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Teacher Scaffolding Strategies to Transform Whole-classroom Talk Into Collective Inquiry in Elementary Science Classrooms

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Inquiry-based teaching has been emphasized to enhance students' knowledge and skills and create a culture of science in science classrooms. Many teachers understand inquiry as hands-on activities, and under the pressure of content-based curriculum, they plan hands-on activities to develop students' science content knowledge described in the curriculum. This leads to science teaching as scripted performance-based teaching rather than creative and co-constructive knowledge building and problem solving. To develop inquiry abilities, students need opportunities to critically and constructively share and discuss their ideas, reasons, and alternatives in problem-solving contexts beyond managing experiments. Whole-classroom talk has been recognized as a cognitive and social tool to create a joint space of learning when teachers go beyond the traditional ground rules of the Initiation-Response-Follow-up/Initiation-Response-Evaluation (IRF/IRE) approach in classroom interactions. This study investigates examples of teacher scaffolding during whole-class discussion where an elementary teacher attempts to connect and expand hands-on activities with knowledge building, reasoning and problem-solving. This study examines specific scaffolding strategies used by the teacher during whole-class discussion and explores how the strategies develop a co-constructive learning community for students to enhance their knowledge, reasoning and problem-solving skills. The study employed a descriptive and explanatory case study model to look closely at a Grade 5-6 classroom over 4 months, with a specific focus on the dynamics of student and teacher interactions during classroom activities and discussions. During the course of the study, one teacher and 23 students worked on the science unit of electricity and electromagnetism. All science classes were video and audio taped and later transcribed to analyze the classroom talk, the teacher's scaffolding strategies, and students' learning. Research findings show that the teacher continuously demonstrated the strategies of a) probing and expanding the boundaries of thinking, b) developing collective reasoning and problem solving, and c) participating and modeling the inquiry process with students. These scaffolding strategies distributed the agency of reasoning and problem solving in a collective learning community and encouraged students to become knowledge inquirers and problem solvers. The study describes the pedagogical implications of whole-classroom talk through a discussion about how these strategies are related to and different from the widely practiced IRF/IRE approach in order for teachers to reflect and transform the practice of classroom talk into inquiry-based teaching.

On a favorisé l'apprentissage fondé sur l'enquête comme approche pour rehausser les connaissances et les habiletés des élèves et pour créer une culture de la science dans les cours de science. Plusieurs enseignants perçoivent l'enquête comme consistant en des activités pratiques et, sous la pression du curriculum basé sur le contenu, ils organisent des activités pratiques pour *développer chez les élèves les connaissances en sciences selon le contenu décrit dans le programme d'étude. Cela mène à un enseignement des sciences qui est structuré et ancré dans la performance, plutôt qu'au développement créatif and collaboratif des connaissances et des capacités en résolution de problèmes. Afin de développer des compétences en enquête, les élèves ont besoin d'occasions de partager et de discuter, de façon critique et collaborative, leurs idées, leurs motifs et leurs solutions aux problèmes dans des contextes qui dépassent celui des expériences gérées. Les discussions impliquant la classe dans son ensemble sont reconnues comme étant un outil cognitif et social qui crée un espace d'apprentissage partagé quand les enseignants vont au-delà de l'approche traditionnelle d'initiation-réponse-suivi et initiation-réponse-évaluation pour gérer les interactions en classe. Cette étude se penche sur des exemples d'échafaudage pendant une discussion impliquant l'ensemble de la classe où un enseignant à l'élémentaire tente de faire le lien entre les activités pratiques d'une part et le développement des connaissances, de la capacité de raisonnement et des aptitudes en résolution de problèmes d'autre part. Cette étude examine des stratégies d'échafaudage spécifiques qu'emploient les enseignants pendant les discussions impliquant l'ensemble de la classe et explore la façon dont ces stratégies mènent au développement d'une communauté d'apprentissage collaborative où les élèves augmentent leurs connaissances, leur capacité de raisonnement et leurs habiletés en résolution de problèmes. L'étude repose sur un modèle d'étude de cas descriptive et explicative pour examiner une classe de 5e-6e pendant 4 mois, en portant surtout attention à la dynamique des interactions entre les élèves et l'enseignant pendant les activités et les discussions en classe. Au cours de l'étude, un enseignant et 23 élèves ont travaillé sur une unité en science portant sur l'électricité et l'électromagnétisme. Tous les cours de science ont été enregistrés sur bande vidéo et sonore et ensuite transcrits et analysés pour les conversations en classe, les stratégies d'échafaudage employées par l'enseignant et l'apprentissage des élèves. Les résultats de recherche indiquent que l'enseignant a constamment employé les stratégies suivantes: a) explorer et repousser les limites de la réflexion, b) développer la résolution de problèmes et le raisonnement collectifs, et c) montrer le processus d'enquête aux élèves et y participer. Ces stratégies d'échafaudage ont distribué les capacités de raisonnement et de résolution de problèmes dans une communauté d'apprentissage collectif et elles ont encouragé les élèves à devenir des chercheurs de connaissances et des personnes capables de résoudre des problèmes. L'étude décrit les retombées pédagogiques des discussions impliquant toute la classe et ce, en discutant des similarités et des différences entre les stratégies d'échafaudage et l'approche courante d'initiation-réponse-suivi et initiation-réponse-évaluation. Cette discussion se veut une invitation à la réflexion aux enseignants afin qu'ils transforment la pratique des discussions en classe en un enseignement reposant sur l'enquête.*

With increasing concerns of socio-scientific and environmental challenges in today's world, developing students' scientific thinking and problem-solving skills has become an important goal of science education (National Research Council [NRC], 2000; Organization for Economic Co-operation and Development [OECD], 2010; Osborne, 2014). To approach this goal, inquiry-based teaching has been promoted to develop students' agency of reasoning and problem solving by providing students with opportunities of questioning, reasoning, communicating, and investigating phenomena (e.g., Chin & Chia, 2006; Gillies, Nichols, Burgh, & Haynes, 2014; Hmelo-Silver, 2004; Pease & Kuhn, 2011). Whereas a teacher-centered traditional approach that follows a specific structure of lesson development for the expected outcomes of curriculum rarely allows students to contribute to the unfolding nature of lesson and to develop higher order thinking skills (Myhill, 2006; Sawyer, 2004), inquiry-based learning is student-centered, participatory, and open to the emergence of knowledge through a problem solving process that shifts teachers from knowledge providers to facilitators and students from passive learners to agents of knowledge building (Anderson, 2002; Hynes-Berry & Berry, 2014).

Despite positive understandings of inquiry-based teaching, it has also been challenged by various barriers such as content-based science curricula, lack of support, and teacher perceptions of inquiry, which make teachers feel pressured, incompetent, and unsupported in inquiry teaching practice (Anderson, 2002; Johnson, 2006; Kim, Tan, & Talaue, 2013; Zion, Cohen, & Amir, 2007). Content-based curricula and assessment lead teachers to focus on science concepts rather than scientific thinking skills, and often put their teaching into a lecture-delivery mode (Kim et al., 2013). Many teachers perceive inquiry approach as “students discover by themselves through hands-on learning”; thus, they tend to provide students only minimal guidance during lab activities, which is often ineffective to develop students’ science knowledge and skills (Kirschner, Sweller, & Clark, 2006). Research shows that it is difficult for students to understand links between what they observe and science ideas embedded in hands-on experiments without teacher guidance (Abrahams & Millar, 2008). In this regard, teachers find inquiry approach unsuccessful, chaotic, and arbitrary to achieve intended curriculum outcomes as students’ inquiry experiments often bring messy or wrong results (Kirschner et al., 2006; Tan & Wong, 2012). To overcome this difficulty, teachers sometimes provide students with detailed instructions of hands-on activities or a summary of activities with correct science concepts as conclusions. Yet, this approach is also criticized as another example of traditional, cookbook-based teaching, which cannot provide students with opportunities to think and solve problems critically and creatively (Clark, Clough, & Berg, 2000). The complexity of hands-on activities, scientific thinking skills, and curriculum contents is an ongoing tension for teachers in inquiry-based science classrooms (Tan & Wong, 2012).

Given that providing hands-on activities is essential for students’ motivation and engagement in doing science (Dhanapal & Shan, 2014; Worth, 2010), what strategies can teachers use to develop students’ scientific thinking skills and curriculum goals through hands-on activities? Given that the balance of hands-on and minds-on is one of the key elements of inquiry-based science classrooms (Louca, Tzialli, Skoulia, & Constantinou, 2013), how do teachers bring that balance into their teaching practice? This study looks into classroom talk as a tool to develop students’ reasoning and problem-solving skills in balance with hands-on activities in science classrooms. By observing, describing, and interpreting specific examples of teacher scaffolding during whole-classroom talk, this study works to develop pedagogical understanding and suggestions about the effectiveness of whole-classroom discussion for inquiry-based science teaching.

The Value of Classroom Talk for Students’ Reasoning and Problem Solving

Inquiry skills such as scientific reasoning and problem-solving need to be experienced, learned, and developed in and through social interactions as higher cognitive skills are developed in intra-psychological relationships first and internalized at inter-psychological levels later (Vygotsky, 1978; Roth, 2013). For instance, to teach students the importance of evidence in science problem solving, teachers provide problem contexts that require evidence-seeking strategies to solve the problems. When a student publicly makes a claim such as “animal extinction does not have strong correlation to climate change,” the teacher and other students with a counter claim could ask the student to provide evidence to justify the statement by saying, “What is your evidence? You can’t convince us without evidence." This interactive dialogue can help students understand the importance of evidence for justification and further develop evidence-seeking skills (Kim & Roth, 2014; Kuhn, 2011). Teachers' facilitation on interactive classroom talk becomes critical to developing students' reasoning and problems solving skills in inquiry-based classrooms (Colley & Windschitl, 2016; Gillies & Boyle, 2005; McNeill & Pimentel, 2009).

Whole classroom talk has been recognized as a cognitive and social tool to develop students' knowledge, thinking, and communication skills through interactive thinking and knowledge building (e.g., Baker, Lin, Chen, Paul, Anderson, & Nguyen-Jahiel, 2017; Colley & Windschitl, 2016; Mortimer & Scott, 2003). Teachers, being responsive to students' ideas, encourage students to engage in classroom talk by using various techniques such as questioning, probing and clarifying, acknowledging and validating, and offering challenges and suggestions for further thinking and learning (Colley & Windschitl, 2016; Gillies & Boyle, 2005; LeBlanc, Cavlazoglu, Scogin, & Stuessy, 2017). When students and the teacher are engaged in classroom dialogue to solve classroom problems, questions, wonders, and ideas are shared, examined, and developed in and through a joint social space of thinking. Mercer's (2000) concept of Intermental Development Zone (IDZ) based on Vygotsky's sociocultural approach to cognitive development is helpful here. Mercer (2000, 2008a) explained that IDZ is a mutual space where both students and teachers take responsibility for developing participation and interactions. In this space, inter-thinking and interactions are motivated and enacted and students' knowledge and skills are developing. Teachers take special responsibility in this space to initiate and maintain the mutuality and joint development of connecting curriculum goals, classroom activities and learners together. To facilitate IDZ for effective learning outcomes, teachers generate "exploratory talk" where students critically and constructively engage in discussion by freely sharing their own questions, reasons, critiques, and alternatives to possibly reaching agreement at the end. This type of talk makes reasoning and problem-solving processes verbal, visible, collective, and publicly accountable in science classrooms (Mercer, 2008a). In science classrooms, students' inquiry process often results in unexpected outcomes and questions which teachers often do not have answers to in the situation at hand. Teachers invite students to think and investigate the questions together and rigorously use students' questions and ideas as resources for collective sense-making and knowledge in classroom talk (Colley & Windschitl, 2016). In this dialogical process, the teacher is a member of the dialogical community, not the authoritative power who evaluates and controls the conversation. Thus, both teachers and students share ownership for reasoning, problem solving, and knowledge building in whole-class discussion (Duschl, 2008). Expanding students' hands-on activities with exploratory talk could develop students' conceptual and procedural understandings of science.

Exploratory talk is often compared with the widely practiced Initiation-Response-Follow-up (IRF) or Initiation-Response-Evaluation (IRE) patterns in classroom talk (Hardman, 2008; Mercer & Hodgkinson, 2008). The IRF/IRE approach is typically incorporated into the classroom with certain ground rules such as: the teacher nominates who speaks, only a teacher may ask a question without seeking permission, only a teacher can evaluate students' answers, and so on. Researchers (e.g., Burns & Myhill, 2004; Hardman, 2008) point out that the IRF/IRE process results in a predominant type of classroom talk, which is not an exception in science classrooms (Bleicher, Tobin, & McRobbie, 2003). This pattern of IRF/IRE that includes teacher-led recitation with closed questions, short answers, minimal feedback, and reporting others' ideas lacks student engagement in questioning and higher-order thinking. Further, it is rare to see teachers shift their IRF patterns from recitation talk to dialogical discourse with and for students' higher reasoning processes (Hardman, 2008; Myhill, 2006). Because of such negative research findings, IRF/IRE exchange in classrooms is often criticized as a non-effective for participatory learning, yet it is still widely practiced in today's classrooms for its practicality to initiate and summarize activities. The question then becomes how might teachers modify and process IRF/IRE interactions. How can they scaffold higher-order thinking such as scientific reasoning and problem solving during IRF/IRE exchanges? How can they develop the process to move away from recitation patterns towards a dialogue with complex, open, and deeper thinking processes? Researchers have emphasized the ground rules of interactive exploratory talk for students' sense making and reasoning by various scaffolding strategies such as looking into the roles of questioning (Chin & Osborne, 2010; Colley & Windschitl, 2016), power and agency of students (Clarke, Howley, Resnick, & Penstein Rosé, 2016; Reinsvold & Cochran, 2012), modifying the triadic pattern of IRE (Ferris, 2015; Friend, 2017; Mercer, 2008b), etc. Yet, there has not been much research on how teachers practice exploratory talk to develop students' reasoning and problem solving in relation to science hands-on activities in inquiry-based science classrooms. In this regard, this study looks into classroom talk in elementary science classrooms with the following questions:

- How can teachers transform whole-classroom talk into exploratory talk that develops students' reasoning and problem-solving skills during hands-on activities?
- How can teachers facilitate whole-classroom talk to create and maintain mutual engagement and responsibility for reasoning and learning?

Based on the questions, this study adopted a descriptive and explanatory case study model to closely examine teachers' scaffolding strategies in classroom talk in elementary science classrooms.

A Descriptive and Explanatory Case Study

A descriptive and explanatory case study is a research method that investigates, describes, and examines cases of research questions in real-life situations (Yin, 2003). It describes how classroom talk emerges and develops through interactions between students and the teacher and explains how teacher scaffolding during classroom talk develops students' learning and reasoning in inquiry-based teaching. This study examined classroom interactions in a Grade 5-6 classroom over a four-month period in an elementary school in Western Canada. One teacher and 23 students participated in the study, during which time their learning focused on two science units listed in the program of studies: Electricity and Magnetism, and Mechanisms Using Electricity. Each week featured two 60 min. science lessons. The unit sub-topics included static electricity, electricity safety issues, types of electrical circuits, conductors and insulators, fruit batteries, electromagnetism, and designing toys that move with electrical energy. The classroom teacher had nine years of teaching experience in elementary schools prior to her participation in the study and she deeply valued an inquiry approach in science classrooms to develop students' knowledge and thinking skills. The teacher provided hands-on activities in small groups or for the whole class, and organized whole-classroom talk at the beginning or end of class. She opened each lesson by introducing new topics or reviewing previous lessons through questioning, recapping, and commenting on students' activities. Sometimes a hands-on experiment took two classes to complete and in the second class, the teacher and students together reviewed their activities from the previous class. When students completed their activities, the teacher asked students to reflect and share their findings, areas of wonder, and further questions with the whole class.

All classroom activities were video and audio taped to develop in-depth data collection and interpretation of classroom activities and interactions. Classroom artifacts, such as students' science notebooks and project outcomes, were collected to further understand students' learning in relation to their actions. Two video cameras and two voice recorders were placed in the classroom—one at the front and one at the back of the room. When students were divided into small groups, the cameras and voice recorders were set up to follow students' interactions in two of the small groups. These two groups were chosen based on active interactions amongst group members. The video/audio data were viewed several times and transcribed for data interpretation purposes. Based on the specific research questions, data involving teacher-students' classroom talk was given priority to understand how such talk was developed in relation to hands-on activities and students' reasoning using both zooming-in strategies (analyzing dialogical interactions) and zooming-out strategies (understanding dialogue in the context of classroom activities and curriculum) (Roth, 2005). Through the use of a zooming-in and zooming-out video analysis strategy, the researcher generated and developed themes based on types of classroom talk. Thematic coding (open, axial, and selective coding) was applied during the data analysis (Flick, 2006). Once various possibilities emerged from viewing the video data (open coding), the researcher watched the videos again and drew on other data sources such as classroom artifacts to revise and synthesize initial ideas and understand overall themes (axial coding). Once themes were decided, certain classroom episodes were selected to understand the depth of teacher-student interactions during classroom talk (selective coding). Throughout this process, data thematization and interpretation were developed.

This study obtained ethics approval from the Research Ethics Boards of the University of Alberta. Consent forms were signed by all research participants for data collection and data sharing for knowledge mobilization. During data collection, the research team was sensitive and responsive to participants' needs and feelings around videotaping through observation and casual interactions. Pseudonyms and blur-out-face function in images are used for students' confidentiality in this paper.

Findings

Probing and Expanding the Boundaries of Thinking

One distinctive strategy the teacher consistently demonstrated in classroom talk was to extend a thread of conversation to the whole class. Every class, the teacher would open the conversation with invitational questions such as "What do you remember from last class?" or "Is there anything you are still wondering about?" In this way, she was inviting a student to start the whole-classroom talk.

In Dialogue #1 below, the teacher invited her students to share their findings from a balloon and Rice Crispies activity and they took turns with the teacher questioning and the student responding. At this point, the talk seemed to follow an IRF/IRE exchange. How, then, did the teacher turn this exchange into exploratory talk where students became the agents of reasoning and problem solving? Before this talk, students in small groups were experimenting with Rice Crispies and balloons (rubbing a balloon and putting it close to the Rice Crispies) to explore the concept of static electricity. After the activity, the teacher-initiated class discussion by questioning what students noticed during their hands-on activity (turn 1, Dialogue #1). She let one student, Eve, answer and the rest of the conversation followed a sequence of turn-taking between teacher and student. On the surface, this turn-taking sequence does not seem any different from a typical IRF exchange in science classrooms. However, rather than providing the answers, the teacher invited other students to contribute their suggestions to Eve's challenge that emerged during the talk. When Eve used the term "charge," the teacher asked her to clarify but Eve could not explain what it meant (turns 2-4). Then, the teacher asked others to contribute to the conversation to develop the meaning of "charging the balloon." The challenge emerged and became shared as a joint problem. In this joint space of problem solving, different words, ideas, and explanations including alternative concepts were shared, which expanded students' thinking and explanation further. The term "charge," which was initiated by a student, became the whole class making meaning together. Accordingly, the teacher's probing and inviting the students to clarify their ideas and contribute to meaning making expanded the boundaries of thinking from the individual to the public.

Dialogue #1.

1. Teacher: What did you notice when you rubbed the balloon either on carpet, a shirt or hair? What happened?
2. Eve: Well, we did charge the balloon but we didn't notice anything happened.
3. Teacher: What do you mean by you charged the balloon?
4. Eve: Errr…When you rub something, you get … err … I don't know how to explain.
5. Teacher: OK! Maybe I am looking for people to contribute what you think she means by charging the balloon.
6. Fran: It means it gives the balloon sometimes statical energy and it charges the balloon.
7. Arthur: When they run it on the hair, maybe it gives the balloon magnetism that is, connect the rice crispies.
8. Teacher: So you are bringing the idea of magnetism? … A lot of people talk about attraction and made connections with magnets. Have we involved magnets in this activity?
9. Stan: It really acted like a magnet and it was flying onto the balloon.
10. Teacher: Yeah? What do you mean by acted like a magnet?
11. Stan: Because when I put it on the Rice Crispies, a bunch of the Rice Crispies went onto the balloon.

The teacher's strategy to "expand the individual to the whole" was evident throughout the study. She probed students' ideas by asking others to contribute to concept building together. When the teacher invited others to extend the discussion topic, she also paid attention to science terminology or misconceptions shared by students and responded to them for further discussion (turn 7). Yet, she seldom corrected or evaluated their ideas immediately after students' response turn. Instead of giving feedback or evaluating right away, she expanded the shared ideas back to the whole class for further inquiry and clarification (turns 8-11). The strategy of clarification and expansion of thinking was observed in whole-class discussion throughout the study.

Developing Reasoning and Problem Solving Collectively

During the study, students had many opportunities to share their surprise, areas of wonder, challenges, and questions that emerged from their group hands-on activities, which often became a whole-class challenge. The following episode (Dialogue #2) shows how a small group challenge is shared and developed as collective reasoning and problem solving through whole-classroom talk. The teacher started the conversation by asking students to reflect on their experiment and share their areas of wonder (turn 1). Fran shared her findings (turn 2) and the teacher expanded Fran's ideas with further questions. The teacher asked Fran to think about why the event happened (turn 3) and how she could test her hypothesis (turn 5). Fran explained that one bulb took energy from the other, thus the brightness of two bulbs was different in a circuit (turn 4), yet she could not come up with how to test it (turn 6). The teacher invited others to help develop the test design (turn 7). Students suggested their ideas to solve the challenge, such as adding more light bulbs (turn 8), trying to make the bulb brightness equal by manipulating materials (turns 12 &14), and adding another battery (turn 15). As seen in Dialogue #1, the teacher also uses the strategies of clarification and expansion.

Dialogue #2.

1. Teacher: What are the things that you enjoyed about that, found interesting, what are you still wondering about? ... So, things are on your mind from working on your circuit?
2. Fran: We created a circuit and there were two light bulbs and we took down one bulb and somehow, that made the other one brighter.
3. Teacher: Ah, so you have two bulbs involved and you got rid of one and the other one was brighter. Is there something you've got to explore today or what is your thought around that?
4. Fran: I think that it's maybe the one didn't get affected, it's bulb A, caught bulb B's energy so, because it's brighter.
5. Teacher: Ok. And what could you try today to build your thoughts around that concept?
6. Fran: Errr ...
7. Teacher: Does somebody have suggestions? What could Fran's group look at today to keep experimenting with [how] bulbs are affecting each other? Kris?
8. Kris: Take four or more light bulbs in.
9. Teacher: Sure. We try extra light bulbs.
10. Kris: Yeah.
11. Teacher: OK! Anybody else have an idea for that one?
12. El: Try and make them both equal
13. Teacher: What do you mean by that?
14. El: I mean try to make them, instead one brighter than the other, but try [to make] both the same bright ...
15. Emma: Add another battery
16. Teacher: Ok, cool! So you have some options today to explore.

During this conversation, the teacher shifts an individual challenge to the whole class by inviting everyone to reason and solve the challenge. The conversation then continues (below) with a new challenge from a different group. During their previous class, Eve's group had connected a buzzer and two bulbs in a series circuit but only the buzzer turned on while the bulbs didn't light, whereas when the group put them in a parallel circuit, the bulbs and buzzer all turned on. They said they kept trying but could not figure out why. The teacher encouraged the group to explore the challenge more today (turn 17, Dialogue #2 cont'd), then Fran raised her hand and suggested an explanation (turn 18). This suggestion developed another question about Eve's challenge (turn 20) followed by Arthur's suggestion for test design (turn 22).

Dialogue #2 cont'd.

17. Teacher: Ok. So maybe you can set that up again today and look at what was going on again? Yes Fran?
18. Fran: I have something for Evelyn. I think maybe the buzzer takes up more energy than light

bulbs, more electrical energy.
19. Teacher: That's an interesting idea. What do you think? (looking at Eve)
20. Eve: The thing is then, why would the buzzer take it? There is also when we moved the buzzer to a different spot, would the light bulb take it? (overlapped with the teacher's talk, 'Uh! You guys have lots to work on today then') or the buzzer wherever we move it?
21. Teacher: (Looking at Eve) So what you could … try as you're experimenting today? What do you think of that one? Arthur?
22. Arthur: Maybe they could find out, why, how why (inaudible) to lights … moving closer
23. Teacher: Ok, we have lots to explore today!

After this conversation, students went back to their small groups and explored the ideas shared and suggested. In this episode, the teacher's initiating and responding questions were open and invitational for further inquiry to the whole class. The teacher hardly suggested any solutions or evaluation of students' ideas but encouraged students to develop each other's ideas. She asked them to make suggestions and to clarify their ideas for themselves in order to move forward with their challenges. Even without teacher initiation, students (e.g., Fran and Arthur) also started to share their ideas for experiments to resolve others' challenges (e.g., Eve's). When a challenge emerged from students, the teacher directed the challenge back to the students so that they could reason through and solve it together. The teacher facilitated the talk to develop collective reasoning and problem solving in the joint space of classroom talk by inviting students to support and help each other. In this space, the students became the agents of reasoning and problem solving and the teacher was facilitating the dialogue exchange to develop problem solving and knowledge building in relation to hands-on experiments.

Participating in and Modeling Inquiry Processes with Students

The teacher's continued use of scaffolding questions encouraged students to build their ideas together. Students' areas of wonder and problems were often discussed and developed with new and alternative hypotheses, test designs with variables, and explanations at a collective level. This collective reasoning process often led class discussion into the culture of scientific inquiry. Students suggested test designs and variables to manipulate and were eager to test the ideas that emerged during classroom talk. The following episode demonstrates how classroom talk developed into a whole-class inquiry.

One day, the class was exploring the topic of insulators and conductors. The teacher introduced an object—an "energy stick" as a provocation to compel the students to consider something new or unknown while reflecting on what they already know. This stick featured a hidden battery that was wired with sound and light resistors and produced lights and sounds when both ends were held by hands. As the teacher demonstrated it with her two hands, the lights and sound were activated. The students got very excited and wanted to try it themselves. In the following dialogue, the teacher asked a student, Diego, to join the activity. When Diego and the teacher were holding hands and each had a hand on the energy stick, the lights and sound were activated. Another student said, "try a pencil!" and others repeated, "yeah, try a pencil!" When the teacher and Diego held onto a pencil together instead of holding hands (Figure 1), the energy stick had neither sound nor lights. The teacher said (turn 1, Dialogue #3):

Dialogue #3.
1. Teacher: Ooooh! Denied! (laugh)

2. Jason: No, no, this is because, (comes close to the teacher and Diego and grabs the pencil) this is con. insulator! Because this is an insulator!
3. Others: Yeah!
4. Mike: Try scissors.
5. Jason: Yeah, scissors!
6. Eve: Is there any metal stick?

As they interacted through discussion and observed the teacher and Diego's experiment, students began to make connections to their previous experiences with conductors and insulators (turns 2-3) and they looked for metals to test (turns 4-6). Diego and the teacher each held the metal part of scissors, and the energy stick once again had light and sound. The students kept suggesting more ideas to test such as elbows, hair, shirts, and so on. As they continued to try new objects, students applied and developed their knowledge of conductors and insulators. The teacher also developed students' inquiry further by asking, "Does anybody have an idea what else could be tried that is reasonable? We are not gonna try feet and such. So what would be ok things to test?" Here, she emphasized the feasibility of test design. One student suggested that more students could join to make a bigger circle (Figure 1b) and another suggested that they could put two fingers into a small plant pot in the classroom (Figure 1c). To both the students' and teacher's surprise, the lights and sound were activated when they put their fingers in the soil of the plant pot. The teacher enthusiastically said in front of the students that she didn't expect to see this and she didn't know why it happened.

Next, the teacher presented another item—a "chirping chick"—that operated on the same principles as the energy stick. Students were excited and they tested how the two objects worked together in a big circle. One student suggested another test (turn 7 below):

Dialogue #3 cont'd.

7. Eve: What if somebody lets go (of the energy stick). See, the chick stops too.
8. Molly: Oh!!!! It's a series circuit.
9. Teacher: Molly, explain what you just said?
10. Molly: I think we are making a circle, like we did it for like… (inaudible) parallel circuit, it's series, so it shows the light bulb, how it went to the other one.
11. Teacher: Molly is saying that we saw in a series circuit, when we had two light bulbs, when one is disconnected, then the other's also not working. Is there a way that with our bodies, we can make a parallel circuit?

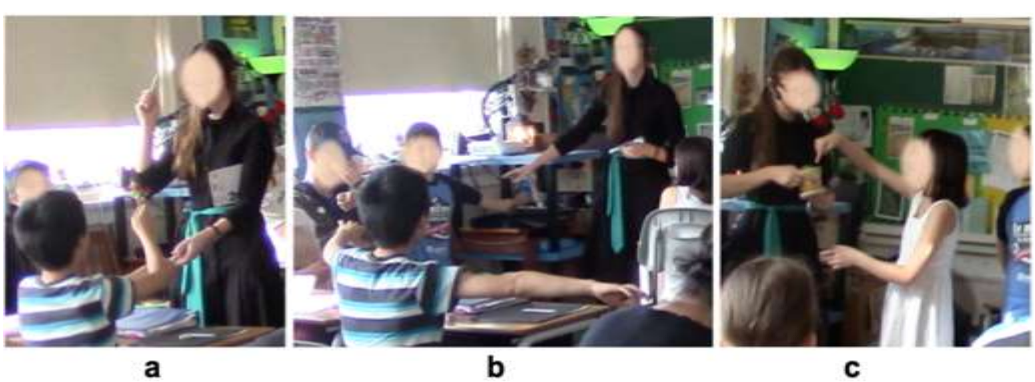

Figure 1. The emergence of inquiry

Figure 2. Making a parallel circuit

Developing Molly's findings and explanation on series and parallel circuits (turns 8 & 10), the teacher brought a new inquiry challenge for students to make a parallel circuit with their bodies (turn 11). Students suggested making a small circle on the inside and a big circle around the smaller one, so the whole class became involved in the test design (Figure 2, turn 11). Yet, they could not make the two objects work. The teacher asked students how to develop their circuit to work and ended the activity by saying (turn 12):

12. Teacher: If we have a chance or if you have some spare time, think about that concept. Can we create, the idea you have right now is, no, we can't but if anybody wants to try something else if we can use our bodies for parallel circuit, we will come back to that.

In this episode, students' responses were unknown to and unpredicted by the teacher. There were no prepared scripts for students' inquiry process. As questions, ideas, actions, materials, and outcomes were all new and emerging both for the teacher and the students, they continued to talk together and interact with their interests and curiosity. The teacher became an inquirer herself and participated in problem solving together with the students. The teacher was modeling and steering the inquiry process, being open and enthusiastic to the unknown while also suggesting guiding questions and conditions during the collective inquiry. Students developed knowledge application, inquiry design, and problem solving throughout their classroom interactions. The whole-classroom talk was a space of co-constructing and co-developing knowledge and inquiry processes for both the students and the teacher.

Discussion

Distributing the Agency of Problem Solving Among Students

Teacher scaffolding with certain structure and autonomy support is critical to enhancing students' engagement in collective reasoning and learning (Baker et al., 2017). The findings of this study show how the teacher distributed the agency of reasoning and problem solving to and among students through classroom talk. Throughout the study, the teacher continuously demonstrated the strategies of *probing and expanding the boundaries of thinking* and *developing collective reasoning and problem solving*. The teacher extended individual students' statements, questions, and areas of wonder to the whole class by inviting others to think through and develop solutions together. When students brought forth scientific terms and concepts that needed clarification, she invited them to clarify and explain further and sought more ideas from others. When a group of students shared their experimental challenge, the teacher encouraged others to suggest test designs and alternatives to experiment with and to solve the challenge. Once an individual student shared a question, idea, or problem, the teacher acknowledged, redirected, and expanded it to the whole class to think and reason collectively. Through this process, students' knowledge, reasoning and problem solving were shared and developed in a joint space.

Most of the classroom talk generally started with the process of teacher invitation—student response—teacher response. It seemed to be following the IRF/IRE exchange patterns on a structural level, yet later developed with more initiation and responses from additional students, which led to a deeper inquiry process. That is, structurally the classroom talk followed an IRF/IRE approach, yet conceptually and pedagogically the talk showed a different level of student participation in learning, reasoning and problem solving, which is what Mercer (2000) described as *explanatory talk*. Through the turn taking between the teacher and students, the role of speaker and hearer was shifting back and forth, yet the agency of knowledge building and problem solving was never moved to the teacher. The problems and ideas that emerged from the students remained in the joint space of classroom talk for students to solve and develop themselves. Table 1 shows how the content of talk was developed between the teacher and students in Dialogue #2. It shows that problems and solutions were mentioned and developed during the students' turns, not the teacher's turns. The majority of the teacher's talk was inviting and repeating students' ideas, redirecting turns, asking to clarify and help each other's problems, and developing students' inquiry.

The agency of reasoning and problem solving was shared, distributed, and built among the students. The teacher did not play the role of knowledge provider but rather was a problem-solving facilitator who encouraged students to contribute to their own problem solving, which was done with pedagogical attention to the curriculum (see Table 1).

Teacher Modeling Scientific Inquiry as a Member of the Problem-Solving Community

As the teacher invited students to develop collective reasoning and problem-solving during class discussion, a lot of new ideas and suggestions came up, which did not allow the teacher to perform scripted teaching, but rather required dialogical inquiry-based teaching. Some ideas from students were vague and some were based on alternative conceptions (e.g., magnetism in Dialogue #1). Some were experimental questions that students were eager to test in class (e.g., energy stick and human body as conductor in Dialogue #3) and some were hypotheses that could not be easily answered in the classroom (e.g., light bulbs and buzzer in parallel and series circuits in Dialogue #2). These became inquiry challenges for the teacher and students to solve together. The teacher motivated students to think critically and creatively about the challenges, and shared her own excitement and curiosity. She praised and encouraged students' ideas for further inquiry development. For instance, when students suggested new variables during the energy stick activity, the teacher shared her excitement and participated in the experiment with the students. The new findings about the soil in the plant pot surprised the teacher and she explicitly acknowledged her curiosity, wonder and uncertainty about knowing why. She said, "Wow, so interesting! I wonder how it happened. I have no idea. Anybody?" At this moment, the teacher was genuinely turning into a member of the collective problem-solving community, who was living in the moment of inquiry with her students to make sense of an unknown phenomenon. She modeled the role of inquirer with curiosity, open-mindedness, and humility to the new and unknown by sharing that she does not know and wants to know more. When engaged in small-

Table 1.

Inquiry Development Through Speaking Turns

Teacher's turn	Student's turn
What are the things you enjoyed …what are you still wondering about? ... Things are on your mind from working on your circuit?	Fran: We created a circuit and there were two light bulbs and we took down one bulb and somehow, that made the other one brighter.
Ah, so you have two bulbs involved and you got rid of one and the other one was brighter. Is there something you've got to explore today or what is your thought around that?	Fran: I think that it's maybe the one didn't get affected, it's bulb A, caught bulb B's energy so, because it's brighter.
What could you try today to build your thoughts around that concept?	Fran: Errr…
Does somebody have suggestions? What could Fran's group look at today to keep experimenting with bulbs are affecting each other, Kris?	Kris: Take four or more light bulbs in
Sure we try extra light bulbs.	Kris: Yeah
OK! Anybody else have an idea for that one?	El: Try and make them both equal
… [turns omitted]	Emma: Add another battery
Ok, cool! You have some options today to explore!	…
OK. So maybe you can set that up again today and look at what was going on again? Yes Fran?	Fran: I have something for Eve. I think maybe the buzzer takes up more energy than light blubs, more electrical energy.
That's an interesting idea. What do you think?	Eve: The thing is then, why would the buzzer take it? There is also when we moved the buzzer to a different spot, would the light bulb take it? … or the buzzer wherever we move it?
So what you could ... try as you're experimenting today? What do you think of that one? Arthur?	Arthur: Maybe they could find out why, how why (inaudible) to lights … moving closer
Ok, we have lots to explore today!	
	⇩
	Ideas and test designs developed from students' reasoning and problem solving

group problem solving, students demonstrated their own inquiry process by sharing areas of wonder and questions, testing hypotheses, and reasoning and applying knowledge to explain their findings. Based on the sociocultural theory of learning (Vygotsky, 1978), students' inquiry skills are developed through participating in inquiry processes; thus, effective teacher scaffolding that invites students to participate in the inquiry process in a collective space is critical. Researchers posit that teacher modeling of higher cognitive thinking skills such as scientific reasoning and inquiry skills is essential for students to learn and practice the skills in their own discourse (Chinn, O'Donnell, & Jinks, 2000; Cohen et al., 2002; Gillies, 2004). The teacher in this study demonstrated how to live and celebrate the moment of emerging inquiry with the students.

The classroom talk was also crucial to connect hands-on activities with reasoning and to develop students' inquiry process as both cognitive and social actions. During the talk, the teacher demonstrated how an inquiry process could emerge and develop, and how the teacher scaffolding strategies expanded students' reasoning and inquiry in a joint space of classroom talk. The teacher spread the agency of problem solving to the students and modeled how she processed her wonder and problem solving. These scaffolding strategies are examples of how to transform the IRF/IRE exchange to exploratory and participatory talk for students' reasoning and problem solving. Based on the findings, this work invites more discussion and research on scaffolding strategies for whole-classroom talk to develop a joint space of reasoning and problem solving in science classrooms.

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