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'Didn't Get Expected Answer, Rectify It.': Teaching science content in an elementary science classroom using hands-on activities

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RESEARCH REPORT

'Didn't Get Expected Answer, Rectify It.': Teaching science content in an elementary science classroom using hands-on activities

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The call for inquiry science to be a part of the school science curriculum is popular in many parts of the world. While some research in this area revealed success stories of students' learning when they are engaged in student-directed, open-ended scientific inquiry activities, others are more sceptical about how these activities impact students' learning in and of science. Using the microanalysis of classroom talk in a grade-six science classroom dealing with the conversion of energy, we illustrate the dilemma in communicative approach used by a teacher when using an inductive hands-on activity to teach canonical science content. We unravel the complexity between dialogic–authoritative approaches in establishing learning as well as the need to fulfil the teaching purposes set for each lesson. Here we illustrate how the use of fine grain analysis of classroom talk and interaction can reveal the details of classroom learning, such as mismatch of teaching purposes and adopting appropriate approach to fulfil the intended teaching purpose.

Keywords: *Hands-on activities; Inquiry science; Elementary school science*

The Problem

Inquiry-based instruction has been defined in a variety of ways, but fundamentally, inquiry is defined as a set of abilities and understandings that include asking scientifically oriented questions, designing different scientific investigations to answer

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different questions, using appropriate tools to interpret and analyse data, formulating scientific explanations using evidence, and being able to communicate and defend relationships between evidence and scientific explanations (National Research Council [NRC], 2000). Amidst the discourses in the science education community about science as inquiry, Anderson (2002) reminded us that research still does not provide a clear picture of how inquiry science can be carried out. Similarly, McNeill and Krajcik (2008) noted that there are 'few research studies that actually examine teachers' instructional practices in inquiry classrooms' (p. 54). Thus, there are few concrete examples for teachers showing what inquiry-based instruction looks like. Moreover, pedagogical issues related to tensions, dilemmas, and problems that teachers and students face in science inquiry classrooms are rarely addressed (McNeill & Krajcik, 2008). To tackle the issues related to conflicting classroom demands and varied student understandings in science inquiry classrooms, it is necessary to examine the events and interactions that occur between teachers and students engaged in science inquiry lessons. These images of interactions between teachers and students will provide the necessary information to help researchers and teachers understand the sources and causes of tensions and dilemma in the enactment of inquiry-based instruction in classrooms.

In Singapore, the science curriculum was reviewed and updated in 2008 to include inquiry as the core and guiding philosophy (Curriculum Planning and Development Division [CPDD], 2008). Science education in Singapore emphasises the acquisition of science knowledge, process, and attitudes, so as to enable students to view the pursuit of science as meaningful and useful. Science as inquiry is identified as a means for scientific knowledge, issues, and questions to be addressed. The choice of inquiry practised is dependent upon the context as well as the abilities and readiness of the learners. For example, inquiry in Singapore is not synonyms to 'open problem-solving' whereby students design and carry out investigations based on scientific questions designed on their own. Instead, the continuum from guided to open inquiry allows for a variety of strategies to be used. As a result of the emphasis on science inquiry, all science teachers have to re-examine their existing practices to enable them to incorporate elements of inquiry into their lessons. This new emphasis on science inquiry is not unproblematic since the Singaporean science classroom thrived on an extremely efficient method of curriculum delivery that is largely routined and teacher-fronted Centre for Research in Pedagogy and Practice (CRPP, 2007). Moreover, as with any educational change, there is the potential that the change may be ignored, resisted, misinterpreted, and/or selectively adopted by teachers (Lefstein, 2008). Further, there is evidence to indicate that teachers' force fit new ideas into their existing practices, often resulting in new hybrid and sometimes lethal mutants' forms of the original curriculum change (Cuban, 1993). Hence, in Singapore, the possible consequence of hastily 'grafting' inquiry into a culture that is strongly transmissive could potentially result in a form of inquiry-based instruction that is piqued by tensions about the contents of science as well as the processes of science. In this article, we present evidence from the microanalysis of classroom talk to illustrate the tensions that arose from using an inductive hands-on practical to teach grade-six students the concept of conversion of energy.

Overview of Study

This study examines the tension that resulted from the use of an inductive hands-on practical to teach the canonical concept of conversion of energy. We focus specifically on the disjuncture between the teacher's intentions and the understanding of inquiry science as well as her need to fulfil the lesson objectives of teaching the scientific content knowledge.

The interaction between a teacher and 40 students from a grade-six elementary science classroom was used as an illustrative example in this study. During the lessons, the students generated hypotheses during a phase of iterative whole class discussion with the teacher and carried out a hands-on activity that required them to hypothesise the relationship between the number of rubber bands used and the height with which their jumping toy would 'jump'. Subsequently, they (1) carried out their investigations in groups of six, (2) completed their laboratory report, and (3) were expected to arrive at the conclusion that the greater the number of rubber bands, the higher the toy would 'jump' since a greater amount of elastic potential energy is converted to greater kinetic energy. The two research questions guiding this research were:

(1) What are the tensions that exist when using hands-on inquiry activity to teach science content?
(2) What can microanalysis of classroom talk reveal about interactions in inquiry science classrooms?

Theoretical Framework

This study is informed by the core constructs of science as inquiry and classroom talk. Classroom talk is distinguished by talk between students (discourse) and talk between teacher and students (dialogic). In the following sections, we review the literature and discuss how the ideas presented in the literature shapes this study.

Science as Inquiry

What is inquiry-based science instruction or 'inquiry'? It is defined as both science content and as a way to learn science (NRC, 2000) here. More generally, inquiry refers to the methods and activities that lead to the development of scientific knowledge (Schwartz, Lederman, & Crawford, 2004). The five essential features of inquiry—(1) questions; (2) evidence; (3) explanation; (4) connections; and (5) communication—aim to stimulate the learning of scientific knowledge, skills, and attitudes among students by provoking students to inquire about the relationships between their observations and natural occurrences (NRC, 2000).

Research into inquiry processes and the influence of inquiry on the learning of science have dominated many areas of research in science education (see Anderson, 2007). In spite of the large volume of research literature in promoting inquiry in science classrooms, Duschl (2008) observed that school science is still largely 'embodied in disconnected, modularised, hands-on, and textbook approaches that have been the hallmark of elementary and secondary science curricula since the 1960s reform efforts' (p. 269). He argued that in these science classrooms, there are few meaningful connections made to the relevant contexts to facilitate the development of conceptual knowledge—there is no emphasis placed on *how* we know and *why* we believe in the presented knowledge. In fact, there have been intense debates about one of the most widespread activities in classrooms for inquiry science practical work. Abrabams and Millar (2008) found from their study that science teachers in England focused more on students' (ages 11–16 years) development of substantive scientific knowledge rather than developing their understanding of science as inquiry. Hence, the choice of practical work chosen for 'inquiry' is structured often in such a way that it is fail-proof and student-friendly. It has widely been agreed that the primary objective of using laboratory practicals in the science classroom is focused on allowing students to make the connections between the domain of concrete objects and the domain of abstract ideas (Abrahams & Millar, 2008). Further, Hodson (1996) issued a timely reminder to teachers and students to be cognised that school science inquiry experiences that allow students to design their own investigations may not be well suited for the acquisition of specific conceptual understanding as required by the curriculum. Adding to the debate on the value of practical work in helping students' learn and develop an interest in science as inquiry, Abrahams (2009) directed our attention to the fact that students' personal interests in science are not likely to develop by being engaged in practical work, but rather, they prefer practical work over writing tasks in science. Further, teachers sometimes use practical tasks merely as a means of behavioural control in the classroom. Hence, the lofty ideals that practical work is fundamental to helping students learn scientific knowledge and understand the nature of science need more attention.

The emphasis on learning science content that is presented in many science textbooks has resulted in an evident imbalance where too much emphasis is placed on 'final form science' in many science classrooms. As such, there exists a tension between the direct instruction of science and the inquiry and discovery learning of science. Teachers are eager for the students 'to do' science merely to verify or replicate results of canonical science. Nott and Wellington (1996) aptly highlighted that 'the teacher's role is to evaluate and criticise the pupils' results, procedures, and apparatus and encourage the pupils to do the same' (p. 816). Pupils, on the other hand, have to conform to the rules of science as well as the nature of schooling. Hence, they have to realise that the school practical work that they engage in does not require them to test or create theories, but rather to they are targeted to test their 'cognitive and experimental abilities as matched to an accepted body of knowledge' (Nott & Wellington, 1996, p. 816).

Before we go on further, it is appropriate to briefly consider the tension between direct teaching and what is commonly referred to as discovery learning. Discovery learning is depicted as the 'best way to get deep and lasting understanding of scientific phenomena and procedures' (Klahr & Nigam, 2004, p. 661), and learning is an active process in which learners are 'active sense makers who seek to build coherent and organised knowledge' (Mayer, 2004, p. 14). However, Klahr and Nigam (2004) found that their research results replicated the findings of other studies that direct instruction was better than discovery learning in facilitating the students' acquisition of control-of-variables strategy, which is important in the development of scientific reasoning and inquiry skills. Likewise, Kirschner, Sweller, and Clark (2006) compared guided instruction (such as direct instruction) and unguided instruction (such as discovery learning, inquiry learning, etc.), and found that the results strongly supported direct instruction during the teaching of beginner-to-intermediate learners. In addition, they found that unguided instruction appeared ineffective and might have 'negative results when students acquire misconceptions or incomplete or disorganised knowledge' (Kirschner et al., 2006, p. 84).

Dean and Kuhn (2006) replicated Klahr and Nigam's (2004) study comparing direct instruction and discovery learning over an extended time frame. They found that in the short term, direct instruction was capable of producing a significant level of positive performance. However, over an extended time period, direct instruction appeared to be 'neither a necessary nor sufficient condition for acquisition or for maintenance over time' (Dean & Kuhn, 2006, p. 384). Similarly, Mayer's (2004) review of pure discovery as a method of instruction over a three-decade period showed that it was not successful and proposed guided discovery as the preferred method. Nevertheless, he cautioned that 'the challenge of teaching by guided discovery method is to know how much and what kind of guidance to provide and to know how to specify the desired outcome of learning' (Mayer, 2004, p. 17). As illustrated later, this posed a challenge for our teacher in question.

Besides the tensions between discovery and structured instruction in science learning, another worrying factor is teachers' beliefs about the status and purposes of scientific inquiry in teaching science. Looking at teachers' views of science, Shimizu (1997) conducted a study on the prevailing instructional method used by inquiry-oriented science teachers. He compared the teaching emphasis on inquiry science and teachers' classroom practices and found that teachers' views of inquiry science are inductive rather than deductive and were influenced by inductive empiricism. Shimizu (1997) warned that as teachers' views of inquiry science were influenced by inductive empiricism, an emphasis on hands-on science might result in students acquiring a restricted view of science. As such, teachers should emphasise both hands-on activities and classroom discussion by creating a meaningful association between the two.

In a National Association for Research in Science Teaching (NARST) panel presentation, Flick, Keyes, Westbrook, Crawford, and Cames (1997) discussed the perspectives on inquiry-oriented teaching practices based on research they conducted. Flick et al. (1997) understood the difficulties teachers faced in attempting to allow students to design and conduct inquiries and yet trying to design inquiries that effectively guide students. It was suggested that working in between the two ends of the continuum (of inquiry and direct instruction) was possible by deciding what is to be learned through inquiry and reducing the tension between freedom to follow curiosity and learning consensual scientific views. For example, one can ensure that students could ask questions keeping in mind the teacher's agenda, providing opportunities for structured inquiry for targeted concepts and divergent investigation. They found that science teachers did not invest in inquiry practices because they did not perceive the laboratory as a source of instruction, and they had very few operation models. Science teachers did not know also how to integrate the processes and outcomes of laboratory investigations with students' content knowledge construction. They proposed developing strategies for classroom discourse that support more productive use of inquiry experiences and a learning community as a model for inquiry teaching where teachers and students collaborate to develop conceptual understanding.

Our knowledge of classroom discourse in inquiry-based classrooms is informed by research studies that explicitly examine classroom interactions and the use of tools and language between teachers and students. Bianchini and Colburn (2000) explored teachers' and students' discourse and practices related to the nature of science within the context of an inquiry classroom. The findings revealed that teachers have a critical role in inquiry science instruction since they must (1) offer hands-on inquiries, (2) explicitly tell students the purposes of the activities, and (3) engage students constantly in discussions that link the activities to ideas related to the nature of science. These responsibilities of teachers will ensure inquiry investigations are coupled with explicit discussions on the nature of science. Wickman and Östman (2002) examined how university students generalised when making observations of insects during practical work. The findings showed that students seldom made generalisations in terms of universal statements, and most statements were suggestive only of induction when they made the observations. The students seemed to rely upon authorities such as textbooks and lectures. However, Wickman and Östman (2002) did not see this as an incapability on the students' part to make generalisations, nor is the reliance on authorities by the students' startling. They suggested teaching students the necessary process skills (such as making inferences and critical thinking) to develop their inductive capability. Wallace and Kang (2004) studied the beliefs of science inquiry teaching and learning of six experienced secondary science teachers. The results indicated that the teachers grappled with tensions such as school culture and hindering factors including beliefs about students and students' efficacy that are associated with the assessment of skills associated with inquiry. Therefore, some teachers believed that they have to teach science concepts and explanation in a canonical way. However, the results revealed also that the teachers believed in inquiry and were able to retain interest and accomplished some level of inquiry-based activities in their science teaching. Hence there exists a misalignment between teachers' personal beliefs and actual practices of science as inquiry. Since the components of science as inquiry and teachers' beliefs are important contributing factors to the enactment in the science classroom, in the next section, we review the research depicting teachers' roles in the science classroom for teaching and learning.

Dialogic and Authoritative Roles of Teachers in Science Classrooms

The promises science inquiry holds in helping students learn science require that teachers be familiar and competent in enacting science as inquiry. How then is a teacher's role in a science inquiry classroom different from that in a traditional, transmissive classroom? How should teachers use canonical science knowledge in a science inquiry classroom? How differently will learning outcomes and learning tasks differ in a science inquiry classroom when compared with a traditional science classroom? Do teachers in an inquiry science classroom face similar challenges and dilemmas as those in traditional classrooms? These questions and many more of a similar nature demand answers so as to ensure successful and accurate enactment of science inquiry in schools. The misalignment of teachers' beliefs, roles, and intended outcomes of science inquiry instruction are often the cause of tensions and ineffective learning among students. As such, attention should be paid to teachers' roles in science inquiry, and how these roles map onto the learning intentions and outcomes of the instruction. Oh (2005) identify three major pedagogical roles that a teacher performed through his talk when guiding students through reporting their findings from scientific investigation. These roles included (1) making the appropriate and necessary scientific knowledge available to their students; (2) coaching students to improve their work; and (3) scaffolding their learning. These roles, she argued, helped to focus students' learning in science and also facilitated the development of learning socially in the classroom. Similarly, Roychoudhury and Roth (1996) and Hogan, Nastasi, and Pressley (2000) suggested one of the roles played by teachers in guiding novice learners of science was to steer students' discussions in the correct and appropriate direction. The fulfilment of these various roles highlighted by the researchers can be achieved through the use of dialogic as well as authoritative discourses between a teacher and students.

Research on communicative approaches in classrooms have shown that talk in classrooms established (1) the norms and patterns of practices and (2) the knowledge development and growth among the participants (e.g. Edwards & Mercer, 1987; Gee, Michaels, & O'Connor, 1992; Lemke, 1990; Mortimer & Scott, 2003). As such, in classrooms, 'the role of the teacher includes both communicating academic tasks and providing information of how students participate in the social activities' (Oh, 2005, p. 1826). To help fulfil the roles stated, different communicative approaches can be adopted. Mortimer and Scott (2003) suggested four classes of communicative approaches along two dimensions of dialogic–authoritative and interactive–non-interactive. Along the continuum of dialogic–authoritative, an interaction is considered dialogic when 'more than one point of view is represented, and ideas are explored and developed' (Mortimer & Scott, 2003, p. 34). With reference to interactive–non-interactive continuum, an interactive approach allows participation of others, whereas a non-interactive approach excludes the participation of others. Based on the ideals of science inquiry, one would expect a pre-dominantly dialogic–interactive form of communicative approach as a teacher leads her students to construct scientific knowledge and disciplinary norms in science. As such, it is important to examine in detail the forms of interaction and communicative approaches that take place in science classrooms in order to determine how communicative approaches can be (re)shaped to become more dialogic and interactive. This article is framed by the forms of communicative approach that are adopted by a teacher as she works with her students to establish science concepts but at the same time tries to teach them the processes of science.

Method

This article uses an illustrative case study to present a detailed episode in an actual classroom that is seemingly 'inquiry' in nature, and we highlight the tensions that arose. The value of using a case study of an actual classroom episode is that it allows us to highlight the actual events that play out in the classroom rather than events that are constructed in retrospect in the minds of teachers and students. By adopting a microanaylatic lens to examine events in the classroom that we normally take for granted, we highlight the tensions between teaching intentions and the inquiry activity chosen to achieve the goal. In an era where curriculum developers are aggressively prompting 'teacher-proof' resources and teaching aids to improve teaching, the lack of thought in implementing these 'inquiry' resources could potentially lead to tensions and misalignment of learning goals as illustrated in the manuscript. We argue here for researchers and teacher educators to privilege microanalytic methods to examine actual classroom interactions rather than merely using observation checklists and anecdotal evidences.

Context and Data Collection

The lesson presented here is taken from a larger study of classroom observations in three schools with 10 science teachers. There were two phases of data collection with a baseline data collection phase in 2007 to study the existing practices in the elementary science classrooms. Data collection was carried out by the researchers in the classroom who audio- and video-recorded the lessons and took field notes.

A year later, in 2008, the teachers read up on inquiry science and with the features of inquiry stated by the curriculum document; they jointly planned their lessons with the five essential features of inquiry referred to earlier (NRC, 2000). Classroom observations of this 'intervention' phase were again carried out by the researchers using audio and video recording and field notes. Data were collected from all the 10 science teachers based on the units of work which the teachers have chosen. Units of work included cells, matter, and energy. All the recorded lessons were transcribed and then analysed both for the phases in the entire lessons and for the turns of talk for selected excerpts. Since 'talking' to explain science is at the core of what science teachers do, the microanalysis of classroom talk that occurred during the interaction between teacher and students offers insights to what is actually happening in an inquiry science classroom (see Childs & McNicholl, 2007; Tan, 2008). In this article, we present a particular episode showing a teacher facilitating students' presentation of their results from their hands-on investigations. To select this episode, we examined the transcripts and found that 90% of classrooms that claimed to practise science as inquiry have a student presentation component. We selected all student presentation excerpts and selected one particular episode as an illustrative example of possible tensions that might be introduced into the classroom system as a result of incorporating science as inquiry into a culture that excels in transmissive instruction.

The teacher (pseudonym: Lynn) is an experienced science teacher who has taught science for 30 years. She is also the head of department for science. Her grade-six class of 40 boys and girls are around 12 years of age and in their last year of elementary school. At the end of their grade-six year, they would be sitting for a national placement examination in Singapore known as the PSLE; Lynn conducted her science lessons in the science room, where the students were seated in groups of five or six, and there were opportunities for students to carry out hands-on activities and experiments.

Lynn planned the lesson on conversion of energy using both the tenets of the five essential features of inquiry (NRC, 2000) and the 5E inquiry model (engage, explore, explain, elaborate and evaluate) (Bybee et al., 2006). This was the second lesson out of six lessons on the unit of energy. In this experiment, the students were supposed to create a 'jumping toy' by joining two cards (8.5 cm × 5.5 cm). They were instructed to determine what height the toy is able to jump when one, two, and three elastic bands are put around the toy, respectively. The step-by-step instruction on how the experiment could be carried out was printed on the worksheet (refer to Appendix) given to each student, and each group of students was given a metre ruler, a measuring tape and handful of elastic bands (these elastic bands came from a new pack of elastic bands and visually have the same length, width, and elasticity).

Data Analysis

The analysis of the video transcripts were carried in a whole to part 'inductive' manner (Erickson, 2006), which means that we (both authors) surveyed the entire recorded event as a whole before selecting segments of interest and relevance for a more detailed analysis. The excerpt is a segment showing students' reporting back after their hands-on session, and this form of reporting occurred in 90% of inquiry-centred lessons we observed. While there was variability in how the students' reporting was facilitated, we agreed that it was important to be cognisant of the possible tensions that might arise in student-reporting phase since it is so popularly used. We are reminded of Abrahams and Millar's (2008) statement that:

> even if the task is carried out as intended, and the apparatus function as it is designed to do, the students still may not think about the task and the observations they make using the ideas that the teachers intended (and perhaps indeed expected) them to use. (p. 1948)

This reminder gives importance to the phase of student reporting, and we used the selected episode to illustrate how the teacher and student negotiated and argued their ideas and observations to link their observations and the knowledge that the teacher intended for them to learn.

The episode selected was analysed using the analytic framework derived from Mortimer and Scott (2003). This framework was chosen because it provided a holistic perspective of all aspects of teaching within a single lesson. In this analytic framework, the act of teaching by the teacher is privileged, and this emphasis on teacher's action is appropriate since the results of a large-scale study carried out by the CRPP (2007) revealed that Singaporean science classrooms are predominantly teacher-fronted. This framework was based on five linked aspects of (1) teaching purposes; (2) content taught; (3) communicative approach; (4) patterns of discourse; and (5) teacher interventions as intended and enacted by the teacher. According to this framework, the following questions were considered during the analysis of each episode:

- What purpose(s) is served, with regard to the science being taught, by this phase of the lesson?
- What is the nature of the knowledge which the teacher and students are talking about during the phase of the lesson?
- How does the teacher work with the students to address the diversity of ideas present in the class during the phase of the lesson?
- What are the patterns of interaction that develop in the discourse as teacher and students take turns in the classroom talk?
- How does the teacher intervene to develop the scientific story and to make it available to all of the students?

The inductive analysis of the entire transcript corpus was performed by the two authors independently, and discussions were carried to check for consistencies in the coding, and a final decision was made about the episodes selected after both authors agreed upon the codes.

Results and Discussion

In this section, we present two key findings from analysis of the teaching episode. Firstly, we discuss the issue of tension between the authoritative and dialogic approaches in enacting science as inquiry. Secondly, we discuss the conflicting issue of teaching purposes that teachers have to grapple with as they shuttle between traditional and inquiry approaches.

Lesson Overview

The lesson began with Lynn asking a series of 12 questions to recapitulate students' knowledge on the concept that energy is needed to do work. All the 12 questions posed required single-word answers from the students. After the recapitulation phase, Lynn moved on to a teacher-led introductory activity using a manipulative (a toy that is able to move when the elastic band is wound up) to engage the students. This phase of the lesson was scaffolded by Lynn giving step-by-step instructions to direct the students what they ought to be doing next. In between giving procedural details to the students, Lynn added explanation of the concept of conversion of energy. The recapitulation and the introductory activity occupied the first 10 minutes of the lesson.

In the second phase of the lesson (lasted for 30 minutes), Lynn gave detailed procedural instructions to the students for jumping-toy experiment by making reference to the details reflected on the worksheet handed out to each student. Lynn asked the students to make predictions and write their group hypotheses for the experiment before they started. She guided them through the phrasing of their hypotheses. Lynn highlighted also the experimental precautions (such as avoidance of parallax errors, positioning of the measuring tape, etc.) which the students have to take. The students proceeded to work on the experiment in groups of six for 14 minutes with minimal input from Lynn. During this time, Lynn walked around the classroom to check that all groups of students were on task. She spoke occasionally to correct off-task behaviour.

The last phase of the lesson was the consolidation phase where there was a whole-class discussion of students' results. In this phase, the students reported their findings by presenting their data and conclusions to the class. This phase lasted for 15 minutes. Lynn maintained tight control through the three phases of the lesson by using questions and giving detailed procedural instructions to the students so that there would be little deviation of the lesson from what had been planned. The episode that we have chosen to illustrate in detail was taken from the last phase of the lesson.

Authoritative and Dialogic Approaches

In the episode presented in Excerpt 1, the specific learning outcome of the lesson, as intended by Lynn, was squarely based on the cognitive gains for the students to learn the concept of conversion of energy, and specifically in this session the conversion of elastic potential energy to kinetic energy via an inquiry mode. No learning outcomes related to inquiry process skills, such as observations and deduction, were spelled out specifically by Lynn. The primary purpose of the phase of the lesson as expressed in Excerpt 1 was to link the empirical content (data collected by the students in an earlier phase where the students worked in groups on the 'jumping toy') to theoretical science content (conversion of elastic potential energy to kinetic energy). Lynn started off this phase of the lesson in an interactive–dialogic manner by inviting students to share the data that they collected and the conclusions that they arrived at based on the data collected. Lynn did this by asking questions and guiding the students in making links between the experimental data and the experimental setup. For example in turns 8–12, Lynn asked the students to suggest reasons for the results that the

Excerpt 1. Didn't get expected answer

Line no.	Speaker		Teaching purpose	Content	Communicative approach	Patterns of discourse	Teacher interventions
1.	S5:	Toy jumped lower with more rubber bands.	Guiding students in comparing different experimental outcomes.	Empirical	Dialogic–interactive	Student's response	
2.	T:	**So do you say that your results are the opposite of the other group?**				Teacher evaluation in the form of a question	Checking student understanding
(S5 nodded)							
3.	T:	**Any reason for that? [to S5] [addressing the whole class] Did you notice that this group's result is the complete reverse of the other group? Is it they measured wrongly?**	Guiding students in making links between experimental data and experimental set up.	Empirical		Initiating another discussion	
4.	S11:	**Some cards are very hard.**				Student's response to question	
5.	T:	**Some card very hard, then?**				Evaluation	Marking key ideas
6.	S11:	**Broken easily.**				Response to evaluation	
7.	T:	Broken easily, then? But you see, the three rubber bands only 3 something (cm). Ok, afterwards can you, can you show us the toy and let's see what happens? Any group that also has some sort of, when it comes to the third rubber band, you get this type of results?				Clarification Initiation	Shaping ideas

Excerpt 1. (*Continued*)

Line no.	Speaker		Teaching purpose	Content	Communicative approach	Patterns of discourse	Teacher interventions
(one group raised their hands)							
8.	T:	**What is wrong with that?**			Dialogic–interactive	Initiation	Checking students' understanding
9.	S:	**The card is soft.**				Response	
10.	T:	The card is soft and then? When you put more rubber bands, what happen?				Evaluation in the form of a question	Checking students' understanding
11.	S11:	It can't take the …				Response (incomplete)	
12.	T:	It just bended, curved up, right, and didn't jump high enough. Ok, that is possible. Can you show us, me the toy? With three (rubber bands), now look at it here. Alright? Yes, you see the curve already. So therefore, maybe that is the reason why their toy didn't jump high. Let's see from here. [demonstrates] you see? Didn't even jump up right? See once more, watch once more. [demonstrates again] three rubber bands, that is the height. This group, are you ready with your presentation?				Initiation	Selecting ideas

Excerpt 1. (*Continued*)

Line no.	Speaker		Teaching purpose	Content	Communicative approach	Patterns of discourse	Teacher interventions
13.	S15:	Toy jumped lower with more rubber bands.				Response	
14.	T:	What is the pattern that you see here?	Guiding students to make comparison of experimental data.			Initiation	Checking students' understanding
15.	Ss:	Decreasing.				Response	
16.	T:	Same pattern as which group?				Evaluate	Checking students' understanding
17.	Ss:	Bin Xiong's group				Response	
18.	T:	Could it be the same problem with the card?				Initiation	Checking students' understanding
19.	Ss:	Yes.				Response	
20.	T:	Yes? So just now remember this card when it is three rubber bands, and now with one rubber band. So it jumped higher up, right? So something to do with this. It's not, not stiff enough. Alright, can I have one that is the, what about your group here? The last one. Can you please present now?				Initiation	Checking students' understanding
21.	S16:	Toy jumped higher with more rubber bands until with three rubber bands — increased in height and then decreased	Guiding students in making links between experimental data and experimental set up.			Response	

Excerpt 1. (*Continued*)

Line no.	Speaker		Teaching purpose	Content	Communicative approach	Patterns of discourse	Teacher interventions
22.	T:	**So you see for this one, what happened there? Increase and third one decrease. What is the reason for yours?**				Initiation	Selecting key ideas
23.	S16:	**Maybe like spoil already.**				Response	
24.	T:	**What did you notice about your card?**				Initiation	Marking key ideas
25.	S16:	**Spoil, bending.**		Empirical		Response	
26.	T:	Oh, so finally with three rubber bands, it's because it is very tight, is it? So one is bent? Alright. Because of certain reason, your card was not able to withstand the, you know as you add more rubber band, what happen?				Initiation	Checking students' understanding
27.	S:	Bend.				Response	
28.	T:	More stored energy. So it becomes very tight. And then the card bend. So in real situation also, sometimes when you do things, the result may not be as what we expect and then you have to ask why. Ask yourself why it is different from others. But, generally, majority has the increasing trend. Right, how many groups have the increasing trend? One, two, three, four. Four groups.	Developing the science concept of conversion of energy.	Theoretical	Authoritative–non interactive	Feedback	Marking key ideas Reviewing

Excerpt 1. (*Continued*)

Line no.	Speaker		Teaching purpose	Content	Communicative approach	Patterns of discourse	Teacher interventions
		Then, but then there is one group half way first, second the trend is ok. Right? Come to the third one with three rubber bands, then it doesn't show the trend (decrease). Alright? **So never mind you can rectify this situation. Get a card, do, err, get a card that is firm enough and you try again. Alright? Try again. Ok.**					
29.	T:	**So for those groups that didn't get expected answers, you have to rectify and change your card to a firmer one, and if you need this (measuring tape), you can borrow from me. Ah, alright? You can try again.**	Facilitating students' formation of the concept of conversion of energy and their experimental data. Getting the students to obtain data that would support the acceptable scientific concept that the more the rubber bands there are (more elastic potential energy), the higher the card will jump (more kinetic energy).	Procedural		Evaluation of all students' presentation	**Reviewing**

Note: The text in bold indicates turns of talk that are elaborated in the discussion session.

groups obtained. In turn 10, she repeated the students' answers and then probed the students to elaborate their answers by asking another question. In turn 12, she continued the dialogue with the students by using questions as well as a demonstration. Later, in turn 21, a group of students presented results that appeared to be a discrepancy in the trend of the height of the jumping toy. Instead of the toy jumping higher with more elastic band attached, the height that the toy gained was decreasing. Lynn continued to engage the students in a dialogic manner to elicit likely explanation for a deviation from the expected results. The students were able to offer alternatives such as the card being damaged and the bending of the cards (from turn 23 to turn 28). Throughout the interactive–dialogic phase of Excerpt 1, Lynn developed the students' ideas by delaying the affirmation on the 'E' (evaluation) move. There were eight R–I (response–initiation) couplets out of 29 turns of talk suggesting that after students response, Lynn immediately reinitiated a new question without evaluating or offering a feedback to the response given.

Once the students presented their results and voiced their opinions about the difference in trends of their results, Lynn took over control of the lesson as she switched to an authoritative voice to consolidate the data presented by the students (turns 28 and 29). Lynn presented the concluding statement of the fact that the more the rubber bands, the more the elastic potential energy, and hence the higher the toy would jump since there is more kinetic energy. The dominant mode of interaction, evident in turns 28 and 29, had Lynn instructing the students who did not get the expected answer to repeat the experiment until they obtain the trend that with more elastic bands, the card would 'jump' higher.

Based on Mortimer and Scott's (2003) framework of communicative approaches in classrooms the excerpt chosen showed that Lynn engaged in interactive–dialogic (inviting the students to present and commenting) and interactive–authoritative (in respond to the students' presentation, she stated the final answer) forms of communicative approaches. We argue here that the shuttling between interactive–dialogic and interactive–authoritative approaches is necessary. In the interactive–dialogic mode, the students have a voice in the common learning space. They are able to present their results, make suggestions about the experiment they were involved in and be aware of how science and scientific knowledge are talked about. This is aligned to the learning of science as characterised by Ford and Foreman (2006) where students need to be engaged in a practice of roles (either as a constructor of claims or as a critiquer of claims). In most instances in Excerpt 1, Lynn critiqued student ideas to direct the students' learning. However, this interactive–dialogic mode in the classroom opened up also to other possibilities in terms of scientific explanations and alternatives that the teacher may not have been ready for. In Excerpt 1, Lynn, clearly, was not ready to accept alternatives to the increasing trend of height achieved by the toy when more elastic bands are attached. It was evident here that while Lynn engaged the students in a dialogue, she maintained her authority as the arbiter of knowledge. She ended the lesson on an authoritative manner by declaring the knowledge that the students were responsible for knowing. While it might appear that this authoritative stance taken by Lynn was contradictory to the dialogic approach she was taking earlier and should be discouraged, we argue that this authoritative voice of Lynn complemented the dialogic process by ensuring that the teaching purpose of the lesson was fulfilled. In fact, Ford and Foreman (2006) reminded us that authority resides with the community, and in this instance, it was the scientific knowledge acceptable by scientists and not merely the community of students in the class. The students in this instance did not have the authority to decide what counted as acceptable scientific knowledge. Clearly, the students were expected to learn that with more elastic bands; there would be more elastic potential energy that would correspondingly be converted to more kinetic energy, and this would result in the toy 'jumping' higher.

Teaching Purposes

The teaching purpose of this lesson was to develop students' conceptual understanding of conversion of energy. Lynn chose to allow her students to carry out a hands-on investigation to teach this concept without explicitly highlighting the gains in inquiry process skills as an outcome of the lesson. When Lynn engaged the students in an interactive–dialogic manner to present their results and findings from their hands-on experience, her purpose was to allow a platform for the students to present their work on how empirical knowledge is linked to theoretical knowledge as indicated by her lesson plan. Through this phase of the lesson, Lynn's intervention appeared largely in the form of checking students' understanding and marking key ideas. There were 12 instances of checking students' understanding and marking key ideas out of 17 turns of talk by Lynn. It appeared that the primary purpose of checking students' understanding and marking key ideas was to prepare the students for the next phase of the lesson. This is evident from turn 28 onwards where Lynn adopted a more authoritative stance by pronouncing the correct empirical knowledge and the accurate scientific knowledge that the students needed to take away with them from the lesson. Since the teaching purpose of the lesson as well as Excerpt 1 was to ensure that the students learn specific science concept, any deviation from what is planned and intended was disturbing. As a result, Lynn instructed to students who did not obtain the expected answer to repeat their experiments until they were able to get the right answers.

This episode highlighted an issue of multiple teaching purposes that science lessons try to fulfil. Teachers have to make decisions at every moment in the lesson about the purposes and learning outcomes of each activity. Judging Excerpt 1 from the lens of inquiry science, it would be easy to dismiss the lesson as a failed attempt at inquiry due to the strong control exercised by Lynn over the progress of the lesson as well as her decision for the students to repeat the experiment despite logical explanation for the deviation in trends. However, if one assesses the lesson from the lens of learning purposes, this excerpt showed that Lynn ensured that the students understood the process of data gathering and critique, but more importantly, they know what is acceptable, and how results relate to the concept of conversion of energy.

Implications

The tension that arose from using an inductive inquiry method to teach canonical science concepts is partially caused by the disequilibrium between the need to teach the correct science content and the need for students to be engaged in the processes of science. While the situation highlighted above presented an opportunity for Lynn to generate a conversation with the students regarding experimental design and how it can be improved—to identify that the two variables (number of elastic bands and the type of card used to make the jumping toy) in the experiment instead of one—she did not view the 'critical incident' (Nott & Wellington, 1996) as a learning opportunity since this was not a teaching purpose she planned for the lesson. As a result, she failed to acknowledge the fact that her students had understood the reasons for deviation from the expected trend and, by offering valid explanations for the deviation, had exhibited what Shepardson and Moje (1999) termed as knowledge restructuring or conceptual change. The interactive–dialogic exchange on the reverse trend offered an opportunity for Lynn and her students to collaboratively engage in knowledge construction and scientific reasoning (Echevarria, 2003) of experimental design and validity of data collected. Conversations between Lynn and her students could also be generated around how the experiment could be redesigned to improve the validity of the experiment in showing the concept of conversion of elastic potential energy to kinetic energy.

Examining Lynn's lesson from a macro perspective suggested that Lynn's science lesson had the elements of inquiry with its scientifically oriented question, hands-on activities, predicting, observations as well as classroom discussion of the results, as intended by using the 5E model to plan the lesson. However, microanalysis revealed some tensions between the intended teaching purpose and the process of inquiry to create a meaningful association between the hands-on activities and the discussion (see Shimizu, 1997). The discussion, while seemingly dialogic, showed evidence of strong scaffolding and control by Lynn since the process of soliciting and confirming students' answers had to align with what Lynn expected to hear. From the interaction between Lynn and her students, we observed also that Lynn nominated her students to answer questions, and feedback was usually given in the form of another question or an explanation by Lynn. She deliberately steered her students down a specific, predetermined path, performing her role of directing students to the correct scientific knowledge as reported by Oh (2005). It was clear that her students were more listening to her than participating in the discussion. As such, there were few opportunities for the students to experience 'the use of talk to actively work on their own thinking and learning experiences' (Burns & Myhill, 2004, p. 47). During the discussion, the explanations offered by her students were not built upon to further the discussion (see Burns & Myhill, 2004; Myhill & Warren, 2005). Lynn used the classroom discussion or talk for teaching rather than for learning purposes and, as a result, missed out on critical moments to fulfil teaching purposes, such as allowing students to experience and practise being flexible and allowing the students to direct the discussion (Burns & Myhill, 2004). A critical moment is defined by Myhill and

Warren (2005) as 'a discourse unit where the teacher's utterance is significant either in supporting the development of a child's understanding or in hindering it, or where an opportunity to build on a child's response was missed' (p. 59).

During a post-lesson conference, Lynn shared that she was caught up in the culture of examination preparation and that the high-stakes examinations would require the students to know the 'correct answer', as similarly described in Wallace and Kang (2004) as one of the hindering factors that limit inquiry. Lynn was, thus, more concerned with the students learning the content and meeting the science content objectives of the lesson than learning and going through the actual inquiry science process.

Lynn's plan appeared to design an interesting inquiry science experiment with the jumping toy. However, during the process of the lesson and in the discussion, we could see how Lynn reverted back to a teacher-centred approach, whereby she tightly controlled the structure and the pace of the lesson as well as the direction of the discussion. In the actual enactment of her lesson, Lynn limited her students' curiosity, and they had to learn consensual scientific views. The balance along the two ends of the continuum between traditional science instruction and inquiry-based science learning (see Flick et al., 1997) was not achieved. As Mayer (2004) put it, teachers needed to know how much and what kind of guidance to provide to the students and to know how to identify the desired outcome of learning in the students. In this case, it is clear that Lynn needs to be guided and supported in the clarity of teaching purposes and the forms of interaction that she should adopt when she endeavours to use inquiry science (Bianchini & Colburn, 2000).

As seen in the excerpt, Lynn led the discussion with questions for the students, and she often gave explanations to the students. When the students responded, they often gave simple answers and seldom elaborated on them. This passiveness in Lynn's students could be attributed to the fact that they looked upon Lynn, the teacher as the authority in science, and thus they relied heavily on Lynn to provide the explanations as she often did in the discussion of the results. As suggested in Wickman and Östman (2002), this was not the incapability on the students' part, but simply that the students were not given any opportunities to develop and use their inductive skills and abilities.

The strong focus on all the students obtaining the same trend (answer) by conducting the experiment and repeating the experiment has led to a loss in the richness of discussion or conversation around how experimental design affects the kinds and types of data and knowledge which is generated. The presence of 'noise' in the experiment is albeit a richer and more meaningful conversation than merely learning about the fact that when there are more elastic bands, there would be more elastic potential energy, which would cause the jumping toy to jump higher. It is unfortunate that pupils and teachers in the school science culture are constrained by the accepted canon of knowledge (Nott & Wellington, 1996) as indicated by the scientific enterprise, curricula documents as well as assessment guidelines. The margin of flexibility is narrow, and hence, the move away from canonical science needs to be given more emphasis as well as the move away from learning science as a procedure, a series of steps and expected results.

Conclusion

In this article, we set out to answer two research questions. The first question relates to the tension which might exist when using hands-on activities to teach science content. We provided evidence that tension could exist possibly when using hands-on activities to teach canonical science content. The emphasis on ensuring the accurate canonical knowledge of science and the process skills in science might result in teachers dismissing one form of knowledge for others. Consequently, students' ideas about science, which are influenced by their experiences in the classroom, could be affected. For example, as seen from the case of Lynn, who gave emphasis to correct answers, and are disregarding experimental evidence and explanation, might ultimately result in students possessing the view that scientific knowledge and the processes of science are fixed. However, if there was an overemphasis on process skills, with little regard for the scientific knowledge, that are already available, then we tend towards relativism where students might start thinking that scientific knowledge could be anything they make it out to be. Hence, the use of dialogic-authoritative modes and the teaching purposes of every activity and interaction needs to be carefully considered to avoid tensions.

The second research question to be answered is 'What can microanalysis of classroom talk reveal about interactions in inquiry science classroom?' To this question, we showed that microanalysis of classroom talk revealed details in the interaction and talk between the teacher and the students that can easily be missed out if we merely analyse an event from a macro perspective. As the burden of education work, be it science education or other discipline areas, is carried out through talk and other gestural forms, Goodwin and Heritage (1990, p. 283) aptly reminded us of the importance of placing emphasis on examining the interaction between people. They claimed that 'social interaction is the primordial means through which the business of the social world is transacted, the identities of the participants are affirmed or denied, and its cultures are transmitted, renewed and modified' (Goodwin & Heritage, 1990, p. 283). In this article, we present evidence that analysis of talk between Lynn and her students using a microanlytic lens of talk revealed the tension between the intent of the lesson and the actual lesson that was enacted. It revealed to us how orderliness was maintained in the science classroom, and how this means of control by Lynn resulted in students experiencing a form of inquiry science learning which is likely to be unique to them. These minute details of how science is presented are not evident when the lesson is viewed through checklists or coding schemes built to analyse the macro structures of the lesson.

The decision to adopt an interactive–dialogic or interactive–authoritative approach in an inquiry classroom depends on the teaching purposes that the teacher is trying to achieve. Within a single lesson, there could be different teaching purposes, and hence the teacher will shuttle between interactive–dialogic and interactive–authoritative approaches. Tensions or conflicts arise when teaching purposes are unclear, or when a teacher tries to incorporate too many teaching purposes within a single activity. The students may not understand the teaching purposes and view the shuttle between interactive dialogic–authoritative modes as confusing. Different teaching purposes demand different modes of operation by the teacher as well as the students, and these will result in different forms of classroom interaction and learning by the students. In this article, we illustrated how Lynn shuttles between interactive–dialogic and interactive–authoritative approaches in trying to establish a balance between students' practice of science inquiry process skills and the establishment of canonical content knowledge in science.

To summarise, in this article, we have highlighted three fundamental issues in examining elementary science classrooms. The first issue is the tension brewing between the teaching of science content using experimentation and teaching the processes of science in the context of a particular content. Is reconciliation between the teaching of content and process possible? While the teaching of science content is important, overemphasis on that would result in learning experiences that ignore how science knowledge is formulated, and why we choose to believe the knowledge as presented to us. Students are at risk of learning a reductionist and simplistic model of science, which is stripped of any tenets of the nature of science.

The second issue is the need for teachers to recognise the importance of critical moments in their classroom discussion or talk to generate meaningful learning. Teachers need to take note of key moments in the classroom interaction which opens up for them to take advantage of, to provide a greater learning opportunity for their students. Myhill and Warren (2005) identified three types of critical moments: (1) those that created confusion in learning, (2) those that carefully steered the discourse along a predetermined path, and (3) those that were responsive to pupil learning, with the first two types being more common in the classrooms. Teachers need to re-examine their roles in classroom discussion or talk and learn to promote learning by exploring ways to make their classroom discussion more participatory and learning-centred for the students.

In the light of the tensions between canonical science and inquiry-based instruction in science, we suggest three aspects where attention could be paid to help teachers reflect upon their practices and also to help science educators develop strategies to help their pre-service science teachers. First, teachers need to be aware of and reflect upon their own epistemological understanding about science teaching as well as science inquiry. This would increase teachers' sensitivity towards their own practices as they move along the continuum from traditional, transmissive mode of instruction to one which is inquiry-based. Teachers need to be cognisant of their location along this continuum before they are able to make sense of their actions in their classrooms. While Lynn did not exhibit evident change in her practice in the classroom, she indicated that her awareness of the different factors affecting science classroom experience of her students has increased. Second, science educators need to develop a perceptive lens to observing practices of teachers in classrooms so that they are more sensitised to actual events and interactions in the classrooms. Rather than to rely on retrospective information and reflection from teachers about their practices to make suggestions for improvements, observing what actually happens in the classrooms offers invaluable insights into how science is enacted in schools. Finally, teachers need to be more cognisant about alignment between the science activities chosen and the teaching purposes that they aim to achieve. In this study, Lynn's exhibited superficial change from being a largely didactic and transmissive teacher to one who allowed her students to work on activities.

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Appendix. Details reflected in students' worksheet

Aim: To investigate elastic potential energy

Materials needed:

2 plastic cards (e.g. phone cards, cash cards, credit cards)
3 rubber bands
Sticky tape or masking tape
Scissors
Metre rule

Method and Results:
Making the toy
Use 2 plastic cards of the same size to make a toy.

(a) Cut grooves on each card.
(b) Join the cards together with sticky tape.
(c) Fix an elastic band to the cards.

Conducting experiment
1. Spread out the toy and press it down on the floor. Then let go your finger to release the toy.

(a) What happened to the rubber band when the toy was spread out?
(b) What happened to the toy when it was released?
(c) What was the toy's energy source?

2. Measure how high the toy can jump when it has

- 1 rubber band
- 2 rubber bands
- 3 rubber bands

Have 3 tries each and record the measurements. Then find the average heights.

(a) What was the pattern between the average height and the number of rubber bands the toy had?
(b) When did the toy receive the most energy? Give a reason for your answer.
(c) Why do you think we need to have 3 tries for each rubber band and calculate average heights?