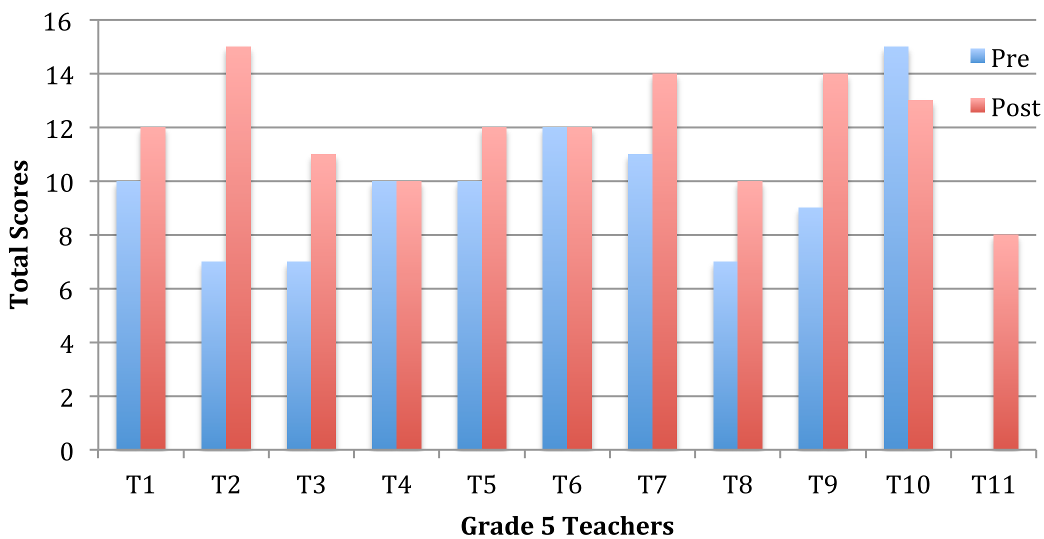
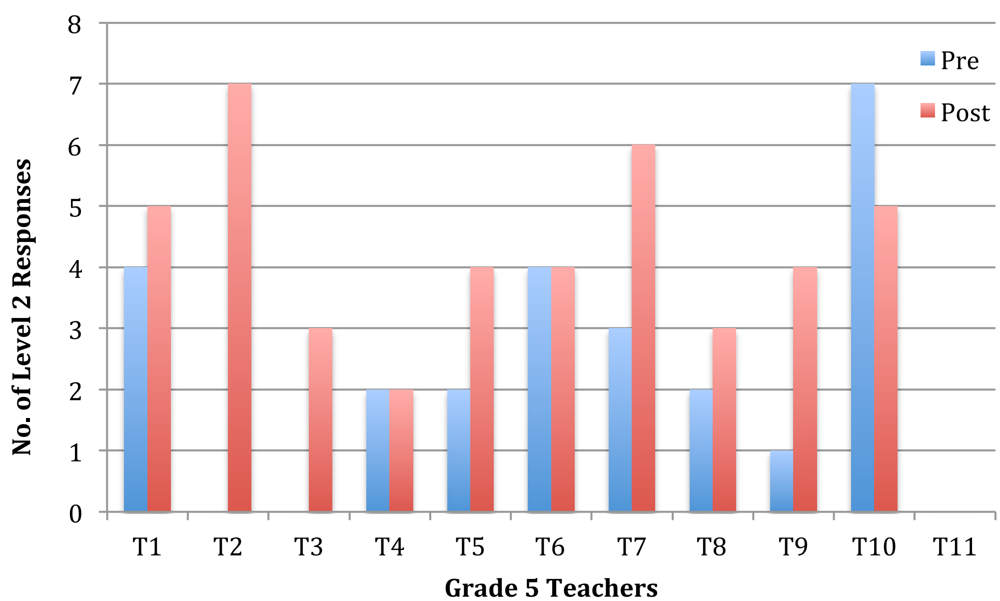


Figure 10. Number of Level 2 Responses: Condensation



Specifically, in responding to the content knowledge questions on the post-interview, more teachers were apt to draw on the particle model introduced in the curriculum, thereby demonstrating deeper reasoning about the science. This shift towards thinking in terms of the underlying water particles is exemplified in the explanation by one of the teachers on the pre- and post-interviews, when asked why water droplets formed on one glass but not on the other as depicted in the concept cartoon:

Pre-interview response: "*The other one is cold; and therefore the warm air coming from its surroundings hits the glass and that's how condensation is created."*

Post-interview response: "*Oh, condensation. Because the ice cubes create a temperature difference, and that causes molecules from the air to draw near to the glass because water molecules that are in the air in the warm temperature are free-floating, but as the temperature cools, they want to come together. As they come together towards where the glass is, they puddle.*"

In responding to the pedagogical questions, more teachers tended to focus on evaluating the accuracy of students' thinking as depicted in the concept cartoon, and were less inclined to ponder the possible reasoning underlying students' ideas. When asked to consider the students' ideas presented in the concept cartoon, few teachers articulated 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."

"So I, I'd like some evidence of why [Deneb] thinks that [the water came over the glass]. Where is the water that moved over the top of the glass and is dripping down the side? Did he not see that at all? Did he not see it happen to start? Or are, these three kids are just coming right to the table, so he's assuming something."

Evaporation

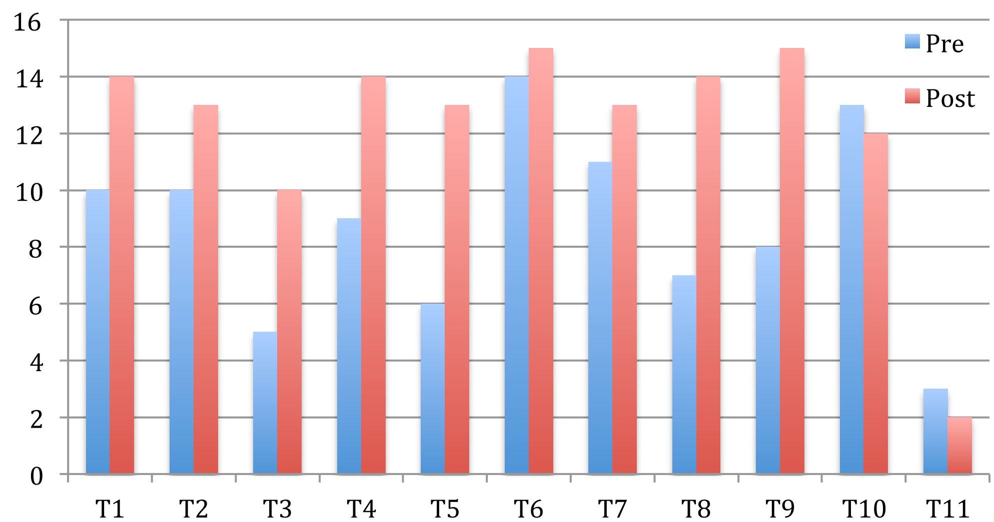
This content area contained eight questions in the context of a concept cartoon, of which five questions tapped into teachers' content knowledge regarding evaporation, and three questions addressed teachers' pedagogical knowledge in terms of their understanding of the student ideas presented in the concept cartoon.

The findings show that overall, teachers' scores for this content area improved on the post-interview. On the post-interview, teachers increasingly understood evaporation as a process whereby water moves from a liquid state to a gaseous state, and were inclined to reference the particle model to explain evaporation in terms of the water particles breaking or spreading apart. On the post-interview when asked to think of ways to test the competing ideas in the concept cartoon, teachers also referred increasingly to the two-bottle system experiment introduced in the curriculum.

Furthermore, with respect to the pedagogical content knowledge questions, our findings suggest that in the post-interview, more teachers engaged deeply with pondering student ideas presented in the concept cartoon. More teachers in the post-interview than the pre-interview attempted to make sense of the canonically inaccurate student ideas in the concept cartoon. Teachers tried increasingly to speculate the reasoning underlying the ideas in the concept cartoon.

Teachers' improved scores for this content area are reflected in an increase in their total scores for this area, and in the greater number of level 2 responses on the post-interview. Of the eleven teachers, nine teachers had higher scores in the post-interview than the pre-interview (see Figure 11); further, eight of the eleven teachers offered more level 2 responses in the post-interview than pre-interview (see Figure 12).

Figure 11. Scores for Evaporation



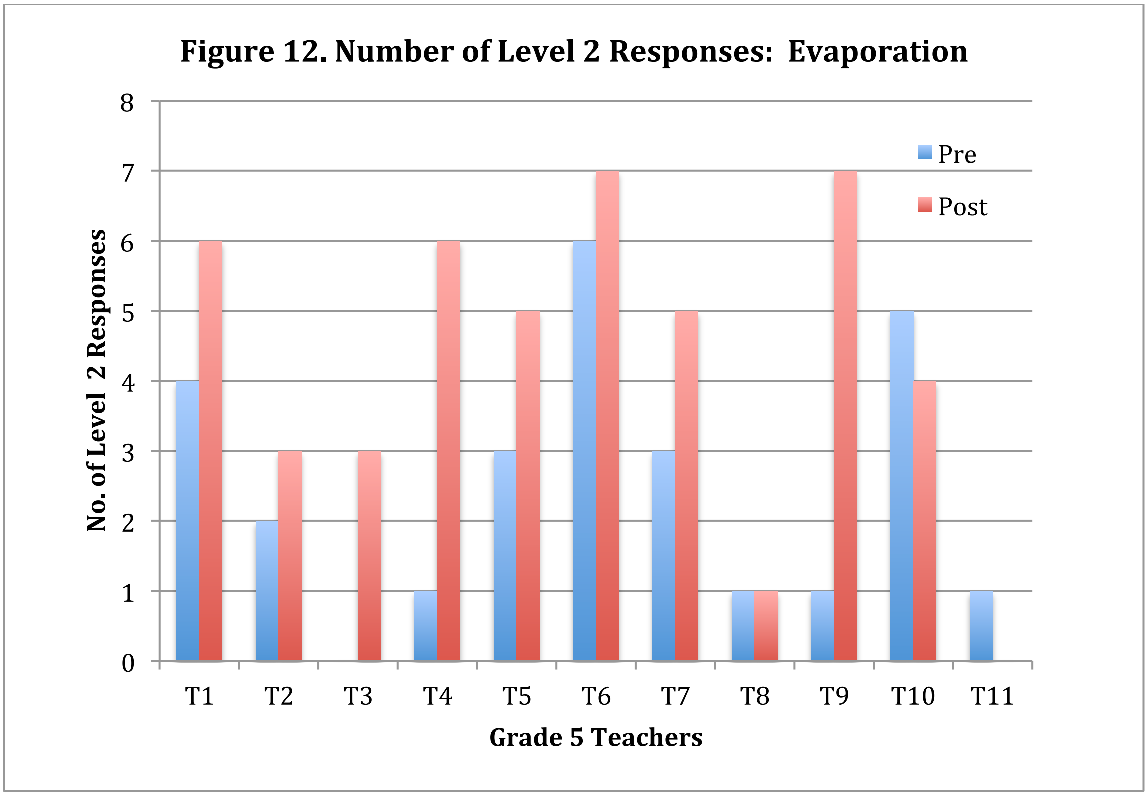


Figure 12. Number of Level 2 Responses: Evaporation
8
7
6
5
4
3
2
1
0
No. of Level 2 Responses
Pre
Post
T1
T2
T3
T4
T5
T6
T7
T8
T9
T10
T11
Grade 5 Teachers

Teachers' Participation in Study Groups

In the third year of the *Talk Science* research (2011-2012), our sample of eleven teachers from Grade 5 met in study groups conducted in their respective school settings. The Talk Science program included a set of six study group meetings, starting at step 2 of the professional development pathway and ending at step 7 of the pathway. The study group meetings were designed to present teachers with opportunities to plan for their classroom teaching, and to reflect on and analyze their classroom practice and science discussions with respect to the web-based professional development resources provided to them.

Study group meetings were held in urban, suburban, and rural school settings. The suburban and rural study groups each included teachers from two schools. Further, the urban and suburban study groups had their schools' science supervisors as designated moderators to facilitate their meetings. We provided all study groups with a study guide for each meeting, which suggested specific topics for discussion during the meeting, and an individual web-study of *Talk Science* professional development resources prior to the meeting. The study guide recommended generally that teachers share their observations of the resource content, and generate plans for incorporating what they learnt from the resources into their own classroom teaching.

We audio recorded teachers' study group meetings, and transcribed the recordings subsequently. We collected audio recordings from the three study groups for the following steps of the *Talk Science* pathway:

Urban Study Group: Study Group Meetings for Pathway Steps 5 and 6
Rural Study Group: Study Group Meetings for Pathway Steps 2, 4, 5, 6, and 7
Suburban Study Group: Study Group Meetings for Pathway steps 2, 3, 4, 5, and 7

Analysis of Teachers' Study Group Discussions

Coding Scheme

We developed a coding scheme to analyze teachers' study group meetings to understand how teachers utilized the meetings to develop their professional practice. Specifically, we were interested in exploring what *Talk Science* web-based professional development resources teachers discussed during the meetings, and how they engaged with the resources. The coding scheme identified nine *Talk Science* professional development resources, and consisted of five categories to capture teachers' engagement with the resources.

The nine professional development resources were: (i) Scientist Cases; (ii) Classroom Cases; (iii) Talking Points and Strategy cases; (iv) Scientist's Essays; (v) Essays on Children's Ideas; (vi) Reflection Tool; (vii) Primer; (viii) In Your Classroom Sheet; (ix) Inquiry Project curriculum.

The five categories described various ways in which teachers engaged with the web-based resources: (i) whether teachers talked about their observations and what they liked about a resource; (ii) whether teachers made connections to their own classroom experiences and events, and talked about how these were similar to or different from what was presented in the resource; (iii) whether teachers made plans for incorporating into their own teaching what they had learnt from a resource; (iv) whether teachers explicitly reported transfer of learning in terms of having utilized a resource in their own teaching; (v) and whether teachers showed an analytic stance by reflecting upon, raising questions, or identifying challenges and issues with their own teaching.

Our analysis shows that teachers across the three schools utilized the meetings for various purposes, and their discussions were fairly consistent with the objective of these meetings and the accompanying study guide. Teachers utilized study group time to formulate plans and generate ideas for what they would like to do in their classrooms in relation to the professional development resources, and shared their observations of and reactions to what they had noted during individual web-study of the professional development resources. Teachers' discussions reflected their intention to transfer their learning to their classroom practice, and their careful engagement with the content presented in the resources. Teachers also made several connections to their own classroom context and present practice, debriefing events and experiences from their classroom as they talked about the resources. Teachers' talk about their own classroom with respect to the various resources reflects their motivation in participating in the *Talk Science* program.

In the following sections, we present details on the findings from our analysis of teachers' study group meetings.

Study Group Findings

Talk Science Professional Development Resources Discussed in Study Group Meetings

The study groups frequently discussed content pertaining to classroom cases and Talking Points/Strategy cases. Specifically, the rural and urban study groups focused most on classroom video cases and their classroom discussions. Across the five rural study group meetings, 47.41% of the teachers' talk pertained to the classroom video cases and their own classroom science discussions. Similarly, across the two urban study group meetings, 57.01% of the teachers' talk involved references to this resource. On the other hand, the suburban study group focused most on content related to the Talking Points/ Strategies, and discussed productive talk, norms, talk goals and talk moves in connection with the resource. Across the five suburban study group meetings, 53.07% of teachers' talk pertained to this resource.

A consistent finding across the three study groups was that teachers devoted less time to talking about the scientist cases, accounting for 21.7% of the talk across all meetings in the rural study group; 7.48% of the talk across all meetings in the urban study group; and 4.47% of the talk across all meetings in the suburban study group.

Study Group	Most Frequently Discussed Professional Development Resource & Content	Percentage of Talk of the Most Frequently Discussed Professional Development Resource & Content	Percentage of 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%

Teachers' Engagement with *Talk Science* Professional Development Resources

Teachers commonly utilized study group time to make connections to and debrief their own classroom situation; describe their observations of and reactions to the professional development resources; and to make plans for the teaching in their classrooms.

Specifically, teachers in the suburban and urban study groups engaged most with the professional development resources by making connections to their own classroom experiences and events, debriefing how things were going in their classroom, and talking about their own present practice and their students' participation and understanding. This type of talk accounted for 50.56% of the discussions across five suburban study group meetings, and for 67.29% of the discussions across two urban study group meetings. In comparison, teachers in these two study groups spent less time generating ideas for practice and formulating plans for action in their classrooms, accounting for 18.72% of the talk in the suburban study group meetings, and for 7.48% of the talk in the urban study group meetings.

These findings may be understood better in light of the fact that the study groups had designated moderators who prompted teachers to debrief their classroom events, talk about what was working well or not well for them, and make connections to their own classroom practice and context. Although the moderators followed the study guide to an extent by enabling teachers to share their observations of and reactions to the professional development resources and to generate plans for their classroom, they adopted a flexible approach in facilitating the meetings by keeping the discussions open and allowing teachers to report their existing classroom situation and experiences in relation to the resources.

At the rural study group meetings, however, teachers mainly described their observations of and reactions towards the professional development resources, accounting for 36.79% of the talk across five meetings; and generated ideas for what they may want to incorporate in their classrooms, accounting for 36.08% of the talk across the meetings. Compared to the time devoted to both describing and planning, the teachers spent less time talking about and debriefing their present classroom experiences and situation, accounting for 29.48% of the talk across the meetings.

These findings from the rural study group meetings may be understood better in light of the fact that the rural study group did not have a designated moderator, and the teachers largely followed the study guide to regulate their meetings. The study guide generally emphasized sharing observations of the *Talk Science* professional development resource recommended for discussion during the study group meeting, and making plans for incorporating the resources into classroom practice.

Study Group	Most Frequent Nature of Engagement	Percentage of Talk with the Most Frequent Nature of Engagement	Percentage of Talk reflecting PLAN
Suburban (5 meetings)	Making connections between own classroom and content of professional development resources	50.56%	18.72%
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%

Transfer of Learning and Analytic Stance

The findings suggest that teachers made attempts to transfer their learning to the classroom, and identified changes taking place in their classroom culture. Across the three study groups, teachers devoted some time to report their experiences with using specific professional development resources to inform their classroom practice. This type of talk accounted for 9.2% of the talk at the rural study group meetings, less than 1% of the talk at the urban study group meetings, and 10.89% of the talk at the suburban study group meetings.

There were also few instances of teachers adopting an analytic stance and generating issues and questions about their teaching. Similar to reporting transfer to the classroom, this type of talk was less common and accounted for 2.12% of the talk at the rural study group meetings, 1.87% of the talk at the urban study group meetings, and 4.47% of the talk at the suburban study group meetings. These findings indicate that teachers devoted less time during study group meetings to reflect critically on their own practice as they attempted to incorporate new ideas and strategies into their classroom teaching.

These findings may be understood in light of the structure of the study guide. The guide generally recommended that teachers describe their observations of the content in the professional development resource, and formulate plans for incorporating the resource content into their classroom teaching. The study guide seldom prompted teachers explicitly to reflect on their experiences with using specific PD resources, and to discuss with colleagues the challenges and issues they experienced in their teaching. In following the study guide, the study groups may have thus utilized the meetings less to engage with the resources in this manner.

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)	10.89%	4.47%

Moderators' Facilitation

The urban and suburban study groups had designated moderators to facilitate their study group meetings. Our analysis suggests that the specifics of which *Talk Science* professional development resources were discussed, and how teachers talked about the resources during study group meetings may be understood better in light of the moderators' facilitation of the meetings. Indeed, the moderators' facilitation may be an important factor shaping teachers' discussions during study group meetings.

The moderators followed the study group guide to an extent in structuring the discussions by prompting teachers to share their observations of and reactions to the resource content, and to generate plans for their classrooms. But the moderators also adopted a flexible approach to allow teachers to make considerable connections to and debrief their present classroom context and practice in relation to the resources. The urban and suburban study group meetings are consistent with these patterns in the moderators' facilitation. Across two meetings, the urban study group devoted 67.29% of the talk to discussing their classroom context; 7.48% of the talk to making plans and generating ideas for the classroom; and 26.17% of the talk to sharing observations of and reactions to the resource content. Across five meetings, the suburban study group devoted 50.56% of the talk to making connections to classroom context; and 18.72% of the talk each for describing observations and reactions towards the resources, and planning for their teaching in the classroom.

There were also key differences between the facilitation patterns of the two moderators. Specifically, in the suburban study group meetings, besides eliciting teachers' connections to their present practice and classroom events, the moderator encouraged teachers to describe their observations of and reactions to the content in the resources, and prompted them to formulate plans of action for their classroom practice. The moderator also encouraged teachers to focus on the issue of productive talk in their classrooms, prompting them to reflect on their experiences with using productive talk moves, and making plans for fostering productive talk in their classrooms.

On the other hand, the urban study group moderator encouraged teachers to talk about mainly their present classroom situation and debrief how things were going for them, but did not focus teachers' discussions specifically on their experiences with productive talk in their classrooms, nor on how they had been utilizing particular *Talk Science* web resources like scientist cases, classroom cases, and Talking Point/Strategy cases. The moderator did not prompt teachers to reflect specifically on how productive talk goals and strategies were going for them, nor to formulate plans for fostering productive talk with their students.

These differences in the moderators' facilitation may shed light on the findings from the urban and suburban study groups. Across the two meetings in the urban study group, there was a predominance of teachers' connections to and debriefing of their own classroom events and practice (67.29%); no mention of the Talking Point/Strategy resource; less focus overall on planning and generating ideas for classroom practice (7.48%); and on reporting experiences with incorporating specific PD resources into classroom practice (< 1%).

In contrast, in the suburban study group, teachers devoted 18.72% of the talk to formulating plans and generating ideas for incorporating the resource content into their classroom practice to support students; and 10.89% of the talk to describing their experiences with using specific resources and their attempts at supporting their students. Furthermore, talk pertaining to Talking Point/Strategy cases accounted for the majority of the references to PD resources in the suburban study group (53.07%).

Alignment of Study Guide Recommendations with Teachers' Classroom Needs

Our analysis points to an important factor that may shape the nature of teachers' study group discussions: the extent to which the topics recommended for discussion on the study guide during the various steps in the *Talk Science* professional development pathway are aligned with the teachers' implementation of the *Inquiry Project* curriculum and their specific classroom needs. The study group meetings revealed variations in teachers' pace of implementing the curriculum. When teachers meet in their study groups, they are often at different points in doing the curriculum lessons in their classrooms. As a result, the topics recommended for discussion for a particular study group meeting are not always synchronized with the teachers' implementation of the curriculum. Therefore, although the steps in the professional development pathway present resources to the teachers in a particular order aligned with the curriculum, teachers are likely to make implicit choices regarding the topics and foci of their meetings on the basis of their actual implementation of the lessons, and on the basis of what is relevant to the teaching and learning in their classrooms at particular points in time. As a result, teachers may not always discuss some resources or discuss them in a manner recommended by the study guide for a particular meeting if the content of the resources is not relevant to what they do at the time.

The study group meetings suggest that the alignment of the recommended topics on the study guide with the teachers' classroom context and curriculum implementation may be important for the specifics of the resources that are discussed in study group meetings during particular steps of the pathway. For example, in Step 5 of the pathway, some of the topics recommended for discussion in the study group meeting included identifying the talk moves in the Talking Point/Strategy case on Listening Carefully, and formulating plans for using talk moves to promote active listening in their own classrooms; and reviewing the scientist case and lesson content pertaining to Section 2 of the curriculum to identify the main science ideas to be emphasized during classroom discussions. In the rural study group meeting for Step 5, two of the three teachers in this group had already completed lessons from curriculum section 2. During the meeting, the teachers made no reference to the curriculum, nor did they talk about the main science ideas they gathered from the lessons and the scientist case corresponding to the curriculum section. The lack of reference to the main science ideas from the curriculum and scientist case may have been due to the fact that two of teachers had already completed the curriculum section and therefore, reviewing the science ideas may have been less relevant to their classroom needs at the time. Furthermore, although the strategy case on Listening Carefully was recommended for discussion, the teachers acknowledged that their students struggled with using evidence during science discussions. Therefore, consistent with their students' needs, the teachers identified deepening students' reasoning and asking them for evidence as the goal of productive talk they wanted to emphasize in their classrooms.

Similarly, across the urban and suburban study groups, a few teachers had already finished doing at least part of this curriculum section, whereas others had not yet started the section when the study group meetings for Step 5 took place. During the meetings in these two study groups, the teachers did not discuss the main science ideas from the scientist case or from the curriculum content to be supported during classroom discussions.

Teachers’ Perspectives On and Reported Use of Classroom Discussions

In the third year of the *Talk Science* research (2011-2012), we interviewed teachers in Grades 4 and 5 regarding their use of whole group discussions to support students’ science learning. The aim was to gain insight into teachers’ understanding of the role of science discussions, and their reported use of discussions for students’ learning.

We conducted pre-post interviews with Grade 5 teachers, interviewing them once prior to and once upon completion of the *Inquiry Project* curriculum and their participation in the *Talk Science* professional development program. The interviews with the Grade 4 teachers were conducted as post-interviews only after the teachers completed the *Inquiry Project* curriculum.

Grade 4 Talk Interviews 2011-2012

We interviewed nine teachers in Grade 4 across four schools upon their completion of the *Inquiry Project* curriculum to understand their use of whole group science discussions. Eight of the teachers had participated previously in the *Talk Science* professional development program during the 2010-2011 academic year, and were teaching the *Inquiry Project* curriculum for the second time in 2011-2012. One of the teachers in the sample was new to teaching Grade 4.

The interview questions were open-ended and prompted teachers to describe whole group discussions in their classroom and their facilitation of the discussions. Findings from this analysis pertain to: 1) teachers’ reported use of classroom science discussions; 2) perceived benefits of whole group discussions; 3) experiences teaching the *Inquiry Project* curriculum; and 4) challenges in facilitating classroom discussions.

1. Reported Use of Classroom Science Discussions

Teachers’ responses reflected: 1) a commitment to conducting classroom discussions; 2) an awareness of the discussion component of the *Inquiry Project* curriculum; 3) how the Inquiry Project discussions were different from those in their other science units; and 4) evidence of changes in their discussion practices based on their experience with the curriculum.

All nine Grade 4 teachers reported doing discussions from the *Inquiry Project* curriculum. Further, all teachers reported doing discussions in other science units, primarily as a way to start and wrap up lessons. The frequency of wrap-up discussions varied for teachers, with some enacting discussions after every lesson and some at intervals throughout units.

All teachers reported having more frequent discussions in the *Inquiry Project* curriculum than with other science units. This was because the curriculum provided *focus questions* to guide the discussions. Three of the teachers explained that discussions in their other units focused more on “*sharing-out*”, such as designating one student from each small group to share the group’s findings. Two teachers described how they had modified other science units to include planned discussions like those in the *Inquiry Project* curriculum.

2. Perceived Benefits of Whole Group Discussions

Teachers' commented that classroom discussions help improve students' understanding. Noted benefits of discussion included: opportunity for students to share ideas with others, to resolve misconceptions, to answer questions or address confusions, and for students to hear their peers' thinking. Teachers stressed the importance of students attending to their peers' thinking, particularly to learn about alternative approaches and differing investigation results.
Teachers commonly talked about students' sharing their individual thinking with peers, but didn't explicitly describe students progressively building a shared, coherent argument *together*. There is only beginning evidence that teachers are using discussions as opportunities for students to "make meaning" in a more dialogic sense.

3. Experiences Teaching the Inquiry Project Curriculum

The eight Grade 4 teachers were teaching the *Inquiry Project* curriculum for a second time. They described having greater familiarity with the structure of the curriculum. They found it easier to set up the curriculum materials, and had better understanding of the goals of the curriculum.
Teachers found the discussions more feasible this time round. They identified the questions provided by the curriculum as particularly helpful in structuring and guiding student talk, and supporting students in responding to one another. They were more comfortable mediating discussions and more confident in their implementation of the curriculum.

4. Challenges Facilitating Classroom Discussions

Challenges described by teachers include: identifying when they should intervene and interject their opinions and when they should let the students carry on the discussion; difficulties ensuring equity in students' participation; knowing the science well enough to facilitate the discussion and acknowledging gaps in their own understanding; the tension between responding to students' misconceptions versus facilitating the discussion such that students resolve their own misconceptions.
Teachers seemed to have conceptualized their role as general facilitators helping students stay on topic and participate equitably. They less often described particular challenges of supporting *science* discussions, such as how to help students develop deeper science ideas through discussions.

Grade 5 Talk Interviews 2011-2012

We conducted pre/post interviews with eleven teachers in Grade 5 across five schools, once prior to and once after they finished teaching the *Inquiry Project* curriculum and participating in the *Talk Science* professional development program. Two teachers who co-taught the curriculum were interviewed together and their responses were examined as one interview, thus resulting in a total of 10 pre- and post- interviews for Grade 5.

The questions were open-ended in nature, inquiring into teachers' use of whole group discussions in their science lessons, and into how they described the nature and qualities of productive whole group discussions. Teachers were encouraged to offer examples of how they facilitated whole group discussions. The analysis focused on identifying the extent to which teachers' perspectives on the role of whole group discussions changed, and if they reported guiding whole group discussions differently after the *Talk Science* program.

The findings are organized into four categories to align with the questions asked during the interviews (note: there are some variations with the categories of Grade 4 talk interviews): 1) making use of whole group discussions in science lessons; 2) perceived benefits of whole group discussions; 3) reported characteristics of the whole group discussions in their classrooms; and 4) factors affecting teachers' continued use of whole group discussions for science.

Although teachers' responses to the interview questions are self-report data, when possible, we corroborate teachers' reported accounts with findings from the analysis of classroom science discussions (see section on Teachers' Facilitation of Classroom Science Discussions).

1. Making Use of Whole Group Discussions in Science Lessons

We asked teachers whether they did whole group discussions during science lessons, and if they did, when in the course of the lessons the discussions tended to occur.

Pre-interviews: All but two teachers reported doing some form of whole group discussions in their science lessons. The discussions generally occurred at the beginning and at the end of a lesson or a unit, functioning as introduction and wrap-up for the lessons. Teachers described having introductory discussions to prompt students' thinking or to identify their prior ideas, and wrap-up discussions to review the main ideas in the lesson. The response below illustrates this pattern:

"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."

Only one teacher mentioned having discussions spontaneously to bring students together when she thought they might benefit from talking together. Along with introductory discussions and a “wrap-up”, she would conduct discussions in the middle of the lesson if students raised several questions.

One teacher commented that her classroom discussions did not usually involve an inquiry approach like the *Inquiry Project* curriculum’s concept-cartoon discussion that she conducted at the start of the curriculum.

Two teachers cited reasons for not having regular whole class discussions. One described her uncertainty with ensuring adequate participation of students during whole group discussions. The other said that the curriculum did not lend itself to discussions. These teachers relied on other instructional practices, such as small group work and partner work, and asking students to “find out information” and write claims and evidence as part of a research-based instructional approach.

Post-interview: After teaching the *Inquiry Project* curriculum and participating in the *Talk Science* professional development program, we asked teachers whether they used whole group discussions in subsequent science units or if they planned to use whole group discussions in the future. Their responses reveal positive shifts in their discussion practices.

Teachers described having incorporated whole group discussions as an integral part of their science lessons:

“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.”

This shift was also noted for teachers who previously reported not doing whole group discussions. They now described discussions as a regular part of their lesson structure in other science units; they were enthusiastic about discussions; and they were confident in their ability to lead discussions with over twenty students in the classroom. One said that she now saw discussions as *opportunities for on-going learning*, not only as a way to wrap up lessons:

“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 . . . .”

Further, the practice of having discussions at multiple points in a lesson persisted after participating in the *Talk Science* program:

“I do it in the beginning to get them thinking and to brainstorm ideas and predictions and just to warm up their brains. I might do it midway through when I’m starting to see people drifting off on a different tangent, perhaps they’re not quite grasping what it is I wanted them to find so I’d bring them back and then have a discussion . . . and then at the end do sort of a post-assessment, if you will, like a formative assessment, to see what they’ve learned.”

Finally, most teachers continued to describe their present practice at conducting discussions in terms of an introduction and wrap-up structure:

“We always do an introduction at the beginning of what the concept is we’re doing and then they have whatever the exploration is and then they share out whatever the

results of their exploration was depending on what the unit is and then we summarize it and move on with the next thing."

2. Perceived Benefits of Whole Group Discussions

In the pre-interviews, teachers identified whole group discussions as places for students to hear their peers' ideas, but in the post-interviews, their perception shifted to viewing whole group discussions as opportunities for students to *build ideas together*.

Pre-interviews: Teachers said whole group discussions allowed students to share ideas and hear different perspectives, and commonly viewed discussion as opportunities for students to describe what they knew rather than as dialogue in which students developed ideas collectively:

"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."

"But I'd like to see more kids participate in the large group discussion too because I think their classmates are interested in what people are saying . . . .I think it gives kids a chance to hear other kid's ideas. I mean I can tell them what I'm thinking about things but I think it's helpful for them to see other kids or hear other kids talk about the ideas they have."

A few teachers commented that discussions provide opportunity to assess students' understanding of an idea or concept; in allowing students to share out their thinking, discussions teachers found discussions to be a more reliable means of assessing student ideas than tests.

"First of all, I think that I would probably have a better understanding of who gets it and who doesn't—not just from [what] they've written on a test or something like that . . . They might have answered a question, multiple choice, or fill-in the blank but really they don't understand it."

A notable exception to the tendency to view whole group discussions as "sharing out" was the response of a teacher who had participated in the *Talk Science* program in the preceding year. In the pre-interview, she said that whole group discussions allowed students to *think together* and respond to each other's questions:

"The reason why I like whole group discussions is that it produces more thinking, it produces more questioning, and it also produces more learning . . . ."

Post-interviews: The view of discussion as co-construction of ideas was more evident in the post-interviews where teachers began to talk about students thinking together and building ideas together during discussions:

" [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."

"They can learn from each other, consolidate their thinking, or enhance what they're thinking about. I also think, and it also helps to kind of identify some misconceptions in sort of a non-threatening way."

3. Perceived Characteristics of Whole Group Discussions

Did teachers report changes in their classroom discussions? This question was important to explore as it would point to possible changes in the culture of classroom talk, changes in teachers' facilitation of discussions, and changes in students' participation during discussions.

To address the question, we asked teachers to describe their whole group discussions, their students' participation, and what was working during the discussions. Teachers' responses revealed several shifts in the nature of their whole group discussions.

Pre-interviews: Teachers reported using introductory discussions to find out what students' preliminary understandings about a topic. Again, teachers characterized discussions largely as times when students *shared* their ideas, with the exception of one teacher who talked about encouraging students to generate hypotheses during the introductory discussions.

Teachers used wrap-up discussions to allow students to report out what their small group conversations, and to hear their peers' thinking. They did not describe students as engaging in discussions with their peers. Rather, their classroom discussions reflected a more monologic pattern:

"I'll usually just pick one student [from the group]. I'll say person in seat number two, share out what your group was saying. . . . I let one person from each group share out and then if any other units or groups have already gone, then I allow them to add to it if they want."

One teacher talked about student-to-student interactions with reference to what she'd like to do in the future, rather than what was presently happening in her discussions:

"I think everything is there, and I'm not opposed or afraid of trying anything, it is just how can I use my time more efficiently? I want to give them more kid-to-kid talk time and then kind of back off a little bit."

Post-interviews: By contrast and as mentioned previously, in the post-interview responses, four significant shifts were observed through teachers' comments:

<u>a. Decrease in the amount of teacher talk</u>: One of the first steps that teachers may make when moving from *share-out* toward *co-construction* is to step back and let students talk more with each other. Certainly, one of the challenges is to ensure that the teacher is not entirely absent in the discussions (which we address in the section on "Factors affecting teachers' continued use of whole group science discussions."). Yet, one of the key indicators of a shift toward greater co-construction may be that students do more talking.

In the post interviews, teachers reported they were talking less during discussions. Eight of the ten teachers indicated that the discussions were more *"student-led."* They now described their role as being less directive, as a facilitator who keeps the discussion moving by using the academically productive talk moves introduced in the *Talk Science* program. They added that their students were showing greater responsibility at guiding their own discussions:

"I don't have to facilitate as much. I mean, depending on the topic. But they have become more independent . . . I didn't have to call on kids. They would call on each other."

"[Y]ou can push [students]. Still you say, you remind them. Who can rephrase that? Or who can challenge them? Can you challenge? Can anybody challenge that opinion and tell me why?"

Teachers' perception that they were talking less during classroom discussions is consistent with the analysis of their concept-cartoon discussions, which showed that teachers took fewer turns at talk than their students in the post-discussions than the pre-discussions (see section on Teachers' Facilitation of Classroom Science Discussions).

<u>b. Increase in student-to-student talk:</u> Half of the teachers mentioned explicitly that students were talking more directly and listening to their peers' ideas:

"More kids are participating . . . And they are talking to each other, which is the goal. They're respectfully disagreeing."

"They are starting to understand. . . that they are responsible for what other people are thinking and saying, not just their own and not just mine . . . . So it's not just wait passively, get the answer from the teacher and move on. It's got to be I have to think about what's going on myself. I have to think about what someone else's thinking about what's going on. I have to compare my views to their views. I have to come up with evidence or something that's going to sway me one way or the other."

In the second comment, the teacher's description points to a shift in how her students were beginning to understand they are responsible for attending to, listening, and responding with evidence to other's ideas. This shift in students' awareness is important for co-constructing knowledge through discussions. Further, teachers described that students were not just sharing their ideas but were now also *responding* to other students' ideas:

"[T]hey definitely were engaged in what other people were saying. It wasn't just like an individual thing. . . .If I look at my classroom discussions last year, it would be, people would share what they had to think. But there wasn't any adding on or connecting or, you know, going further. . . I think it's more student-run. I feel like the kids have a better understanding of what a discussion sounds like and . . . how to respond to people differently. I think they listen to what the people have to say."

This comment is consistent with our analysis of their concept cartoon discussions, which indicated that students attempted more often in the post-discussions than pre-discussions to build their science understanding together with peers (expressing agreement/disagreement with peers' ideas; asking for and offering clarification of ideas; restating peers' ideas; challenging peers' ideas; and building on peers' ideas).

<u>c. More students participate:</u> Teachers reported greater student participation in the discussions. Two teachers talked about students participating who previously would not have.

"[E]arlier in the year, it would be my top students . . . . that would participate, where . . . the others . . . would say, "Oh, they know it, let's just let them speak." So now I feel like they have developed confidence to say what they know, too . . .because they've had

more opportunities to prove to each other and prove to themselves that they do have a lot they can contribute to the class."

"I think they feel really smart and . . . they just sort of sit up taller when they have their little notebook there with what their findings are. So I think . . . that goes along with the confidence. So they're really talking to each other. It's that comfort level within the classroom. They're looking at data and not so much at who the person is that's making a statement."

d. Increase in students' use of data and evidence: In the post-interviews, we asked teachers how the *Inquiry Project* curriculum had changed their students' understanding about participating in science discussions. All of the teachers reported greater student awareness of justifying their claims with evidence. One of the teachers also described that her students knew they needed to be specific in offering ideas to the discussion. Students were more likely to draw on ideas learned in the curriculum to support their claims, and had begun to use evidence and data to support their claims:

"I think the Inquiry Curriculum . . . has really helped [students] to think outside the box, and stretch out their thinking . . . given them more confidence to say what they want to say, say it respectfully without offending, and back up their thoughts with evidence. This helps them to come up with hypotheses by thinking out loud."

"They wouldn't say, well, the temperature went up. They'd now talk about why they think the temperature went up and what they would see if they were molecules . . . They really have a little more understanding than just, say, it got hotter."

Teachers' comment that students were providing more evidence for their claims, and calling upon science ideas in the curriculum is consistent with our analysis of the concept cartoon discussions. We found that students were more often referring to science principles and their investigations in the curriculum in the post-discussions than in the pre-discussions.

4. Factors Influencing Teachers' Continued Use of Whole Group Science Discussions

Most teachers were keen on having whole group discussions in other science units after completing the *Inquiry Project* curriculum and the *Talk Science* professional development program. Factors influencing teachers' continued use of discussions are as follows:

a. Role of well-designed curriculum materials: In the post-interviews, teachers acknowledged the importance of curriculum and the benefits of explicit support and prompts for guiding whole group discussions. For example, the *Inquiry Project* curriculum's support for discussions made it feasible for them to conduct more interactive discussions in their classrooms. Teachers recognized the usefulness of having guiding questions, prompts and discussion formats.

Two teachers expressed uncertainty with having discussions in other science units because the units did not explicitly support inquiry-style discussions. These teachers did not talk about modifying other units to support discussions.

b. Timing of the curriculum: Teachers described teaching science units like the *Inquiry Project* curriculum early in the school year to help students learn how to engage in science discussions. They explained that the curriculum introduces

students not only to science content but also to scientific practices and norms of discourse. Learning scientific practices and norms earlier in the school year would enable students to draw on these skills during subsequent science units:
"I think that I would do the whole entire TERC unit at the beginning of the school year because it is so organized and hands on, it really lends itself to the rest of the year and it's a way to get kids excited and engaged about science . . . There is a purpose to it, there's a certain flow, there's a certain language which is why I think it is much more valuable to start the school year like that then to wait a couple of months into the school year."
c. Management of classroom time: A key challenge for the teachers was finding adequate time for discussions. Unless time was carefully managed, the investigation activity would take the full period and not allow sufficient time for discussion. Differences in students' pace also compounded this problem, because not all students were ready for discussions when these were scheduled during lessons. Time is a challenge reported by all teachers.
d. Tension between supporting students in thinking together and ensuring deeper learning: In the pre-interviews, teachers focused on student participation; maintaining a balance between student and teacher talk; and managing the tension between student-guided discussions and staying on topic. These issues persisted in the post interviews.
Two teachers explicitly talked about supporting *substantive* and *robust* science discussions in the pre-interview. They pondered the quality of their discussions, and their struggle to deepen students' science understanding:
"I was going to say, maybe to go deeper . . .and by deeper, I mean if they all said, "oh, we think that it's definitely air has weight, because . . .we weighed the balloon, and the balloon had weight when we blew it up. So like, to go deeper than that, I wanted to be able to do that. But I didn't know where to go."
The same teacher reiterated her point in the post-interview:
"I think I need to make it go deeper, instead of just being accepting of, OK, this is, yes, you did connect to that, or, oh, yeah, OK. You know, adding on. I just feel like I want to go deeper. I want . . . them to be able to think beyond."
Another teacher described specifically what she wanted to improve in her science discussions. This teacher wanted to ensure that her students not only constructed claims and used evidence during discussions, but also that they drew on *robust* evidence. This comment was a rare instance where a teacher talked about the quality of students' contributions to the discussions:
"I definitely want to improve the actual content of the claims and evidence. You know, they were just dabbling in it. This was the first time. But I'd want to practice that a lot more -- because that was new to me."
These reflections are notable because they represent *potential next steps* for teachers in supporting productive science discourse. As students contribute more ideas during discussions, teachers need to listen carefully, understand the ideas that are emerging, and support students in thinking together. At the same time, they need to keep in mind the purpose of the discussion, where the talk is going, and how to ensure that the discussion contributes to deeper learning of the science.

Teachers' Facilitation of Classroom Science Discussions

We examined audio and video recordings of classroom science discussions in Grades 4 and 5 as teachers participated in the *Talk Science* professional development program and implemented the *Inquiry Project* curriculum. The purpose of this analysis was to study changes in the culture of science talk in classrooms as teachers conducted science discussions to support students' reasoning.

Here we present findings from the analysis of teachers' facilitation of and students' participation in classroom discussions.

Grade 4 Science Discussions 2010-2011

In the second year of our research (2010-2011), we audiotaped pre- and post-concept cartoon discussions from nine teachers in Grade 4, who were teaching the *Inquiry Project* curriculum for the first time. As part of the *Talk Science* professional development, teachers were introduced to a set of *academically productive talk moves* (APT moves). The APT moves were designed to promote students' scientific reasoning and co-construction of scientific understandings with peers. Our analysis focused on the extent to which teachers utilized APT moves to guide discussions; the extent to which students explicated their thinking by offering reasons and evidence, and responded to the ideas of their peers.

Coding Scheme and Procedure

We developed the following coding scheme to examine the extent to which teachers used academically productive talk moves (APT Moves) in their turns at talk to facilitate science discussions:

Teachers' Facilitation of Science Discussions:

1. <u>Expand Moves</u> (Say More; Revoice; Wait Time; You-Repeat; Turn and Talk; Written Reflection): This set of moves was designed to encourage individual students to elaborate on their ideas (e.g., "Okay. Can you say a little more about that?").

2. <u>Listen Moves</u> (Who Can Repeat; Who Can Explain): This set of moves focused on encouraging students to listen carefully to their peers' ideas (e.g., "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?").

3. <u>Press for Reasoning Moves</u> (Why; Challenge; What If): This set of moves was designed to prompt students to push their understanding by digging deeper into their reasoning and providing evidence for their ideas (e.g., "Why? What is it about container A or the liquid in A that makes you think there's not a lot in there?"; ""How do you know it didn't rise? Did you measure it?").

4. Think With Others Moves (Add-On; Who Agrees/Disagrees): This set of moves engaged students to think with and respond to their peers' ideas in fostering co-construction of their understanding (e.g., Anyone want to, maybe want to revise Mario's idea, maybe change it, add to it?").

The coding scheme below was used to examine students' turns at talk to identify the extent to which students explicated their thinking by presenting reasons and evidence for their claims, and made attempts to co-construct science understandings with their peers.

Students' Scientific Reasoning and Co-construction:

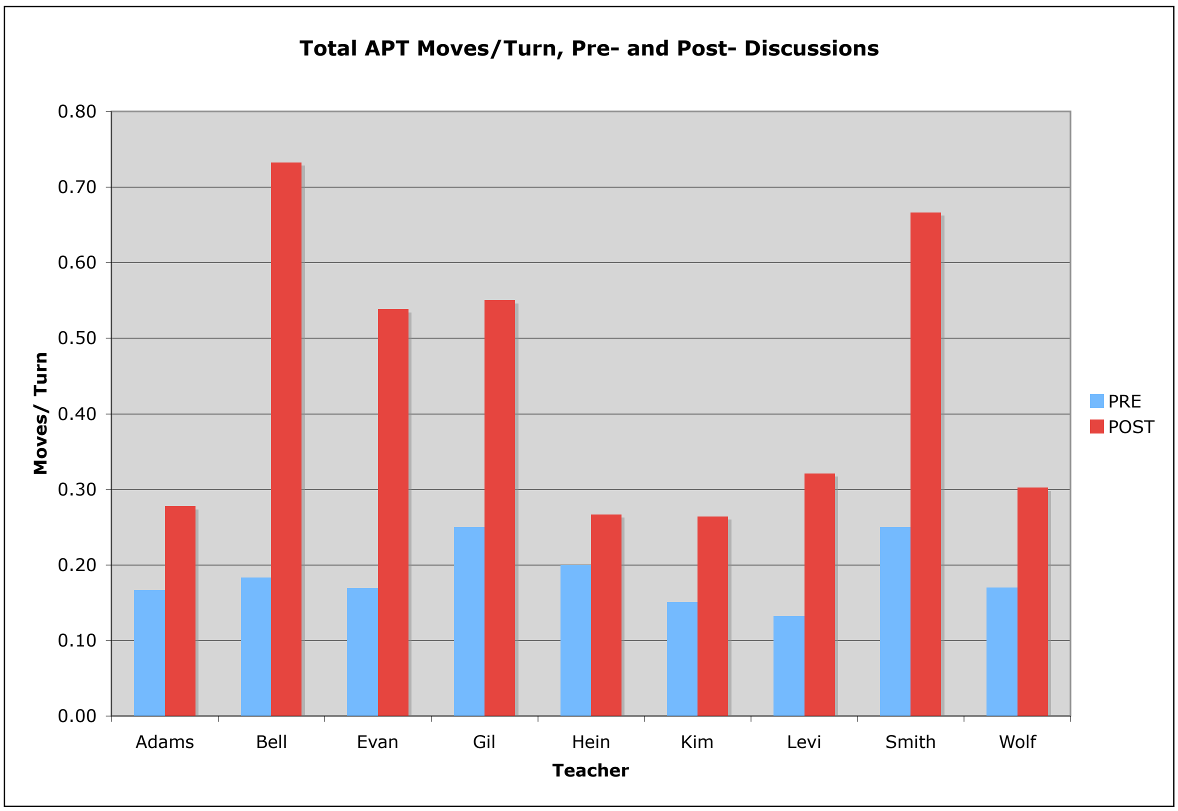
1. Claim: A statement a student makes whose truth value can be tested or can be backed up with reasoning (e.g., "I think it was the volume that made the water rise").
2. Reas-C: A complete reason which supports a claim (e.g., "Because it's uh, bigger, it's a lot more water than in that container"; "Because usually ice is made from frozen water").
3. Reas-INC: An attempt at reasoning that is incomplete or unclear (e.g., "Because um, so that you like you wouldn't waste like more time, using, using two containers and I think if you just put the um, the sandstone, … I can't explain it.").
4. Revise: Evidence of revised thinking, marked by an explicit indicator, such as "First I thought X… (e.g., "Actually, I kind of changed mine cause I thought of evidence that if—I agree with Tomas now because, like, salt is—begins as a rock but after you slice it up into little minerals, they get lighter and lighter, and if you put 'em in a wagon, they'd be much easier to haul up a hill.")
5. Agree: Explicit marker of agreement with a previous idea (e.g., "I agree with Jasmine").
6. Disagree: Explicit marker of disagreement with a previous idea (e.g., "Well I kind of disagree").
7. Clarify: Clarification of someone else's idea (e.g., "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").
8. Ask: Requesting clarification of a peer's idea (e.g., "What do you mean when you say..?").
9. Challenge: Challenge an idea, without an overt marker of disagreement (e.g., " I have a question for you Frank. What if the eraser had like buoyancy?").

10. Add-On: Student adds on to a previous idea, without an overt marker of agreeing, disagreeing, clarifying, or challenging (e.g., “Um I also wanted to add on to Louie’s..”).

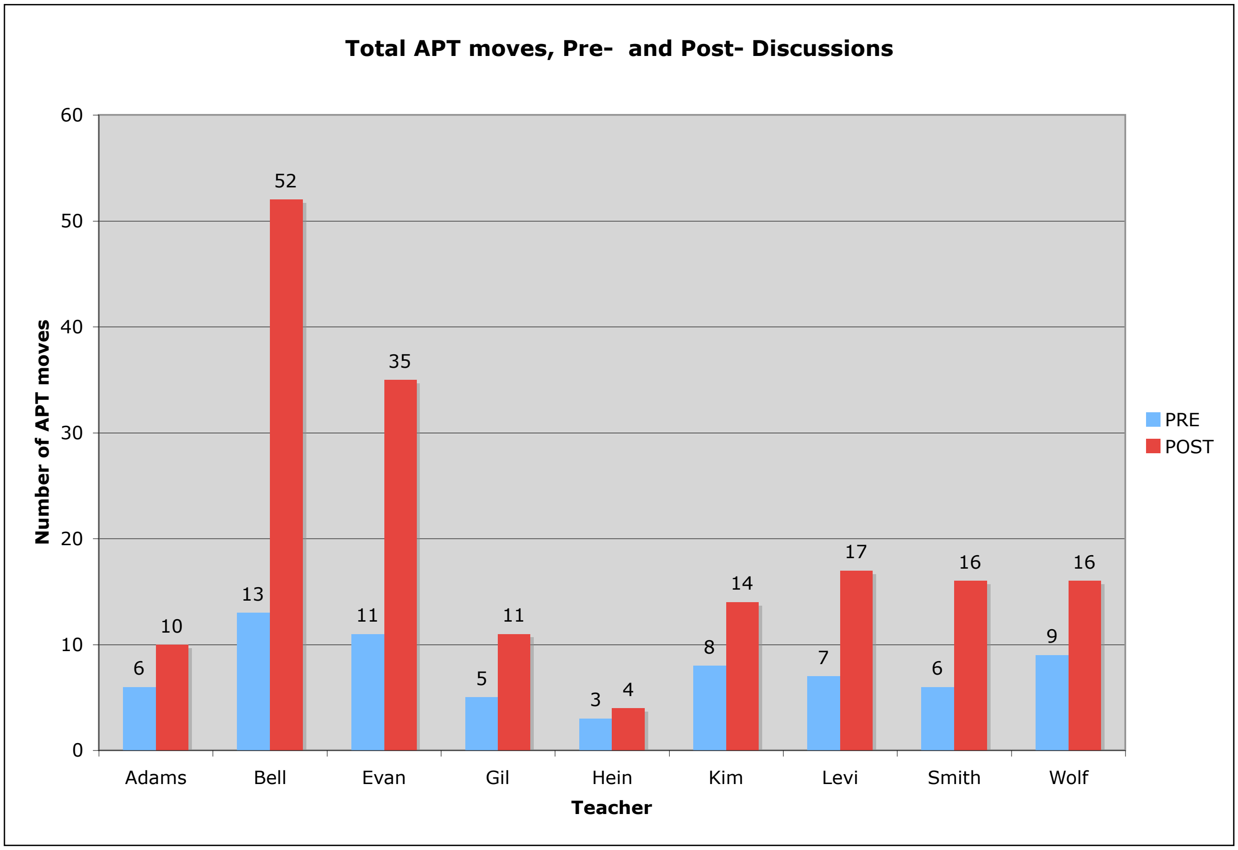
11. What If: This move presents a thought experiment, often with imagined data (e.g., “How would we get the exact size of it? What if like, say, we made a model of Tomas's.”).

Classroom Discourse Findings

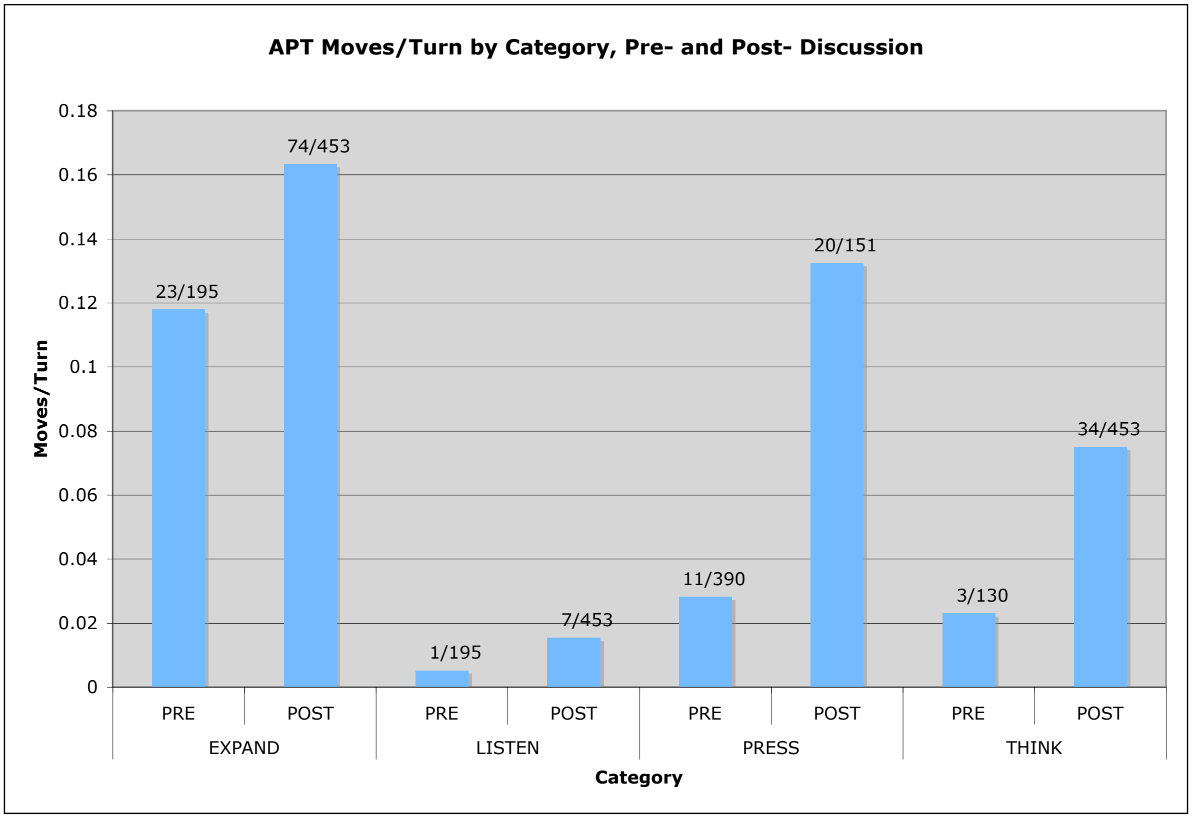
The analysis revealed that teachers incorporated various academically productive talk moves (APT moves) into their practice in facilitating classroom discussions (teacher names appearing in the report are pseudonyms). The teachers used talk moves more often in the post-concept cartoon discussions than in the pre- concept cartoon discussions.



In the post-concept cartoon discussions, the range of total moves was from four to fifty-two moves, whereas in the pre-concept cartoon discussions, the range of moves was from three to nine moves. There were also variations among teachers in the extent to which they used the moves. Some used noticeably more moves, whereas others used fewer moves.



Specifically, the teachers increased considerably their use of Expand and Press for Reasoning talk moves in the post-concept cartoon discussions to encourage students to explicate their thinking, and also used noticeably more Think With Others moves to promote co-construction of ideas among students. On the other hand, they focused less on using Listen moves to prompt students to listen carefully to their peers' ideas.



Our findings regarding students' talk indicate that students showed slight increase in their attempts at providing complete reasons for their claims, and in co-constructing ideas with their peers in the pre- and post-discussions and during the lessons from the *Inquiry Project* curriculum. However, these results need to be understood in light of the nature of the concept cartoons used for the pre- and post-discussions. The pre-concept cartoon presented students with three perspectives, and students typically participated in the discussion with the help of moves like agreeing and disagreeing, resulting in a high number of co-construction moves and complete reasons for their claims. On the other hand, the post- concept cartoon asked students to offer ideas for designing experiments to test different perspectives, but did not encourage them explicitly to co-construct ideas with their peers or provide complete reasons for the claims. This analysis prompted us to use the same concept cartoon for pre- and post-discussions during subsequent data collection in 2012.

Grade 4 Science Discussions 2011-2012

In the third year of our research (2011-2012), we collected audio recordings of concept cartoon discussions from eight Grade 4 teachers. Recordings of pre-discussions were gathered from eight teachers and recordings of post-discussions from six teachers. Of the eight teachers, four teachers – Evan, Hein, Wolf, and Smith - had participated in the *Talk Science* research in the previous year in 2010-2011 (teacher names appearing in the report are pseudonyms).

As part of the *Talk Science* professional development, teachers were introduced to a set of *academically productive talk moves* (APT moves). The APT moves were designed to promote students' scientific reasoning and co-construction of scientific understandings with peers. The purpose of this analysis was to study teachers' use of the APT moves to facilitate classroom discussions; students' engagement in the discussions; and with a subset of teachers who were now participating in the *Talk Science* program for the second time, we wanted to also compare teachers' practice over the two years of their experience with the talk moves to support discussions.

Coding Scheme and Procedure

Similar to the coding scheme and procedure followed in the analysis of Grade 4 teachers' facilitation in 2010-2011 (see section on Grade 4 Science Discussions 2010-2011), we coded and counted teachers' turns at talk to examine their use of academically productive talk moves (APT moves). The coding scheme for teachers' talk was as follows:

Teachers' Facilitation of Science Discussions:

1. <u>Expand Moves</u> (Say More; Revoice; Time to Think): This set of moves was designed to encourage individual students to elaborate on their ideas (e.g., "The bigger the size the more space it takes up and then the more volume it has. Is that what you're saying – is that what you are – and so?").

2. <u>Listen Moves</u> (Who can Restate/Repeat): This set of moves was designed to encourage individual students to elaborate on their ideas (e.g., "Can someone repeat what Avery said in their own words?").

3. <u>Dig Deeper Moves</u> (Press for Reasoning/Why; Challenge): This set of moves was designed to prompt students to push their understanding by digging deeper into their reasoning and providing evidence for their ideas (e.g., "Why do you think it's important to have the same type of container and the same size of container? Why do you think that's important?").

4. <u>Think With Others</u> (Add On; Who Can Explain; Do you Agree/Disagree): This set of moves engaged students to think with and respond to their peers' ideas in fostering co-construction of their understanding (e.g., "No way to know for sure. Okay. Okay. Anyone want to add anything to that or disagree with that or anything?").

We also coded and counted students' turns at talk to identify the extent to which they attempted to co-construct science understandings with their peers, and to make sense of the science. The co-construction attempts consisted of the following:

Students' Co-construction:

1. Agree (e.g., "I agree with Bianca and Shereen…")
2. Disagree (e.g., "No. But I disagree with what Daniel said with the salt being hot.")
3. Ask for Clarification (e.g., "What do you mean when you say?")
4. Clarify Others' Idea (e.g., "I think what Shereen is trying to say…")
5. Challenge (e.g., "I have a question for you. What if the eraser had like buoyancy?")
6. Restate Other (e.g., "She said there's more space in the air particles.")
7. Add-On (e.g., "I also wanted to add on to Louie's…")

Students' Scientific Sense-Making:
Students' attempts to make sense of the science consisted of the following:

1. Revise (students provide evidence of revised thinking, e.g., "Actually, I kind of changed my idea now…")
2. Raise a related question (e.g., "I have a question. Where does the water go when it evaporates?")
3. Propose Test (Propose solution to determine volume of the candles, e.g., "You could put them in water and see the water level rise"). In the analysis, this code is also used to identify the extent to which students *applied* ideas from the curriculum in proposing tests to evaluate the conflicting claims presented in the concept cartoon.

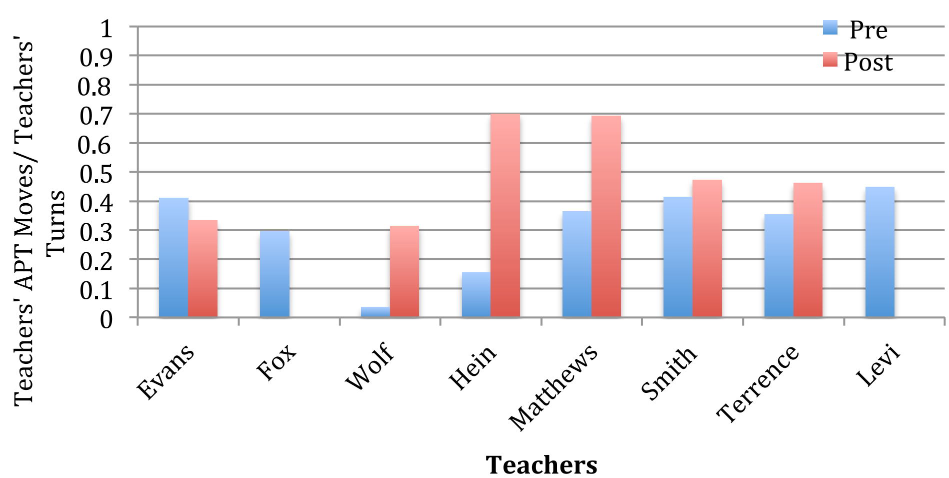
The analysis found that teachers utilized various APT moves in facilitating classroom discourse, and generally used moves more often in the post-discussions. Further, teachers attempted to develop certain aspects of their practice, which is seen in the greater use of two sets of talk moves in the post-discussions - Dig Deeper and Listen moves – whereas these moves were either non-existent or used rarely in the pre-discussions.
Moreover, with the four teachers who were participating in the *Talk Science* program for the second time, the analysis showed they had used more often Dig Deeper and Think With Others talk moves in post-discussions than pre-discussions in their first year, and continued using these moves in the pre-discussions of their second year. For facilitating post-discussions in their second year, the teachers also drew on Listen moves and increased their use of Dig Deeper moves substantially. Further, three of the four teachers increased their use of APT moves in the second

year, and they made the greatest use of talk moves in the post-discussion at the end of the second year.
With respect to students' participation, the findings revealed that students made several attempts at engaging with and contributing to the discussion. They generated ideas and proposed tests for evaluating competing claims in the concept cartoon more often in the post-discussions than in the pre-discussions. Further, in proposing tests to evaluate the claims, students drew more on the formal science ideas they learned in the curriculum than on ideas from outside the curriculum. The findings suggest that students attempted to apply their understanding of the formal science ideas from the curriculum to the concept cartoon problem.
Here we elaborate on various findings from our analysis of the Grade 4 pre- and post-concept cartoon discussions from 2011-2012. Please refer to the NSF report for more details.

Classroom Discourse Findings

Our analysis showed some kinds of talk moves were already part of the teachers' practice, as seen in their use of talk moves in guiding pre-discussions (see Figure 1). Further, five of the six teachers from whom we have pre-post data used more academically productive talk moves (APT moves) in the post- discussions than in the pre- discussions. (see Figure 1). There was also considerable variation in teachers' use of talk moves to orchestrate classroom talk in pre-and post-discussions.

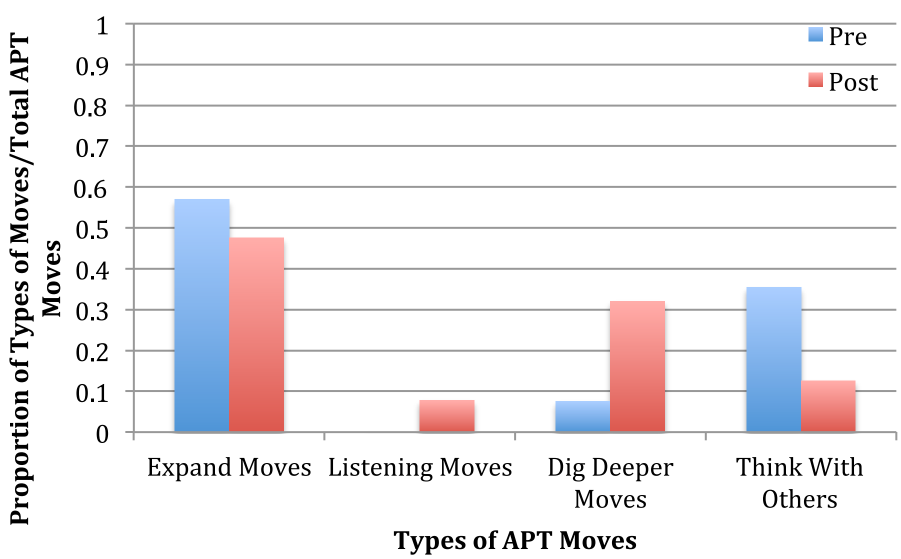
Figure 1. Teachers' Use of APT Moves



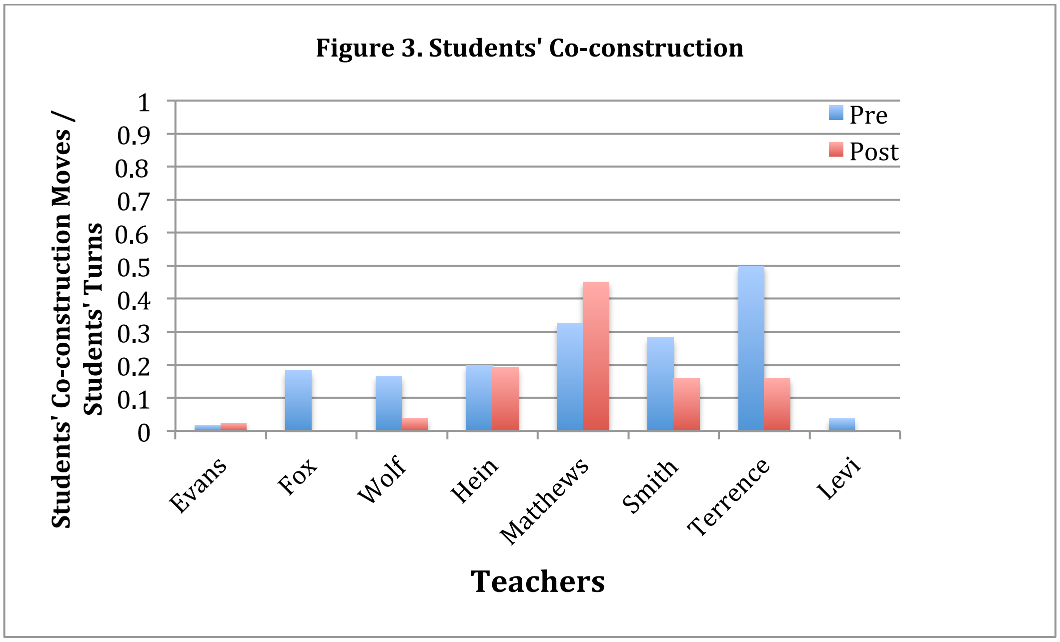
A closer examination of teachers' use of APT moves revealed that the greatest increase in the use of moves across the six teachers (pre-post data) occurred with respect to the Dig Deeper Moves (Press for Reasoning/Why; Challenge moves). For example, *"Why do you think it's important to have the same type of container and the same size of container? Why do you think that's important?"* (see Figure 2; the data are calculated as proportion of different types of APT moves used from the total number of APT moves used by the teachers). Figure 2 shows that approximately 8%

of the total APT moves used involved Dig Deeper moves in the pre discussions, whereas approximately 32% of the total APT moves used in the post-discussions were Dig Deeper moves.
Further, in the pre-discussions, the teachers did not use any listening moves, whereas the listening moves accounted for 7.77% of all APT moves used in the post-discussions. For example, *"Can someone repeat what Avery said in their own words? [9 second pause] Grace, give it a try."*
On the contrary, there was a remarkable decrease in teachers' use of Think With Others moves, which accounted for 12.62% of APT moves used in the post-discussions, as opposed to 35.44% of the APT moves used in the pre-discussions.
 (Add On; Who can Explain; Do you Agree/Disagree). For example, *"No way to know for sure. Okay. Okay. Anyone want to add anything to that or disagree with that or anything?")*

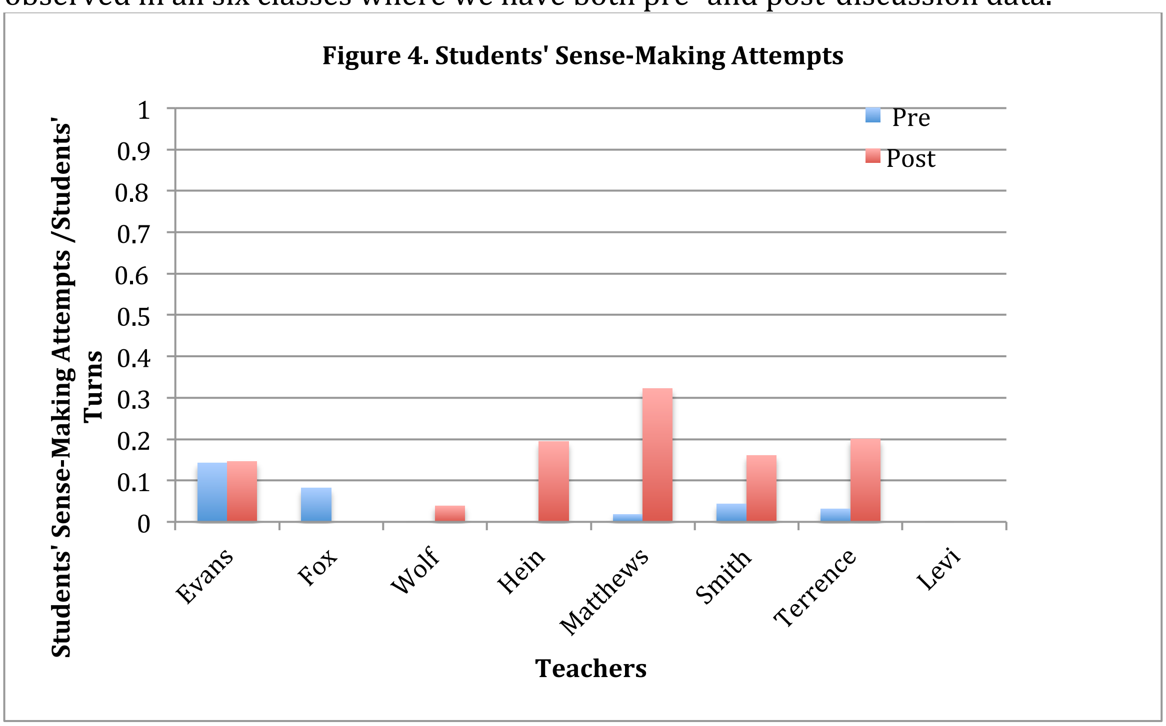
Figure 2. Teachers' Use of Different APT Moves



Our analysis of students' talk indicated that they made attempts at co-constructing ideas with their peers in the pre-discussions (see Figure 3). Of the six teachers' classes, students in two classes made more co-construction attempts in the post-discussions.



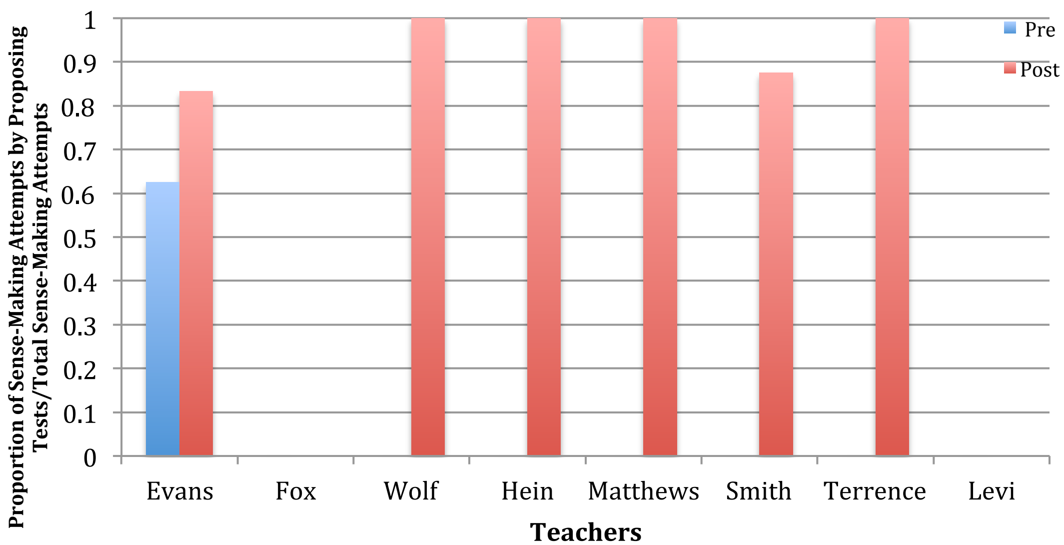
Further, students made more sense-making attempts in their turns at talk in the post-discussions than in the pre-discussions (see Figure 4). This pattern was observed in all six classes where we have both pre- and post-discussion data.



Upon a closer examination of students' sense-making attempts in the post-discussions, we found that sense-making involved mainly proposing ideas for testing the competing claims presented in the concept cartoon. There were few instances of students generating new questions related to the science content, and revising their thinking in light of the discussion and their experiences. Figure 5 shows the proportion of students' sense-making attempts involving proposing tests to determine the volume of the candles.

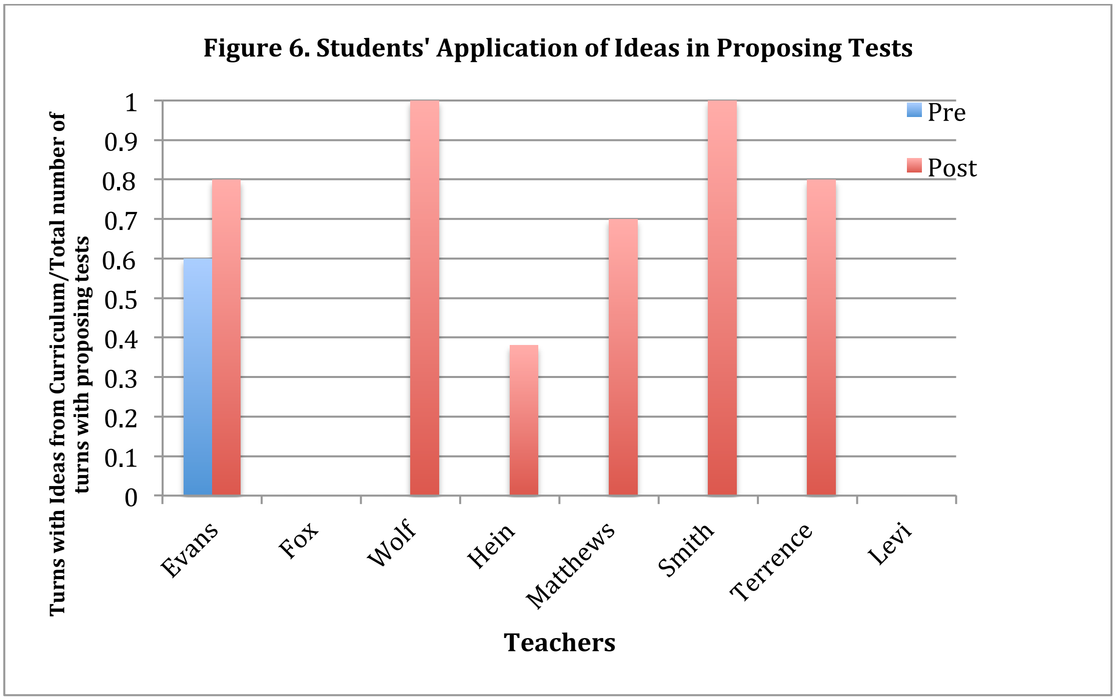
The elicitation of students' ideas for testing the claims was part of the recommended question for this concept cartoon. More of students' talk in the post-discussion than the pre-discussion involved proposing ideas to evaluate the competing claims. Whereas this is a positive finding that students generated ideas for testing claims more often in the post than in the pre discussions, an additional analysis of the extent to which the teachers prompted students to propose ideas for evaluating claims in the pre- and post-discussions may shed light on this finding. It is possible that teachers encouraged students to propose tests more often in the post-discussions than pre discussions. A preliminary examination suggests that in the pre-discussions, two of the teachers prompted students explicitly to discuss ways to test the concept cartoon ideas. In the post-discussions, on the other hand, all six teachers encouraged students explicitly to propose experiments to test the ideas. A further study of the discussions is needed to clarify the trend observed in students' use of scientific moves.

Figure 5. Students' Talk Involving Proposing Tests



With respect to students' turns involving proposing tests to determine the volume of candles, we examined also the extent to which the turns contained ideas based on the curriculum (see Figure 6). Figure 6 shows the proportion of turns involving ideas from the curriculum out of the total turns that presented tests to determine the volume of the candles. Specifically, the analysis identified the extent to which students applied ideas from the curriculum, such as water displacement, measuring the volume of liquids (liquid wax), using centimeter cubes for estimation, and measuring the weight in proposing tests to assess the competing claims presented in the concept cartoon. Ideas from outside the curriculum included using a mathematical formula to calculate volume of candles; reshaping the candles to make them comparable; determining the time taken to melt/burn the candle, etc.
Figure 6 indicates that in five of the six teachers' classes, more than half of students' proposed tests in the post-discussions contained ideas based on the curriculum than from outside the curriculum. This finding indicates that students tried to apply their

understanding of the science from the curriculum while discussing the concept cartoon.

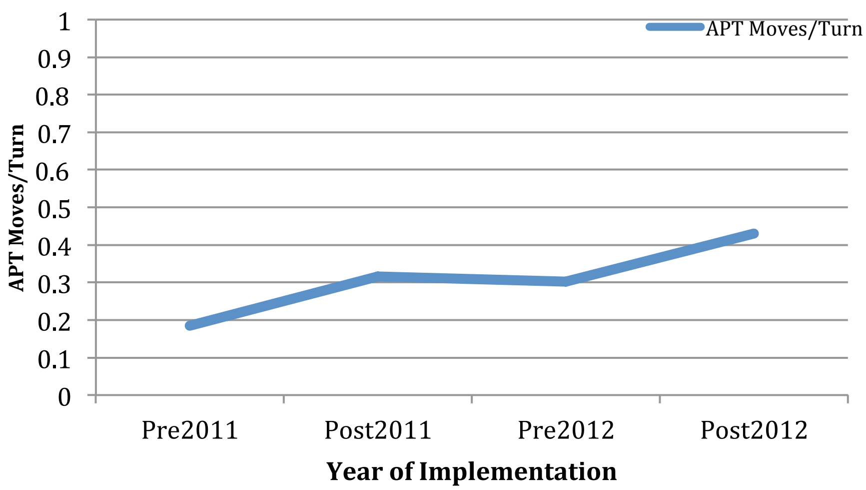


Looking across all the findings, the decrease in teachers' use of the Think With Others moves and the general decrease in students' co-construction moves are patterns that need to be examined further. The Think With Others moves were designed to facilitate students' engagement with their peers' ideas. One would expect that in the case of a judicious, strategic use of talk moves by a teacher, there would be less explicit prompting and support provided to the students to engage in particular discourse practices as the students begin to appropriate and display increasing fluency in the practices. The present analysis shows, however, that whereas teachers made less use of Think With Others moves, the students did not increase their attempts at co-construction. This finding points to the need to examine further the relationship between teachers' use of talk moves and students' participation in the discourse.

Comparative Analysis of Findings from 2010-2011 & 2011-2012

It should be noted that the concept cartoons used for pre- and post-discussions in 2011-2012 were different from those used in 2010-2011. Furthermore, the coding rubric for students' talk underwent some changes between the two years. These differences notwithstanding, certain comparisons were drawn for four teachers - *Evans, Smith, Hein, and Wolf* - who participated two times in the *Talk Science* program, and have pre and post discussion data for both years. The comparative analysis between 2010-2011 and 2011-2012 revealed the following patterns: During both years, teachers used more talk moves in the post-discussions than the pre-discussions (see Figure 7). The APT moves accounted for 18.47% of teachers' turns in pre-discussions in 2011; 31.56% in post-discussions in 2011; 30.16% in pre-discussions in 2012; and 42.93% in post-discussions in 2012.

Figure 7. Comparison of Teachers' Use of APT Moves in 2011 & 2012



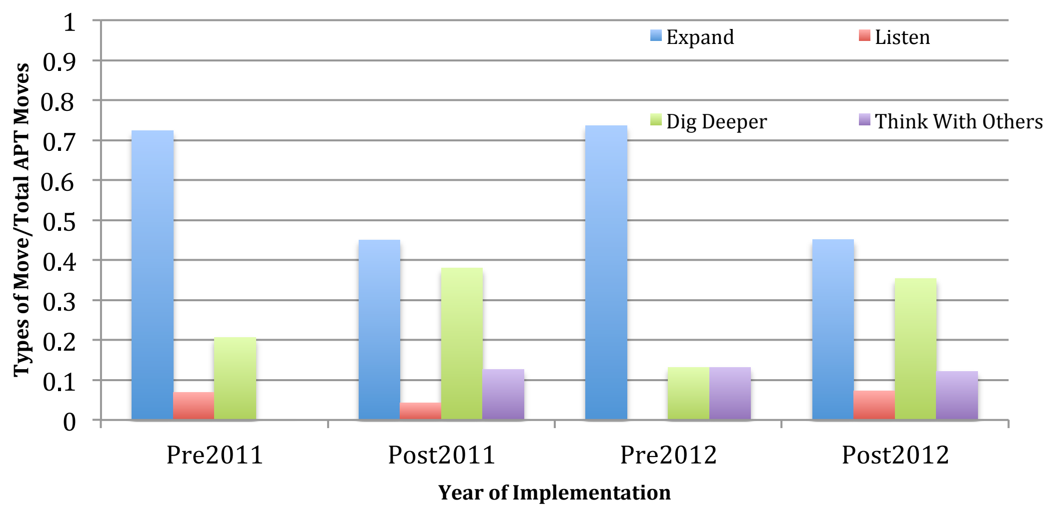
We analyzed further the four teachers' use of the various APT Moves (4 categories of moves: Expand; Listen; Dig Deeper; Think with Others). See Figure 8. Figure 8 shows that when considering the *total number of APT moves* used by the four teachers, in 2011, the teachers (when examined together) predominantly used the Expand moves in the pre-discussions (72.41% of all the APT moves in pre2011). There was less use of Dig Deeper moves, an even lesser use of the Listen moves (6.9%), and no use of the Think with Others moves in the pre-discussions in 2011. In post 2011 discussions, whereas the teachers continued to show a fair amount of use of the Expand moves (45.07%), they showed a marked increase in their use of the Dig Deeper moves (about 38%). They also incorporated the Think with Others moves in the post-discussions in 2011 (12.68%). These are positive findings indicating that teachers were able to draw on these two sets of moves through participation in the *Talk Science* program. But they continued to make less use of the Listen moves in the post-discussions in 2011 (4.23%).
In 2012, similar to their facilitation in the previous year, the four teachers (when examined together) continued to use the Expand moves in the pre- and post-discussions to a large extent (73.68% in pre2012; 45.12% in post 2012). Similar to 2011, the four teachers started their facilitation in 2012 with less use of the Dig Deeper moves (13.16% of their APT moves in pre 2012), but showed marked increase in the use of this type of moves in the post-discussions (35.37%).
With respect to the use of Think with Others moves, we found that in 2012, teachers started by making some use of this set of moves they had learnt through the *Talk Science* program from the previous year (13.16% of the APT moves in pre 2012 discussions). This is an encouraging finding because in pre 2011 discussions, teachers had not made any use of these moves. Their initial use of these moves in

2012 was almost as much as where they had ended in 2011 (13.16% in pre 2012; 12.68% in post 2011), suggesting that teachers had retained this set of moves in their practice. However, there was not much increase in the use of these moves in post 2012.

Finally, with respect to the use of Listen moves, we found that similar to their facilitation in 2011, the four teachers (when examined together) continued to make less use of the Listen moves in 2012. They did not use any Listen moves in pre 2012 discussions, but made some use of this move in the post 2012 discussions (7.32% of the APT moves).

Overall, the comparative analysis indicated that teachers were able to incorporate various talk moves into their practice, particularly the Dig Deeper moves, for guiding science discussions. Furthermore, although they made some use of the Think with Others and Listen moves, in general, teachers tended to focus less on these two sets of talk moves.

Figure 8. Comparison of Types of Moves in 2011 and 2012



Grade 5 Science Discussions 2011-2012

We analyzed pre- and post-concept cartoon discussions conducted by eleven Grade 5 teachers in 2011-2012 (teacher names appearing in the report are pseudonyms). It should be noted that Ms. Linden and Ms. Cowell co-taught the science class and the data from their classroom are represented as a single data point "Linden-Cowell" in this analysis. The sample size for the analysis consisted 14 pre- and post-discussions because three of the teachers taught multiple classes.
As part of the *Talk Science* professional development, we introduced teachers to a set of *academically productive talk moves* (APT moves). The APT moves were talk strategies designed to promote students' scientific reasoning, and their co-construction of science understandings with peers. The purpose of this analysis was to identify changes in the culture of science talk in classrooms as teachers used APT moves to foster students' scientific reasoning.

Coding Scheme and Procedure

We coded and counted teachers' turns at talk to study their use of academically productive talk moves (APT moves) in facilitating science discussions. The coding scheme for teachers' talk was similar to the one used in analyzing Grade 4 discussions, and was as follows:
Teachers' Facilitation of Science Discussions:

1. Expand Moves (*Say More, Revoice, Time to Think*) (e.g., "Okay. Can you say a little more about that?").
2. Listen Moves (*Who can Restate/Repeat*) (e.g., "Can someone repeat what Avery said in their own words?").
3. Dig Deeper Moves (*Press for Reasoning/Why, Challenge*) (e.g., "What is your evidence?").
4. Think With Others (*Add On, Who Can Explain, Do you Agree/Disagree*) (e.g., "Oh! Hmm..What do we think? Anyone want to, maybe want to revise Mario's idea, maybe change it, add to it?").

The analysis examined also various aspects of students' participation in the discussions: students' attempts to reason with and without core science ideas; their attempts to make sense of the science through various discourse moves; and their attempts to co-construct knowledge with peers. We coded and counted students' turns at talk for the following:

Students' Co-construction:

1. Agree (e.g., "I kind of agree with Daniel, because when you're going to kick a soccer ball of course if it's deflated you can't really kick it that far.").
2. Disagree (e.g., "No. But I disagree with what Daniel said with the salt being hot.").
3. Ask for Clarification (e.g., "What do you mean when you say..?").
4. Clarify Other (e.g., "I think what Shareen is trying to say, the water might dissolve into the salt and the salt might get dissolved, so the water level might go down a little bit.").
5. Challenge (e.g., "But aren't you pumping hot air into the ball? Because if you blow up, like a balloon, sometimes you pump in hot air and after that it starts making it rise kind of, and after that.").
6. Add-On (e.g., "Um I also wanted to add on to Louie's.").
7. Restate Other (e.g., "She said there's more space in the air particles. I mean when the particles are pushed like – yeah, pushed.").

Students' Reasoning:

Sense-Making Attempts: This category captured students' efforts at making sense of the science.

1. Revise their own thinking (e.g., "Yeah, I agree that it's Lela. Because after the-- well, at first I thought it was Fern because I didn't know that air had weight. Then after my education, I learned that Lela is probably correct.").
2. Raise a related question (e.g., ""I have a question. Where does the water go when it evaporates?").
3. Propose test/thought experiment (e.g., "When Christiani said that if you put a cup and air in, but we're not talking about a cup, we're talking about a ball. So, if you have a scale and we fill it up with air, and it would not stay on zero. It would go-- it would, um, go out between two, three—").

Reasoning With Core Science Ideas: This category captured instances of students' reasoning about the concept cartoon by drawing on core science ideas (classroom science investigations and scientific principles from the curriculum).

1. Reference to Classroom Science Investigations – Students referred to quantitative data and/or observations from previous and/or present science curriculum units (e.g., "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. Reference to Scientific Principles (Principles such as air is matter; matter has weight and takes up space; the particulate nature of matter, etc.) - Students referred to scientific principles, ideas from the particle model (e.g., "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 Without Core Science Ideas : This category captured instances where students drew on ideas outside of formal scientific understandings.

1. Reference to Outside Experience – Students described experiences from everyday life (e.g., "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. Presenting Assertions/Opinions – These were instances where students presented assertions that were either opinions or facts that may have been accurate or inaccurate with respect to canonical science (e.g., "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. Analogy – This code captured instances where students drew similarity to other hypothetical situations (e.g., " 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. Logical Train – This code captured "if…then" statements expressing axiomatic reasoning and counterfactual thinking (e.g., "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.").

The analysis examined also the accuracy of students' ideas as they contributed to the discussions. One set of pre- and post-discussions each from two teachers was studied to understand the extent to which students offered correct ideas to the discussions.

Our findings suggest that after being introduced to various academically productive talk moves through the *Talk Science* program, the Grade 5 teachers incorporated the moves into their practice. In particular, they utilized talk moves to enable students to share and elaborate their thinking, and to deepen their reasoning with the help of data and models.

Students, on their part, engaged in the discussions actively by trying to make sense of the science and co-construct science understandings with peers. Further, in the post-discussions, students attempted to apply their understandings of core science ideas from the curriculum, as they drew on scientific principles and classroom investigations to reason about the concept cartoon.

A careful examination revealed that despite using more talk moves overall in guiding discussions, the teachers made less use of talk moves designed specifically to promote students' active listening and responding to peers' ideas. Further, although students made greater attempts at co-construction in the post-discussions, the attempts accounted for less than 20% of their turns at talk. These findings suggest that students may need support for listening and responding to their peers' ideas. Therefore, teachers may need to guide students explicitly by using talk strategies to foster active engagement with peers' ideas.

Here we amplify these findings with details regarding various aspects of teachers' facilitation and students' participation during pre- and post-concept cartoon discussions.

Classroom Discourse Findings

In combining data across all classes, we found that teachers utilized more academically productive talk moves (APT moves) in post-discussions than pre-discussions (calculated as total talk moves used across all teachers/total teacher turns across all teachers). See Figure 1. In the pre-discussions, 19.55% of the teachers' turns involved the use of productive talk moves, whereas this figure rose to 26.03% in the post-discussions. This finding suggests that in facilitating students' discussions, overall, the teachers incorporated into their practice the talk strategies introduced through the *Talk Science* PD program.

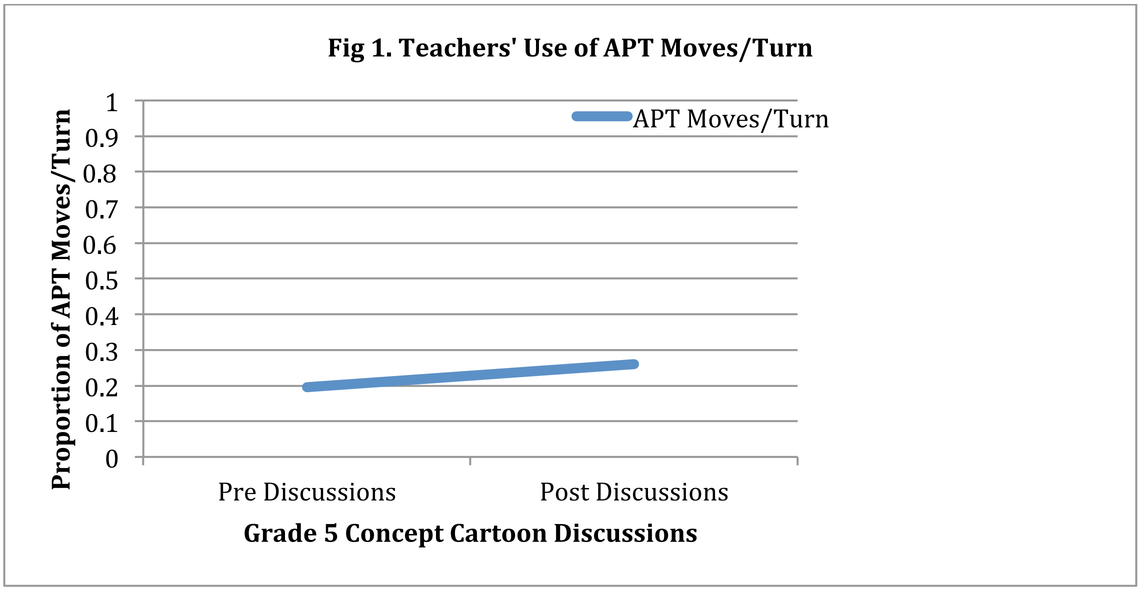
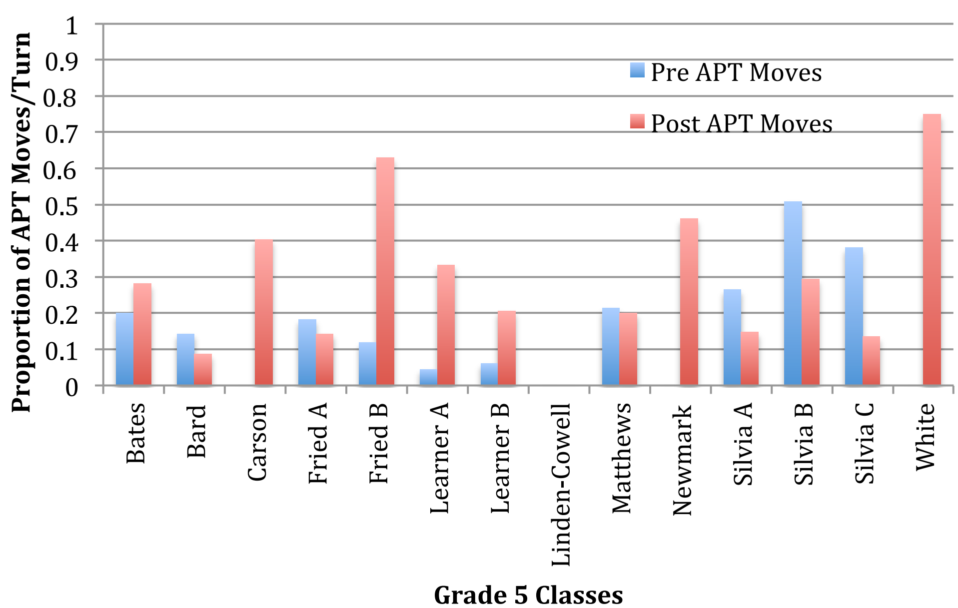


Fig 1. Teachers' Use of APT Moves/Turn
APT Moves/Turn
Proportion of APT Moves/Turn
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
Pre Discussions
Post Discussions
Grade 5 Concept Cartoon Discussions

Teachers varied in the extent to which they utilized the talk moves in facilitating discussions (see Figure 2; the data are calculated with the total number of turns taken by each teacher as the denominator for the proportion of talk moves used by that teacher). For example, six of the ten teachers used some types of talk moves in the pre-discussions before participating in the *Talk Science* program. Furthermore, of the four teachers who did not use any talk moves in the pre-discussions, three teachers used talk moves to a considerable extent in the post-discussions, whereas one of them did not use any even in the post-discussion.

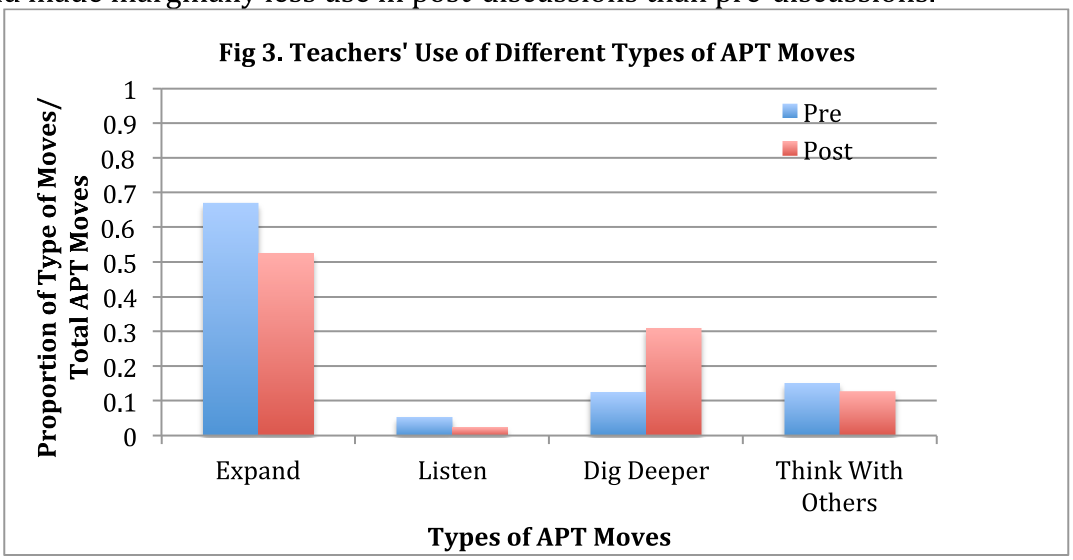
Additionally, teachers varied in their facilitation of post-discussions. They did not always increase their use of APT moves in post-discussions as compared to pre-discussions. In half of the classes, teachers used more talk moves in the post-discussions than pre-discussions.

Fig 2. Variation in Teachers' Use of APT Moves

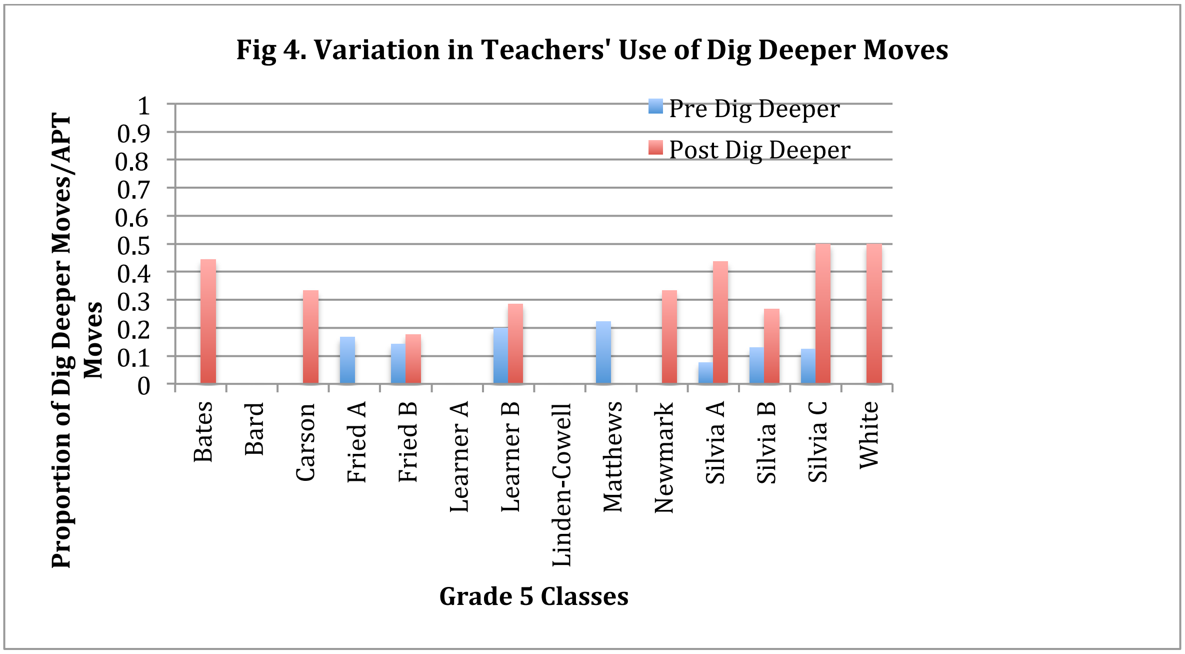


With respect to the talk moves that were already part of teachers' practice in the pre-discussions (see Figure 3; the data are calculated by taking the total APT moves used across all teachers as the denominator), teachers mainly used the Expand talk moves (Say More, Revoice, Time to Think) that enable students to share and clarify their ideas (66.96%; e.g., "When you use the word "volume" is there something that we could all agree on that volume is - - could you say what you think volume - - like how would you describe volume? What is that?"). This was followed by talk moves belonging to the Think With Others category to help students respond to their peers' thinking (15.18%; e.g., "Okay so the air inside of this inflated soccer ball makes it weigh more why does it make it weigh more? Does anyone want to follow that idea? So he's saying that he think that the air inside of the inflated soccer ball makes it weigh more, yes."), and closely by Dig Deeper talk moves like challenging students and asking them for evidence and reasoning (12.5%; e.g., "So the inflated one if heavier? Okay and is there a reason why?"). Finally, teachers made least use of Listening talk moves that emphasized active listening among students (5.36%; "Okay and can you say that in your own words. Well who was saying that and can you say it in your own words?").

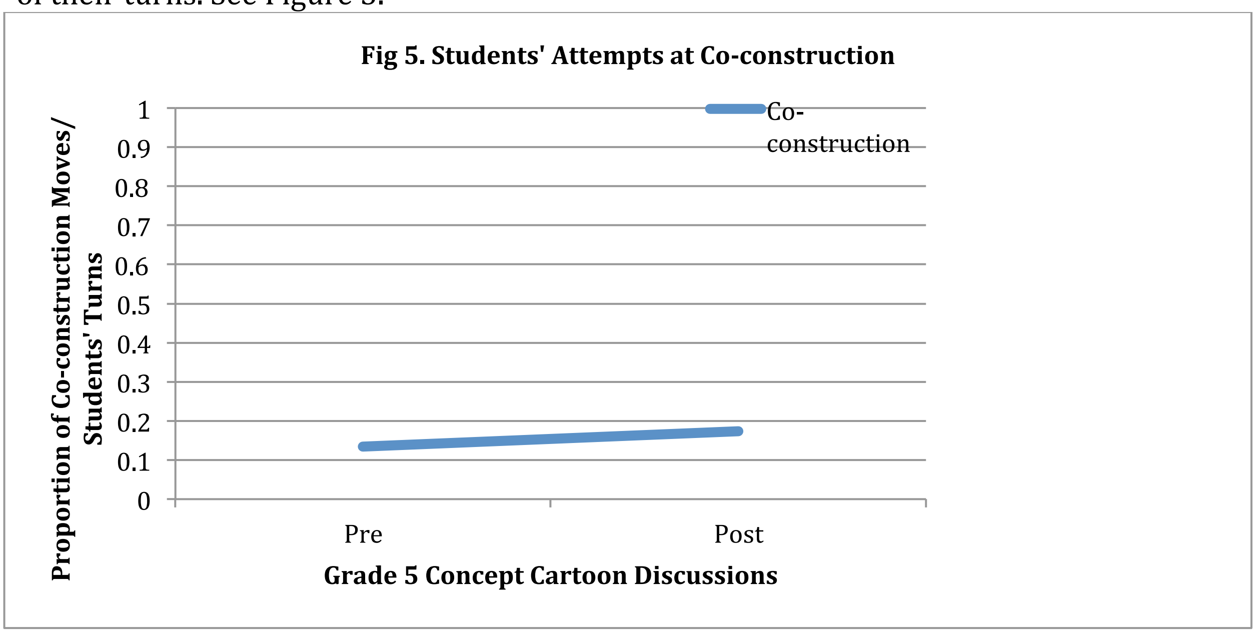
A similar trend characterized the post-discussions. The Expand talk moves again dominated teachers' practice (52.38%). Teachers increased their use of the Dig Deeper moves remarkably in the post-discussions (30.95%), suggesting that teachers began to draw increasingly on this set of talk strategies for their classroom facilitation. Further, teachers continued to use Think With Others moves (12.7%) and Listen moves (2.38%) in the post-discussions, although with both categories of talk strategies, the teachers did not increase their use in the post discussions but instead made marginally less use in post-discussions than pre-discussions.



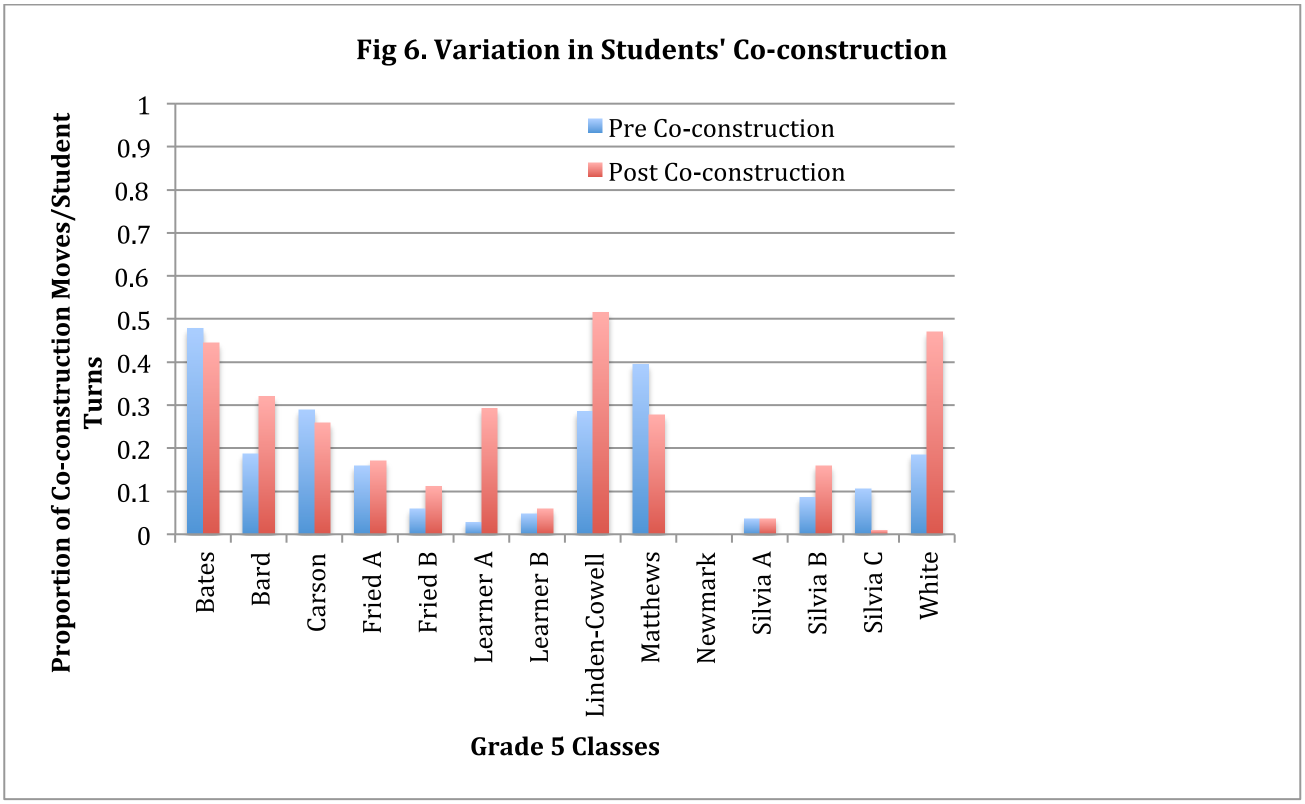
Whereas overall the teachers increased their use of the Dig Deeper talk moves, there were differences among teachers in the extent to which they used this category of talk moves in the post-discussions (see Figure 4; proportion of dig deeper moves used by each teacher is calculated by considering the total number of talk moves used by that teacher).



With respect to students' talk, combining data from all classes, we found that students increased their attempts at co-constructing ideas with peers in the post-discussions (17.34%). In the pre-discussions, co-construction accounted for 13.42% of their turns. See Figure 5.

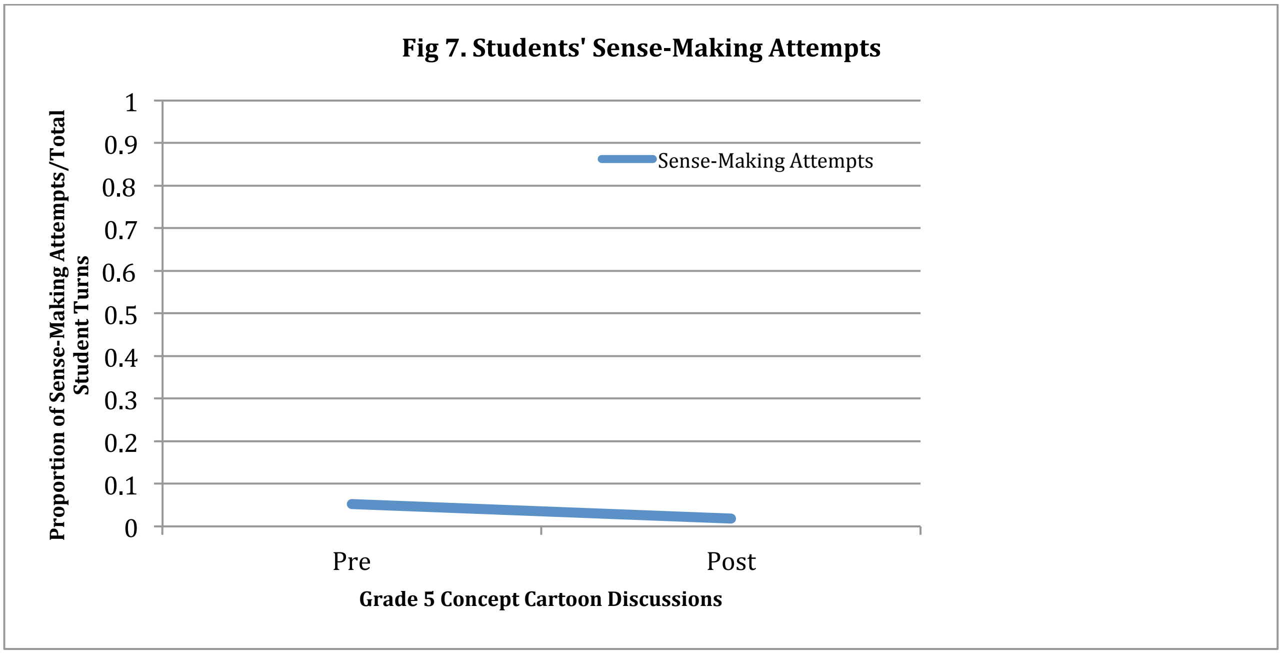


Although there was an increase overall in students' co-construction, it was a small difference and could be understood better by looking at the data separately for each of the classes. Specifically, a closer examination revealed that students in eight of the fourteen classes made greater attempts at co-construction in the post-discussions than pre-discussions (see Figure 6).



Our analysis also identified students' attempts at making sense of the science, which consisted of revising one's thinking; raising related questions pertaining to the science during the discussion; and proposing experiments or generating thought experiments to test ideas in the concept cartoon (see Figure 7; data combined from all 14 classes). In the pre-discussions, 5.21% of students' talk involved sense-making attempts (e.g., (propose experiment) "Well I think there is a way you can tell if air weighs anything, like just take a jar with the cap off and just leave it somewhere and weigh it, like a very accurate scale, so it weighs something, and then put it in like an anti-gravity chamber where there's no air and weigh it again and see if there's a difference"; (raise related question) "Well I just have a question, like because when you're pumping up a ball or like the bicycle tire or whatever it says how many pressure of air, so I'm wondering if that would make a difference on the weights?").

In the post-discussions, students made fewer sense-making attempts in their turns at talk, accounting for 1.84% of their talk. This decrease in students' sense-making attempts may be understood further in light of changes in students' use of the three types of sense-making attempts, and changes in their reasoning with and without the science ideas from the curriculum.

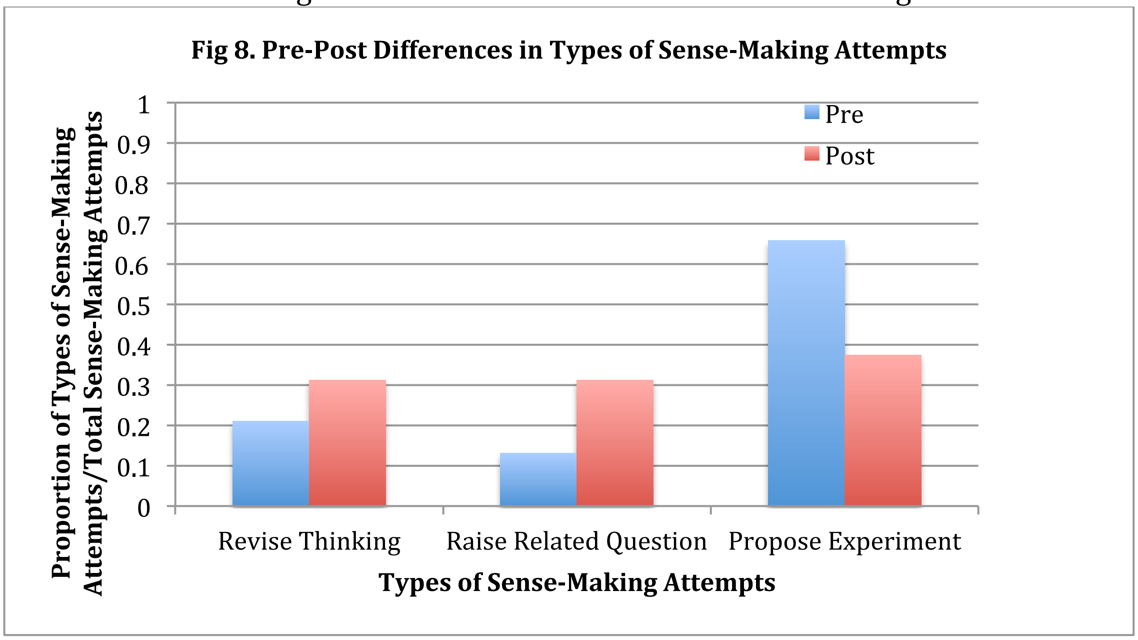


A closer examination of students' sense-making attempts focused on the extent to which they made three types of attempts in pre- and post- discussions (See Figure 8; these data are taken from all 14 classes, and are calculated as the proportion of particular types of sense-making attempts from the total number of sense-making attempts made by students). The findings showed that in the pre-discussions, students mainly proposed ways to test the ideas in the concept cartoon (65.79%), followed by attempts to revise their own thinking (21.05%), and raising new questions related to the science in the discussions (13.16%).

In the post-discussions, the principal difference occurred in the extent to which students proposed experiments and tests for the competing claims in the concept cartoon. These attempts accounted for 37.5% of the total sense-making attempts made by students, thereby revealing a substantial decrease in this type of attempt compared to the pre-discussions. On the other hand, the other two types of attempts (revising their thinking, and raising related questions) each accounted for 31.25% of the total sense-making attempts in the post-discussions. See Figure 8.

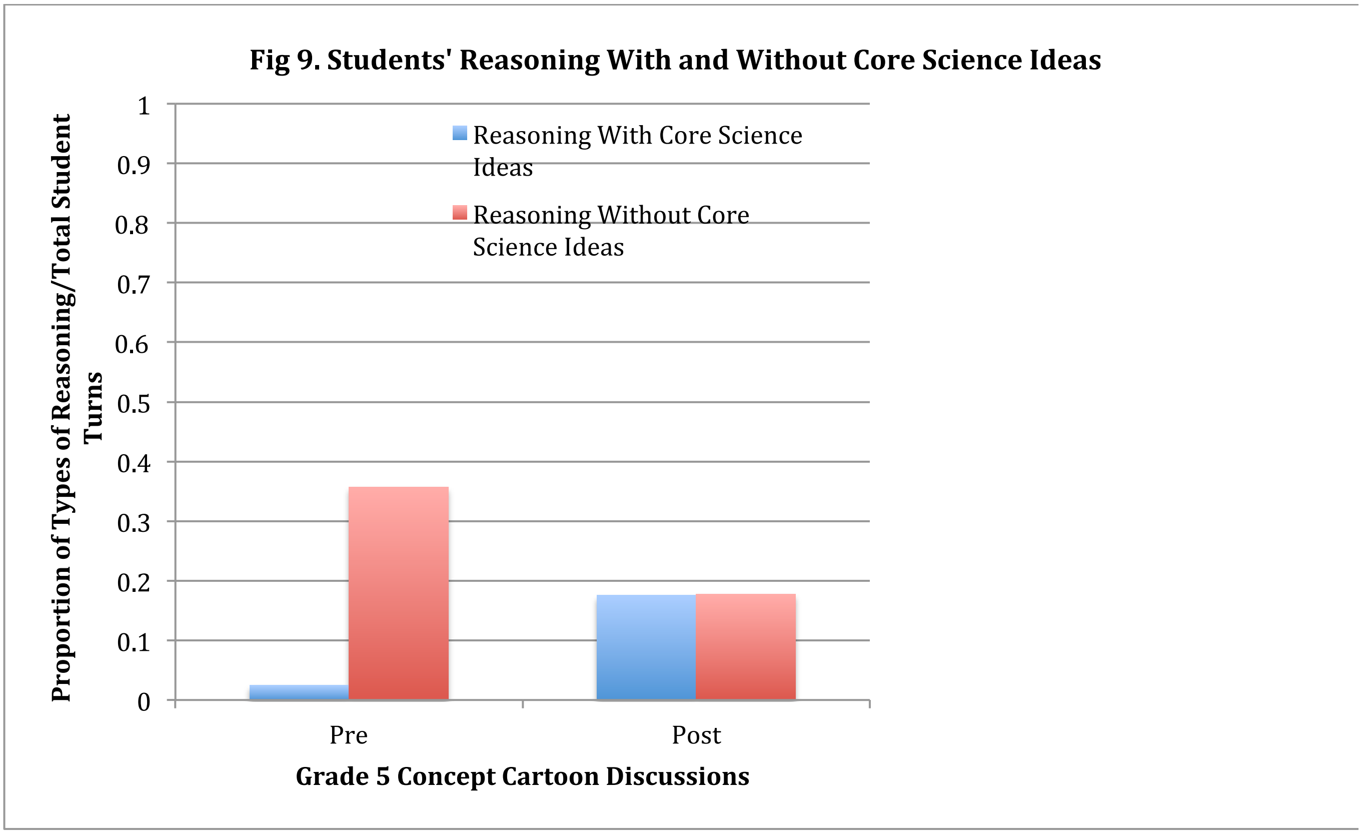
A possible explanation for the decrease in students' attempts at proposing tests and thought experiments is as follows: In the pre-discussions when students do not always have a solid understanding of the science concepts and principles that are introduced subsequently through the curriculum, students may generate ideas frequently for testing the concept cartoon claims as a way to make meaning of the science and resolve conflicting claims. On the other hand, when students participate in post-discussions after having several investigations and conversations about core science ideas, they may be able to draw on their understandings of the core ideas from the curriculum to resolve the conflicting claims.

The explanation proposed needs to be examined further because the analysis did not identify the extent to which teachers prompted students to propose tests and thought experiments in the pre- and post-discussions. The prevalence of tests and thought experiments proposed in the pre-discussions may be a function of greater probing by the teachers to do so prior to introducing the curriculum. The teachers may have made fewer explicit attempts in the post-discussions to probe students' ideas for testing the claims, particularly if there was greater convergence in students' thinking by the end of the curriculum, or if students were drawing often on the science learned through the curriculum to formulate their thinking.



With respect to reasoning with and without core science ideas (see Figure 9; data combined from all 14 classes; proportions are calculated based on total student turns), in the pre-discussions, students' reasoning on the basis of core science ideas (scientific principles and prior classroom investigations) accounted for 2.47% of their talk (e.g., "Like it would weigh about the same but like exactly the ball, the inflated ball, would weigh more probably because air does have weight but just very little and so it's, kind of, true"; " Well I agree with Aaron because a couple of years ago I learned that the only reason you weigh something is because that's the amount of air from pressure pushing down on you, but you don't feel it because you're used to it, so the only reason something will weigh something is because the air is pushing down on it and that's going to weigh something. So the air does weigh a little.").

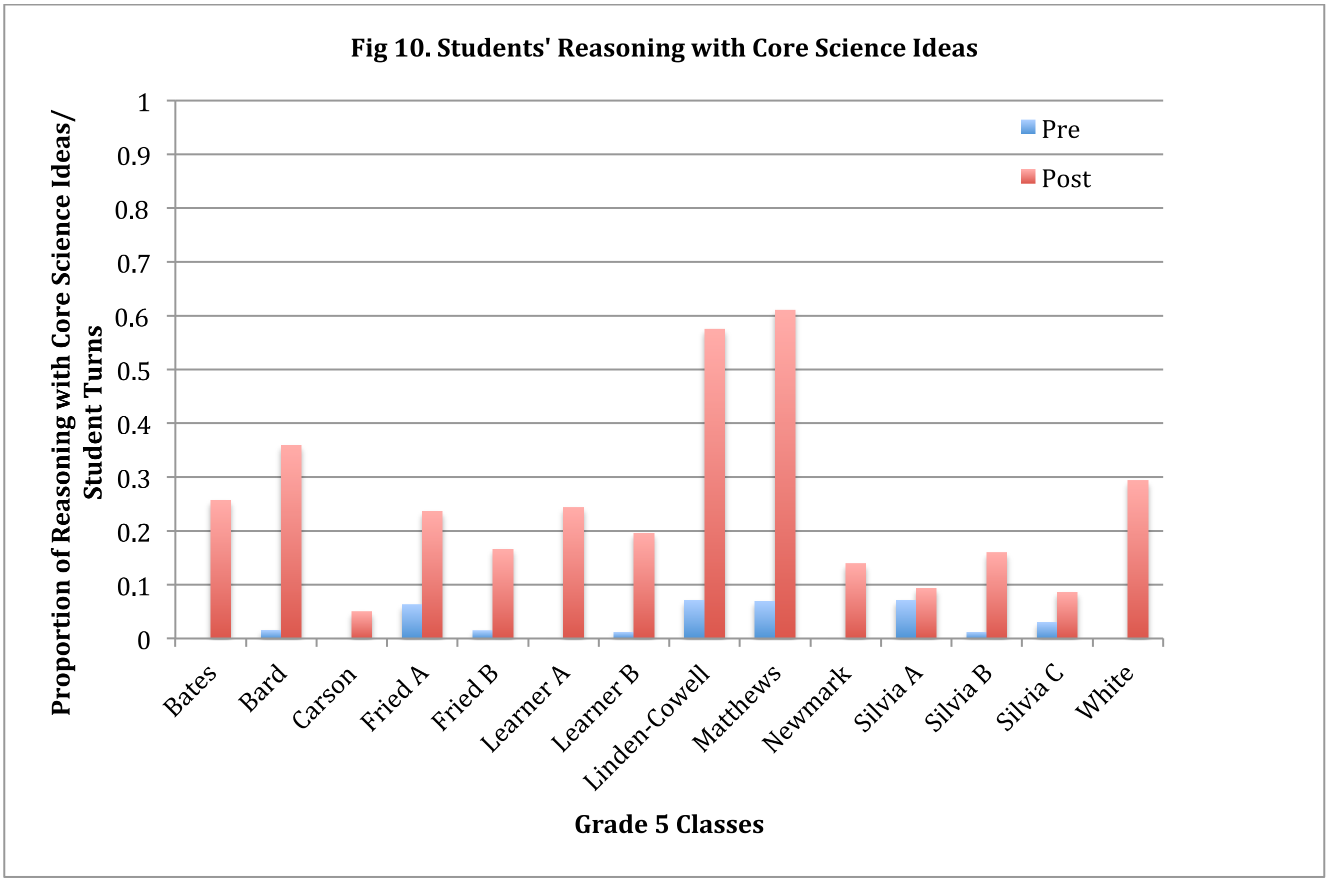
On the other hand, students' reasoning without core science ideas (everyday experiences, asserting facts/opinions, analogies, etc.) accounted for 35.75% of their talk in the pre-discussions. This trend in during pre-discussions was not surprising because prior to the curriculum, with little first-hand experience with the core science ideas, students are likely to reason more on the basis of their everyday experiences and ideas.



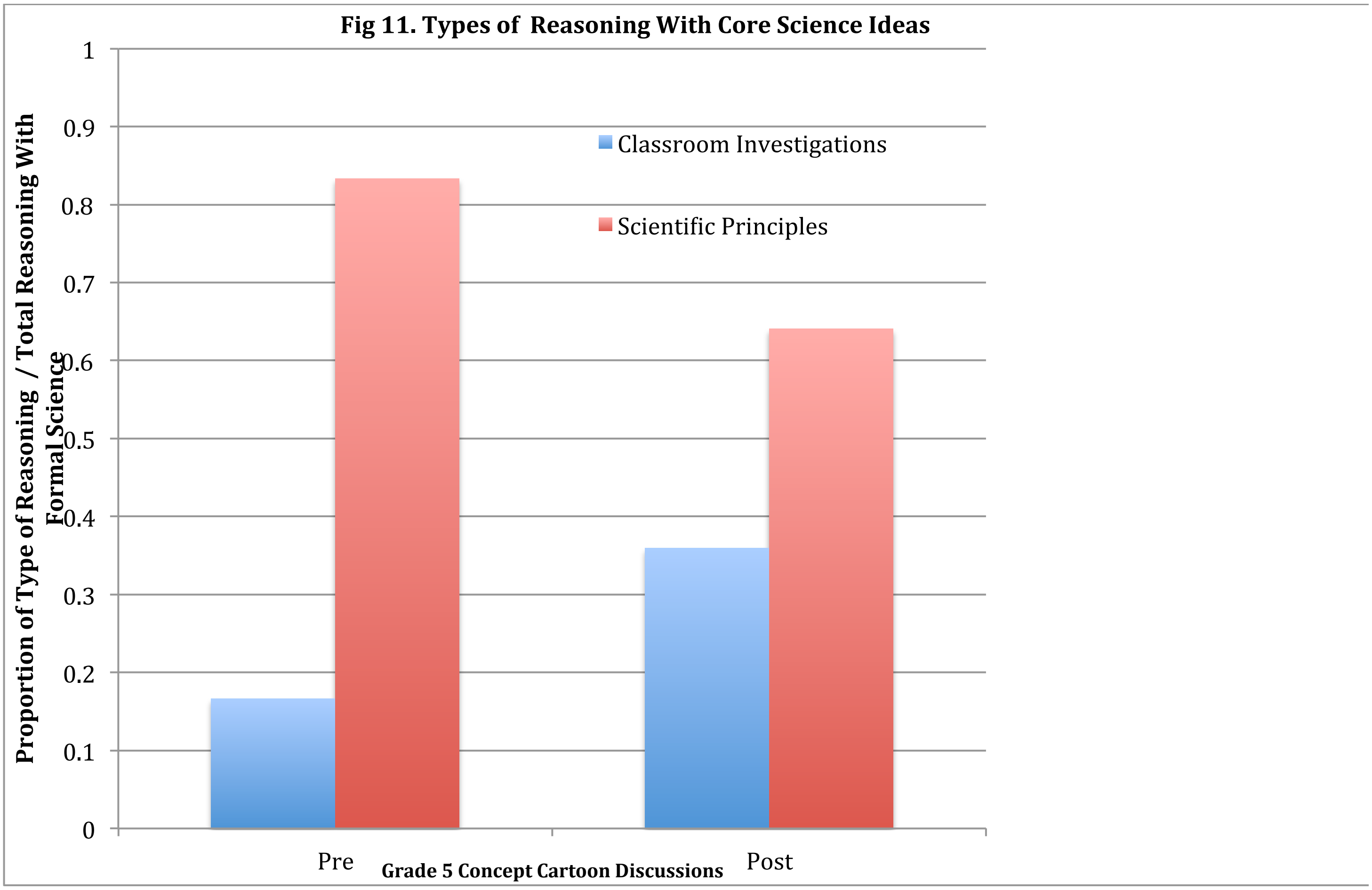
In the post-discussions, students drew often on classroom investigations and scientific principles from the Grade 5 curriculum, accounting for 17.56% of their talk. They continued also to reason on the basis of ideas and experiences from outside the curriculum, accounting for 17.8% of their talk. It should be noted that there was only a marginal difference in the two forms of reasoning in the post-discussions as compared to the pre-discussions. This finding shows that in contributing to the post-discussions to make sense of a novel task (the concept cartoon), students tried to apply actively their understanding of core science ideas from the curriculum (through references to scientific principles and classroom investigations), and were apt to reason almost equally with and without the core science ideas.

The related findings that students drew almost equally on scientific principles and classroom investigations, and their ideas and experiences from outside the curriculum in the post-discussions, and that they referred more often to core science ideas in post-discussions than in pre-discussions may shed light on a prior finding that students made fewer attempts at proposing experiments in the post-discussions (see Figures 7 and 8). It is possible that after being introduced to scientific concepts and principles through the curriculum investigations, students could draw on the core science ideas to resolve conflicting claims, and hence felt less need to generate ideas and thought experiments.

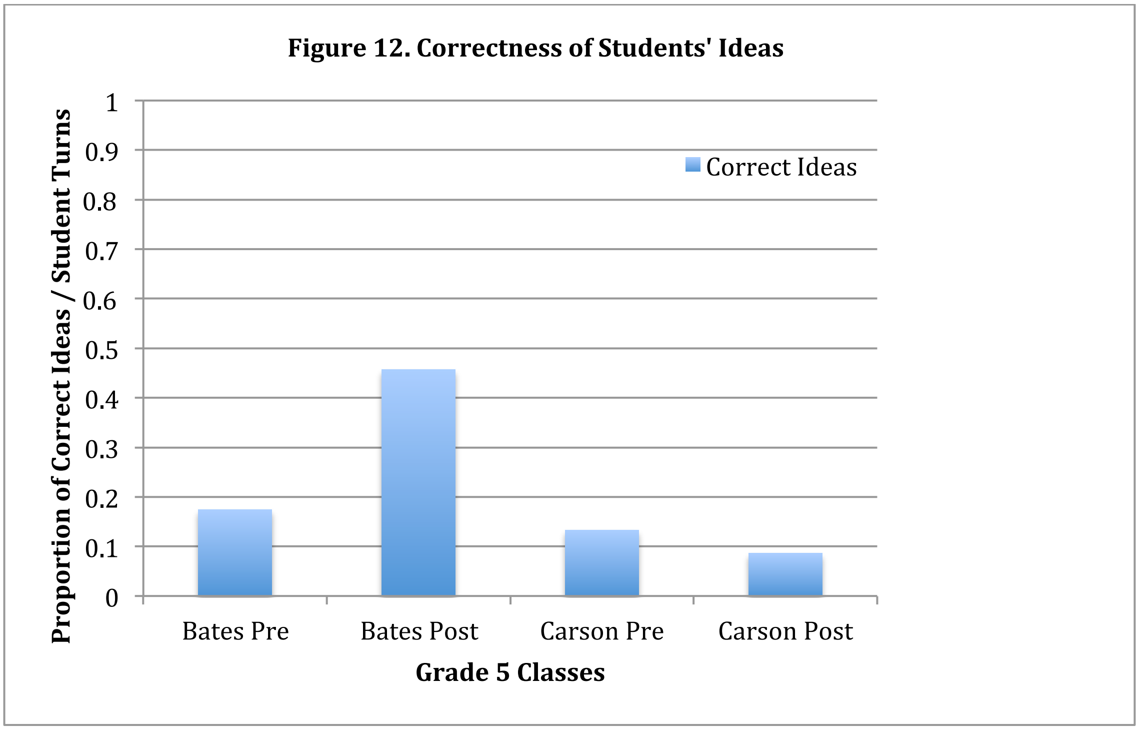
The reader should note that the increase in students' reasoning with core science ideas in the post-discussions was found in all 14 classes. See Figure 10.



A careful study of students' reasoning with core science ideas revealed also that students referred more often to data and observations from their classroom science investigations in the post-discussions (see Figure 11; data combined from 14 classes; proportions calculated from total attempts at reasoning with core science ideas). This finding shows that after conducting the investigations, students could utilize their observations and experiences to reason about a novel task.



Finally, as stated before, our analysis examined a subset of pre- and post-discussions from two of the classes, Ms. Bates' and Ms. Carson's, to understand the extent to which students offered correct ideas during the discussions (see Figure 12). We found that a greater number of student turns in the post-discussions in Ms. Bates' class presented correct ideas to the discussion (approximately 46% of students turns) than in the pre-discussion (approximately 17% of students turns). On the other hand, there was an opposite trend in Ms. Carson's class, where approximately 13% of student turns in the pre-discussion presented correct ideas, whereas fewer turns in the post-discussion contained correct ideas (approximately 9%). This finding shows that at least in one of the classes, students generated correct ideas more often in the post-discussion than in the pre-discussion. These data allow us to glimpse into the accuracy of students' reasoning, and additional analysis is needed to determine specifically the extent to which students applied correctly the core science ideas they learned *from the curriculum* in contributing to the discussion.



Grade 5 Inquiry Project Curriculum Discussions 2011-2012

In the year 2011-2012, we video-taped and transcribed four classroom discussions led by three teachers from the Grade 5 sample, as they participated in the *Talk Science* professional development program and enacted the *Inquiry Project* curriculum, both for the first time. The teachers were Ms. Carson, Ms. Silvia, and Ms. Bates (teacher names appearing here are pseudonyms). During the approximately ten-week long professional development program, teachers used web-based resources to develop their practice in promoting students' science learning: they studied video cases depicting exemplary classroom discussions to become familiar with four types of science discussions - elicitation, data, explanation, and consolidation discussions- and with various academically productive talk moves (APT moves) to lead the discussions. Teachers also studied scientist cases to understand the science more deeply, and to understand how scientists reason and talk about phenomena.

The findings presented here focus on teachers' use of the APT moves to facilitate various science discussions in their classrooms. We conceptualized the APT moves as *talk tools* for teachers to utilize in leading classroom discussions. In conceptualizing the APT moves as tools, the underlying expectation was that with support, teachers would begin to use the moves *strategically* to suit the emergent teaching and learning needs in their classrooms. We did *not* expect that teachers would use the various APT moves uniformly in the discussions, or consistently increase or decrease their use of particular types of talk moves over time, or even use the moves in each of their turns at talk. Instead, the professional development program was designed to help teachers develop their practice by identifying appropriate talk moves to incorporate into their facilitation while guiding discussions. We examined four discussions led by each of the three teachers to understand how they used various talk moves in facilitating their classroom discourse, and how their students participated in and reasoned about the science during the discussions. The discussions were video taped and transcribed and occurred during two lessons early in the curriculum (Investigations 5 and 6), and two lessons late in the curriculum (Investigations 16 and 17).

Our initial research plan was to study temporal changes in classroom discourse as teachers participated in the *Talk Science* program. However, a careful examination of the classroom discussion transcripts revealed that the four lessons selected for analysis each lent itself to a different type of discussion. For example, the discussion for Investigation 5 required students to formulate claims and provide evidence from their measurement data, whereas the discussion for Investigation 6 required students to propose initial ideas regarding the process of evaporation from their classroom observations and prior experiences instead of measurement data. Therefore, to understand better teachers' facilitation and students' participation during these discussions, one needed to know the science investigation framing the discussion, and the learning goals of the discussion. Each of the four lessons involved a different kind of investigation and learning goals, and these differences appeared to have shaped the emerging classroom interactions. The transcripts showed that teachers' facilitation and students' reasoning varied according to the learning goals and science investigations guiding the discussions. In other words, a simple temporal analysis of changes in teachers' facilitation over time was no longer appropriate owing to the differences in the nature of the discussions. Hence, in analyzing the data, we focused less on overarching temporal changes and more on how teachers used particular talk moves and how students reasoned about the science by considering carefully the investigations and learning goals shaping the discussions.

As stated before, the *Talk Science* program provided video cases on four broad types of science discussions: Elicitation, Data, Explanation, and Consolidation Discussions. The general purpose of these discussions was to enable students to make meaning of their classroom investigations and experiences, but each discussion also had a particular focus. The four foci of the discussions were as follows: eliciting students' initial ideas; interpreting data; generating explanations; and consolidating understanding. The reader should note that the four discussions we selected for video recording and included in this analysis mapped on to one of the four types of discussions that were presented in the video cases. Below is a table with contextual information on the four discussions we selected for analysis from the *Inquiry Project* curriculum, and how these relate to the four types of discussions depicted in the *Talk Science* video cases.

Grade 5 Lesson	Purpose of the Lesson Discussion/Learning Goals	Discussion Type and Focus
Investigation 5: What changes & what stays the same when salt dissolves in water? Students record measurement data (weight and volume) to track the presence of salt dissolved in water	Students use the weight and volume measurement data they have collected to make claims addressing the investigation question, and to provide evidence for the idea that the weight of a substance stays the same as it dissolves in water, and that tiny things have weight and take up space.	Data Discussion This type of discussion occurs after students collect data to help them connect the investigation question with their data; grapple with discrepant or anomalous data; identify data that can serve as evidence to support a claim; and link data to a representation
Investigation 6: What happens to the water? Students observe evaporation of water from a paper towel and surface of a plastic cup	Students use their observations of water evaporating from the paper towel and plastic cup, their prior experiences and reasoning to propose initial ideas about the process of evaporation	Elicitation Discussion This type of discussion is conducted prior to instruction or at the beginning of a new unit to uncover students' prior knowledge and experience; increase students' awareness of their own relevant ideas and experiences; and help them expand and broaden their ideas by listening to others
Investigation 16: What are some properties of air (3)?	Students use the particle magnifier model to explain in	Explanation Discussion

Students observe the effects of heating and cooling air through a class demonstration with soap and plastic bottle. Students also observe a computer-based particle magnifier model to understand the changes that occur at the particle level when air temperature changes	terms of the motion of air particles the expansion and contraction of air they observed during a class demonstration	This type of discussion builds on students' analysis of the data to help them identify evidence and explain the reason(s) it justifies or supports a claim; and to describe a scientific principle or reasoning that explains the findings
<u>Investigation 17: What's the story behind the graph?</u> This investigation occurs towards the end of the curriculum. Students annotate their graphs describing changes in their mini-lakes over several weeks.	Students tell the story of the transformations in their mini-lakes by first describing and accounting for the changes occurring in their mini-lakes at the macroscopic, visible level (the weight of the mini-lakes). Then they use the particle model and describe the changes occurring at the microscopic level to account for the changes at the macroscopic level.	<u>Consolidation Discussion</u> This type of discussion is conducted at the wrap-up of an investigation or when connecting to the one that Follows to ensure that students can describe what they did, why they did it, and what they found out; and to replicate what a class did in words, including giving a rationale for their methods and describing their findings

Coding Scheme and Procedure

We developed a coding scheme for this analysis through a preliminary examination of the transcripts, and by modifying the coding schemes for classroom discourse from our previous work. The coding scheme examined multiple aspects of classroom discussions: teachers' use of academically productive talk moves (APT moves) to guide students' reasoning; students' attempts at co-co-constructing science understandings with peers; and students' attempts at reasoning about the science.

We coded teachers' turns at talk for the following talk moves.

Teachers' Facilitation of Science Discussions:

a. Expand Moves (*Say More, Revoice, Time to Think*) (e.g., "Okay. Can you say a little more about that?"; "So you think the amount of space these take up depends on the room that they're in or the house that they're in?"; "Let's all take a minute to think about that")

b. Listen Moves (*Who can Restate/Repeat*) (e.g., "Can someone repeat what Avery said in their own words?")

c. Dig Deeper Moves (*Press for Reasoning/Why, Challenge*) (e.g., "What is your evidence?"; "How do you know it didn't rise? Did you measure it?")

d. Think With Others (*Add On, Who Can Explain, Do you Agree/Disagree*) (e.g., "Oh! Hmm..What do we think? Anyone want to, maybe want to revise Mario's idea, maybe change it, add to it?"; "What do we think that means? What do you think Amalia means when see says it causes physical breakdown?"; "Anyone disagree with that?")

We coded students' turns at talk for the following attempts at co-constructing ideas with their peers, and at reasoning about the science.

Students' Co-construction Moves:

1. Agree (e.g., "I kind of agree with Daniel, because when you're going to kick a soccer ball of course if it's deflated you can't really kick it that far.")
2. Disagree (e.g., "No. But I disagree with what Daniel said with the salt being hot.")
3. Ask for Clarification (e.g., "What do you mean when you say..?")
4. Clarify Other (e.g., "I think what Shareen is trying to say, the water might dissolve into the salt and the salt might get dissolved, so the water level might go down a little bit.")

5. Challenge (e.g., "But aren't you pumping hot air into the ball? Because if you blow up, like a balloon, sometimes you pump in hot air and after that it starts making it rise kind of, and after that.")
6. Add-On (e.g., "Um I also wanted to add on to Louie's..")
7. Restate Other (e.g., "She said there's more space in the air particles. I mean when the particles are pushed like – yeah, pushed.")

Students' Reasoning:

Sense-Making Attempts: This category captured students' efforts at making sense of the science.

1. Revise their own thinking (e.g., "Yeah, I agree that it's Lela. Because after the-- well, at first I thought it was Fern because I didn't know that air had weight. Then after my education, I learned that Lela is probably correct.").
2. Raise a related question (e.g., ""I have a question. Where does the water go when it evaporates?").
3. Propose test/thought experiment (e.g., "When Christiani said that if you put a cup and air in, but we're not talking about a cup, we're talking about a ball. So, if you have a scale and we fill it up with air, and it would not stay on zero. It would go-- it would, um, go out between two, three—").

Reasoning With Core Science Ideas: This category captured instances of students' reasoning by drawing on core science ideas (classroom science investigations and scientific principles from the curriculum).

1. Reference to Classroom Science Investigations – Students referred to quantitative data and/or observations from previous and/or present science curriculum units (e.g., "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. Reference to Scientific Principles (Principles such as air is matter; matter has weight and takes up space; the particulate nature of matter, etc.) - Students referred to scientific principles, ideas from the particle model (e.g., "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 Without Core Science Ideas : This category captured instances where students drew on ideas outside of formal scientific understandings.

1. <u>Reference to Outside Experience</u> – Students described experiences from everyday life (e.g., "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. <u>Presenting Assertions/Opinions</u> – These were instances where students presented assertions that were either opinions or facts that may have been accurate or inaccurate with respect to canonical science (e.g., "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. <u>Analogy</u> – This code captured instances where students drew similarity to other hypothetical situations (e.g., " 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. <u>Logical Train</u> – This code captured "if…then" statements expressing axiomatic reasoning and counterfactual thinking (e.g., "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.").

Summary of Classroom Discourse Findings

The analysis of the Grade 5 *Inquiry Project* curriculum discussions reveals how teachers guided students' reasoning, and the various ways in which students engaged in the discussions. As stated before, the four lessons selected for videotaping and analysis each had a different kind of investigation and learning goals that shaped the emerging discussion. To better understand the findings, one needed to know the context of the discussions with respect to the underlying science investigations and learning goals. Therefore, we report here on each of the four discussions separately. Furthermore, within each discussion, we describe each teacher's practice separately, documenting her facilitation and her students' talk to identify similarities and variations among teachers' practice, and to enable us to relate teachers' practice to their students' participation. Here we present a summary of the findings across the four discussions and three teachers from our analysis. Please refer to the NSF report for more details on the quantitative data from this analysis.

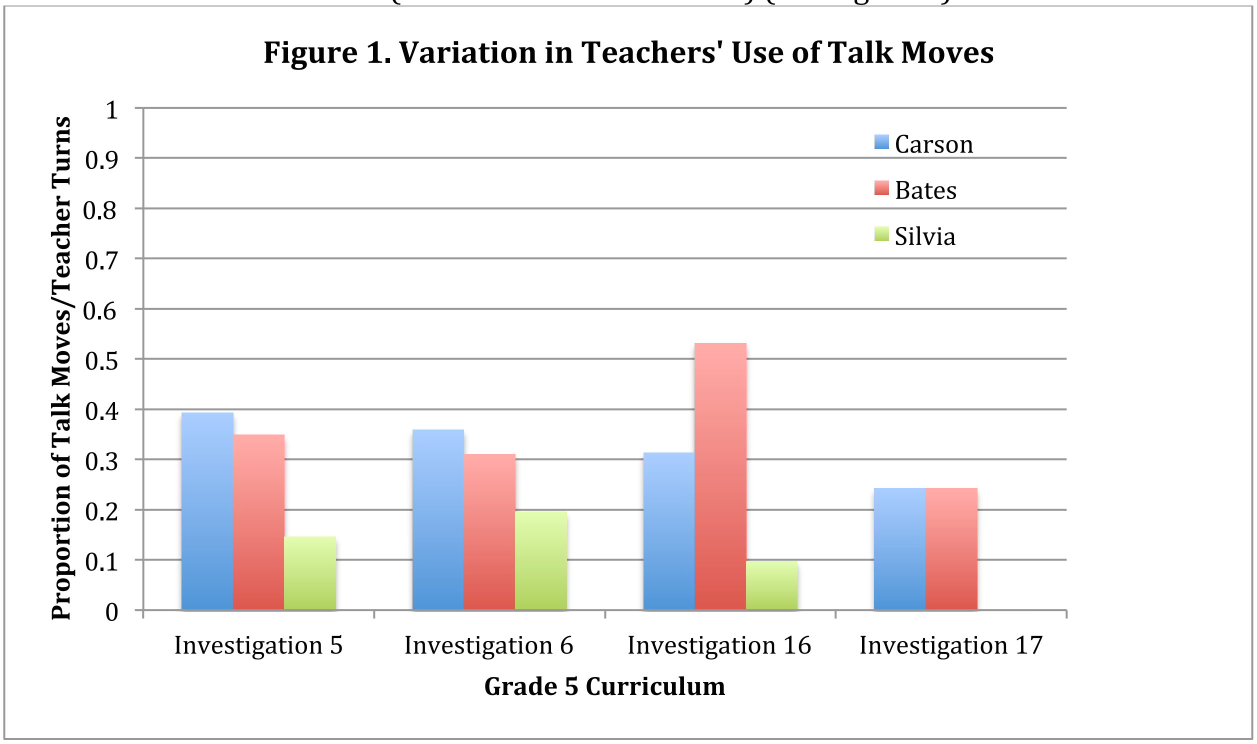
The findings show that teachers drew on various *academically productive talk* moves (APT moves) to guide their classroom discussions. They used the talk moves often to encourage students to expand their ideas, and to deepen their reasoning. The teachers also used talk moves to encourage students to listen and respond to their peers' ideas, albeit to a much lesser extent. Overall, the findings indicate that while participating for the first time in the *Talk Science* professional development program, the teachers took on board the APT moves and incorporated various talk strategies into their classroom practice.

Further, in the case of two of the three teachers (Ms. Bates and Ms. Carson) examined in this analysis, their use of Expand and Dig Deeper sets of talk moves was aligned with the underlying purpose of the discussions, and varied with the different types of discussions. When the purpose of the discussion was to elicit students' initial ideas about the process of evaporation (Investigation 6), the teachers utilized strategies to draw out students' preliminary thinking (Expand Moves), and probed students less often to provide evidence and explanations (Dig Deeper Moves). On the other hand, when the purpose of the discussion was to encourage students to construct scientific explanations, the teachers utilized talk moves often to help students deepen their reasoning with the help of evidence and scientific principles. These findings suggest that the two teachers may have understood the different types of science discussions (elicitation, data, explanation, and consolidation) they were introduced to in the *Talk Science* program, and used talk strategies differently in leading their discussions to address the underlying learning goals. The present analysis, nevertheless, provides a quantitative overview of the classroom discourse; a more detailed examination is needed to clarify how the teachers adjusted their use of talk moves to the moment-to-moment interactions to accomplish differing goals of these discussions.

Our analysis revealed that students participated actively in various ways to make meaning of the science. To reason about the science, they drew often on their classroom investigations, referring to the experimental procedures and the data and observations gathered during the investigations. They included also formal scientific principles from the curriculum in generating their explanations. Additionally, students drew on ideas from outside the curriculum, incorporating everyday experiences, facts or opinions, analogies, and so forth as they tried to understand the science.

Furthermore, in two of the three classes (Ms. Bates' and Ms. Carson's), students' reasoning with the help of ideas from within and outside the curriculum was fairly consistent with the type of discussion and the investigation framing the discussion. When the students did not have measurement data and the particle model to generate explanations (Investigation 6), they tended to invoke their everyday experiences, facts or opinions, and analogies to formulate their ideas. On the other hand, when students were provided with measurement data and a computer-based particle model (Investigation 5 and Investigation 16 respectively), they recruited these resources more often to construct explanations and reasoned less with the help of ideas and experiences from outside the curriculum.

Our examination of teachers' practice showed also considerable variation among the teachers. One of the teachers (Ms. Silvia) used talk moves consistently less often than the other two teachers (Ms. Carson and Ms. Bates) (see Figure 1).



Further, there was variation in teachers' use of different types of talk moves, with Ms. Bates using the Think With Others and Listen moves more often than the other two teachers. These differences notwithstanding, the general pattern was that teachers used more often talk moves designed to help mainly *individual* students explicate their ideas and deepen their own reasoning (Expand and Dig Deeper set of moves), and used much less often talk moves designed explicitly to foster *active listening* and *co-construction* of ideas by prompting students to attend carefully and respond to their peers' thinking (Listen and Think With Others set of moves).
The low emphasis on using the Listen and Think With Others talk moves should be noted because overall the students also made few attempts at co-constructing science understandings with their peers. Further, students' co-construction was generally consistent with the teachers' use of Listen and Think With Others talk moves. Specifically, we observed that students tended to actively restate and respond to their peers' ideas in discussions where the teachers utilized strategies to encourage them to engage with their peers' thinking. Our findings suggest that students may need explicit teacher guidance to make meaning of the science collectively with their peers through a communal exchange of ideas. Students' co-construction and teachers' use of the Listen and Think With Others talk moves are critical in bringing about a dialogic exchange of ideas, where students go beyond *sharing out* their own ideas to *building* on their peers' thinking, and work toward critiquing and refining the emergent shared understanding of the science within their classroom community.

Overall, our findings indicate that teachers' participation in the *Talk Science* professional development program for the first time laid a foundation for developing their practice by including certain types of talk strategies into their teaching. Future research and design of professional development needs to explore ways to increase teachers' facility at leading a more dialogic discourse to promote students' scientific reasoning.

Impact

Grade 4

The Grade 4 teachers participated in the *Talk Science* research in 2010-2011, and a subset of the same teachers participated a second time in 2011-2012. Our work with the teachers in 2010-2011 allowed us to develop and test a collection of web-based multimedia resources for teachers' professional learning, and to test our initial research design and analytic instruments. Based on feedback from the teachers, we refined the multimedia resources, and began developing the *Talk Science professional development pathway* to help teachers visualize and understand the scope and structure of the program. Preliminary research with the Grade 4 teachers in 2010-2011 also helped inform our research questions, and plans for data collection and analysis for subsequent work with Grade 5 teachers in 2011-2012.

Research with the Grade 4 teachers provides evidence of certain changes in their facilitation of classroom science discussions. The findings show that after participating in the *Talk Science* program in 2011-2012, almost all teachers increased their use of academically productive talk strategies to guide students' science learning, and specifically, they more often used talk moves to deepen students' reasoning and to promote active listening of peers' ideas. Furthermore, through a comparative analysis of a subset of teachers who participated two times, we found that during both years teachers increased their use of productive talk strategies to guide discussions after the program. At the end of their second time with the program, teachers' use of the strategies was the greatest. Teachers focused more frequently on deepening students' reasoning, and began to draw on strategies to foster active listening and students' co-construction of science understanding after participating in the program.

Grade 5

Our research with Grade 5 teachers in 2011-2012 provides evidence of key shifts in teachers' knowledge, understandings, and practice as they participated in the *Talk Science* professional development program:

1. Teachers' knowledge of core science concepts and ideas regarding matter improved after they implemented the *Inquiry Project* curriculum as part of the *Talk Science* program. After teaching the curriculum, teachers could draw increasingly on the particle model of matter from the curriculum to articulate their reasoning. All teachers obtained higher scores for their understanding of the science, and presented elaborate scientific explanations (Level 2 responses) based on core ideas from the curriculum more often in the post-interviews than in the pre-interviews.

2. Changes were observed in teachers' understandings of the role of classroom discussions in students' science learning, as they began to recognize the value of science discussions not only for participation and sharing out individual ideas, but also for students to develop ideas and make meaning together. After participating in the *Talk Science* program, teachers reported making discussions an integral part of their science lessons, and described several shifts in the nature of their classroom discussions.
3. There were shifts in teachers' facilitation of classroom science discussions after they participated in the program. Specifically, teachers utilized academically productive talk strategies to guide students' understandings of the science more often. Further, teachers incorporated into their practice a greater use of talk strategies to specifically probe students' reasoning, and to help them deepen their reasoning with the help of data and evidence from their classroom investigations.

We discuss these findings briefly in the following sections.

Shifts in Teachers' Knowledge of Science Concepts

Our pre-post interviews with the Grade 5 teachers revealed that after participating in the *Talk Science* program and implementing the *Inquiry Project* curriculum as part of their professional development, the teachers improved their ability to explain core scientific ideas regarding matter by drawing on the scientific concepts and particle model of matter presented in the curriculum.

In the post-interviews, most teachers had higher scores and articulated a margin of error argument and effects of rounding in accounting for differences in weights when multiple blocks were measured individually instead of together. Teachers also identified correctly that weight was a more accurate measure of the amount of matter (sand packed in a cylinder) than volume. Further, most teachers drew on the particle model to explain that air was matter because it was made up of particles that had weight and took up space, and they applied their understandings of the particle model to explain why air was thinner at higher altitudes.

With regard to the questions on phase change, most teachers obtained higher scores in the post-interviews, described phase change as the movement of a substance between solid, liquid, and gaseous states, and identified correctly a key characteristic of phase change that weight stays the same but volume may change.

Teachers also referenced the particle model in the post-interviews to explain processes of dissolving, condensation, and evaporation. To explain why dissolved salt was no longer visible, most teachers described specifically that particles of salt broke apart and were too small to see when salt dissolved in water, and offered correctly the idea from the curriculum for using weight to verify the presence of a substance dissolved in water. Further, most teachers provided elaborate responses in describing condensation with respect to particle movement and temperature difference. Finally, most teachers gained in their ability to explain the process of evaporation in terms of water particles breaking or spreading apart.

Shifts in Teachers' Perspectives On and Reported Use of Classroom Discussions

After the *Talk Science* program, the Grade 5 teachers shifted from a *share-out* model toward a *make-meaning* model of classroom discussions. At the start of the program, in articulating what they believed were benefits of classroom discussions, teachers tended to view discussions as opportunities for students to share their individual ideas, hear ideas from peers, and as a means to assess students' understandings. Teachers generally also described doing discussions to introduce lessons and identify students' preliminary ideas, and to wrap-up lessons by allowing students to report out findings and ideas from their individual or small group investigations, and by reviewing key ideas from the lesson.

After participating in the program, notable differences were found in teachers' perspectives on the role of classroom discussions, in their reported practice at leading science discussions, and in the reported characteristics of their discussions. Teachers now began to perceive discussions not simply as opportunities for students to externalize individual ideas but to co-construct ideas with peers, think collectively and develop understandings together. The recognition that discussions offered a means for students to make meaning together was more evident in the post-interviews. Teachers revealed greater willingness and confidence to facilitate discussions, to do them not only as introduction and wrap-up but also for continued learning. They reported leading discussions regularly in their science lessons.

With respect to changes in the features of their classroom discussions, teachers reported that after the *Talk Science* program, their science discussions involved less teacher talk and direction and greater student responsibility at leading discussions; greater student willingness and confidence in contributing to the discussions; greater student participation not only in sharing their individual ideas but also attending to and addressing their peers' ideas; and finally, greater student awareness and use of evidence to reason about science during discussions.

The differences in the nature of classroom discussions reported by the teachers point to shifts in the culture of classroom talk, as seen in changes in teachers' orchestration of discussions and in students' participation during discussions.

Shifts in Teachers' Facilitation of Classroom Science Discussions

Our analysis of pre-post concept cartoon discussions revealed that the Grade 5 teachers made greater use of academically productive talk strategies, or *APT moves*, to guide students' science learning through discussions after they participated in the *Talk Science* program. In the pre-discussions, 19.55% of the teachers' turns involved the use of APT moves, whereas this figure rose to 26.03% in the post-discussions.

Specifically, in seven of the fourteen classes, teachers made greater use of the APT moves in the post-discussions. Additionally, of the four teachers who did not use any APT moves in the pre-discussions, three teachers made considerable use of the strategies in their post-discussions.

Teachers' practice showed changes not only in their overall use of the talk strategies, but also in particular *types* of strategies. Although teachers continued to draw mainly on Expand strategies to enable students to explicate their individual ideas, they increased their use of DIG DEEPER strategies designed to deepen students' reasoning with the help of data and scientific principles.

The greater use of academically productive talk strategies in general, and of the Dig Deeper set of talk moves in particular, points to a positive shift in teachers' practice at leading productive science discussions for students' learning.

Further, our analysis revealed changes in students' participation in discussions. Students made slightly greater attempts to co-construct science understandings with peers in post-discussions (13.42% of the turns in pre-discussions v/s 17.42% of the turns in the post-discussions). This increase in students' co-construction was found in eight of the fourteen classes.

Students' attempts at reasoning also changed after teachers implemented the *Inquiry Project* curriculum as part of the *Talk Science* program. After engaging with the various science investigations and learning about the particle model of matter through the curriculum, students made several efforts to apply their understanding of core scientific ideas to reason about a novel situation (the concept cartoon problem). In the post-discussions, students' reasoning with the help of core science ideas rose to 17.56% of their talk from a negligible 2.47% in the pre-discussions. It should be noted also that students in all fourteen classes attempted to draw on core science ideas in their reasoning in the post-discussions.

Conclusions

The *Talk Science* professional development program was designed to promote teachers' capacity to facilitate productive science discussions to guide students' learning. In the second and third years of the project (2010-2011 and 2011-2012 respectively), the development and research teams worked separately but in parallel to design the *Talk Science* web-based multimedia resources and to conduct research with the participating teachers. Our work with Grade 4 teachers in 2010-2011 allowed us to refine the web-based resources for teachers' professional learning and informed the design of the professional development *pathway* for the following year, test the initial research design and instruments, and guided subsequent data collection and analysis for research with Grade 5 teachers in 2011-2012. The Grade 5 teachers were participating in the *Talk Science* pathway and implementing the *Inquiry Project* curriculum for the first time.

The findings to date suggest that the blended model of the *Talk Science* program involving web-based independent learning, face-to-face learning with grade-level colleagues, and classroom trials holds promise for teachers' professional development. In the *Talk Science* model, teachers engage in independent study of web-based multimedia resources like scientist cases and classroom cases. The resources are readily accessible anywhere, anytime, and can be used flexibly to meet varying needs of teachers in different schools. Further, teachers meet with grade-level colleagues in school-based study groups to discuss the resources, and to reflect and plan for their classroom discussions. Face-to-face study group meetings offer teachers a means to share their successes and challenges in leading productive science discussions. Finally, teachers are encouraged to also transfer their learning into actual practice through classroom trials. Teachers' professional learning is situated closely within the science curriculum they teach, thus making their learning relevant to their classroom practice. Moreover, web-based resources like *In Your Classroom* planning sheets and study group guides focus teachers' attention explicitly toward applying new strategies and understandings in their teaching.

Our research shows that the blended model underlying the *Talk Science* program allows teachers to participate actively and learn at their own pace through independent study of readily available web-based resources. The model allows teachers to also develop their knowledge, understandings, and practice through collaboration with colleagues, and supports transfer of professional learning into classroom practice. The findings indicate that in shifting the culture of classroom talk toward more productive science discourse and student reasoning, the model enables teachers to not only begin incorporating new instructional strategies, but to also begin developing their knowledge of core scientific ideas, and to begin conceptualizing classroom discussions in more dialogic terms.

In our research, the teachers' engagement with their learning was evidenced in the study group meetings, where they discussed the web-based resources, debriefed classroom trials and experiences, and generated ideas for classroom teaching. As teachers participated in the program and taught the *Inquiry Project* curriculum aligned with it, they developed more accurate understandings of the core science concepts and ideas regarding matter.

Furthermore, there were shifts in teachers' perspectives on classroom discussions, and their capacities at leading discussions to promote students' science learning. After the program, teachers displayed greater willingness to conduct science discussions regularly, and began to conceptualize discussions in terms of a more dialogic, *make-meaning model*, where they started recognizing discussions as opportunities for students to not only externalize their own thinking but to also develop understandings together and to continue learning. This shift, although small, marks a departure from their initial *share-out model* of discussions, where teachers conceptualize discussions primarily as opportunities for students to report out and listen to individual ideas at the introduction and conclusion of science lessons. Along with shifts in teachers' perspectives, participation in the *Talk Science* program helped teachers incorporate various discourse strategies for orchestrating productive science discussions. Teachers increased their use of academically productive talk strategies, and began to draw on various talk moves to encourage students to explicate their ideas and deepen their reasoning.

The insights gained from the *Talk Science* research suggest that changes in all three aspects of teachers' professional learning – knowledge of the science, underlying perspectives on classroom discourse, and instructional practice – are critical for teachers' sustained development. Therefore, professional development programs may need to consider carefully how to provide explicit guidance in these three areas: (i) promoting teachers' knowledge of core scientific concepts and principles; (ii) promoting a model of dialogic discussions and students' co-construction; and (iii) promoting actual practice at leading productive science discussions.

Implications for Future Research

Our research indicates that the *Talk Science* program helped lay a foundation for developing teachers' knowledge, understandings, and practice as they participated in the program for the first time. This foundation provides an important springboard for teachers' professional learning, and points to other aspects of their learning that may benefit further from more careful and continued guidance. Specifically, teachers may need support for generating more dialogic science discussions in the classroom. Whereas teachers in our research recognized the value of discussions for fostering collective meaning-making, and began to utilize talk strategies to help students explicate their individual ideas and deepen their reasoning, the teachers less often used strategies that were designed to explicitly foster co-construction of scientific knowledge among students. Less attention was given to promoting active listening and thinking with peers' ideas. This finding was consistent with some of the interview responses, where Grade 5 teachers seldom pondered how they could guide their students to work with peers' ideas, and where Grade 4 teachers seldom described benefits of discussions or reported doing discussions in terms of students co-constructing scientific arguments and developing understandings together. Therefore, future research could explore ways of helping teachers to foster students' scientific reasoning through more dialogic, student-student exchanges during science lessons.

The research calls also for fostering an *analytic stance* among teachers to promote greater reflection on their professional development and on their students' learning. Across the multiple data we examined, there is limited evidence of teachers analyzing their practice and their students' understandings. For example, during study group meetings teachers seldom described issues and challenges in their own instruction to support students' scientific reasoning through discussions. Similarly, during interviews, teachers did not always ponder how they might improve their facilitation to generate more robust discussions, or how they might probe into and follow up on students' understandings about the science. Our findings suggest that teachers may need more help with reflecting on their practice to enhance their orchestration of classroom science discourse for students' learning.

The insights gained from this research inform future work on guiding teachers' professional learning. To promote deeper reflection among teachers, future iterations of the *Talk Science* program will aim at providing teachers with ongoing feedback from their own classrooms. Although teachers in the present program met regularly in study groups, they did not have continual evidence from their classroom interactions for sustained reflection and planning, and therefore may have found it difficult to analyze their instruction in the absence of objective feedback. Hence, in future research, we plan to provide teachers with video records of their own classroom interactions. The video records will offer objective, verifiable evidence of their own teaching and of their students' participation and reasoning during science discussions, and allow teachers to identify how they might lead rigorous, coherent science discussions to deepen students' learning.