Guidance, Conceptual Understanding, and Student Learning: Enactment of an Inquiry-Based Science Curriculum

Erin Marie Furtak
University of Colorado, Boulder

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Abstract

How does inquiry-based teaching help students to learn standards-based science content? This paper is a multiple-method exploration of the nature of guidance four middle school teachers provided during discussions during an inquiry-based physical science unit about density. Pre and posttests of students' conceptual understanding identified teachers whose students had high and low learning gains through the course of the unit. Videotapes of each teacher's lessons were then coded according to a framework of authoritative, dialogic, and blended guidance, as well as the conceptual levels addressed during discussions. Results indicate that the teachers whose students had higher learning gains at the end of the unit shifted more often between authoritative and dialogic communicative approaches, and led discussions which more closely mapped onto the expected conceptual progression underlying the unit. The study highlights the importance of actively shifting guidance to develop students' conceptual understanding during inquiry-based teaching.

Investigating Guidance at the Intersection of Inquiry-Based Teaching and Standards-Based Content

During the current era of unprecedented accountability to educational standards in the United States, inquiry-based teaching, or the method of learning and teaching science in which students engage in the activities and thinking processes of scientists, has been the centerpiece of reform (NRC, 1996; 2001; 2007). Teaching science in ways consistent with inquiry-based reforms necessitates fundamental shifts in the ways teachers and students interact, particularly in scientific classroom discourse, and many obstacles exist to creating a balance between simple scientific facts and deeper, sustained investigation (Yerrick, 2005). These realities raise the question of how teachers can scaffold inquiry-based dialogue so that students learn standards-mandated science concepts. The teacher must facilitate student participation in discussion of the evidence collected while simultaneously making sure that students reach conclusions based upon accepted scientific facts and principles. Despite the wealth of studies conducted to date on classroom talk during inquiry-based lessons, Scott, Mortimer, and Aguiar (2006) argue that "there is a limited body of evidence that shifts in communicative approach can have a positive impact on measured student-learning outcomes in relation to science concepts" (p. 624). This paper explores the discussions led by four middle school teachers at the end of inquiry-based investigations to guide students' construction of an understanding of relative density.

Inquiry and Conceptual Understanding

Research spanning the last 40 years has shown that engaging students in lessons in which they receive little or no guidance is not the most effective way to help students achieve specific learning goals (Brown & Campione, 1994; Hardy, Jonen, Möller, & Stern, 2004; Klahr & Nigam, 2004; Mayer, 2004; Shulman & Keislar, 1966). More recent approaches to inquiry-based teaching and learning incorporate a Vygotskyian perspective which relies upon the concept of the ‘zone of proximal development,’ the space in which all learners are able to perform tasks under the guidance of more knowledgeable others that they would not be able to do alone (Vygotsky, 1978). This conception of social constructivism acknowledges that social interaction is integral to conceptual development (Palinscar, 1998). Within a classroom, there will be multiple zones of proximal development that must be simultaneously mediated by the teacher in order to facilitate meaningful student learning (Brown & Campione, 1994).

The scaffolding metaphor often has been used to describe the way teachers manipulate the zone of proximal development around multiple students during lessons. In the early days of science education reform, Bruner (1960) defined scaffolding as “a way that assures that only those parts of the task within the child’s reach are left unresolved, and knowing what elements of a solution the child will recognize though he cannot yet perform them” (p. xiv). In the last decade, educational researchers have explored how various strategies and tools aid teachers in the process of scaffolding student activities during inquiry-based investigations. These important contributions include, but are not limited to, what Ball & Cohen (1996) called ‘educative curriculum materials’ that support teachers in developing knowledge and skills appropriate for reform-based science teaching (Davis & Krajcik, 2005; Schneider, Krajcik & Blumenfeld, 2005); scaffolding student inquiry with technology-based learning environments (e.g. Linn, Clark, & Slotta, 2003; Quintana et al., 2004); metacognitive supports (White & Frederiksen, 1998); and texts that resemble scientists’ research notebooks (Hapgood, Magnusson, & Palinscar, 2004).

Putambekar & Hübscher (2005) found that these tools address the pedagogical challenges of helping students through complex tasks by providing organizing structures for constructing arguments and explanations, consequently making the scientific process less opaque. However, they argued that these tools simultaneously present an over generalized conception of scaffolding that has evolved beyond its original focus upon the relationship between tutor (more knowledgeable other, e.g. the teacher) and tutee (learner). The form of support these tools take is 'blanket support', meaning it is constant for all learners and is not sensitive to changing levels of understanding and not reactive to the multiple zones of proximal development present in classrooms. Putambekar & Hübscher concluded that the teacher, as the more competent individual, is the one who is best able to adapt to the evolving knowledge and skills of their students, resulting in interactions that vary from individual to individual. They concluded that while these tools are an important step in providing instructional supports to students, more research is needed to explore how these tools can be made less static and more adaptive. Furthermore, they echoed Palincsar's (1998) assertion that researchers should consider the "relationship between scaffolding and good teaching" (p.1).

Guidance in Teacher-Student Discourse

Any reform-based science lesson where students have some amount of autonomy in conducting investigations involves a point at which data collection is complete, and the teacher must facilitate a discussion in which students analyze the evidence they have collected and develop some kind of explanation for the phenomenon they have been investigating. The teacher must simultaneously allow students to engage in the process of knowledge construction and to make sure the discussion results in the concepts they are expected to learn.

Brown & Campione (1994), in a now-classic exploration of guided discovery, asserted that the teacher plays the most important role in orchestrating activities in the classroom, creating a balance of guidance and discovery to develop students' understanding. Through the strategies teachers use during discussions, they can coordinate a zone of proximal development as a halo of social learning around students (e.g. Lave & Wenger, 1991; Vygotsky, 1978). This halo has the students and what they are able to collectively establish through discussion at its center, and on the outside the assistance the teacher provides in reaching scientifically accepted conclusions.

Therefore, to explore how teachers establish and work within this halo of social learning during discussions, it is necessary to develop an analytic framework that makes possible identification of the different instructional moves teachers make during discussions.

Numerous studies have analyzed the role of teacher talk as one type of scaffold that supports the introduction of scientific knowledge and ways of explaining; these studies have clarified the ways in which teachers make scientific knowledge available to students during classroom discussions (Scott, Asoko, & Leach, 2007; Yerrick & Roth, 2005). For example, some studies have explored the changing role of the teacher at different grouping levels (Hogan, Nastasi, & Pressley, 2000; Kelly & Crawford, 1997; Roth, 1996), while other studies identified the questioning strategies teachers used to elicit students' thinking in different instructional contexts (Bell & Cowie, 2001; vanZee, Iwasyk, Kurose, Simpson, & Wild, 2000; Vellom & Anderson, 1999). Still others have emphasized the importance of the teacher having extensive knowledge of how students learn a particular concept so that the teacher may recognize students' thinking and move them toward learning goals (e.g. Carpenter, Fennema, & Franke, 1996).

In terms of defining teacher and student conversations as they relate to scaffolding students' understanding in inquiry-based lessons, Lemke (1990), Cazden (2001), and Scott (2005) contribute the most relevant frameworks. Lemke (1990) divided teacher strategies into two categories, *Dialogue* and *Monologue* strategies. While dialogue strategies feature the students and teacher constructing meaning collaboratively, monologue strategies involve the teacher as the primary speaker soliciting only minimal contributions from students. As a result, monologue strategies allow the teacher to maintain more control over the pattern of thematic (conceptual) development; that is, the monologue strategies are more guided.

Similarly, Cazden (2001) elaborated on Mehan's (1979) original framework for three-part instructional sequences. This sequence, commonly referred to as 'IRE,' involves the teacher

Initiating a sequence by asking a question, the student *Responding*, and the teacher *Evaluating* the student's response. Alternately, the teacher can conclude the sequence by providing some form of *Feedback* to extend the student's response (IRF). The IRE/IRF pattern, commonly employed in what Cazden called "traditional" lesson structures, allows the teacher to maintain control over the course of a discussion. In contrast, "nontraditional" patterns feature 'real' questions to which the answer is not known to the teacher, and meanings are shared and negotiated among teacher and students. Cazden emphasized that teachers need "to have a repertoire of lesson structures and teaching styles, and the understanding of when one or another will be most appropriate for an increasingly complex set of educational objectives" (2001, p. 56).

Scott (1998), following Vygotsky (1978), explored how higher mental functioning was made possible for students in a social context, explicating what he called *Features of Authoritative and Dialogic Discourse.* Authoritative discourse involves information transmission, with a controlled outcome, where students speak in response to teacher questions, and their contributions are often single words or short phrases interspersed in longer sections of teacher talk. In contrast, Dialogic discourse involves several voices, and makes possible the joint construction of knowledge (Varelas, Pappas, & Rife, 2005). Teacher questions are meant to make students think, and statements are open to challenge and debate. Student contributions are longer, complete thoughts, and are also often tentative and open to the interpretation and elaboration of others.

Taken together, the different kinds of instructional strategies described by Lemke and Cazden, and further developed by Scott, can be used to characterize the nature of guidance provided by teachers during discussions as scaffolds for conceptual understanding (Table 1).

Table 1. Teaching Strategies Featuring More or Less Teacher Guidance (based on Cazden, 2001; Lemke, 1990; Scott, 1998)

Dialogic Teaching Moves – *Teacher and students jointly construct narrative/discussion*	
Asking "real" or open questions	Teacher asks a question of a student or entire class to which the answer is not necessarily known or expected by the teacher
Spontaneous contributions	Students provide unsolicited comments not directly elicited by teacher
Revoicing/reflecting student responses	Teacher repeats verbatim what a student has responded without changing or altering the meaning of the statement. Includes when a teacher repeats in a question-style format or asks student to clarify what s/he said, or to refer that comment to another student.
Meaning into Matter	Teacher uses materials to illustrate or respond to a point or idea raised by student or teacher
Promoting disagreement/ leaving lack of consensus	Teacher asks students to share divergent ideas, air differences, or encourages students to disagree or not reach consensus.
Providing neutral responses to students	Teacher repeats student responses, or provides comments that do not indicate whether student statements are correct or incorrect
Authoritative Teaching Moves - *Teacher controls course of narrative/discussion*	
Cued elicitation of students' contributions	Teacher asks questions while simultaneously providing heavy clues, such as the wording of a question, intonation, pauses, gestures, or demonstrations, to the information required.
Sequence of repeated questions	Teacher asks the same/similar questions repeatedly to seek a particular answer, and continues asking the question/s until answer is provided by students.
Selecting and/or ignoring students' contributions	Teacher ignores a student's contribution, or selects a particular contribution from a chorus of different ideas stated by students
Reconstructive paraphrase or recap	Teacher recasts or paraphrases what student has said in a more complete or acceptable form, or in preferred terminology, including when the teacher adds to or changes the meaning of what the student has said
Narrative	Teacher lectures, reviews storyline of unit, lesson, or activity, or speaks in an uninterrupted flow to students
Formulaic Phrases	Teacher uses a particular phrase that is easy for students to remember and repeats it over and over again
Marking significance	Speaking slowly or changing tone so students know what is being said or what has been said is important
Promoting/establishing consensus	Teacher encourages students to agree or come to a consensus
Providing Evaluative Responses	Teacher clearly indicates, through words or intonation, that a student's comment is correct or incorrect

Scott (1998) suggested that teachers should shift between authoritative and dialogic features of discourse, achieving a balance between opportunities to explore ideas and present information in a “rhythm” to the discourse (p. 85). More recently, Scott, Mortimer, & Aguilar (2006) argued that “Any sequence of science lessons, which has as its learning goal the meaningful understanding of scientific conceptual knowledge, must entail *both* authoritative and dialogic passages of interaction” (p. 606).

If Scott’s framework for the ‘rhythm of the discourse’ is an effective way to build students’ conceptual understanding, then teachers whose students have higher learning gains will exhibit teaching that features a blend of authoritative and dialogic discourse strategies. Furthermore, teachers who blend discourse strategies would also be expected to have students that show clear development of conceptual understanding through the course of a unit. To address these hypotheses, this paper applies Scott’s framework of dialogic and authoritative discourse strategies to teacher-led discussions during inquiry-based science lessons.

Method

The research reported in this paper is a multiple-method analysis of whole-class discussions that took place at the end of inquiry-based investigations (Smith, 2006). Two sources of data were relevant: first, classroom videotapes of teachers as evidence of discourse strategies used during an inquiry-based unit; and second, embedded assessments, administered at four measuring points through the unit, which exhibited the extent to which students met conceptual learning goals.

Curriculum

The unit explored in this study was taken from *Foundational Approaches to Science Teaching* (FAST; Pottenger & Young, 1992), a standards-aligned middle school science curriculum. The investigations in FAST combine inquiry-based activities with a conceptual progression of student understanding, building understanding through a sequence of inquiry tasks. The unit studied in this project, *Introduction to the Properties of Matter,* consists of 12 investigations designed to support students' construction of the concept of relative density as it relates to sinking and floating. FAST moves students away from alternative conceptions (e.g. things float because they have air in them) through investigations that explore the effect of mass on sinking when volume is controlled, then volume when mass is controlled, density, and finally relative density. Given this conceptual progression, the most important investigations within the unit are those during which students must develop particular understandings that will become the foundation of more complex concepts later on. Thus, within the unit, the important investigations are those that happen right before a 'step' is made to a more advanced conceptual level.

FAST models scientific practices for students, incorporating multiple roles for student and teacher. While students create hypotheses, perform experiments, analyze data, and develop consensus on scientific ideas, the teacher is acts as director of research and colleague who stimulates and makes possible deeper inquiry (Pottenger & Young, 1996). A unique feature of FAST is its dependence upon professional development as a basis for the marketing of its curriculum materials. FAST is only sold to schools in which teachers have been formally trained. Teachers attend 10-day institutes where the teaching practices of FAST are modeled and teachers participate in discussions of learning, teaching, and assessing with FAST (CRDG, 2003).

Participants

Four middle school physical science teachers and their students contributed data to this study. The four teachers were selected from the six members of an experimental group in a larger experiment, in which the effects of formative assessment on student learning were being investigated. As part of the larger study, these teachers participated in a summer workshop that focused upon formative assessment activities and strategies. The summer workshop provided teachers with authentic teaching experiences, where teachers had the opportunity to practice teaching the lesson to real 7th grade physical science students and receive feedback from a mentor and peer who observed the lesson (see Putnam & Borko, 2000). The curriculum materials prepared and provided to the teachers in this summer workshop were designed to promote teacher learning and met several of Davis & Krajcik's (2005) 'Heuristics for Educative Science Curriculum Materials.' More specifically, the curriculum materials support teachers in engaging students with topic-specific phenomena in the form of predict-observe-explain assessment; anticipating, understanding, and dealing with students' ideas about science in terms of providing teachers with the buoyancy progression and talking abut common student misunderstandings; engaging students in questions to elicit their understandings during the formative assessments; and engaging students in making explanations based on evidence in all the formative assessments. All teachers communicated weekly with a mentor during the unit via phone or email to discuss the curriculum, student knowledge and implementation.

The four teachers whose practices are explored in this study were selected on the basis of their students' performance on a pre-post achievement test of students' understanding of relative density administered as part of the larger experimental study. The pre-post achievement test included proximal and distal multiple-choice and short-answer items addressing the concepts of mass, volume, density, relative density and sinking and floating, and graph interpretation (Yin, 2005). Thus, student performance on the pre-post test can be identified as a measure of various aspects of students' conceptual understanding. (Pretest: $N_{students}$=931, N_{items}=38, Cronbach's α=.72; Posttest: $N_{students}$=870, N_{items}=43, Cronbach's α =.86). While there was no difference between classes on the pretest, there were significant differences on the post-test even when the pretest was controlled ($F_{(3,99)}$=1.69, p=0.18). Tukey's HSD identified pairs of teachers whose students showed lower gains (Pete, Doug) and higher gains (Christy, Alice).

Sources of Data

Videotapes

Videotapes of classroom discussions served as the primary data source to provide information about the nature of each teacher's guidance and the scientific concepts addressed. Teachers videotaped their own classes using a Canon ZR60 Digital Video Camcorder, a tripod, and a lapel microphone with pocket transmitter. Each teacher placed the camera at the back of their classroom so that the teacher and students could be seen. Sound quality was generally clear during whole-class discussions on the majority of tapes.

Videotapes for three lessons were separated for analysis. These lessons were selected for two reasons: first, they represent points in the curriculum at which students need to develop particular conceptual understandings; and second, they are followed by embedded assessments, implemented as part of the larger study, which provided both additional prompts for discussions as well as measures for tracking student learning through the unit. These assessments provide a longitudinal picture of students' developing understanding through the course of the unit.

Transcripts were prepared by writing down verbatim what the teacher and students said, identifying the student speakers by name when possible. Transcribers were instructed to record all classroom dialogue, marking text as "inaudible" when necessary, to prepare a readable "text" to accompany viewing of the transcripts.

Measures of Student Learning

Asking students to predict an event, observe that event take place, and explain the accuracy or inaccuracy of their own predictions is an effective way to engage students, elicit their ideas, and to promote argumentation (White & Gunstone, 1992). As part of the larger study, students were administered Predict-Observe-Explain (POE) embedded assessments after three investigations and at the end of the unit. The POE's presented students with a unique prompt at each administration, allowed changes in students' responses before and after a discussion to be tracked, and provided direct measures of students' conceptual understanding. The POE's consisted of three elements: First, students were presented an experimental situation and asked to predict what might happen; for example, to predict the depth of sinking of straws containing different amounts of sand. Second, students observed as the teacher placed the straws in water and measured their depth of sinking. Third, students were given an opportunity to indicate if their prediction was correct or incorrect and to explain their reasoning or how it changed given their observation. The POE prompts and expected student responses are summarized in Table 2.

Table 2. Summary of assessment prompts

Measuring Point	Prompt	Targeted Concepts
1	Predict which of four straws with filled with different amounts of mass will sink to the greatest and least depth in water.	More mass equals more sinking.
2	Three different-sized bottles filled with the same amount of mass have different displaced volumes. Which of the three bottles will sink, which will float, and which will subsurface float in water?	Mass of a floating object is equal to the mass of the volume of water it displaces.
3	Given six different-sized blocks, three with a density of 0.91 g/cm^3, and three with a density of 1.2 g/cm^3, predict which will sink, float, or subsurface float in water.	In water, objects with a density greater than 1 will sink, less than 1 will float, and equal to one will subsurface float.
4	A whole piece of soap sinks in water. If the soap is cut into a large and small piece, will the large and small piece sink, float, or subsurface float in water?	Density is a property of a material.

Data Analysis

Videotapes

A coding system based on Scott's (1998) characterization of discourse and further elaborated by the descriptions of Cazden (2001) and Lemke (1990) was developed to identify the nature of guidance provided within the discussions analyzed for each teacher.

Segmenting the data. After watching entire lessons, transcripts of discussions occurring at the end of investigations were identified and then chunked into smaller segments that served as the primary unit of analysis. Segments were marked in each transcript by determining when students and teacher changed from talking about one topic, idea, example, or piece of evidence to another. Each segment preserved the context of a particular interaction sequence; that is, teacher questions were clustered with their subsequent responses and other dialogue that could be traced to the original initiating question. The author and another researcher read through the transcripts together to identify and mark transitions, discussed disagreements, and made a joint decision on where to draw the line between segments or chunks. Once only small differences remained between the two researchers, the author finished segmenting the remaining data independently. Each segment was marked according to the time at the beginning of the segment, and then was given a code indicating its position in the unit and the lesson to it belonged.

Guidance Codes. Based on the framework of dialogue strategies presented in Table 1, individual segments were coded according to the dialogue strategies being employed by the teacher in that particular segment. Coders noted the strategies as they occurred and then made a summary judgment of the nature of the guidance within a segment. For example, if a segment consisted of a teacher asking open or authentic questions, or the students spontaneously asking their own questions or speaking to each other, that segment was coded as "dialogic". Segments with discourse strategies identified as more guided were coded as "authoritative". Those segments with a mixture of discourse strategies; i.e., with at least one dialogic and one authoritative statement, were coded as “blended." These codes are explained in Table 3; to illustrate how these codes were applied, Table 4 shows a sample transcript with guidance codes.

Table 3. Guidance Codes

Code	Description

Unclear Dialogue /Not applicable	Evidence contained in the segment cannot be interpreted or insufficient to be coded according to the other categories.
Dialogic	All or most of the segment contains teacher moves that are classified as 'dialogic.' *Example*: Teacher asks an open question, student responds, and the teacher revoices or provides a neutral response to the student. Also code if entire segment is filled with student talk.
Blended	Teacher moves in the segment are mixed with no clear majority of moves classified as dialogic or authoritative.
Authoritative	All or most of the segment contains teacher moves that are classified as 'authoritative.'

Table 4. Example of Segmented Transcript with Guidance Codes

Speaker	Dialogue	Dialogue Strategy	Code
T:	Alright. Now, I almost forgot that you guys hadn't seen this last little bit.	*Authoritative:* Teacher controls narrative	*Authoritative*
T:	So we'll try it right now. As you can see, I just…I'm using…or methyl, excuse me, isopropyl alcohol in our in here and you guys had a chance to already make predictions and all of that, right?	*Authoritative:* Teacher controls narrative	
S:	Yeah.		
T:	Alright. So…Jeff, leave the book closed. Everyone, just close your book. Close your book, everybody. Don't leave it open.	*Authoritative:* Teacher controls narrative	
T:	But you can leave this out.		
T:	Okay. It says I want you to predict what was going to happen when I put this…I'm sorry. .95 grams. If you don't have one of these, get them out so you at least have to share with a partner or something, okay? Alrighty? So who said it was going to sink or float or sub surface? Chad?	*Dialogic*: Open/real question;	*Dialogic*
S:	Yeah.		
T:	Why?	*Dialogic:* Open/real question	
S:	Because it's a different liquid.		
T:	Because it's a different liquid.	*Dialogic:* Repeats	
T:	So if I put this in like acid, hydrochloric acid, it will sink differently because it's a different liquid.	*Dialogic*: Rephrases student comment	
S:	Right. [*inaudible*]		
T:	You guys, I can't hear Carl, okay?		

S:	Wouldn't it melt?		
T:	Good point! (laughs)	*Dialogic:* Neutral response	
T:	Jake?		*Blended*
S:	Alcohol is a lot thinner than water and so it'll sink.		
T:	Thinner. What do you mean by thinner?	*Dialogic:* Asks student to clarify	
S:	It's like in a swimming pool and you just lay there, you'll float and if you had a pool of alcohol, you'll just go to the bottom, it's so thin that things won't float.		
T:	So what do you mean by thin? What's a word…	*Authoritative:* Cues for term	
S:	The density of is not as high.		
T:	The density is not as high?	*Dialogic:* Repeats	

Scientific Concept Codes. Segments were also coded according to the different concepts being discussed. These codes were an expansion of those developed by Yin (2005) and were based upon the progression of conceptual understanding embedded in the first unit of FAST. For example, if a student that mass has an effect on the depth of sinking of a straw filled with ballast, that segment would be coded as "Mass *or* Volume." Concept codes were used to mark the presence or absence of a particular concept within a given segment, and were marked according to whether the concept was first introduced into the segment by a student or by the teacher. Multiple codes could be applied to a particular segment; however, each code could be only applied once. For example, if the concept of density came up multiple times within a single segment, it was still only coded once as having appeared within that segment. The scientific concept codes are listed and described in Table 5. The application of these codes is illustrated in a sample transcript in Table 6. This lesson is taken from the middle of the unit, when students are expected to provide an explanation based a comparison of mass and volume.

Table 5. Scientific Concept Codes

Scientific Concept Code	Student or Teacher explanation of sinking and floating based

	upon…
Alternative Conceptions	<u>Only</u> Air, having a particular size or shape, having holes, or being hollow/solid
Naïve Scientific Conception	Conceptions that are incorrect but may be on the right track to being correct, e.g. Chemical/material/component, force/pressure/buoyancy.
Mass and/or Volume	Mass or volume or both influencing why things sink and float in the same direction, with no explicit comparison between them Includes words like heavy, weight, big, small, thin, fat, and size.
Mass and Volume	Mass and volume used in a directional comparison.
Density	Density of object or density of liquid, but no explicit comparison between densities. Can also be applied when the words compactness or thickness are used to describe an object or liquid.
Relative Density	Comparing object and liquid's density

Table 6. Sample transcript with concept codes

Speaker/Dialogue		Concept
T:	…In all related situations, why do things sink and float? Alex?	
S:	Because more mass...Never mind.	*Mass <u>or</u> volume*
T:	Okay, think about it, and if you get it, [*inaudible*]. Okay?	
T:	Mark, what do you think?	
S:	[If it has] more mass, it sinks.	*Mass <u>or</u> volume*
T:	More mass than what?	
S:	Than volume.	
T:	Okay, so if there's more mass than volume, it sinks. Keep going... Okay, and you're saying here if there's less amount of mass, or the same amount of mass as the volume, it will float. Okay, good. Anna.	*Mass <u>and</u> volume*
S:	Air bubbles.	*Alternative Conception*
T:	What about air bubbles? Where do you keep getting these air bubbles from? Well, because remember, when you're doing this you have to provide evidence. Can you support it? Have any of the graphs or anything talked about air bubbles that you can tell me about? No, so why do you keep insisting that there's air bubbles?	
S:	Because there's air bubbles in the water.	
T:	So what do you think it has to do with sinking and floating, though? You have to be more specific than just say there's air bubbles. Because here we have, like if I ask Mark, give me an example to support what you just said. That more mass, less volume is sinking.	*Mass <u>and</u> volume*

Training Procedure and Reliability Data. Transcripts were coded while watching videotapes to capture both explicit and implicit meanings of discussions (Aulls, 1998; Osborne, Erduran, & Simon, 2004). The training process took place between the author and two other coders on a random sample of transcripts distributed evenly across the four teachers. Each rater independently coded 136.5 minutes of videotape (approximately 21% of the total 645.5 minutes), and inter-coder reliability was determined (Percent direct Inter-rater agreement: Mean=94%, Min. = 79%, Max. = 99%; Cohen's Kappa: Mean= .59, Min. = .26, Max. = .93).

Measures of Student Learning

Coding System. The different POE's were scored according to a process developed by Yin (2005), based upon the expected level of explanation given the position of the POE in the unit. Each POE had a unique scoring system tailored to the content of the particular prompt; thus the total possible score for each POE varied according to the number of predictions and explanations possible. In general, scores consisted of whether or not students made a correct prediction, provided explanations at the level expected at that point in the unit, used the same explanation for each prediction, and whether their explanation for the reconciliation was correct. Multiple raters scored a 20% sample of the assessments; agreement was above 88%.

Results

Results of the study are organized by data source. Results of videotape analysis are presented by code, beginning with the nature of guidance, turning to the scientific concepts introduced into the discussions, and then comparing the results of guidance and conceptual coding. Then, the development of conceptual understanding through the unit, as measured by POE embedded assessments, are presented.

Nature of Guidance

Variation within segments. Comparison of the four teachers reveals differing patterns.

The lower-gain teachers spent less time holding discussions and had fewer segments (N) than the higher-gain teachers. It also shows small differences between teachers in the percentage of segments coded as authoritative or dialogic. However, the main difference between teachers is in the percentage of segments coded as dialogic; the lower-gain teachers have 15% or fewer segments in this category, while the higher-gain teachers had about 15% or more (Table 7).

Table 7. Percentage of segments coded for each type of guidance by teacher

			Percentage of Segments			
	Time (min)	N Segments	Dialogic	Blended	Authoritative	N/A
Lower-Gain						
Pete	131.33	162	35.2	15.4	35.8	13.6
Doug	71.07	111	52.3	9.9	24.3	13.5
Higher-Gain						
Christy	192.04	209	19.1	32.5	40.2	8.1
Alice	234.56	277	33.6	24.9	27.1	14.4

Note. Segments were coded ‘N/A’ when dialogue was inaudible, confusing, or otherwise unclear.

Variation within discussions. To examine how segments were distributed within individual discussions, segments coded as ‘N/A’ were excluded, and the percentage of segments coded as authoritative, blended, or dialogic was found for each teacher (Figure 1).

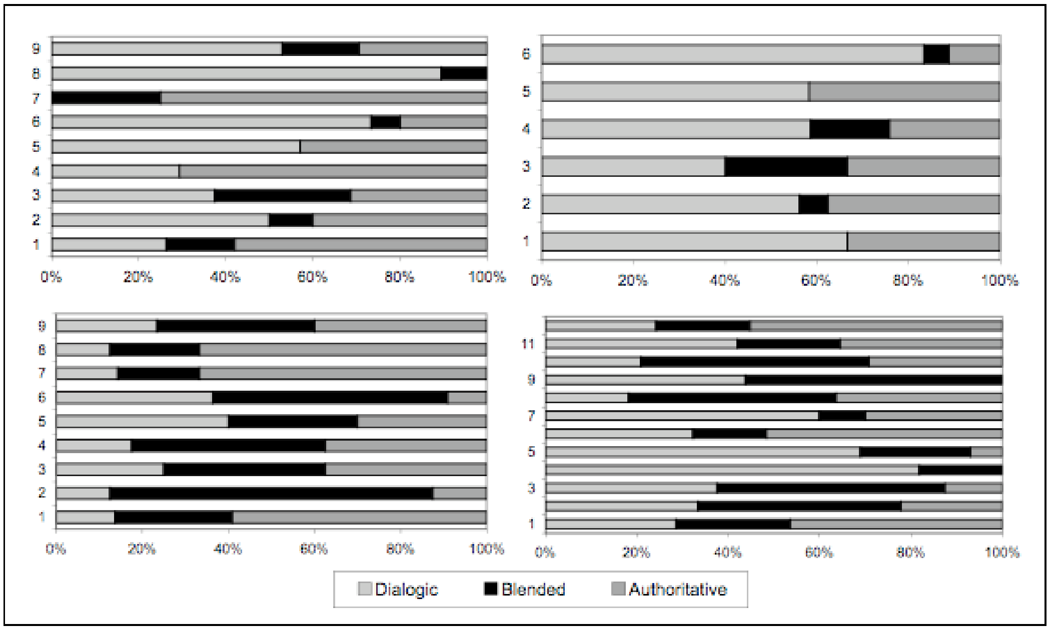

Figure 1. Percentage of segments from each discussion coded as Dialogic, Blended, and Authoritative, by teacher (Pete and Doug, top, left to right; Christy and Alice, bottom, left to right)

Figure 3 shows that the lower-gain teachers, shown at the top of the figure, had fewer segments coded as blended than the higher-gain teachers at the bottom of the figure. Doug, who had the fewest discussions of the four teachers, had two lessons with no dialogic segments at all, and two segments amounting to about 20-30% of the segments. The figure also shows that all but one of Doug's lessons featured more dialogic segments than authoritative. Similar to Doug, Pete had two lessons with no blended segments at all, and several lessons with 20-30% blended segments. Although two of Pete's lessons had a majority of authoritative segments, the remainder of his discussions had a majority of dialogic segments.

In contrast to the lower-gain teachers, Christy and Alice had many lessons with high percentages of blended segments, most of which constituted 20% or more of the total, and neither teacher had a discussion with no blended segments. In fact, in many of Christy's and Alice's discussions, the majority of segments were blended. A difference arises when looking at the predominance of authoritative or dialogic segments; whereas Christy's lessons are weighted more toward authoritative segments, Alice's discussions were weighted more toward dialogic.

Scientific Concepts

To explore the ways that different concepts were provided by students across the span of the unit, each segment was plotted versus time according to the level of its conceptual content. If multiple concepts were mentioned during a particular segment, they were all plotted on the graph for that segment; that is, each point represents the presence of at least one statement made during that segment relating the particular conceptual level to sinking and floating; squares denote conceptual statements made by students, X's denote statements made by the teacher. The shaded areas of the figure represent the conceptual understanding students are expected to develop by that point in the unit; for discussions held at the beginning of the unit, this level is mass *or* volume; mass *and* volume in the middle, and density in later lessons (Figure 2).

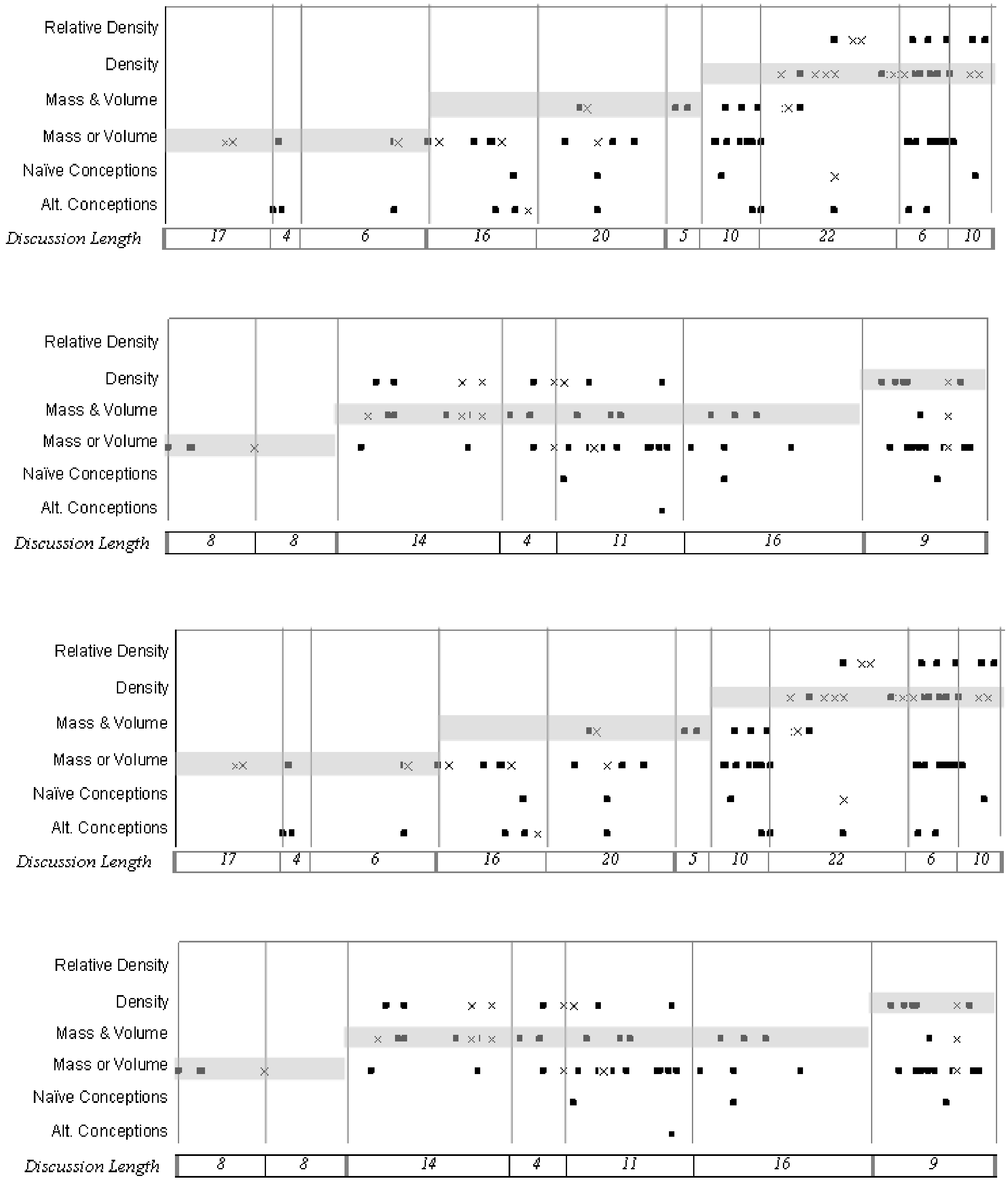

Figure 2. Frequency of conceptual levels by discussion for (top to bottom) Pete, Doug, Christy, and Alice

Figure 2 shows many patterns, so each teacher will be discussed separately. The concepts in Pete's discussions follow the same pattern laid out by the shaded areas, indicating that the concepts being discussed were similar to those expected by the curriculum. Second, the figure also indicates that alternative conceptions, naïve conceptions, and the concept of mass *or* volume causing sinking and floating persisted to the end of the unit, indicating that some students still maintained these conceptual understandings. Third, when Pete mentioned a concept as it related to sinking and floating, he would usually make a statement at the expected level.

The concepts used in discussions in Doug's classes, in contrast, did not show a progression as expected. In the beginning, students expressed the relationship of mass and depth of sinking. In the later lessons, some students mentioned the relationship between mass and volume, but lower-level conceptions persisted. The figure also indicates that Doug was not always making statements at the expected level. In addition, very few of the statements were credited to Doug, indicating that students were making most of the conceptual statements.

In Christy's discussions, alternative conceptions dropped out in the last two lessons, indicating that students did not bring up these ideas later in the unit, although there were many of these lower-level statements earlier. During some discussions, the only concepts mentioned were at the expected level, while in some later lessons, concepts mentioned showed more of a spread across the conceptual levels. In two of these lessons, Christy's statements were below the expected level, parallel to those made by the students. In the last lessons, the concepts mentioned in discussion show a clear progression toward density.

In Alice's classroom, the students' ideas centered on mass and volume early in the unit, with some discussions involving lower levels. The concepts almost explode later in the unit, with multiple ideas coming up, often above the expected level. Alice's comments were not always at the expected level; in fact, at several of the discussions, Alice's comments paralleled those made by her students. Later, Alice's comments were actually lower than those being made by the students, and at the end, they matched the ideas being put forward by the students.

Comparing Nature of Guidance and Scientific Concepts

An analysis of the concepts introduced into the discussion by the students, organized according to the nature of guidance in each segment, reveals patterns between nature of guidance and concepts mentioned. Collapsing the codes according to whether or not students provided explanations at the expected level given the placement of a discussion within the unit reveals differences between the classrooms (Table 8).

Table 8. Percentage of authoritative, blended, and dialogic statements by conceptual level and by teacher

		Student Conceptual Level		
		None	Below	At or Above
Authoritative	Pete	95	2	3
	Doug	100	0	0
	Christy	74	11	15
	Alice	89	3	8
Blended	Pete	44	28	28
	Doug	55	18	27
	Christy	38	18	44
	Alice	70	10	20
Dialogic	Pete	30	37	33
	Doug	29	33	38
	Christy	48	20	33
	Alice	58	12	30

A majority of segments for all of the teachers coded as authoritative had no conceptual content; however, while Pete and Doug had almost all of their segments in this category, Christy and Alice also used authoritative segments to discuss below and at or above-level segments. When guidance was blended, the conceptual level shifted away from ‘none’ toward ‘below’ or ‘at or above,’ although Doug and Alice still had a majority of segments falling into the ‘none’ category. Pete’s segments that were *not* coded as ‘none’ were more balanced between ‘below’ and 'at or above,' whereas Christy's remaining blended segments were more often 'at or above' the expected conceptual level. When guidance was dialogic, all teachers had about one-third of segments coded as 'at or above,' Pete's and Doug's segments were divided between 'none' and 'below,' and Christy's and Alice's segments were more likely to be coded as 'none.'

A series of randomized-blocks analysis of variance (RBANOVA) were run on the percentage of segments at each level of guidance, to look for significant differences between the recoded conceptual levels. This method was used because the inter-relatedness of the segments violates the independence assumption necessary for chi-square and ANOVA analyses.

Authoritative Guidance. There was a significant difference between the frequency of the three conceptual categories in segments with authoritative guidance ($F_{2,6} = 5.466$, $p<.05$). A higher percentage of segments were coded as 'at or above' the expected level when guidance was authoritative.

Blended Guidance. When guidance was blended, there was also a significant difference between the percentage of segments coded as having no concepts, or that were below, or at or above the expected level ($F_{2,6} = 6.560$, $p<.05$). The majority of blended-guidance segments were coded as having no conceptual content provided by the students across all teachers, with Alice having the largest percentage (70). A closer analysis of Alice's transcripts indicates that the high percentage in this category came from discussions in which students brought up topics related to sinking and floating but not on the buoyancy trajectory, such as gravity and air resistance.

Dialogic Guidance. There was not a significant difference between the conceptual level coded in segments where guidance was dialogic. ($F_{2,6} = 1.464$, $p>.05$). This result suggests that when teachers allow students to lead discussions on their own, there is not as a clear difference in the type of concepts students will share.

Development of Student Conceptual Understanding

A comparison of the students' scores on the assessments embedded within the unit reveals that the significant differences between the four teachers identified at the beginning of the study developed across the course of the unit (Figure 3).

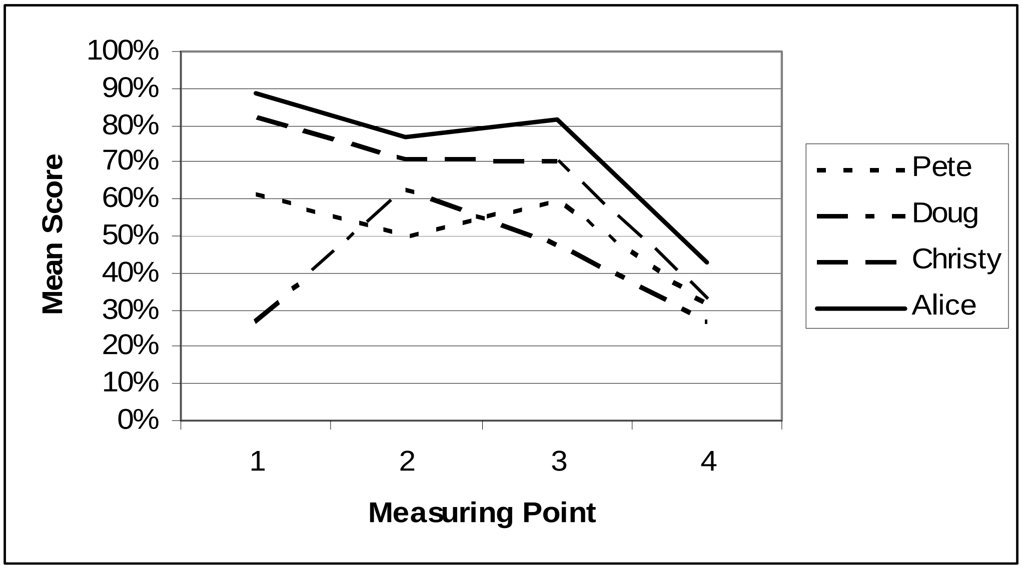

Figure 3. Mean assessment score by teacher

These results indicate that although there was not a significant difference between classes at the beginning of the study, significant differences in student learning had already developed by the first measuring point. While differences persisted to a certain degree throughout the unit, all students were challenged by the post-assessment. A 4 x 4 (Teacher x POE) split plot ANOVA with the achievement pretest as a covariate was run to examine mean differences between teachers. Mean differences were statistically significant ($F_{(3,79)} = 18.82$, $p < 0.05$), as was the interaction between teachers and POE ($F_{(6, 158)} = 3.63$, $p < 0.05$); consequently, the interaction and present teacher effects results separately for each POE are elaborated in the sections below.

Measuring Point 1. There was a significant difference between teachers at the first measuring point. Tukey's HSD indicated that Pete's and Doug's students were, on average, significantly different from each other, as well as from Christy's and Alice's students. There was not a significant mean difference between Christy's and Alice's students.

Measuring Point 2. A comparison of the students' mean scores across teachers in the middle of the unit again indicated a significant difference between teachers. Tukey's HSD indicated that Pete's students scored significantly lower than Christy and Alice's students; on average, and there were no other significant differences between teachers.

Measuring Point 3. Comparing students' mean scores late in the unit indicated a significant difference between teachers. According to Tukey's HSD, there was a significant difference between Alice's students and those of Doug and Pete; in addition, Christy's students scored significantly higher than Doug's. There was not a significant difference between Christy and Alice, Doug and Pete, or Christy and Pete.

Measuring Point 4. Despite the significant differences observed between teachers on the Reflective Lessons at 4, 7, and 10, student performance dropped across all teachers at the conclusion of the unit. There was not a statistically significant difference between any of the teachers at the fourth measurement point.

Discussion

This study explored the relationship between guidance and conceptual understanding during inquiry-based, post-investigation discussions held in the classrooms of four physical science teachers. Comparison of students with lower learning gains (those of Pete and Doug) with those having higher gains (those of Christy and Alice) indicate that, in general, pairs of teachers shared several similarities in terms of the nature of guidance they provided to students, the concepts addressed during lessons, and student performance.

Comparing the teachers of students with lower and higher learning gains indicates that the higher-gain teachers were more likely to vary the kind of guidance they provided students *within* segments than the lower-gain teachers, who spent more segments in dialogic interactions and ‘teacher talk’ sequences. Furthermore, the higher-gain teachers also provided more varied guidance *between* segments, as evidenced by each discussion featuring at least one-fourth of segments coded as authoritative, dialogic, or blended.

Finer-grained analysis revealed that the pairs of teachers were using authoritative guidance in different ways; almost all of the low-gain teachers’ authoritative segments were coded as having no conceptual content, whereas the higher-gain teachers used authoritative segments to speak about below, at, and above-level conceptions. Statistical analyses indicated this difference was significant. There was also a difference in the conceptual levels discussed when guidance was blended; closer examination of the data indicates that Alice had a high percentage of segments coded as having no conceptual content.

Results of conceptual coding indicate that while students in the higher-gain classrooms advanced in the concepts they discussed through the course of the unit, there was less progression less in the lower-gain classrooms, and lower-level conceptions were more likely to persist at the end of the unit. Analysis of student learning showed a significant teacher effect; however, this finding is tempered by the fact that all students were challenged to respond to the final assessment, indicating that regardless of which classroom they were in, their conceptions about sinking and floating were resistant to change.

While the design of this study precludes making causal attributions, the data presented nevertheless brings evidence addressing the need identified by Scott, Mortimer, and Aguiar (2006) for research into how shifting amounts of guidance are associated with conceptual learning gains. The results support Scott’s (1998) contention that a ‘rhythm to the discourse’ – helps to build students’ conceptual understanding. The teachers whose students had higher learning gains through the unit varied guidance within and between discussion segments, and more frequently used their authority in leading discussions to address concepts. The study thus supports the argument that effective inquiry-based science teaching, in the presence of expected conceptual understandings, should involve shifts between authoritative and dialogic exchanges between teacher and students. The results of this study also underscore the importance of active involvement by teachers during inquiry-based discussions. The teachers of higher-gain students in this study were actively and continuously manipulating the halo of social learning during discussions, providing different amounts of guidance at different times to scaffold student learning.

Based on the foundation of the work cited and the results presented in this paper, future research might involve an experimental study with a factorial design exploring the effects of varied nature of guidance on students' conceptual understanding. A unique feature of such a study would involve blended and instructionally responsive guidance as a condition. Additional studies might also explore how the metaphor of shifting guidance, rather than the more common 'teacher-as-facilitator' helps practicing teachers implement inquiry-based investigations in their classrooms. It is possible that helping teachers to be aware of the function the dialogue strategies they use in their classrooms could help them be more cognizant of the nature of guidance they are providing to their students. In addition, examining inquiry-based curriculum materials prior to instruction could help teachers to determine when students might be provided more authoritative or dialogic guidance, given the learning goals for a particular day or unit.

Like so many other 'either/or' dichotomies that have been, over time, proven to be false, this study similarly suggests that authoritative or 'traditional' classroom discourse is not by definition 'bad,' while 'nontraditional,' dialogic discourse is 'good.' Rather, this study suggests that it is the manner in which these types of discourse are actively used by teachers to develop student understanding that is important. Clearly, if teachers only use authoritative discourse to show students that they are right or wrong, it will be difficult, if not impossible, to build classroom environments that are supportive of inquiry learning. However, selectively interspersing authoritative interactions with those that are more dialogic can serve the purpose of highlighting inconsistencies in students' thinking, pushing students toward consensus, or introducing important concepts that would not have been otherwise addressed. Integrating varied amounts of guidance into current models of inquiry-based teaching may therefore contribute to the development of students' conceptual understanding.

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