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Revisiting the Authoritative–Dialogic Tension in Inquiry-Based Elementary Science Teacher Questioning

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Building on the 'questioning-based discourse analytical' framework developed by Singapore-based science educator and discourse analyst, Christine Chin, this study investigated the extent to which fifth-grade science teachers' use of questions with either an authoritative or dialogic orientation differentially restricted or expanded the quality and complexity of student responses in the USA. The author analyzed approximately 10 hours of classroom discourse from elementary science classrooms organized around inquiry-based science curricula and texts. Teacher questions and feedback were classified according to their dialogic orientation and contextually inferred structural purpose, while student understanding was operationalized as a dynamic interaction between cognitive process, syntacto-semantic complexity, and science knowledge type. The results of this study closely mirror Chin's and other scholars' findings that the fixed nature of authoritatively oriented questioning can dramatically limit students' opportunities to demonstrate higher order scientific understanding, while dialogically oriented questions, by contrast, often grant students the discursive space to demonstrate a greater breadth and depth of both canonical and self-generated knowledge. However, certain teacher questioning sequences occupying the 'middle ground' between maximal authoritativeness and dialogicity revealed patterns of meaningful, if isolated, instances of higher order thinking. Implications for classroom practice are discussed along with recommendations for future research.

Keywords: *Teacher Questions; Inquiry-Based Science; Dialogic and Authoritative; Classroom Discourse Analysis*

Perhaps the most visible trend in elementary and secondary science education reform over the last two decades has been a fundamental pedagogical shift away

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from teacher-centered transmission models toward inquiry-based science teaching and learning. Firmly grounded in the sociocultural–constructivist paradigm, inquiry theories of science education began to emerge as early as the late 1950s with the overarching goal of recasting students as active participants in the co-construction of both novel and canonical scientific knowledge (DeBoer, 1991). Despite several decades of inquiry-focused research and practice, a cursory glance at the recently published titles in influential science education journals (e.g., Lederman & Lederman, 2013; Lin, Hong, Yang, & Lee, 2013; Patchen & Smithenry, 2013) suggests—along with the recommendations of several federally commissioned expert reports (American Association for the Advancement of Science, 1993; National Research Council [NRC], 1996, 2000)—that inquiry-based science education continues to enjoy currency among both scholars and policy-makers alike. Yet even as we have reached some degree of consensus on the merits of its basic principles, successful school-level implementation of inquiry-based science education has historically eluded even its most enthusiastic proponents.

One among many areas of science education research that has attempted to diagnose and address the challenges in implementing inquiry at the instructional level is discourse analysis. Alternating their analytical lens between macro- and micro-level structures in classroom discourse, discourse analysts have worked to identify those linguistic features, conversational turns, and pragmatic moves that appear to either promote or constrain inquiry-based teaching and learning. One such structure that has received considerable attention from not only science education discourse analysts, but also from scholars across the educational spectrum has been teacher questioning, and in particular what have come to be known as 'Initiation–Response–Evaluation or Feedback' (IRE/IRF) sequences (Mehan, 1979; Sinclair & Coulthard, 1975). The pervasiveness of these 'triadic' (Lemke, 1990) teacher question sequences has been widely documented in nearly every educational subject area, including second and foreign language teaching (Gourlay, 2005; Miao & Heining-Boynton, 2011; Waring, 2009), social studies (Shams-un-Nisa & Khan, 2012), and mathematics (Herbel-Eisenmann & Breyfogle, 2005; Temple & Doerr, 2012). In science education, discourse analyses of teacher questioning practices have commonly sought to identify ways in which triadic question sequences support or run counter to the goals of inquiry-based teaching and learning (Aguiar, Mortimer, & Scott, 2010; Chin, 2006, 2007; Nassaji & Wells, 2000; Scott, Mortimer, & Aguiar, 2006; Tan & Wong, 2012; van Zee & Minstrell, 1997a, 1997b). The purpose of the present study was to build on this work by describing how fifth-grade science teachers used two common forms of triadic question sequences—authoritative and dialogic—to differentially restrict or expand both the quality and complexity of student responses in an inquiry-based science classroom.

Guiding Principles and Challenges of Inquiry-Based Science Education

Though definitions of what precisely constitutes inquiry-based science education have historically varied, most appear to converge on the common underlying goal of 'engag[ing] students in the investigative nature of science' (Haury, 1993). Varying

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interpretations of this basic guiding principle have led to different curricular and instructional movements, including relative emphases on providing students with regular 'hands-on' science activities 'to make sense of concrete and realistic experiences' (Roychoudhury, 1994, p. 87); 'minds-on' instruction to promote higher order and rational scientific thinking (Duckworth, Easley, Hawkins, & Henriques, 1990); and, more recently, sustained opportunities to develop skills of evidence-based argumentation and explanation through classroom discussion (Abell, Anderson, & Chezem, 2000; McNeill & Pimentel, 2010). Each of these components of inquiry-based science education is reflected in the National Science Education Standards' definition of inquiry:

> Inquiry requires identification of assumptions, use of critical and logical thinking, and consideration of alternative explanations. Students will engage in selected aspects of inquiry as they learn the scientific way of knowing the natural world, but they also should develop the capacity to conduct complete inquiries. (NRC, 1996, p. 23)

While the National Science Education Standards' definition of inquiry appears to espouse a constructivist approach to learning science through student-led inquiries and critical reflection on 'alternative explanations', the notion of learning '*the* scientific way of knowing the natural world' underscores a critical tension between open-ended, discovery-oriented learning and the diffusion of canonical science knowledge. For while inquiry-based instruction in principle favors the idea of learning as process, the reality that students are ultimately assessed on their ability to recall an ever-increasing body of scientific facts on standardized tests places considerable constraints on inquiry. As science teachers work to reconcile their students' process- and product-oriented learning objectives, questioning then becomes an important tool to push students to think critically and independently about observed scientific phenomena while simultaneously guiding them toward the 'official', state-sanctioned facts that will appear on their end-of-year examinations. These tensions are often negotiated through authoritative and dialogic question sequences.

Discourse Analyses of Authoritative and Dialogic Triadic Question Sequences

In the science education literature, analyses of IRE/IRF question sequences have commonly distinguished between two basic forms—authoritative and dialogic. As with many theoretical constructs, authoritative and dialogic sequences have been understood and operationalized differently across studies. Some scholars differentiate between the two through reference to the global shape of the interactional sequence. Authoritative sequences can be understood as those that follow a strictly three-part or 'triadic' pattern, while dialogic sequences can extend beyond three turns to form larger 'chains of interaction' between the teacher and the students (Scott et al., 2006; Wells, 1999). Others (including the author) maintain that even the most extensive dialogic sequences are still inherently triadic, as the epistemic asymmetry (Drew, 1991) between teachers and students in formal school settings still overwhelmingly

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grants the ostensibly more knowledgeable teacher the interactional right to final word (see Results and Discussion). That having been said, most education researchers characterize as authoritative those sequences that are premised on a single, typically canonical, voice or epistemology, while dialogic sequences, by contrast, elicit and explicitly or implicitly validate multiple voices or epistemologies. Put differently, *authoritatively oriented* (AO) questions are satisfied by a fixed response, while *dialogically oriented* (DO) questions can accommodate responses beyond those already known to or predetermined by the questioner.

Given the strong constructivist orientation of inquiry-based science education, it is perhaps unsurprising that discourse analysts in the science education literature have tended to emphasize the value of dialogic question sequences as an effective tool to promote student-centered learning, while generally disparaging the discursive and pedagogical limitations that authoritative question sequences place on students (Chin, 2006, 2007; Roth, 1996; Russell, 1983; van Zee, Iwasyk, & Kurose, 2001; van Zee & Minstrell, 1997a, 1997b). For example, in her analysis of teacher questioning in a science class of middle school children in Singapore, Chin (2006) found that when teachers limited their use of AO devices such as 'explicit evaluation or put-downs' and increased their use of DO moves such as 'acknowledgement of students' contributions, restatements of students' responses, and . . . pos[ing] subsequent questions that built on students' earlier responses', they were able to 'promote productive talk activity in students at a level beyond mere recall' (p. 1343).

While many researchers have recommended that teachers adopt more DO questioning practices, others have argued that a balance between authoritative and dialogic sequences is necessary given the diverse goals that teachers establish for their students (Aguiar et al., 2010; Nassaji & Wells, 2000; Scott et al., 2006; Tan & Wong, 2012). Based on their analyses of classroom discourse in an inquiry-based high school science class in Brazil, Scott et al. (2006) concluded that teachers navigated a 'necessary tension' between authoritative and dialogic question sequences. They argued that 'transitions between dialogic and authoritative interactions [were] fundamental to supporting meaningful learning of disciplinary knowledge' (p. 605). Efforts to understand this tension have been complicated in certain international contexts, such as Singapore, 'where students are expected to show respect for the teacher and where it is less socially acceptable for students to compete with the teacher in dominating the conversational floor, lest this be interpreted as their being disrespectful' (Chin, 2006, p. 1343). The goal of the present study was to build on this past scholarship by investigating the extent to which differences in student response quality were associated with variation in teachers' use of questions with either an authoritative and dialogic orientation in US schools. Special attention was also devoted to certain 'in-between' cases that failed to fit neatly into the typical or idealized patterns of discourse. A better understanding of the middle ground between authoritativeness and dialogicity may help educators to more effectively negotiate the pedagogical tensions that Scott et al. (2006) and others have described.

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Methodology

Data Collection

This study draws on a subset of qualitative data from a curricular and teacher professional development intervention for fifth-grade inquiry-based science and language development (Buxton, Lee, & Santau, 2008). The intervention was developed with the goal of providing both language minority and native English-speaking students with a science curriculum that engages them in inquiry-based science learning and language development, while simultaneously preparing them for standardized state assessments in science content knowledge (Buxton et al., 2008). At the time of this study, the intervention was in its first of three years of implementation as a scale-up project in fifth-grade classrooms throughout a large southeastern state. Participating in the project were a total of 66 schools in 3 counties, including 33 schools who used the treatment textbook and received treatment professional development and 33 control schools who conducted 'business as usual' for their science curricula and professional development.

Given its size, the research design of the intervention relied primarily on quantitative data sources, including a range of surveys, questionnaires, and pre- and post-tests to gather baseline and impact data. However, primarily as a measure of fidelity of implementation, the project conducted a series of classroom observations, with one teacher from each participating school receiving two classroom observations per academic year. The observation data take the form of a near-verbatim transcript of the teacher and student dialogue, along with general descriptions of the classroom environment.

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Sampling. A subsample of these transcripts was the focus of analysis in the present study. Given my interest in documenting the discourse practices of inquiry-based science classrooms in particular, I elected to limit my analysis to observation data collected from one of the three counties, where both treatment and control schools had inquiry-based fifth-grade science curricula and texts.[1] As outlined earlier, the treatment schools received the intervention curriculum and text, whose 'units are designed to move progressively along the continuum of teacher-explicit to student-initiated inquiry' (Buxton et al., 2008, p. 501). Each unit features hands-on activities that follow an inquiry framework with seven sequential steps: (a) questioning, (b) planning, (c) implementing, (d) concluding, (e) reporting, (f) inquiry extension (i.e. reflection), and (g) application to the real world and/or novel contexts (Lee & Associates, 2012). The control schools meanwhile used a district-developed inquiry-based science textbook adapted from the Understanding by Design® curriculum framework (Wiggins & McTighe, 2005). Each unit requires students to conduct investigations or inquiry activities to develop understanding in targeted science content benchmark topics. To generate a manageable sample of schools and teachers, of the 44 total classroom observations (22 treatment and 22 control) that were conducted in this county, I randomly selected 10 transcripts for close analysis, from 5 treatment and 5 control classrooms. This sample amounted to approximately 10 hours of classroom discourse (or 23% of the total number of observation hours for this county).

Data Analysis

The primary aim of the present study was to describe the ways in which teachers and students communicated orally in an inquiry-based science classroom to determine to what extent the use of authoritative and dialogic question sequences provided differential opportunities for student higher order thinking and knowledge-building. Drawing primarily on Chin's (2006) 'questioning-based discourse analytical' framework, I developed a deductive coding scheme during preliminary analyses to classify (a) the different functions of teacher questions and feedback and (b) the varying cognitive and structural characteristics of student responses. Scott et al. (2006) characterized dialogic sequences as those in which the classroom discourse appeared to 'recognize and attempt to take into account a range of students', and others', ideas' (p. 610). In advancing their definition of dialogicity, the authors' made clear that while a questioning *sequence* can be classified as either dialogic or authoritative, discourse analysts 'cannot classify a single utterance as being dialogic or authoritative' on the grounds that dialogicity and authoritativeness are collaboratively co-constructed by the teacher and the students (p. 627). While I agree with Scott et al. that an isolated teacher move cannot be considered definitively dialogic or authoritative independent of the student response, I propose that certain teacher questions, by virtue of their structure and inferred purpose, can display an *orientation* to either dialogicity or authoritativeness, which the student(s) may either ratify or resist with their responses. Teacher questions were therefore classified according to their dialogic orientation and contextually inferred structural purpose. DO questions were those which designedly accommodated non-fixed responses or multiple voices and epistemologies. In contrast, I coded teacher questions as AO when they appeared to elicit normative or formal school-based canonical knowledge. In the service of concretizing dialogic orientation, I adopted Chin's (2006) classifications of teacher question purposes, which varied according to the pragmatic function that the question was contextually structured to generate. Examples of teacher question purposes included eliciting, probing, extending, clarifying, challenging and prompting. With respect to teacher feedback, my analytic framework departs from those used in previous studies (e.g. Scott et al., 2006) in that I do not make use of the dichotomous categories of 'evaluation' and 'feedback' to classify teacher moves that follow up student responses. By recasting the third-position teacher move as a single generic category, 'feedback', with *multiple functional variants*, it becomes possible to characterize a much wider range of what I call utterance 'purposes' (Chin, 2006). Teacher feedback was therefore coded (much like the teacher questions) according to the apparent pragmatic function of the move, with examples including direct affirmation, affirmation plus elaboration, neutrality, explicit or implicit correction, restatements (of individual student responses), and consolidation (of several student responses into a single, coherent summary).

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During early rounds of coding, I classified student responses on two dimensions from Chin's (2006) analytical framework: (a) the cognitive process involved in answering the teacher's question and (b) the syntacto-semantic complexity of the utterance. Given the infeasibility of 'gain[ing] direct access to the minds of the students', I followed Chin's example and determined the cognitive process for each student response by considering the apparent function of the response in both the immediate context of the preceding teacher question and the broader context of the discourse of the focal and entire lesson (p. 1322). Examples of cognitive processes inferred from student responses included simple factual recall, as well as 'higher order cognitive processes' such as observation (i.e. of scientific phenomena experienced in the classroom), hypothesis formulation, evaluation (i.e. of a student or teacher thought; agreement/disagreement), explanation, deduction, and prediction (Chin, 2006, p. 1321).

Though the structural features of student responses were not a primary focus of her study, Chin (2006) suggests in the discussion of her findings that syntacto-semantic complexity may provide a reasonable proxy for evaluating student understanding in classroom discourse analyses. As an example, she cited the Structure of Learning Outcomes (SOLO; Biggs, 2003; Biggs & Collis, 1982) as one potentially useful existing taxonomy for classifying students' understanding according to the syntactic and conceptual complexity of their responses. Though SOLO has historically been used to evaluate evidence of student understanding in short-to-extended written responses, for the present study, I adapted the five categories of the taxonomy—prestructural, unistructural, multistructural, relational, and abstract—to the predictably sparser utterances of oral student responses in elementary classroom discourse. Thus, for the purposes of the present analysis, prestructural responses involved no more than one or two words or a single noun phase; unistructural responses had at least one clause or sentence; multistructural responses had more than one clause or sentence; relational responses drew connections between concrete phenomena and one or more larger concepts; and abstract responses demonstrated evidence of higher order understanding of concepts beyond the immediate context.

After conducting preliminary analyses of student responses according to cognitive process and syntacto-semantic complexity, I determined that a third, separate dimension that could account for the nature of knowledge demonstrated would provide a fuller picture and more theoretically robust operationalization of student understanding. I therefore carried out a subsequent set of analyses using Shavelson, Ruiz-Primo, Li, and Ayala's (2003) framework of science knowledge to classify student responses as demonstrating one of four distinct categories of knowledge: declarative ('knowing that'), procedural ('knowing how'), schematic ('knowing why'), and strategic ('knowing when and where'; pp. 7–8). In sum, after three rounds of coding, the final combined construct operationalized student understanding as a dynamic interaction between cognitive process, syntacto-semantic complexity, and science knowledge type.

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Results and Discussion

To illustrate the larger patterns in the data, I have elected to present three episodes that represent three points on a theoretical continuum of dialogicity and student understanding. At one end of the continuum are teacher question sequences that are maximally authoritative with very limited evidence of student higher order thinking, while on the opposite end of the continuum lie triadic sequences that are maximally dialogic with strong evidence of student higher order thinking. Toward the middle of the continuum we encounter authoritative or dialogic teacher question sequences in which students demonstrate at least some evidence of higher order thinking. In the three episodes to follow, I provide a brief account of the classroom context and overall lesson of each episode before proceeding to describe the noteworthy patterns of teacher and student discourse.

Episode 1: Authoritative Question Sequence with Very Limited Cognitive, Structural, and Epistemological Diversity

In the lesson from which this first episode was taken, the students and their teacher were exploring the theme: 'How can electricity light a bulb?' Notably, over half of the class time was dedicated to a hands-on inquiry task in which students investigated electricity with a battery to light a bulb. In this activity, students were arranged in small groups and each was given the opportunity to manipulate three materials—a battery, a wire, and a light bulb—in an effort to discover for themselves how energy is transferred in a closed circuit. Students worked in their groups to hypothesize how they might arrange the materials in order to successfully light their bulb based on their theoretical knowledge of a closed circuit, and then they proceeded to experiment with multiple configurations until they found the correct one(s). Illustrations of the correct configuration were then recorded in their notebooks for later discussion. The excerpt in Table 1 was taken from the beginning of this lesson, during a teacher-led review of the relevant concepts of light energy, heat energy, and chemical energy, along with the processes of transferring and transformation.

Description of general discourse patterns. Episode 1 provides a very clear example of a maximally authoritative teacher question sequence that affords students minimal discursive space to demonstrate breadth or depth of knowledge. This episode began at Turn 1 with a triadic sequence that the teacher initiated with a question that was structured to elicit a fixed factual student response about a specific property of energy in Turn 2. Feedback, though generally thought of as an overt teacher move, need not be explicit and in fact was not for many of the highly authoritative sequences in the data set. This first sequence of Episode 1 provides an instructive example, wherein tacit affirmative feedback was provided in Turn 3 by simply moving on to a new question about a different theme or process (here, energy transfer). This pattern of *fixed AO question → satisfactory student response → new fixed AO question* repeated unaltered from Turn 1 through Turn 13. It was not until the triadic sequence

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Table 1. Example of an authoritative question sequence with very limited cognitive, structural, and epistemological diversity

Turn	Speaker	Utterance	Move[a]	Purpose of utterance	Cognitive process	Type of knowledge	Syntacto-semantic complexity
1.	Teacher	Now look at 10.2. Energy cannot be . . . ?	I	Elicit, fixed	–[b]	–	–
2.	Student 1	Created or destroyed.	R	Reply	Recall	Declarative	Prestructural
3.	Teacher	What's another word for moving? What do you call it when you move to another school?	I	Elicit, fixed	–	–	–
4.	Student 2	Transfer.	R	Reply	Recall	Declarative	Prestructural
5.	Teacher	There's a series of movies out. What are these things that change? It's one of my favorite movies. . . .	I	Elicit, fixed	–	–	–
6.	Student 3	Transformers!	R	Reply	Recall	Declarative	Prestructural
7.	Teacher	Transform means to what?	I	Elicit, fixed	–	–	–
8.	Student 4	Change.	R	Reply	Recall	Declarative	Prestructural
9.	Teacher	If I take the sun, and I shine it down on the sidewalk, what am I doing?	I	Elicit, fixed	–	–	–
10.	Student 5	Transferring.	R	Reply	Recall	Declarative	Prestructural
11.	Student 6	Transforming.	R	Reply	Recall	Declarative	Prestructural
12.	Teacher	I'm transferring the energy from the sun that's then going to transform into what?	I	Elicit, fixed	–	–	–
13.	Student 7	Heat energy.	R	Reply	Recall	Declarative	Prestructural
14.	Teacher	Glow sticks. What kind of energy is in a glow stick?	I	Elicit, fixed	–	–	–
15.	Student 8	Light.	R	Reply	Recall	Declarative	Prestructural
16.	Teacher	No. . . .	F	Correct, implicit	–	–	–
17.	Student 9	Chemical energy.	R	Reply	Recall	Declarative	Prestructural
18.	Teacher	Yes, that's transformation from chemical energy into light energy.	F	Affirm	–	–	–

[a]Moves are coded "I" for Initiation, "R" for Response, and "F" for Feedback.
[b]For the purposes of Tables 1–3, a dash (–) indicates that a given code category does not apply to the speaker.

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beginning at Turn 14 that the pattern was slightly adjusted, when the teacher asked an AO question about glow sticks, in this case structured to elicit the fixed response of 'chemical energy'. When the student in Turn 15 responded, 'Light', he failed to reproduce the fixed factual content that the teacher's AO question had attempted to elicit. This effectively triggered a break in the pattern, at which point the teacher provided overt feedback for the first time in the episode via an implicit correction in Turn 16 by signaling that the student response was unsatisfactory ('No. … ') but without explicitly stating why. This leads to another student offering a second attempt at a factual response in Turn 17 to the teacher question posed in Turn 14. This time the student response satisfies the fixed content originally sought by the teacher, who closes the sequence with overt affirmative feedback to signal to the student and the rest of the class that the answer was indeed the correct one.

Perhaps the most striking pattern in Episode 1 is the total uniformity of student response quality throughout the episode. The three right columns in Table 1 (and all subsequent tables) represent the three indices—cognitive process, type of knowledge, and syntacto-semantic complexity—that together constitute student understanding. Virtually every student response in this episode was characterized by simple factual recall, expressed in one to two words or a phrase (prestructural) that demonstrates only a declarative form of knowledge (e.g. the student response in Turn 2 provides only evidence that the student knows that energy cannot be created or destroyed, not how (procedural), why (schematic), or under what circumstances (strategic)). Though Episode 1 represents one extreme of the continuum of dialogicity and student understanding, this pattern of *closed AO teacher question → declarative, prestructural recall student response → affirmative (tacit or explicit) or corrective feedback* was very common across all transcripts analyzed in this study. This pattern of discourse is contrasted directly with the discourse analyzed in the following episode, which features a highly dialogic triadic question sequence with student responses that encompass a wide range of cognitive processes, syntacto-semantic complexity, and knowledge types.

Episode 2: Dialogic Question Sequence with High Cognitive, Structural, and Epistemological Diversity

In this second episode, much like the first, the majority of class time was devoted to a hands-on inquiry activity. In this case, the students were investigating how to 'measure the volume of irregular objects' using the water displacement method. The class began with a very brief teacher-led review of how to use a graduated cylinder and read it correctly from the bottom of the meniscus at eye level. The students were then arranged in small groups and equipped with water, a graduated cylinder, and three irregularly shaped objects—a linking cube, a crayon, and a marble. The students took turns filling the graduated cylinder with water and recording the base volume of water before dropping each of the irregular objects into the graduated cylinder and recording the new volumes. The excerpt in Table 2 is a teacher-initiated, but student-led

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Table 2. Example of a dialogic question sequence with high cognitive, structural, and epistemological diversity

Turn	Speaker	Utterance	Move	Purpose of utterance	Cognitive process	Type of knowledge	Syntacto-semantic complexity
1.	Teacher	Alright, so today's topic is going to be on how do we find volume of irregular matter. ...	I	Elicit, open	–	–	–
2.	Student 3	I want to start.	R	Reply	–	–	–
3.	Teacher	Okay you can start. You have 3 minutes. Ready? Go.	F-I	Affirm, elicit, open	–	–	–
4.	Student 3	Texture, size, and irregular shapes are all properties of matter.	R	Reply	Explain	Declarative	Abstract
5.	Student 10	Well not irregular shape, but any shape.	R	Reply	Evaluate	Strategic	Multistructural
6.	Student 8	We find the volume of irregular shapes by finding a certain um. ... I'm not quite sure what it is called. Volume if I can assume, and you put an irregular shape in water and see how it is going in.	R	Reply	Explain	Declarative	Multistructural
7.	Student 15	Volume is the amount of space an object takes up and mass is like weight, but different. That is what volume is.	R	Reply	Explain	Declarative	Abstract
8.	Student 11	To find the volume of something that can roll ... um ... never mind.	R	Reply	–	–	–
9.	Student 12	I agree with [Student 8], but you find the volume of the water first, and then you put the object in the water and measure the difference.	R	Reply	Evaluate	Strategic	Relational
10.	Student 2	The way I would find the volume of an irregular shape is I would put water into a graduated cylinder, and then I would put an object in the graduated cylinder making sure the water would cover the whole object. And I would see if the water would increase or decrease.	R	Reply	Explain	Procedural	Multistructural
11.	Student 13	I agree because that is how I did it. I put an object in water.	R	Reply	Evaluate	Procedural	Multistructural

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12.	Student 5	Volume is what is inside an object ... like how much.	R	Reply	Explain	Declarative	Relational
13.	Student 11	How would you measure the volume of an object if it didn't fit in a graduated cylinder?	I	Elicit, open	–	–	–
14.	Student 15	You could get a bigger graduated cylinder.	R	Reply	Hypothesize	Strategic	Unistructural
15.	Student 5	There is probably a different graduated cylinder that is used in science maybe.	R	Reply	Hypothesize	Strategic	Multistructural
16.	Student 7	I agree with [Student 8].	R	Reply	Evaluate	Declarative	Unistructural
17.	Student 16	What are the properties of matter that we could use?	I	Elicit, open	–	–	–
18.	Student 2	Could you say that again?	I	Clarify	–	–	–
19.	Student 8	All of them.	R	Reply	Recall	Declarative	Prestructural
20.	Student 6	Getting back to [Student 11's] question, you could use a measuring cup or something really big because they have those measuring notches.	R	Reply	Hypothesize	Strategic	Multistructural
21.	Student 5	You could find one that's as big as you would probably use, like he was saying, like this huge object, so maybe there is something else that you could use.	R	Reply	Hypothesize	Strategic	Multistructural
22.	Student 15	That is a lot.	R	Reply	Evaluate	Declarative	Unistructural
23.	Student 8	To answer, you might use something small.	R	Reply	Hypothesize	Strategic	Unistructural
24.	Teacher	Time's up. I did let you go over a little bit, but that is because you really started having a great discussion.	F	Affirm	–	–	–

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Table 3. Example of an authoritative question sequence with moderate cognitive, structural, and epistemological diversity

Turn	Speaker	Utterance	Move	Purpose of utterance	Cognitive process	Type of knowledge	Syntacto-semantic complexity
1.	Teacher	Plants are found in two groups. What are they?	I	Elicit	–	–	–
2.	Student 1	Flowering and not flowering.	R	Reply	Recall	Declarative	Prestructural
3.	Teacher	What's the difference?	F-I	Probe	–	–	–
4.	Student 21	One has flowers and one no flowers.	R	Reply	Explain	Declarative	Unistructural
5.	Teacher	True? No.	F	Correct, implicit	–	–	–
6.	Student 20	Use flowers to reproduce.	R	Reply	Recall	Declarative	Unistructural
7.	Teacher	Good. They use flowers to reproduce. What do roots do?	F-I	Affirm, elicit	–	–	–
8.	Student 22	They bring in water.	R	Reply	Recall	Declarative	Unistructural
9.	Teacher	What else?	F-I	Extend	–	–	–
10.	Student 4	They work like an anchor?	R	Reply	Recall	Declarative	Unistructural
11.	Teacher	Ok. What about the stem?	F-I	Elicit	–	–	–
12.	Student 13	It's like a backbone.	R	Reply	Deduce	Declarative	Unistructural
13.	Teacher	What?	F	Clarify	–	–	–
14.	Student 19	Also an elevator.	R	Reply	Deduce	Declarative	Prestructural
15.	Teacher	Where you gettin' this crazy stuff?	F	Challenge	–	–	–
16.	Student 19	Cuz it takes stuff to the upper parts.	R	Reply	Explain	Schematic	Unistructural
17.	Teacher	Raise your hand if [Student 19] confuses you? What function makes the stem like an elevator?	F-I	Challenge, probe	–	–	–
18.	Student 19	Stem transports water and nutrients.	R	Reply	Explain	Declarative	Relational
19.	Teacher	Ok. The leaf?	F-I	Affirm, elicit	–	–	–
20.	Student 13	Turns sun into sugar.	R	Reply	Recall	Declarative	Unistructural
21.	Student 24	Attracts pollinators.	R	Reply	Recall	Declarative	Unistructural
22.	Teacher	What part is the male part?	I	Elicit	–	–	–
23.	Student 24	Stamen.	R	Reply	Recall	Declarative	Prestructural
24.	Student 14	Anther.	R	Reply	Recall	Declarative	Prestructural

25.	Teacher	Filament and anther—don't worry about those crazy words. What would happen if plant did not have its stamen?	F-I	Affirm, extend	–	–	–
26.	Student 20	The plant wouldn't be able to make pollen.	R	Reply	Hypothesize	Strategic	Unistructural
27.	Teacher	What's the female part of the plant called?	I	Elicit	–	–	–
28.	Student 2	Pistil.	R	Reply	Recall	Declarative	Prestructural
29.	Teacher	What's at the bottom of the pistil?	I	Elicit	–	–	–
30.	Student 25	Ovary.	R	Reply	Recall	Declarative	Prestructural
31.	Teacher	What is inside the ovary?	I	Elicit	–	–	–
32.	Student 15	Eggs.	R	Reply	Recall	Declarative	Prestructural
33.	Teacher	How does an egg become a seed?	I	Extend	–	–	–
34.	Student 1	The egg gets fertilized when pollen goes into female pistil from male part.	R	Reply	Explain	Declarative	Multistructural
35.	Teacher	What's that called that she talked about—egg gets fertilized when pollen goes into female pistil from male part?	F-I	Extend	–	–	–
36.	Student 4	Fertilization?	R	Reply	Recall	Declarative	Prestructural
37.	Teacher	No.	F	Correct, implicit	–	–	–
38.	Student 2	Pollination?	R	Reply	Recall	Declarative	Prestructural
39.	Teacher	Yes.	F	Affirm	–	–	–

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discussion that took place toward the end of the lesson, immediately following the completion of the hands-on inquiry task described earlier.

Description of discourse patterns. In Episode 2, we encounter a triadic question sequence that is maximally dialogic; the teacher provided ample discursive space for her students to not only demonstrate considerable breadth and depth of scientific understanding but also lead the discussion quasi-autonomously. Episode 2 began with the teacher initiating a dialogic sequence in Turn 1 with an open question about the methods of determining the volume of irregularly shaped objects. In the context of the lesson, which culminated in an open discussion of the outcomes of the students' in-class inquiry activity, the teacher question was structured to accommodate a range of possible student interpretations, as opposed to a single, fixed, and canonically informed response. After initiating the sequence with the open question in Turn 1 and accepting a student's request to begin discussion in Turn 3, the teacher did not speak again for another 20 turns, when she signaled the end of the discussion (Turn 24) and provided general positive feedback. Once given the floor in Turn 4, Student 3 prefaced the discussion of specific methodological techniques with a declarative explanation of relevant properties of matter. Coded at the abstract level of syntacto-semantic complexity, this student's response drew upon several abstract properties to offer a synthesized and decontexualized account of the properties of matter. In the following turn, Student 10 evaluated Student 3's response by qualifying (and thereby employing strategic knowledge of where or when) the latter's explanation of the properties of matter in a multistructural (in this case, biclausal) response. The discussion proceeded in this fashion throughout the episode, with students demonstrating a wide range of cognitive processes (explanation, evaluation, hypothesis formulation, and recall), knowledge types (declarative, procedural, and strategic), and syntacto-semantic complexity (prestructural, unistructural, multistructural, relational, and abstract). Two students even extended the original teacher-posited question by asking their own DO questions in Turns 13 and 17.

Just as in Episode 1, Episode 2 represents another extreme on the continuum of dialogicity and student response quality, with the teacher affording sufficient space for a variety of student voices and with students demonstrating a diverse range of cognitive processes, syntacto-semantic complexity, and knowledge types. However, in contrast with Episode 1, this pattern of open, primarily student-led discourse was comparatively rare across the data set. More common were authoritative and dialogic sequences that fell toward the middle of the continuum, as in Episode 3, where certain types of teacher questions—and student responses—appeared to trigger isolated instances of higher order thinking, even within an authoritative sequence.

Episode 3: Authoritative Question Sequence with Moderate Cognitive, Structural, and Epistemological Diversity

The lesson from which this final episode was taken also featured a significant inquiry-based activity, this time with the aid of technology. Using an interactive online

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simulation program known as Gizmos^{TM}, the students were able to examine the effects of the independent variables of light, water, soil type, and fertilizer on several dimensions of plant growth, including plant height, plant mass, leaf color, and size. Gizmos^{TM} models the growth of plants over 50 days under the environmental conditions specified by the user, enabling students to conduct controlled experiments in a short lesson that might otherwise have taken several weeks in real time. For this lesson, students were instructed to grow three plants controlling for light, water, and soil type and then create two experimental groups—one that would receive compost and another that would receive fertilizer. The students took note of several indices of plant growth, such as height and mass, on charts and index cards. The excerpt in Table 3 was taken from the end of the lesson, during a teacher-led follow-up discussion of the key concepts from the activity and a relevant reading on plant characteristics.

Description of discourse patterns. Episode 3 began in much the same way as Episode 1, with the teacher initiating an authoritative triadic sequence with a series of questions structured to generate fixed factual student responses. However, what distinguishes Episode 3 from Episode 1 is the variety of teacher question purposes found in Episode 3. Whereas the majority of teacher questions in Episode 1 merely elicited isolated surface facts before moving on, in Episode 3 the teacher frequently followed up her fact-eliciting questions with questions that probed (Turns 3 and 17), extended (Turns 9, 25, 33, and 35), or challenged (Turns 15 and 17) student understanding.

The potential function of teacher extension questions. A notable example began at Turn 22, when the teacher asked an AO question, 'What part is the male part [of the plant]?' that was structured to be satisfied by the fixed response, 'the stamen'. The student in Turn 23 then responded correctly with a typical declarative, prestructural factual recall response, 'Stamen'. Rather than moving on upon eliciting the fixed response, the teacher follows up in Turn 25 with a conditional extension question, 'What would happen if [the] plant did not have its stamen?' This question effectively required students to apply their knowledge of the target concept—in this case the reproductive function of the stamen—to a situated, hypothetical context beyond that discussed in the class. The result was a student response in Turn 26 that featured a cognitive process of hypothesis formulation and demonstrated strategic knowledge—the only examples of either in Episode 3. Another important example of the function of extension questions emerged in the sequence that began at Turn 31. As in the previous example, the teacher began by asking a fixed question, 'What is inside the ovary?', which generated a declarative, prestructural recall response, 'Eggs', from a student in Turn 32. The teacher then extended in Turn 33 by asking a 'how' question—the first and only in this episode—that resulted in a multistructural student response—also the only case in this episode.

The potential function of challenging student responses. Apart from a greater variety of teacher question purposes, what further distinguishes Episode 3 from Episode 1 is an isolated, but important instance of higher order thinking that was actually triggered not by a teacher question, but a provocative student response. In Turn 11, the teacher

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asked the students an AO question about the function of plant stems that led in this case to student responses that took the form of deductive analogies—'a backbone' (Turn 12) and 'an elevator' (Turn 14)—the latter of which the teacher challenged, saying in Turn 15, 'Where you gettin' this crazy stuff?' Whether this was intended as an implicit correction or a request for elaboration, the student appears to have taken it as an opportunity to explain himself further in Turn 16 in what is the only example of schematic (why) knowledge demonstrated in any of the three episodes: 'Cuz it takes stuff to the upper parts [like an elevator].' The teacher pushed back again in Turn 17, asking the class if the student's analogy was confusing to them before probing the student to once more explain his meaning, 'What function makes the stem like an elevator?' This finally prompted the student in Turn 18 to connect his concrete, experientially derived understanding of stems to the more abstract concept of stems serving the biological purpose of 'transporting water and nutrients'—the only example of a relational level of syntacto-semantic complexity in this episode.

Final Thoughts

One of the primary goals of this study was to determine whether (and to what extent) teachers' use of AO or DO questions was associated with different qualities of student responses. The contrasting examples of Episodes 1 and 2, though occupying extreme ends of a continuum, closely mirror Chin's (2006) and others' general findings that the fixed nature of AO questioning can dramatically limit students' opportunities to demonstrate higher order scientific understanding, while DO questions, by contrast, often grant students the discursive space to demonstrate a greater breadth and depth of both canonical and self-generated knowledge. Analyzed as the interaction between cognitive process, syntacto-semantic complexity, and knowledge type, student understanding in Episode 1 was uniformly limited to declarative, prestructural recall responses. In sharp contrast, the student responses in the highly dialogic Episode 2 demonstrated four different cognitive processes, five levels of syntacto-semantic complexity, and three different types of knowledge.

The discourse analyzed in Episode 3 speaks to a second fundamental goal of this study, which was to examine how teacher question sequences that occupy the 'middle ground' between maximal authoritativeness and dialogicity may enable some significant, if isolated instances of higher order thinking. Though Episodes 1 and 3 were both classified as authoritative, certain moves in Episode 3—by both the teacher and the students—resulted in a few student responses that displayed a greater diversity of cognitive processes, syntacto-semantic complexity, and knowledge types than was seen in Episode 1. The most salient difference was the use of extension questions, especially those that took a form other than simple 'What is X?' questions, which characterized every teacher question in Episode 1. Simply by asking follow-up conditional 'what would happen to X if Y?' or 'how' questions, the teacher in Episode 3 was able to push students to speak more (increasing syntacto-structural complexity), think about different aspects of scientific concepts (diversifying knowledge types), and move beyond simple recall (toward higher order cognitive processes).

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What these findings ultimately suggest is that there may be ways that teachers can encourage what Chin (2006) described as higher order, 'productive talk' within an authoritative sequence—without reinforcing a detrimental trend 'towards relativism where students might start thinking that scientific knowledge could be anything they make it out to be' (Tan & Wong, 2012, p. 217). In addition, that a student response in the form of a provocative, experientially conceived deductive analogy was able to move the sequence of questioning toward higher order thinking reinforces a critical need that has been echoed by others (Scott et al., 2006; van Zee et al., 2001) to consider more closely the role of student-, rather than teacher-, initiated dialogue. Thus, as educators reflect on their discursive practices and attempt to reconcile their students' product- and process-oriented learning goals, they need not straddle the polar strategies of maximally AO and DO questioning. A simpler, and possibly more effective practice, may lie somewhere in between.

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Note

1. To clarify, though the larger experimental study from which these data originated incorporated control schools in order to systematically compare differences between the treatment and control group schools with regard to multiple measures involving teachers and students, a meaningful, rigorous comparison of discourse practices between the two groups was neither feasible nor relevant for the present study. Instead, control schools were included simply to draw on a wider range of inquiry-based discourse practices.

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