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RESEARCH ARTICLE

Examining Patterns in Teacher-Student Classroom Conversations during STEM Lessons

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Abstract
Teacher-student conversations are central to student learning within the science classroom. Educational literature recommends teachers aim to build a common scientific language and, through dialog, develop shared meanings with students. This study examines teacher-student conversations in the specific situation of an integrated science and engineering curriculum, involving lessons on heat transfer. The findings identify critical nuances and discourse patterns in the conversations that may pose barriers to student engagement and learning. The study illustrates the need for teachers to plan dialogic, authentic interaction with students to build shared meanings about scientific concepts in order to enhance STEM learning.

Keywords Classroom discourse patterns · Heat transfer · Science and engineering integration · Middle school

Introduction

In a socio-cultural setting, learning is considered to be situated, which suggests that learners tend to reason meanings and generate new information from authentic and real-world practices (Rogoff 1998; Vygotsky 1978). In the United States, K-12 science education promotes learning science through a methodical practice: making observations and collecting data, designing experiments, analyzing data collected from experiments, and interpreting and communicating the results (NRC 1996, 2000). The goal of science teaching is comprehensive lessons that encompass multiple categories of Bloom's taxonomy (Anderson and Krathwohl 2001), as well as subcategories such as learning objectives for students to understand, classify, categorize, compare, infer and explain scientific evidence.

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Teacher-student conversations are central to learning within the science classroom. Students build on their everyday language and experience to develop scientific proficiency (Wellington and Osborne 2001; Vygotsky 1978). While teachers have specific goals and purposes for teaching each lesson plan, educational literature suggests that teachers can build common scientific language and develop shared meanings with students through the use of everyday language (Alexander 2008; Warren et al. 2001). Educational literature also suggests that science lessons with rich classroom discourse provide students a setting in which to express their ideas, construct reasoning, and build shared meanings with peers as well as with teachers (Alozie et al. 2010; Wellington and Osborne 2001).

To better understand the process of building shared meanings, the present study examines teacher-student classroom conversations during STEM lessons in order to identify and analyze patterns. The study is a qualitative investigation of the discourse within a science classroom between teacher and students in the specific situation of an integrated science and engineering lesson. The present paper particularly examines Initiation-Response-Feedback/Follow-up (I-R-F) discourse patterns (Sinclair and Coulthard 1975), which are the most common patterns of classroom conversation (Lin 2007; Nassaji and Wells 2000). Within the literature, there has been intense debate about the use of I-R-F conversation in the classroom. Some researchers believe that I-R-F produces more monologic talk, rather than dialogic talk (Alozie et al. 2010; Bakhtin 1981; Christodoulou and Osborne 2014; Lyle 2008; Mchoul 1985). Conversely, other researchers suggest that depending on how teachers use it, I-R-F potentially could be a powerful dialog pattern that helps build common scientific language (Lin 2007; Nassaji and Wells 2000; Scott and Mortimer 2005; Scott et al. 2006; Tsui 2004).

To address this debate in the literature, there is an imperative for research in the field to study classroom discourses and interactions in order to improve effectiveness of science education teaching methods (Molinari et al. 2013). The present research study applies a qualitative approach to analyze a teacher's classroom conversations with students. The study examines discourse patterns that flowed throughout integrated science and engineering lessons on the concept of heat transfer. Students from elementary level through college find it challenging to learn the concepts and process of heat transfer (Jacobi et al. 2003; Neumann and Hopf 2012). Moreover, research has found that students learning the concept of thermodynamics analyze everyday phenomena — such as melting ice cubes, boiling water or the wearing of coats — in order to construct new meaning for heat transfer by analyzing and interpreting their previous learning and experience (Rosebery et al. 2010).

The research question for the present study:

> RQ: *In integrated science and engineering lessons, to what extent did the teacher's use of the I-R-F conversation pattern engage or disengage students in building shared meaning between the teacher and students?*

The findings of this study potentially have applied value in science education by increasing teachers' understanding of the importance of language and interactions with students, and the need to use specific teaching methods that enhance learning by developing shared meaning with students during integrated science and engineering lessons.

Literature Review and Conceptual Framework

It is expected when teachers use integrated science and engineering approaches, that students learn and apply cross-cutting concepts from different disciplines to solve problems (Bybee 2010; NGSS Lead States 2013; NRC 2009, 2014). Broadly, an integrated learning environment, using an integrated curriculum, has potential to connect science content to real-life issues, thus facilitating a deeper understanding of science content for students (Fortus et al. 2005; Hmelo-Sliver et al. 2007; Kolodner et al. 2003; Schnittka and Bell 2011). Although an integrated curriculum has the potential to connect to a learners' everyday life, learners' life experiences give meaning to language when they try to use the words or phrases to understand, to reason and to describe a new experience (Piaget 1970).

Effective teaching approaches that promote meaningful and productive dialog are essential in order for learners to make connections between the classroom and their everyday life experiences. Although science education has gone through a few nation-wide educational reform movements — such as inquiry-based (NRC 1996, 2000) and integrated STEM teaching (NGSS Lead States 2013; NRC 2009, 2014) — research studies found these educational reforms may not attain expected learning outcomes because teachers still mainly using triadic conversations in their classrooms (Alozie et al. 2010; Scott et al. 2006). Triadic dialog is a form of interaction in which a teacher asks students questions (to which the teacher knows the answer, but the answer is not obvious), and after students answer the questions, the teacher responds by either giving feedback or evaluating whether the students' answers are "acceptable" or not. This conversation pattern is referred to as I-R-F (Sinclair and Coulthard 1975), which is Initiation, Response, and Feedback (or Follow-up), or I-R-E (Mehan 1979), which is Initiation, Response, and Evaluation.

Within the educational literature, there is a debate on the effectiveness of I-R-F. While some research posits that I-R-F may reduce classroom discursive interactions, other research supports I-R-F as a process to develop alternative types of dialog sequences to promote discursive interaction in classrooms (Lin 2007; Scott and Mortimer 2005; Scott et al. 2006). In the I-R-F pattern, both Initiation and Feedback/ Follow-up phases involve teachers asking questions. Teachers should ask questions that help students retrieve prior knowledge and adapt/reconstruct that knowledge with classroom experiences. Research studies suggest that, given the importance for teachers to understand students' existing knowledge and to ask questions to deepen students' scientific thinking, a teacher's basic act of asking a "why" question could prompt students to engage in internal reasoning to explain the answers that they gave (Brown and Kane 1988; Martin and Pressley 1991; Pressley et al. 1992). Leading classroom conversations with "why" question also helps teachers scaffold shared meanings with students (Lin 2007; Nassaji and Wells 2000; Scott and Mortimer 2005; Scott et al. 2006; Tsui 2004). Conversely, a teacher who asks "why" questions might end up creating a nebulous context for students, who may then respond with answers too broad to channel the specifics that a teacher wants to elicit from students within a limited time. Therefore, the literature should examine whether, instead of advocating for teachers to ask "why" questions, it may be more essential to help teachers develop the ability to be more thoughtful, and use probing questions during classroom conversations. In teaching the concept of thermodynamics in a science classroom, a teacher can try to strategically use I-R-F discourse patterns to understand students' initial scientific ideas about heat transfer through discussion of their everyday life experiences. The teacher may then be able to foster shared meaning with students, which can help students develop in-depth understanding of the concept of thermodynamics (Lewis and Linn 1992; Rosebery et al. 2010).

Research Methods

The case study applies the Analytical Framework (Table 1) (Scott and Mortimer 2005; Scott et al. 2006) to facilitate qualitative, in-depth analysis of a teacher's classroom practices. The study focuses on discursive interactions between a teacher, Ms. Lee, and her students in the context of integrated science and engineering lessons. The purpose of this study is to analyze the pattern of I-R-F classroom conversations (i.e. questions the teacher asked, student responses to teacher questions, and the teacher's feedback to students). The principle source of data are videotaped recordings of classroom activities.

Context of Study

Ms. Lee (pseudonym) was the teacher participant. She was assigned to teach science to sixth-grade students. At the time this study was conducted, Ms. Lee had begun her third year of teaching and expressed excitement about teaching integrated science and engineering lessons.

Table 1 The Analytical Framework to analyze meaning-making interactions in science classrooms

Aspects	Aspect of Analysis	Patterns Identified
Focus	Teaching purpose	a) Opening up the problem b) Exploring and probing students' view c) Introducing and developing the scientific story d) Guiding students to work with scientific ideas and supporting internalization e) Guiding students to apply, and expand on the use of, the scientific view and handing-over responsibility for its use f) Maintaining the development of the scientific story.
	Content	a) Subject content knowledge b) Apply content knowledge in different settings
Approach	Communicative approach	a) Interactive/Dialogic b) Noninteractive/Dialogic c) Interactive/Authoritative d) Noninteractive/Authoritative
Action	Patterns of discourse	a) IRF b) IRE c) IRP
	Teacher interventions	No specific guideline

Table 1 summarizes research studies of Scott and Mortimer (2005), and Scott et al. (2006)

The school where Ms. Lee taught is located in a suburb area of Minnesota. In the science class studied for this research, there were 23 students, 13 females and 10 males. Two students were African American, two students were Hispanic American, three students were Asian American, and the rest of the students were white. Ms. Lee is also white.

For the curriculum, Ms. Lee used the *Save the Penguins* science curriculum (Schnittka 2009) to teach her sixth graders scientific concepts that describe heat transfer. The *Save the Penguins* curriculum is a well-developed science and engineering teaching-kit curriculum that focuses on the content of heat transfer and engineering design. Ms. Lee modified the curriculum to fit her class and to address the sixth-grade learning outcome benchmarks for her state.

Ms. Lee planned to teach the concept of thermodynamics over a period of six days in the classroom. She spent the first three classroom days (about 135 min) introducing the scientific concepts of heat transfer, focusing on conduction, convection and radiation. She talked about the definitions of heat transfer, conduction, convection, and radiation, and used activities in the *Save the Penguins* curriculum to demonstrate heat transfer. During days four to six, Ms. Lee had students work in small groups to solve an engineering design challenge. The design challenge was to build a penguin house that could prevent an ice cube penguin from melting while it was in a heat bin. Ms. Lee intended for students to solve the problem and design their penguin houses by thinking about heat transfer through conduction, convection and radiation.

The researcher and Ms. Lee had no personal relationship. Ms. Lee was trained in teaching the *Save the Penguins* curriculum (Schnittka 2009) at a teacher professional development workshop aimed at assisting teachers to adapt Next Generation Science Standards (NGSS Lead States 2013). The researcher also attended the workshop and shared the research idea for classroom observation of discourse. Afterward, Ms. Lee introduced herself to the researcher and offered her classroom as a potential research site. Ms. Lee expressed enthusiasm and commitment to adopt the *Save the Penguins* curriculum for her classroom lessons.

The researcher applied for human subject research with the university Institutional Review Board and received approval. Several months prior to classroom observations, the researcher met twice with Ms. Lee to review her lesson plans and to discuss data collection and the process for classroom observation. During planning, Ms. Lee and the researcher did not identify pre-determined questions that Ms. Lee should use in her classroom. After Ms. Lee presented her lesson plans and learning objectives on the *Save the Penguins* curriculum (Schnittka 2009), the researcher only provided feedback that focused on learning objectives and content knowledge to align with state standards. The researcher did not engage in any conversation with Ms. Lee related to classroom discourse prior to the study. The researcher and Ms. Lee discussed the extent that classroom activities and assessments, such as a content knowledge survey, were addressed in this study's discussion section.

Data Collection

Video recordings To collect primary data, the researcher made video recordings of classroom activities and written observations each day. Three video cameras (camcorders) were set up in the classroom: One facing front and focused on the teacher, and two on each side of the classroom to record students' conversations and movements. During times of collecting data, the researcher tried to minimize disturbing students and did not engage in any interactions with students. The first three days of video recordings spanned about 135 min during which Ms. Lee taught the scientific concepts of heat transfer (conduction, convection, and radiation). During days four to six of the lesson plan, the reported data was derived from edited videos when Ms. Lee had interactive conversations with a student focus group. These conversations occurred during the classroom time when students were designing and building their penguin house (13 min), as well as when the designated student focus group presented their penguin house in a class presentation (8 min).

The focus group had three students, Peyton, Tina, and Connor (pseudonyms). The researcher chose this group due to the group's proximity to one of the stationary camcorders in the classroom. The video recording of this group offered the best audio quality for the researcher to clearly identify conversations. It should be noted that the focus group conversations were dominated by Connor, a white male student described by Ms. Lee as playful, talkative, and a student with average grades in science coursework.

Data Analysis

The Analytical Framework (Scott and Mortimer 2005; Scott et al. 2006) was used to conduct data analysis for this study. Scott and Mortimer (2005) and Scott et al. (2006) identify five aspects, (a) teaching purposes, (b) content, (c) communicative approach, (d) patterns of discourse, and (e) teacher interventions (Table 1), as a framework to analyze teachers' discourse in classrooms. Based on their observations of science lessons, Scott et al. (2006) developed a list of teaching purposes. These purposes are (a) opening up the problem; (b) exploring and probing students' views; (c) introducing and developing the scientific story; (d) guiding students to work with scientific ideas and supporting internalization; (e) guiding students to apply, and expand on the use of, the scientific view and handing over responsibility for its use; and (f) maintaining the development of the scientific story (Table 1).

Teaching content and applying knowledge to solve problems are the two purposes that drive the direction of integrated science and engineering lessons. These teaching purposes fit the Scott et al. model (2006) to guide students to work with scientific ideas and to support internalization to apply and to expand on the use of the scientific knowledge (Table 1). In addition to patterns of discourse, there are four categories of communicative approach in teaching based on communicative approach and discursive pattern: (a) Interactive/Dialogic, (b) Non-interactive/Dialogic, (c) Interactive/Authoritative, and (d) Non-interactive/Authoritative to work with students in classrooms (Table 1). The dialogic communicative approach is defined by Scott et al. (2006) as teaching in which the teacher recognizes students' perspectives and attempts to bring students' ideas in structuring classroom conversations. The authoritative communicative approach is defined as teaching in which the teacher focuses on only one meaning from their perspective.

As for the actions of discursive pattern, Scott et al. (2006) add the Prompt phase (P) to the I-R-F conversation pattern as one additional step. They suggest that the I-R-P pattern is a feedback loop (open chain pattern) to prompt students to elaborate their answers. I-R-P pattern could unlimitedly circulate back and forth between a teacher and students, such as I-R-P-R-P-R-P, until the teacher closes the pattern by a final feedback or evaluation (Table 1).

If teachers use the Prompt sensibly in their classroom conversation with students, the dialogic patterns could provide teachers extra information to better understand students' logic and reasoning for their answers (Scott et al. 2006). Scott et al. (2006) emphasize that triadic dialog is not an obstacle for students to develop their ideas, as long as teachers take into consideration the sequence of the four communicative approaches.

Using the Analytical Framework (Scott and Mortimer 2005; Scott et al. 2006) (Table 1), the present study analyzed the data to distill Ms. Lee's instructions and her classroom conversations with students, particularly with the student focus group. This research analyzed the data applying these four aspects of the Analytical Framework: (a) teaching purposes, (b) content, (c) communicative approach, and (d) patterns of discourse. Since the framework did not provide specific guidelines for the teacher intervention aspect, that aspect of the Analytical Framework was not included.

To identify the teaching purposes and content, the researcher had discussions with Ms. Lee prior to each lesson she taught and, at the end of each lesson, reviewed field notes from classroom observations to pinpoint the teaching purposes and content. In conducting the data analysis, the aspects of communicative approach and patterns of discourse were combined.

For the discursive segment, conversations were analyzed for the I-R-F pattern, starting with the Initiation and ending with Feedback (or Follow-up). The Prompt phase, as a feedback loop, was added into I-R-F patterns based on the nature of conversations. The I-R-F patterns were also coded for Interactive/Noninteractive and Authoritative/Dialogic. For example, a phase could be coded as $I_{(IA)}$ (Initiation/Interactive/Authoritative) or $P_{(ID)}$ (Prompt/Interactive/Dialogic).

To reduce research bias and check for reliability, the researcher and a third party (a faculty member from a department of science education) did coding checking. The third party coded part of the transcripts and discussed the coding with the researcher. The third party and the researcher debriefed the coding and pattern of the data. Based on the feedback from the third party, the researcher carefully addressed bias and gaps. Then, the third party and researcher had another coding debrief meeting to check coder reliability. To enhance the credibility and accuracy of the study, the researcher also conducted member checking with Ms. Lee. The intent was to authenticate the interpretation of the teacher's classroom practices and discursive interactions with students.

Additional Assessment Data: Pre- and Post-Tests of Content Knowledge

A pre- and post-test survey for content knowledge was conducted with the students observed in the science lessons, to add triangulation and to expand on the findings of the discourse analysis. The survey data was not a core resource for the study and not intended as stand-alone findings. Rather, the survey data aided in understanding the process of the teaching method used in the classroom.

A faculty member of a university department of physics worked with the researcher and Ms. Lee to co-design the content knowledge survey. Ms. Lee made sure her lesson plans on heat transfer covered all content tested in the pre- and post-tests.

The test consisted of 15 multiple-choice questions divided into four sections: four questions each for the concepts of conduction, convection, and heat transfer from objects at higher temperatures to objects at lower temperatures (12 questions) and three questions addressing the concept of radiation. Students were instructed to select the best answer for each multiple-choice question. Ms. Lee administered the pre-test two days prior to beginning the lessons for the heat transfer unit. She administered the post-test one week after the unit was taught. The statistical software R and the dependent t-test (paired samples t-test) were used to analyze the pre- and post-test results from the content knowledge test. The study set up the level of significance for inferential comparison at the .05 level.

Results

The study analysis is presented in three parts of research which examine discourse between Ms. Lee and her students in the situation of an integrated science and engineering lesson. The first part of the analysis describes the context of how Ms. Lee taught the concepts of heat transfer: conduction, convection, and radiation. The second part of the analysis focuses on the teacher's classroom conversations with a student focus group of students as they apply the lesson in activities and presentation. The analysis applies the I-R-P framework and seeks to identify the patterns of discourse within that framework. The third part is the assessment of the discourse with data from the students' pre- and post-tests for content knowledge as supportive reference. The survey data adds context to the interactions of teacher and students in the classroom.

In summary, the analysis aimed to reveal findings about Ms. Lee's classroom conversations in order to determine the extent to which the conversations helped students retrieve prior knowledge; scaffold shared meanings of heat transfer; and guided students to apply their knowledge of heat transfer to solve an engineering design problem.

Part One: Teaching Heat Transfer, Conduction, Convention and Radiation

Part one summarizes how Ms. Lee taught the scientific concepts of heat transfer, conduction, convection and radiation the first three days of the lesson plan. It illustrates the main features of the class and offeres insights into what Ms. Lee believed to be the most important learning outcomes. The examples offer specific details of language and interactions to enhance understanding of the teacher's efforts to engage students.

Teaching Purpose: Definitions Are the most Important Learning Outcomes Each day, when Ms. Lee taught a new concept of heat transfer, she wrote the definition on the whiteboard. She asked students to take out their notebooks and write down the definition. For example, on the first day of the class, she had a slide on the whiteboard with the definition of heat transfer stating, "Heat transfer always occurs from the place where there is a higher temperature to the place where it is cooler," and "Heat energy (or just Heat) is a form of energy which transfers among particles in a substance (or system) by means of kinetic energy of those particles. In other words, the heat is transferred by particles bouncing into each other." After she showed a slide with definitions, she consistently instructed students in the class, "Here are some definitions that you need to write down." In another example, Ms. Lee put a PowerPoint slide on the whiteboard with the definition of conduction stating, “Conduction is a way that heat transfers from one substance to another by direct contact.” She also structured students to write down the definition.

Content: Omitting a Thorough Review to Connect New and “Old” Concepts Ms. Lee did not do a thorough review of scientific concepts taught in prior units that came up in classroom conversations during the heat transfer lessons. After students wrote down the definition of heat transfer, Ms. Lee asked, “How many of you have heard the word kinetic energy?” No students raised their hands. She tried to give a hint by saying, “Kinetic means…moving.” A few students made some noises, but still no one raised their hands. She stated, “Moving energy. Ok? You probably heard about potential energy and kinetic energy. This should be a review to you.” By omitting a thorough review to connect new concepts to previous lessons, or “old” concepts, the teacher assumed students retained knowledge from previous lessons.

In teaching the concept of convection, Ms. Lee tried to use density to explain why warm air ascends, but cold air descends. She said, “Density…Density is mass divided by volume, and density is something that you have learned in your pervious science class.” She asked, “What do you [students] remember…what you did when you measured mass and volume a few weeks ago?” In these situations, the teacher utilized an authoritative approach when querying students on essential foundational concepts that they had learned in prior classes.

Communicative Approach: Primarily Non-interactive/Authoritative and Occasionally Interactive/Authoritative Ms. Lee used many of her life experiences to explain the scientific concepts but offered limited opportunities for students to use their own everyday life examples. In using a campfire as an example to explain the concept of radiation. She explained, “If you stand in front of a campfire and you can feel the heat is coming from…that campfire, and that is radiation. Heat travels through electromagnetic waves.”

This again illustrated Ms. Lee’s authoritative approach. The students may or may not share the life experience of a “campfire.” Rather, the teacher makes assumptions in describing a sensory experience with heat, without engaging the students to interpret their experience (or lack thereof) with campfires or to apply their own life experiences with heat sensing.

Another example, when she taught convection, she said, “Convection occurs when moving fluids… what is the first thing when you hear the word ‘fluids’?” A student answered, “Water.” Ms. Lee did not acknowledge or elaborate on the student’s answer, but said, “Fluids are gases or liquids. Ok, make sure you understand that the air in this room is considered a fluid. So, convention occurs when fluids rise and fall due to differences in density caused by differences in thermal energy.”

The second example showed that although Ms. Lee asked questions, her intention was not to interact with students to explore or understand their ideas about heat transfer (or ‘fluids’), but to focus on the mission of “delivering” the concepts to students.

Patterns of Discourse: I-R-F and I-SR-SF Were the Primary Patterns of Discourse that Were Used Ms. Lee frequently used information gathering types of questions (Chin and Chia 2004) to check if students could correctly answer her. The teaching purpose had not extended beyond opening up the problem (Table 1). Occasionally, the teacher asked "why" questions, which could prompt students' to elaborate on their answers (Brown and Kane 1988; Martin and Pressley 1991; Pressley et al. 1992). But instead of waiting for students to answer, she provided her own answers. This was identified and coded as the I-SR-SF (Initiation, Self-Response, and Self-Feedback/Fellow-up) pattern in the data analysis. For example, when Ms. Lee demonstrated heat transfer through conduction, she asked, "Which one [metal or plastic spoon] melts the ice cube faster than the other one?" Students answered, "Metal spoons." Ms. Lee asked, "Why?" While some students murmured their answers, no student directly answered. The teacher ignored those responses and said, "Remember yesterday we talked about insulators and conductors, right? A metal is what?" Without waiting for students to answer, Ms. Lee followed her own question with, "A conductor, right?" In another example, Ms. Lee put a cardboard house under a lamp and said, "I am going to put this house under this lamp for about five minutes, and I will measure the temperature inside the house. Do you think the bottom and the upper floor of the house would have the same temperature? Why?" However, she did not wait for students to answer the question. Instead, she asked another question. She asked students to predict the temperature inside the house. Then, she connected the definition with the demonstration and said, "The bottom floor has lower temperature then the upper floor, because hot air has less density… more thermal energy, so it moves up and pushes cool air down to the bottom."

Part Two: The Teacher and Student Focus Group's Classroom Conversations in the Context of Engineering Design

Part two examines the discourses (I-R-F patterns) between Ms. Lee and a student focus group. The detailed analysis of the focus group conversations offers another perspective on the discourse and interactions in the science classroom, in this situation within a small group discussion. The conversations contain three episodes that highlight key discursive moments between the teacher and students in the group.

Two factors that impact the teacher's interaction with the focus group, distinctly differ from the teacher's lessons to the entire class. The first factor is that in the focus group, the students have transitioned from primarily building knowledge from the lesson's concepts to design challenges, with expanded learning objectives to apply, analyze, create and evaluate. The second factor is the implicit expectation for the students, within the small setting of the focus group, to interact with the teacher.

Episode No. 1: Defining Radiation This episode was recorded at the end of Day 4 of the heat transfer lessons. Ms. Lee looked at the group's sketch of their penguin house and asked questions. The direction of her conversation with the students was to understand if the students were able to distinguish the concepts of conduction, convention, and radiation.

Line	Speaker	Dialog	Phase	Pattern
001	Ms. L	But what about...so you already have…which one was that?	*I*nitiation/Interactive/Authoritative	
002	Peyton	Conduction.		
003	Ms. L	Conduction. And what...give me an example of conduction.	*P*rompt/Interactive/Dialogic	
004	Connor	Oh, Oh, when it collides...to make heat.		
005	Ms. L	So which one is...wait, so you have convection and conduction.	*F*ollow-up/ Noninteractive/Authoritative	$I_{(IA)}$-R-$P_{(ID)}$-R-$F_{(NA)}$
006	Ms. L	they're very similar. Which one...uhm transfers heat through solid object?	*I*nitiation/Interactive/Authoritative	
007	Connor	…Conduction?		
008	Ms. L	Conduction does, right?	*F*eedback/ Noninteractive/Authoritative	
009	Ms. L	Good!	*F*eedback/ Noninteractive/Authoritative	$I_{(IA)}$-R- $F_{(NA)}$- $F_{(NA)}$
010	Ms. L	Which one through air?	*I*nitiation/Interactive/Authoritative	
011	Connor	Radiation!		
012	Ms. L	Radiation?	*P*rompt/Interactive/Authoritative	
013	Peyton	Convection.		
014	Connor	Radiation?		
015	Ms. L	Convection does.	*F*eedback/ Noninteractive/Authoritative	$I_{(IA)}$-R-$P_{(IA)}$-R-R-$F_{(NA)}$
016	Ms. L	Um…What is radiation?	*I*nitiation/Interactive/Authoritative	
017	Connor	Heat…Wait…What?		
018	Ms. L	What is the definition of radiation? Look the handout that I gave to you.	*P*rompt/Interactive/Authoritative	
019	Connor	…The definition of radiation is heat transfer of light by waves…in the form of elec...tro...magnetic wave.		
020	Ms. L	So, is there radiation in our bin over there, where we put the penguin house in there?	*P*rompt/Interactive/Authoritative	
021	Peyton	Yes.		
022	Ms. L	Where is the radiation coming from?	*P*rompt/Interactive/Authoritative	
023	Peyton	The lamp.		
024	Ms. L	The lamp, right? OK.	*P*rompt/Interactive/Authoritative	
025	Ms. L	The transfer of heat from a warmer object to a cooler object caused your ice cube to melt.	*F*eedback/ Noninteractive/Authoritative	

Line	Speaker	Dialog	Phase	Pattern
026	Ms. L	That's an example of conduction. Make sense?	*F*eedback/ Noninteractive/Authoritative	$I_{(IA)}$-R-$P_{(IA)}$-R-$P_{(IA)}$-R-$P_{(IA)}$-R-$P_{(IA)}$-$F_{(NA)}$-$F_{(NA)}$
027	Ms. L	So, which types of heat transfer do you think are present in your penguin house?	*I*nitiation/Interactive/Authoritative	
028	Peyton	Radiation and convection		
029	Tina	All of them!		

In analysis of Ms. Lee and the focus group's conversations using the Analytical Framework (Table 1) (Scott and Mortimer 2005; Scott et al. 2006), the closest teaching purpose that matched Episode No. 1 was exploring and probing students' view of conduction, convention, and radiation. The focus was on whether the students could distinguish between the three concepts by answering the teacher's questions correctly. The science content in Episode No. 1 was definitions for conduction, convention, and radiation. Ms. Lee attempted to see if students were able to define conduction, convection and radiation through their activity to design the penguin house. The phases of discourse that Ms. Lee frequently used were $I_{(IA)}$ (Initiation/Interactive/Authoritative, five times), $P_{(IA)}$ (Prompt/ Interactive/Authoritative, four times), and $F_{(NA)}$ (Feedback/ Noninteractive/Authoritative, five times). Although Ms. Lee tried to initiate questions and prompted students to answer her questions, she consistently used the authoritative communicative approach (Table 1) in the episode.

In addition, if students' answers were not acceptable, she kept asking questions and guided students to the correct answers that she was looking for, concluding the conversations in the $F_{(NA)}$ phase. Ms. Lee also used Self-Feedback/Self-Fellow-up phase in this episode. In lines 8, and 24, she asked questions, but if students' answers were not what she expected, she provided "correct" answers herself. For example, when Connor's answer didn't meet her expectations, Ms. Lee directed him to look up the definition [of radiation] and emphasized the concept of heat transfer through conduction by responding to the questions she posed rather than by having the students respond.

The feedback posed by Ms. Lee in the form of questions, such as "Conduction does, right?" may on its surface sound as though the teacher is guiding the students through the process of inquiry. But in providing the correct answer to students, the teacher is using authoritative voice and not engaging the students in language they would use to build shared meaning.

As for the students, Episode No. 1 showed that Connor's image of heat transfer was an object "colliding" (line 4) with heat, when Ms. Lee asked him to give an example by using $P_{(ID)}$ phase. Lines 10–15 indicate that Connor might see that radiation had something to do with air. His understanding of radiation as being a type of heat transfer through air was persistent, because he answered the teacher's question twice, even after the teacher repeated the question to prompt a different answer (line 12). This dialog indicated that Ms. Lee could potentially use I-R-P-R pattern conversation to determine where the concept might be unclear to Connor, but the dialog instead transitioned to her using the authoritative approach.

Episode No. 2: The "Right" Path for Heat Transfer This episode was recorded at the middle of Day 5. The conversation happened after the students had tested their penguin house for the first time. Ms. Lee tried to determine if the students had applied the scientific concepts that they learned in the design of their penguin houses.

Line	Speaker	Dialog	Phase	Pattern
030	Ms. L	Didn't you have…Uhm a roof on your house, though?	*I*nitiation/Interactive/Authoritative	
031	Connor	Yeah...but…?		
032	Ms. L	Did the lamp directly affect the ice cube?	*P*rompt/Interactive/Authoritative	
033	Connor	Well, not directly. It travels through the...ooh, wait...I think...it collides in the house.		
034	Ms. L	OK. Heat travels and heats the house, right?	*F*eedback/ Noninteractive/Authoritative	$I_{(IA)}$-R-$P_{(IA)}$-R- $F_{(NA)}$
035	Connor	Yeah. It travels to the house.		
036	Ms. L	And makes the inside…?	*I*nitiation/Interactive/Authoritative	
037	Connor	Air...?		
038	Ms. L	Air…warmer, right?	*F*eedback/ Noninteractive/Authoritative	$I_{(IA)}$-R-$F_{(NA)}$
039	Ms. L	Remember when we talked about...when it gets really hot in the house, where it usually gets warmer?	*I*nitiation/Interactive/Authoritative	
040	Connor	At bottom?		
041	Ms. L	At bottom or upstairs?	*P*rompt/Interactive/Authoritative	
042	Peyton	Upstairs, because…		
043	Ms. L	Upstairs, right? Why does warm air rise?	*P*rompt/Interactive/Authoritative	
044	Connor	Because it's not as dense as cold air!		
045	Ms. L	So, in your house, where it the ice cube touching?	*P*rompt/Interactive/Authoritative	
046	Tina	The ground, which is hot.		
047	Ms. L	The ground, which is hot, right?	*P*rompt/Interactive/Authoritative	
048	Ms. L	So, you have a hot surface touching a cold surface, what's going to happen?	*P*rompt/Interactive/Authoritative	
049	Connor	Melts.		
050	Ms. L	It melts. Why? It's the transfer of what?	*P*rompt/Interactive/Authoritative	
051	Connor	Heat.		
052	Ms. L	OK, the transfer of heat from a warmer object to a cooler object caused your ice cube to melt.	*F*eedback/ Noninteractive/Authoritative	
053	Ms. L			

Line	Speaker	Dialog	Phase	Pattern
		That's an example of what? Conduction, right?	*F*eedback/ Noninteractive/Authoritative	$I_{(IA)}$-*R*-$P_{(IA)}$-*R*-$P_{(IA)}$-*R*-$P_{(IA)}$-*R*-$P_{(IA)}$- $P_{(IA)}$-*R*- $P_{(IA)}$-*R*- $F_{(NA)}$-$F_{(NA)}$
054	Ms. L	So, which types of heat transfer do you think are present in your penguin house? Why?	*I*nitiation/Interactive/Dialogic	
055	Peyton	Radiation and convection.		
056	Tina	All of them.		
057	Ms. L	Why?	*P*rompt/Interactive/Dialogic	
058	Connor	Because the waves...umm...heat...travel… collides… into the air, and the air gets warmer. The air...is convection, and...?		
059	Ms. L	You're absolutely on the right track. The heat waves from the light, which is radiation, travel to the air and the house, makes the air warmer and makes the surfaces warmer that the penguin is touching.	*F*eedback/ Noninteractive/Authoritative	$I_{(ID)}$-*R*-*R*-$P_{(ID)}$-*R*-$F_{(NA)}$

In Episode No. 2, Ms. Lee's teaching purposes were to explore and to probe students' views of the scientific concepts that they used to design their penguin houses and to determine if students could explain how heat transfers through the concepts of conduction, convection, and radiation. The science content in the conversation was the path of heat transfer. In Episode No. 2, Ms. Lee directed students to "see" how heat was transferred from the lamp to the ice cube (lines 34 to 52) from her perspective. Ms. Lee guided students toward the answers that she wanted. Once the students responded to her questions correctly, she moved on and asked other questions without listening to the students' explanations. In lines 34 to 52, Peyton, Connor, and Tina were able to respond to Ms. Lee's questions correctly, but the dialog lacked the students' own voices. In this episode, the phase of discourse that Ms. Lee frequently used was $P_{(IA)}$ (seven times), and $F_{(NA)}$ (five times). In addition, she also used $I_{(ID)}$ (Initiation/Interactive/Dialogic, one time) and $P_{(ID)}$ (Prompt/ Interactive/Dialogic, one time). Although Ms. Lee used Prompt (P) frequently in this episode, she used the authoritative communicative approach. Students' answers were short and mostly factual (e.g. lines 42, 44, 46, 49, and 51). This episode displays yet another situation in which Ms. Lee used Self-Feedback/Self-Fellow-up phase. For example, in lines 38 and 47, she asked questions, but if students' answers were not what she expected, she provided students the correct answers.

When Ms. Lee used the dialogic communicative approach (line 57), Connor was able to share his view of how he thought heat transferred in the penguin house (line 58). However, when Ms. Lee concluded the conversation with $F_{(NA)}$ phase, Connor did not share additional information. The data suggests that Connor's understanding of conduction seemed to come from his knowledge of "colliding" rather than "traveling" (line

33). He seemed to have trouble distinguishing “waves” and “heat”, and “travel” and “collides”. When Ms. Lee used the word “travel” (line 34) by using the $F_{(NA)}$ phase to explain heat transfer, Connor changed the language from “collides” to “travels” as well (line 35). Based on his responses, Connor’s logic of heat transfer was through “collides”, not “travels.” By following $I_{(ID)}$ and $P_{(ID)}$, Ms. Lee could have helped Connor elaborate on his thoughts. She also might have been able to “see” the process of heat transfer from Connor’s view and then guided the conversation to build shared meaning.

In addition, Peyton did not change her response when she was asked what types of heat transfer were present in their penguin house (line 55). Based on her response, Peyton appeared to think that the penguin house was only affected by heat transfer through radiation and convection as in Episode No. 1 (line 28).

Episode No. 3: Radiation Is Heat Transfer through Air This episode was recorded at the end of Day 6. Students were presenting their penguin house and findings. The dialog involved both Ms. Lee and the students in the conversations.

Line	Speaker	Dialog	Phase	Pattern
060	Ms. L	All right, let’s give them our full attention, please.		
061	Peyton	Our claim is the penguin melted because of conduction, radiation and convection.		
062	Peyton	Our evidence is… we know this because the lamp makes heat travel through heat waves and then it travels through the air and heats the house,		
063	Peyton	and when it heats the house, it heats the air inside and when it heats the air inside, it heats the ground, and the ground collides with the penguin and it melts.		
064	Ms. L	Do you want to say something about the materials you used?	*I*nitiation/Interactive/Dialogic	
065	Tina	We used foam and the blanket paper and tape.		
066	Ms. S	What questions do we have for this group?	*P*rompt/Interactive/Dialogic	
067	Student A	Why did you choose those materials?	*P*rompt /Interactive/Dialogic	
068	Connor	Because, well.., we put the foam on the inside and we put the blanket paper on the outside. We thought that would reflect the heat.		
069	Student B	You said that conduction melted your penguin, too. How was that?	*P*rompt /Interactive/Dialogic	
070	Connor	Because it heats the floor, and the floor collides with the penguin.		
071	Ms. L	Good question, Austin.		

Line	Speaker	Dialog	Phase	Pattern
			*F*eedback/ Noninteractive/- Authoritative	$I_{(ID)}$-R-$P_{(ID)}$-$P_{(ID)}$-R-$P_{(ID)}$-R--$F_{(NA)}$
072	Student C	Did your house have a floor?	*I*nitiation/Interactive/Dialogic	
073	All	No.		
074	Student C	How did that affect your penguin?	*P*rompt /Interactive/Dialogic	
075	Peyton	Badly.		
076	Ms. L	Why?	*P*rompt /Interactive/Dialogic	
077	Connor	Because the bottom of it (the heat bin) was black and darker colors attract heat more.		
078	Student D	Did you get the results you expected?	*P*rompt /Interactive/Dialogic	
079	All	No.		
080	Peyton	We expected it maybe not to be that low. We will add a floor to prevent conduction next time.		
081	Ms. L	Do you guys also want to talk about where the convection maybe happened? You claimed that convection was a part also.	*P*rompt /Interactive/Dialogic	
082	Connor	When the travel through the heat… no...radiation traveled through the air...uhm…to the house...and heated the air inside, just like heating the floor.		
083	Ms. L	Any other questions? Rock on. Good job answering the questions you guys.	*F*eedback/ Noninteractive/- Authoritative	$I_{(ID)}$-R-$P_{(ID)}$-R-$P_{(ID)}$-R-$P_{(ID)}$-R-R-$P_{(ID)}$-R-$F_{(NA)}$

The teaching purpose in Episode No. 3 was for students to share their results. Students were instructed to talk about the concepts involved in heat transfer and the design of their penguin houses. No content was taught by Ms. Lee in this episode. The phases of discourse that Ms. Lee frequently used were $P_{(ID)}$ (Prompt/ Interactive/ Dialogic, three times), and $F_{(NA)}$ (Feedback/Noninteractive/Authoritative, twice), and discourse phases students used were $I_{(ID)}$ (Initiation/Interactive/Dialogic, twice), and $P_{(ID)}$ (Prompt/ Interactive/Dialogic, twice). In this episode, when Ms. Lee and the students used $P_{(ID)}$ phase, Connor talked about the reasons the group chose certain materials to build their penguin house (line 68); gave his views of conduction, convection and radiation (lines 70, and 77); and explained how heat transferred inside and outside of their penguin house (lines 70, and 77). The $P_{(ID)}$ phase provided a venue for the group to "talk" about the logic of their design and to help other students "see" the logic behind the design.

When Connor explained the materials that the group had chosen to design their penguin house, he mentioned that the materials could help reflect heat (line 68). However, Connor's answer revealed that he still did not have a clear understanding about convection and radiation (line 82). Connor still believed radiation is heat transfer through air and that it heated both the air inside of the house and the floor of the hot bin.

The penguin house that this group built did not have a floor (line 73). This indicated that when the group designed their penguin house, they did not think about preventing heat transfer through conduction. However, the group did express an understanding of the concept of conduction in their presentation (lines 70, 75, and 77).

Part Three: the Pre- and Post-Tests for Content Knowledge

Part three of this study examines the results of the statistical analysis for the pre- and post-tests for content knowledge. This analysis offers additional context to the study. The survey data contributes to the purpose of the study by bridging the interactions of the science lessons in a particular situation.

Twenty-three students in Ms. Lee's class completed both the pre- and post-test for content knowledge. The p value in all the four areas, Conduction, Convection, Radiation, and Heat transfer, were greater than 0.05. Therefore, the heat transfer unit did not make any significant improvement (or deterioration) in the students' knowledge of heat. Table 2 shows that there were no statistically significant changes from pre-test to post-test across the four content areas.

Discussion

This qualitative analysis of classroom conversations offers insight into the research question posed in the current study. The findings identified the teacher's use of the I-R-F pattern of discourse. More importantly, the study identified the need for interactive dialog to engage students in building shared meaning.

The analysis supports the application of the Analytical Framework (Table 1) to examine the meaning of classroom conversations and to analyze conversations for combined patterns of discourse and communicative approach. Scott et al. (2006) discussed the open and closed chain patterns, and suggested in order to sustain the interaction chains, a teacher should use more Prompt and Follow-up phases.

A key finding from the analysis of conversations is the need for the teacher to structure conversations through a dialogic, rather than the authoritative, communicative approach, using Prompt and Follow-up phases. In Episodes No. 1 and 2, Connor was able to give correct answers to Ms. Lee when $I_{(IA)}$ and $P_{(IA)}$ phases showed in the

Table 2 Paired-t test result for the pre- and post-tests content knowledge

	Conduction	Convection	Radiation	Heat transfer
T	0.20	−0.41	−1.24	−0.65
P value	0.84	0.69	0.24	0.53
Confidence interval	−0.17 to −0.21	−0.22 to −0.15	−0.22 to −0.06	−0.31 to 0.17
Mean of difference	0.01	−0.04	−0.08	−0.07

patterns of interactions. Yet Connor still did not understand the concepts of convection and radiation. In addition, when Ms. Lee used $I_{(IA)}$ and $P_{(IA)}$ phases, students gave short answers to Ms. Lee and tried to provide the correct answer that she was looking for (e.g. lines 10–14, and 36–42). Such interactions did not demonstrate that students had in-depth understanding of the concepts. The authoritative approach in the $I_{(IA)}$ and $P_{(IA)}$ phases did not appear to engage students' views of heat transfer. While students might be able to memorize concept definitions for heat transfer in order to respond to the $I_{(IA)}$ and $P_{(IA)}$ phases, they did not develop a deep understanding of the concepts.

Conversely, in a dialogic conversation, the teacher would generate meaningful, discursive interactions to construct shared meanings with students and help them gain in-depth understanding of the concepts of heat transfer. The findings reveal that when the Interactive/Dialogic communicative approach was present in conversations, the students were able to describe and explain their view of heat transfer. In Episode No. 3 lines 64–71, Connor was able to describe his view of conduction until Ms. Lee closed the conversation with an $F_{(NA)}$ phase. The Interactive/Dialogic communicative approach in science and engineering integrated lessons opens up the possibility for a teacher to support students' understanding and then construct shared meaning of concepts.

The analysis also discovered the teacher's "self" pattern of discourse. Ms. Lee frequently referred to herself in teaching the concepts of heat transfer, demonstrating the pattern of I-R-SF (Initiation, Response, Self-Feedback/Follow-up). This pattern was the most detrimental discourse pattern to constructing shared meaning with students. The words that Ms. Lee used in her heat transfer unit, (such as particles, fluids, density, and electromagnetic waves) have situated meaning in a science classroom. Students walked into her classroom with prior knowledge about these words. When she used the I-R-SF pattern, Ms. Lee relied solely on personal experiences and definitions that she wanted students to remember instead of acknowledging and elaborating on students' answers in order to construct shared meaning. In addition, Ms. Lee asked many questions in her classroom conversations, but her questions centered on students giving correct answers rather than generating dialog. Although her learning objectives fit the teaching purpose in the Analytical Framework, in her classroom practice, Ms. Lee did not extend beyond her presentation of the problem nor did she structure conversations to explore and probe students' views.

The present study's detailed level of analysis is important in identifying points at which the teacher makes assumptions or adopts an authoritative voice. In the classroom setting, as the teacher guides students through lessons with examples or questions, it may appear that the teacher is engaging students in building shared meaning. But the findings of this study reveal critical nuances and the need for teachers to engage students in their own language and discourse. The use of the I-R-F conversation pattern to engage students is supported in this study and demonstrates a valuable approach for teachers in the classroom. However, teachers may subconsciously categorize conversation patterns as effective, even though they may not be authentically engaging students.

In the group activity to design the penguin house, the student focus group considered using foam to reflect heat, but then designed a penguin house that did not have a floor to help prevent heat transfer through conduction. This implied that the students did not apply what they had learned about conduction to design their penguin house. In addition, the pre-and post-test results showed no significant improvement on students' content knowledge. Overall, the lessons on heat transfer may not have increased student understanding of conduction, convection, and radiation, and the process of heat transfer.

Conclusions, Limitations and Future Direction for Research

Insights from the analysis of classroom conversations advances the argument by Lin (2007) for qualitative methods of research of science education. The patterns of discourse in this study seem to support the use of the I-R-F pattern of discourse and the need for authentic teacher-student interactive dialog.

The conceptual stage of a science lesson, which establishes the foundation of discourse and language for subsequent scientific experiments, may benefit from additional time for classroom discussions, in which teachers try to engage students in "seeing" the concepts from their own points of view. Teachers should also allow students to draw from their own experiences and language to describe the concepts.

When teachers ask questions to facilitate learning, the recommendation should be for teachers to resist the temptation to self-respond with "correct" answers, which reinforces rote learning and puts students at risk of not meeting learning outcomes. This authoritative approach to classroom conversations also appears to prevent students from applying the knowledge that they need to learn. It may cause teachers to miss the opportunity to uncover the conceptual understanding, or more importantly the misunderstandings, that students bring or develop in the classroom. Teachers need to be sensitive to conversational cues that indicate where students are struggling in their learning process.

By applying the Interactive/Dialogic communicative approach to classroom conversations, a teacher encourages interaction by listening to students' reasoning, thus learning from their perspectives and structuring the conversation to develop shared meaning of scientific concepts (Levin et al. 2012; Marbach-Ad and Sokolove 2000).

Multiple research studies have described the importance of using scientific language to communicate and explain students' experience of everyday events (Brown and Kane 1988; Haglund et al. 2012; Kesidou and Roseman 2002; Rosebery et al. 2010). It is important to value the language that students use to describe science concepts, because that helps teachers "see" from the students' perspectives and then use those insights to successfully construct shared meanings. For example, Ms. Lee talked about "particles bouncing" when she taught the concept of heat transfer, and Connor seemed to internalize that concept as "collisions" which he then used to describe all types of heat transfer. If Ms. Lee had been attentive to the meaning of "collisions" as Connor visualized it in the context of heat transfer, she might have been able to help Connor understand how heat "travels" (the word that Ms. Lee used to describe heat transfer), and then construct shared meaning.

The lack of interactive dialog in classroom conversation and assumptions of shared meaning pose greater barriers for students from diverse backgrounds. Research shows that underrepresented student populations in scientific fields struggle to learn in the current education system due to limited forms of varied and culturally appropriate classroom practices (Rosebery et al. 2010; Warren et al. 2001). Even students from populations dominant in scientific fields struggle with specific, situated discourse in the science classroom, as demonstrated by Connor's classroom conversations. This study echoes the importance of dialogic discourse in science classrooms and the need to design instructional dialogic discourse to support students' meanings and interactions for shared meanings.

This case study has shown that students' ability to apply knowledge in a science and engineering integrated learning environment does not happen spontaneously. Teachers need to intentionally facilitate the process of building applied knowledge. Curriculum without interactive dialog does not achieve intended educational outcomes. Teachers cannot assume students will retain what they have learned in one context and apply those lessons to another context. This study builds on existing literature that argues for structuring classroom conversations as dialogs in order for students to learn and apply the concepts of heat transfer. In other words, teachers who simply ask questions are presenting ineffective instructional discourse.

This research has limitations in terms of generalizability due to the small sample size. Due to the restrictions of digital recording equipment, the study was limited to 21 min of a student focus group's conversation with the teacher. Therefore, the dialog patterns might not represent the focus group students' daily classroom conversations. In addition, the research could be furthered with evidence to show whether students were applying relevant scientific concepts in solving their design problems, especially with the fact that students did not appear to have an improved understanding of the scientific concepts being taught. Future research with more teachers and students, in more diverse classroom settings, is needed to study the discourse patterns in an integrated learning environment, particularly as it relates to authoritative or interactive dialog approaches to communication.

Compliance with Ethical Standards

Conflict of Interest The author states that there is no conflict of interest.

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