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Examining Teacher Talk in an Engineering Design-Based Science Curricular Unit

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Abstract Recent science education reforms highlight the importance for teachers to implement effective instructional practices that promote student learning of science and engineering content and their practices. Effective classroom discussion has been shown to support the learning of science, but work is needed to examine teachers' enactment of engineering design-based science curricula by focusing on the content, complexity, structure, and orchestration of classroom discussions. In the present study, we explored teacher-student talk with respect to science in a middle school curriculum focused on genetics and genetic engineering. Our study was guided by the following major research question: What are the similarities and differences in teacher talk moves that occurred within an engineering design-based science unit enacted by two teachers? Through qualitative and quantitative approaches, we found that there were clear differences in two teachers' use of questioning strategies and presentation of new knowledge that affected the level of student involvement in classroom discourse and the richness and details of student contributions to the conversations. We also found that the verbal explanations of science content differed between two teachers. Collectively, the findings in this study demonstrate that although the teachers worked together to design an engineering designed-based science curriculum unit, their use of different discussion strategies and patterns, and interactions with students differed to affect classroom discourse.

Keywords Classroom talk · Engineering design-based curriculum · Life science

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The advances in theories and methodological approaches in education over the last several decades have contributed to a better understanding of the complex relationship between teachers' teaching practices and student learning. When this body of research is considered collectively, several premises can be extracted that have been used as elements of a framework for the recent science education reform in the USA (National Research Council [NRC] 2012). The principal premise, which is also used in the Next Generation Science Standards (NGSS; NGSS Lead States 2013), is that learning is multidimensional, and *all* students should engage in scientific inquiry and engineering design, and apply crosscutting science concepts to enhance their learning of these core ideas. This new vision of science education requires teachers to explore and implement effective instructional practices to provide students with much needed opportunities to develop a deep understanding of science and engineering content and their practices. Thus, the multidimensional teaching requires that students should actively engage in their learning of science as they practice science content (National Research Council 2012).

A number of research studies have been conducted to examine the importance of effective classroom discourse, academically productive classroom talk (Michaels & O'Connor 2012). Specifically, researchers have studied teacher statements or talk (Christodoulou & Osborne 2014; Moje 1995), scientific classroom discussions (Alozie et al. 2010; Pimentel & McNeill 2013; Oliveira 2010), and enactment of inquiry-based discussions in reform-based science classrooms (Hmelo-Silver et al. 2015; Puntambekar et al. 2007). In some work, quantitative studies have been conducted to identify effective and less effective teaching strategies or teacher moves in framing classroom discussion (Correnti et al. 2015; McNeill et al. 2013). In these studies, in general, teaching strategies are linked to or correlated with student achievement. Others have investigated the effects of teaching practices on student learning through conducting qualitative studies (e.g., Lemke 1990). These studies grounded in discourse analysis have provided rich contexts and unique insights to the teacher-student interactions in class discussions (Correnti et al. 2015; Pauli & Reusser 2015). Classroom discourse is complex, and how and when this discourse occurs differs from classroom to classroom. This body of work highlights the value of examining and evaluating the effectiveness of classroom instruction. Furthermore, this work suggests the strong connection between classroom discourse and student learning.

Previous studies have offered some important insights into classroom discourse that support student learning of science, but there is still much to learn about the ways, purposes, and forms that teacher and student science talk occurs in engineering design-based science units. Since engineering is new to many science teachers, it is critical to examine teachers' enactment of engineering-based curricula by focusing on the content, complexity, and structure of classroom discussions and ways teachers orchestrate class discussions to provide strategies by which science and engineering content and practices can be developed together in instruction. To that end, this research was framed, in conjunction with sociolinguistics aspects of classroom discourse, to study two teachers' enactment of an engineering design-based science curriculum unit. Despite designing the curriculum unit together and teaching the same science and engineering content, the two teachers implemented the curriculum unit in somewhat different ways. Our objective in conducting this research study was to describe their classroom discourse in two cases; therefore, the major research question that guided this study was:

> RQ: What are the teacher talk moves that occurred within an engineering design-based science unit enacted by two teachers?

Background

Drawing on sociocultural theoretical traditions, we see classrooms as learning communities in which students construct new knowledge and skills as they participate in knowledge building practices. In this view, learning is a socially organized activity, which requires providing opportunities for students to participate in the practices of a learning community (Lave & Wenger 1991). In line with this, students in today's classrooms are expected to be active participants in meaningful, authentic science and engineering practices. In other words, learning science means engaging in practices of science and engineering, including asking questions, conducting experiments, designing artifacts, sharing ideas with others, and making sense of data through arguing and reflecting (National Research Council 2012). As students participate in learning communities in science classrooms, they learn to negotiate ideas, engage in various scientific and engineering practices, and learn the ways of thinking and reasoning shared in their communities.

A critical condition to support student learning in effective science instruction is that students must participate in classroom discourse to construct, share, and refine knowledge as this discourse is integral to the practices and learning of science (Lemke 1990). From this perspective, teachers should provide students authentic learning activities and facilitate classroom discourse that allows students to acquire scientific concepts and practices in a similar way as scientists and engineers (National Academy of Engineering National Academy of Engineering and National Research Council 2014; National Research Council 2012). Classroom discussions should allow students to learn and "use the specialized language of science in speaking, writing, and reasoning" (Lemke 1990, p. 167). This would require teachers to move away from traditional teaching strategies, facilitate productive discussions, and ensure all students contribute to the co-construction of the knowledge. Teachers can use different tools or discourse moves to facilitate productive discussions. Teacher discourse moves are "strategic teacher moves designed to open up the conversation and support student participation, explanation, and reasoning" (Michaels & O'Connor 2012, p. 7). For example, a specific teaching move is questioning which would require a student to clarify or extend what has been said or provide evidence. Correnti et al. (2015) studied teacher moves in the context of whole classroom discussions with focus on *initiating moves* that aim to invite students into classroom discussions and *rejoinder moves* that are teachers' responses to student ideas, explanations, or questions. This strategy showed that the type of questions teachers use to initiate or extend discussions is associated with teachers' reform-based practices. For example, asking more open-ended questions (e.g., *uptake*) is aligned with productive classroom discussion. However, the authors pointed out that simply using a great number of uptake questions does not necessarily lead to effective instruction if the classroom discourse does not support deep understanding of the academic content.

Additionally, researchers (Nassaji & Wells 2000) recommended choosing more thought-provoking questions and using less evaluative follow-up questions and requesting justification. These strategies allow students to make more contributions to classroom discourse and thus turn classroom talk into a more conversation-like genre. Similarly, Chin (2007) suggested the need to use questioning strategies that "elicit students' ideas, scaffold student thinking, prompt students to think aloud and verbalize their ideas, and nudge students toward conceptual development instead of just assessing the correctness of their responses" (p. 837). From this perspective, we view the teacher as the manager of the classroom discussion who provides questions that promote higher-level student thinking and decides on the direction of the talk.

To further understand how classroom talk affects students' learning gains in a science unit, research has focused on the types of *explanations* employed by educators to disseminate science content as they orchestrate classroom discourse. These verbal explanations not only support student learning of science but also serve to supplement other teaching strategies or instructional texts (Wittwer & Renkl 2008). A major study by Dagher and Cossman (1992) found that in a junior high school classroom, science teachers used several different types of explanations to teach a science lesson, which serves as a framework for future studies. From these categories, many verbal explanations in these classrooms were labeled as analogical, meaning that they describe a familiar situation that is similar to that which is unknown. Analogies are thought to provide some level of conceptual change for students, meaning that analogies help students comprehend science in more meaningful ways (Dagher 1994). However, to date, there is little research on the effectiveness of teacher's talk of verbal explanations, such as through analogies or models and the depth of science content, on student learning gains (Geelan 2012).

Teachers' moves or questioning strategies and explanations have been further examined in curriculum enactment studies. For example, Pimentel and McNeill (2013) worked with five secondary science teachers who used interactive approaches and dialogic whole-class discussions, but found that teachers acted as the main "directors," "evaluators," and "feedback providers" which caused simple and short student contributions to classroom dialogue. The lack of occurrences and time spent on science talk between both students and teachers was found to be the main reasons for limited, teacher-centered science talk observed in these classrooms. Similarly, Alozie and colleagues (2009) studied high school teachers' enactment of science discussions in project-based science classrooms. Students engaged in dialogic, inquiry-based discussions in the project classrooms; however, teachers varied in their success with productive discussions. Teachers tend to use triadic dialogue, which results in minimal student participation in classroom discussions. The authors concluded that teachers need continuous and explicit support to enhance the quality of scientific discourse in high school project-based classrooms. Moreover, Puntambekar et al. (2007) investigated teacher-led classroom discussions during implementation of an inquiry-based curriculum unit. Differences in facilitating classroom discussion resulted in variations in student outcomes. When teachers' facilitated classroom discussions to support student understanding of the connections between science concepts and activities, students understanding of science content benefited more from these types of discussions.

Establishing a classroom community where students share ideas and reasoning and engage in others' reasoning require teachers to effectively orchestrate classroom discussions. Given that each classroom community is unique, teachers then need to appropriately tailor their talk moves or questioning strategies and explanations to address the cultural and language practices of their students. For example, English language learners may not have proficiency in ways of talking science, thus they need more and better structured opportunities to learn to talk science and make meaning of the science being taught (Moje et al. 2001; Ryu 2015). Science learning and discourse in a classroom with diverse student population were investigated by Moje et al. (2001). Specifically, the authors studied the language demands of project-based science pedagogy for seventh grade English language learners. The authors addressed the need for the teacher to engage students in science and everyday language for productive, successful classroom discourse. The studies described above and others (cf. Chen et al. 2017; Moje 2015; Pauli & Reusser 2015) support the critical importance of teaching practices that support student engagement in productive discussions that are central to powerful science learning.

Research Design and Methods

In this study, we explored classroom discussions with respect to science in engineering design-based science classrooms through applying the research framework of ethnomethodology, which "keenly attuned to naturally occurring talk and social interaction, orienting to them as constitutive elements of the settings studied" (Holstein & Jaber 2011, p. 343). Specifically, we framed our research to study classroom discourse from a social interaction perspective (Sacks et al. 1974; Sinclair & Coulthard 1975). Accordingly, we examined whole-class discussions, classroom language, and teacher and student participation in classroom discourse through using conversation analysis methods (Sacks et al. 1974). Since the study is grounded in sociolinguistics, we argue that classroom discourse serves multiple purposes, form and function of talk may not correspond to each other, and talk is a vehicle of action. Thus, this study not only focuses on what gets said but also the purposes of the talk (e.g., to explain), ways the science language is used to present something and science activities in which the talk occurred. Teaching science is a social process and classroom discourse or science talk creates a learning community in the classroom (Lemke 1990). These members of the social learning community, teachers, and students interact with each other and talk science to reason, argue, and share particular concepts or ideas.

Engineering Design-Based Science Curriculum Unit

Engineering is broadly defined as "any engagement in a systematic practice of design to achieve solutions to particular human problems" in the recent reform documents (National Research Council 2012, p. 11). The goal of integrating engineering in science then to encourage more K-12 students to explore engineering design, learn about the interconnection of science and engineering, and apply scientific knowledge and skills to help them solve engineering challenges presented in science classes. The key engineering practices involve defining problems, developing and using models, planning and carrying out investigations, analyzing data, using mathematics and computational thinking, designing solutions, engaging in argument from evidence, and obtaining, evaluating, and communicating information (National Research Council 2012, p. 3). These practices provide opportunities to students to purposefully follow a design process for solving engineering problems or challenges at the K-12 level. Engineering design process is highly iterative and open to the ideas that a problem may have many possible solutions.

With these principles in mind, three middle school science teachers, a graduate student with 8 years of teaching experience and the third author of the study designed the unit, entitled *Got GMOs?*. The unit aligns with the teachers' state standards and NGSS (NGSS Lead States 2013). The unit addresses NGSS disciplinary core ideas: MS-ETS1: Engineering Design, MS-LS3: Heredity: Inheritance and Variation of Traits, and the crosscutting concepts, cause and effect and structure and function. In addition, the unit includes the practices of science and engineering practices described in NGSS: defining problems, developing and using models, planning and carrying out investigations, analyzing and interpreting data, using mathematics and computational thinking, designing solutions, engaging in argument from evidence, obtaining, evaluating, and communicating information. Within the unit, grade-level appropriate, standards-based mathematics is included such that it supports the science and engineering learning. The mathematics fits both the NGSS' call to use mathematics but also addresses Common Core State Standards related to proportional reasoning and geometric scaling (7.RP and 7.G.1). Table 1 shows the lessons and objectives of each lesson. Briefly, in this unit, students completed several science experiments and inquiry lessons to explore cells, to consider the relationship of the structure and function of DNA, to study sexual and asexual reproduction, and to explain basic heredity patterns found in nature. At the outset of the unit, students were introduced to Genetically Modified Organisms (GMOs) and the client, a Midwestern University's Agricultural Extension Office, who had been asked to design a solution that effectively reduces cross-contamination of non-GMO fields from GMO fields.

Participants

The participants were identified based on purposeful sampling. Mr. Evans and Mrs. Cooper (pseudonyms) participated in a professional development (PD) project, which aimed to help upper elementary and middle school science teachers improve their understanding and practices of reform-based science instruction. The 3-week summer PD provided teachers with many opportunities to engage in activities designed by the authors that focus on science and engineering teaching. Teachers completed a variety of engineering design-based science activities as *students* during the PD. At the end of the PD, teachers were asked to design a unit that teaches science and engineering in an integrated manner. Mr. Evans and Mrs. Cooper designed the *Got GMOs?* unit.

Mr. Evans teaches sixth grade and Mrs. Cooper teaches seventh grade life science in a Midwestern state. Their teaching experience range from 6 to 8 years. During the time of the study, Mr. Evans taught in a suburban school (School A) whereas Mrs. Cooper taught in a school with a diverse student population (School B, see Table 2 for student demographics). A total of 137 students participated in the study. The different student characteristics in two schools allowed researchers to study curriculum implementation in different contexts. The other teacher who designed this curricular unit was also a member from School A and had similar talk moves as shown by Mr. Evans. However, we did not include him in this study since a substitute teacher taught several days of the unit. It is important to note that Mr. Evans

Table 1 Overview of the Got GMOs? unit

Lesson	Days	Content focus	Lesson summary
1. Introduction to the Engineering Challenge	1, 2, 3	Engineering, Science	Introduction to engineering challenge and GMOs
2. Introduction to DNA Structure and Function	4, 5, 6, 7	Science	Introduction to structure/function of DNA; build DNA model
3. Genes and Trait Expressions	8, 9	Science	DNA connection to genes and alleles; PTC strips activity; DNA extraction experiment
4. Introduction to Heredity	10	Science	Introduction to heredity and reproduction; stations to explore inheritance, a/sexual reproduction, plant fertilization via pollination
5. Applied Heredity	11	Science	Introduction to heredity and probability with Punnett squares
6. Genetic Modification	12	Science	Intro to genetic engineering; plasmid cutting activity
7. Scale Model Research	13, 14	Mathematics	Scaling problems; determine model scale factor
8. Engineering Challenge	15, 16, 17, 18	Engineering, Science	Prototype for prevention; re-design; presentation to client

and Mrs. Cooper considered differences in their student demographics (e.g., English language learners) when developing the unit, such as taking into consideration areas that could be modified to suit classroom demographics.

Data Collection Procedures

The main data collection procedure for the study involved videotaping eight science and engineering lessons in two teachers' target classrooms over a month. Each teacher spent approximately the same amount of classroom time (~20 classroom periods) to implement the lessons. Each lesson was videotaped and transcripts of over 50 h of classroom instruction were prepared. To determine that this curriculum leads to student learning gains, we administered a science content test. The content assessment includes ten multiple choice items scored correct/incorrect and was administered before and after the curriculum unit (pre, posttest).

The assessment was developed, scaled, and validated following the process described in the Standards for Educational and Psychological Testing (American Educational Research Association, American Psychological Association,, and National Council on Measurement in Education, 1999; Authors, 2015). A group of content experts, educational researchers, and classroom teachers developed the assessments. First, a pool of multiple choice items was generated and each assessment item was mapped to the state standards. All items were initially obtained from public item banks linked to the Trends in International Mathematics and Science Study (Mullis et al. 2008), National Assessment of Educational Progress (NAEP; National Center for Education Statistics 2010), and the American Association for the Advancement of Science (American Association for the Advancement of Science 2014). Items were in some cases modified slightly to be consistent with state standards. Next, the assessments were piloted in two waves with the goal of identifying final versions of each assessment via item analyses and scaling students' responses to produce an estimate of their proficiency. In the first wave, the assessments were administered to a small group of about 20 students. The purpose was to obtain and analyze preliminary item response data as well as obtain feedback on characteristics of the assessments. In the second wave of piloting, the revised assessments were administered to approximately 300 students. Data from wave 2 were used to conduct extensive item analyses of the assessments (Lord, 1980). IRT-based reliability estimate was .83 for the science test which is relatively high. See Fig. 1 for an example item.

Table 2 School demographics

Variable	School A (%)	School B (%)
Race/ethnicity		
White, non-Hispanic	73	10
Black, non-Hispanic	9	31
Hispanic	6	19
Asian	12	40
Special Ed.	10	18
ELL	3	49
Free/reduced lunch	9	92

A mouse's tail gets caught in a mouse trap. When the mouse pulls free, its tail gets cut off. If the mouse has babies later, how will this affect the length of the tails of its babies? (From AAAS Assessment)
a. It will affect the length of the tails of all the babies.
b. It will affect the length of the tails of some of the babies.
c. It will not affect the length of the tails of any of the babies.
d. It depends on how old the mouse was when its tail was cut off

Fig. 1 Sample test item from content assessment

Data Analysis Procedures

A number of analytic frameworks have been developed to explore classroom discourse. Gee's discourse analysis (Gee 2005), Fairclough's (1992) critical discourse analysis, Lemke's thematic analysis, and Sinclair's (1975) structural and functional analysis of spoken discourse are just several of the commonly used techniques; however, each analysis technique has its strong and weak points. In this study, we applied conversation analysis methods (Sacks et al. 1974) to study the videotapes of science lessons in each of the classrooms to correspond with our interest in the linguistic aspects of the classroom discourse, in other words language interactions inside the classroom. We examined each utterance to understand the discourse function (e.g., question, response).

We used slightly modified version of Correnti et al.'s (2015) sufficiently detailed and reliable coding framework, Analyzing Teaching Moves Guide (ATM) for measuring the patterns of discourse moves. ATM grouped teacher discourse moves in three categories: *initiating moves* which include launching an open-ended question, extending or re-initiating the launch, asking literal questions; *rejoinder moves* which involve repeating a student response, which uptakes a student response or elaborating discussion, collecting additional student responses and connecting student ideas; *other moves* includes providing information related to the instructional task, and teacher's think aloud. Since our teachers used short and/or long lectures in their teaching, we added the code "explain" to the ATM as a new *other moves* code. Selected examples are provided in Table 3. In addition, we further analyzed teacher explanations of science concepts in terms of detail since this was not part of Correnti et al.'s (2015) study and suggested by the authors to better understand teacher discourse moves and how they may affect student learning. This additional step of comparison of major themes that

Table 3 Examples for select codes

Code		Example
Initiating moves	Launch	Why is it important to understand DNA if we are going to address our client's needs eventually?
	Literal	All right, we have our nucleus, our nucleus has to be where though? Where does the nucleus belong?
Rejoinders	Uptake	Okay, your concern would be that if people get sick from those that they would sue you? You're saying that they shouldn't be fully regulated. Are you saying they shouldn't be allowed to be used at all forever?
Other moves	Explanation	We call it fission. It's like mitosis, but it's a little bit different. They reproduce asexually.
	Provides Information	The first thing I'm going to do is I'm going to take this little balloon, we're going to open it up and she's going to take these two little pieces of yarn and she's going to put them in this balloon.
	No code	Raise your hand when you're ready to go, I'll dismiss you.

emerged from teacher discourse of explanation helped us make connections between science and engineering talk in two classrooms with different student demographics.

All the authors were involved in coding to analyze the large qualitative data set. First, we randomly selected transcripts of a lesson from each teacher and coded the transcripts individually. We then met to discuss our codes to identify and discuss any discrepancies. Next, we chose a different lesson, coded a new set of transcripts from that lesson, and met again to discuss codes. After several rounds of this coding procedure, an inter-rater reliability of $\kappa = 0.76$ (substantial agreement as defined by Landis & Koch 1977) was obtained for five raters. Inter-rater reliability was calculated using Fleiss's kappa statistic. Afterwards, the rest of the transcripts were randomly assigned to the raters to code using the abovementioned framework. Transcripts were coded and quantified using NVivo 11 (QSR International). We quantified the number of words used for each code for each teacher. Comparison between number of words and teacher moves for several codes revealed that word counts are proportional to teacher moves.

Analysis of Student Outcomes To assess students' content knowledge of science concepts based on the enactment of the curriculum, we compared student's pre-and posttests for each teacher using a matched pairs *t* test. These data are to be considered as contextual data, and not meant to be used to determine or compare the efficacy of each teacher's enactment of the curriculum, as doing so would be inappropriate considering the different student populations of each teacher.

Findings

In this section, we present the results from our analyses of classroom discourse and student learning outcomes. We report the differences in both teachers' enactment of the curriculum unit. Recall, the two teachers implemented all the curriculum materials in their classrooms as they were structured and spent approximately the same amount of time to deliver the materials. However, the process or the quality of delivery varied, and we report these differences in questioning and verbal explanations of science content.

To situate our analysis of how each teacher enacted their curriculum, we first report student learning outcomes based on a pre- and post-science content assessment. Analysis of students' scores revealed that both Mr. Evans' students and Mrs. Cooper's students demonstrate significant learning gains after participation in the curriculum ($p < 0.001$ and $p = 0.007$, respectively). Of the 10 assessment items, Mr. Evans' students scored highly on the pretest with a mean of 7.59 correct questions answered. After the enactment of the curriculum, student scores improved an average of 13.0%. Mrs. Cooper's students began with a lower mean pretest score of 5.08 correct questions, and improved 14.8% after instruction. In both cases, students improved on the posttest suggesting gains in science learning as a result of the curriculum unit.

Teacher Moves

Using conversation analysis methods, we coded the transcripts of teachers and quantified the total number of words aligned with each category (Table 3). Upon quantifying the total words used in each teacher's discourse, we observed that Mr. Evans spoke more than twice as much as Mrs. Cooper throughout the enactment of the curriculum (53,754 words vs. 22,601 words, respectively). We then analyzed the composition of each teacher's classroom talk. Initiating moves and Rejoinders were only a small portion of each teacher's discourse, whereas the majority (86.11–88.24%) of teacher talk was categorized under Other moves. Initiating moves (Launch, Launch-Extension, Reinitiate, and Literal) made up 6.64% of Mr. Evan's dialogue, and 10.67% of Mrs. Cooper's (Table 4). Among these codes, we observed that Mr. Evans had more than twice as many words/moves coded as Launch moves compared to Mrs. Cooper. Additionally, Mr. Evans had nearly double the amount of words coded as Launch-Extension compared to Mrs. Cooper. It was interesting to note that despite Mrs. Cooper speaking less throughout the enactment of the unit, she proportionally had more Literal moves (6.95%) compared to the Mr. Evans (3.06%).

We also observed noticeable differences in the Rejoinder moves between the two teachers. Despite having similar proportional usage of Rejoinders (7.23 and 5.62%), Mr. Evans had more than three times the amount of words associated with Rejoinders compared to Mrs. Cooper (Table 4). The most abundant code among the Rejoinder moves is Repeat followed by Collect, then Uptake. Mr. Evans and Mrs. Cooper use approximately similar frequency of Collect moves (~ 1.7%). We notice that Mr. Evans uses Repeat moves much more than Mrs. Cooper, 2144 words compared to 688 words, respectively.

The most abundant teacher move was Provides Information. It is interesting to note that Mr. Evans's classroom talk contained proportionally fewer words coded as Provides Information (45.41%) compared to Mrs. Cooper (51.27%). The second most prevalent code categorized under Other Moves was Explanation, which made up 33.9% of Mr. Evan's discourse, whereas Explanations made up substantially less of Mrs. Cooper's dialogue (21.9%). We observed that Mr. Evans provided substantially much more explanations to his students (18,213 words) in comparison to Mrs. Cooper (more than threefold, Table 4). Taken together, these differences in

Table 4 Distribution of teacher moves (word counts and percentages)

	Code	Teacher	
		Mr. Evans	Mrs. Cooper
Initiating moves	Launch	585 (1.09%)	216 (0.85%)
	Launch-Extension	940 (1.75%)	523 (2.31%)
	Reinitiate	399 (0.74%)	103 (0.46%)
	Literal	1644 (3.06%)	1570 (6.95%)
	Total Initiating Moves	3568 (6.64%)	2412 (10.67%)
Rejoinders	Uptake	604 (1.12%)	175 (0.77%)
	Collect	921 (1.71%)	403 (1.78%)
	Connect	0 (–)	4 (0.02%)
	Lot	215 (0.40%)	0 (–)
	Repeat	2144 (3.99%)	688 (2.91%)
	Total Rejoinders	3884 (7.23%)	1270 (5.62%)
Other Moves	Provides Information	24,412 (45.41%)	11,558 (51.27%)
	Explanation	18,213 (33.88%)	4958 (21.93%)
	Think Aloud	63 (0.12%)	0 (–)
	No Code	3614 (6.76%)	2428 (10.74%)
	Total Other Moves	46,302 86.11%	19,994 (88.24%)
	Total Words	53,754	22,601

frequency and composition of teacher moves characterize how the curriculum was enacted with two different student populations.

Initiating Moves and Rejoinders Initiating moves capture teachers' efforts to invite student thinking and participation in classroom talk, while rejoinders capture teachers' responses to student contributions in class discussions (Correnti et al. 2015). Most notably, we observed that Mr. Evans' classroom talk included more rejoinders than initiating moves. Conversely, Mrs. Cooper's teaching moves consisted of more initiating moves. In the following sections, we examine the characteristics of Mr. Evans' and Mrs. Cooper's use of initiating moves and rejoinders.

Initiating Moves As previously mentioned, we observed that Mr. Evan's classroom talk contained proportionally fewer moves related to Literal questions compared to Mrs. Cooper (Table 4). Mrs. Cooper asked students a lot of questions during instruction to foster productive, effective classroom discourse; however, she mostly maintained Initiation-Response-Feedback patterns of instruction. The following is a representative example of Mrs. Cooper's dialogue, demonstrating a triadic interaction with her students about DNA:

> Mrs. Cooper: To learn more about DNA. Once we take it out, we can look at it with specialized technologies, and that's how they figure out the structure of DNA. This about other reasons. Do you know your genetic code if you can't take the DNA out of the cells? No, so now they can code your DNA, know more about genetics because they can take it out. Number five, is there DNA in your food?
> Students: Yes.

Mrs. Cooper explained a concept, asked a question that requires students recall recently introduced facts. Even though Mrs. Cooper asked questions that required student's elaboration, many times she answered questions herself without giving opportunities for students to respond. Regardless of the topic or the question posed by Mrs. Cooper, students' responses were frequently short-one-word responses that does not provide an explanation, and Mrs. Cooper accepted them without encouraging students' discussion, or additional explanation from the other students. In other words, students were not asked to elaborate their thoughts behind their short answers as illustrated above the excerpt. Thus, student contributions to classroom discussions in Mrs. Cooper's class were very limited. It is important to note, however, that Mrs. Cooper's classroom demographics (e.g., higher population of ELL students) may also play a role in the more limited classroom discussions observed in this context.

Interestingly, when we examined Mr. Evans' use of Literal questions, we found that he used proportionally less Literal moves overall compared to Mrs. Cooper. We noticed that 30% of the Literal moves he used throughout the curriculum unit were concentrated in a single lesson (Lesson 7). In this lesson, students employed mathematics to determine a scale factor to utilize in their engineering design challenge. Mr. Evans asked 50 literal questions during the scaling lesson compared to Mrs. Cooper who only asked 19. Both teachers asked similar literal questions (e.g., what is the answer for this problem), but Mr. Evans also supplemented his dialogue with rejoinders that further propelled student-teacher discussion.

Rejoinders Rejoinder moves incorporate student responses into teacher talk. This can be by repeating student answers, asking students to elaborate on their answers, or collecting additional responses. We observed that both teachers made use of rejoinder moves to extend, clarify, or deepen the classroom discussion; however, we observed that Mr. Evans used more Uptake moves compared to Mrs. Cooper (proportionally and number of words, Table 4). Furthermore, Mr. Evans repeated students' responses during classroom discussions more often than Mrs. Cooper (Table 4). Mr. Evans frequently used students' responses to formulate questions that prompted students elaborate their explanations in order to elicit students' knowledge. In many cases, Mr. Evans asked a series of open-ended questions as a way to help students to get an explanation (e.g., what does that mean?). For example, the following excerpt is a representative example of an uptake question along with other probing questions posed by Mr. Evans about the structure of DNA:

> Mr. Evans: Does anybody want to first raise their hand and share a couple of things that you know about this [this refers to a picture of DNA]? Know about. Lydia.
> Lydia: It's colorful.
> Mr. Evans: Good, the picture is colorful, right? Good, John?
> John: I believe it's a double helix.
> Mr. Evans: Oh interesting, what is a double helix John? What does that mean?
> John: It's that two of the strands come together.
> Mr. Evans: Is that to do with what? What about this picture, what this makes it a double helix? That there's two strands?
> John: That there's two strands and a connector

Here, Mr. Evans uses an interplay of Repeat and Uptake moves to help John better define the term "double helix." We see that Mr. Evans repeats John's words and reformulates them into an Uptake question. By repeating students' responses and immediately following up with an Uptake question in this manner, Mr. Evans guided his students to refine their answers. The use of Repeat moves in conjunction with Uptake moves led to more fruitful conversations throughout the unit which allowed students to deepen their understanding of science content.

Providing Information and Explanations The two major categories of teacher talk moves were Provides Information and Explanation. It is not surprising that these two categories were most prominent because it was expected that teachers would need to provide instruction for the many activities embedded within this unit and explain the science and engineering content as they moved through these activities. The difference in number of words that were coded as Provides Information were minimal between the two teachers; however, Mr. Evans' classroom talk contained proportionally less Provides Information, but only by a small percentage (Table 4). This does not necessarily mean he spent less time giving instruction on the task at hand, but it appears he did not repeat instructions multiple times—as observed in Mrs. Cooper's classes. Other than a slight difference in the proportion of classroom talk spent on this discourse move and repeating instructions, it was observed that the two teachers provided instruction on how students perform activities in a similar manner throughout the unit.

Analysis of teacher moves highlight that Mr. Evans spent more time on explanation discourse than Mrs. Cooper (Table 4). To further understand whether the explanations themselves also differed among the two teachers, we comparatively analyzed their explanations within the science content, as this was the major focus of the unit. Our analysis revealed differences in how the teachers used verbal explanations to teach science content throughout the unit, specifically in the depth of their explanations, utilizing analogies as a teaching tool, and their ability to connect physical and conceptual models together.

In this unit, there were three major science constructs: structure and function, gene expression, and variation of traits. This structure and function construct was a major focus of the unit so we will highlight key differences in teachers' explanations around this concept; however, it is important to note that similar differences between Mr. Evans and Mrs. Cooper were observed in the other constructs as well. For the *Got GMOs* unit, structure and function refers to the cells' genes and how these genes carry information that determines the inherited traits of the organisms and thus covers the structure of those genes within the cell.

In these structure and function lessons, the two teachers first described the structure of DNA to their students and then participated in a DNA extraction lab. To describe the canonical helical structure of DNA, both teachers employed the same example: that DNA resembles a twisted ladder. We noticed, however, that the further details (e.g., nitrogen bases, phosphate backbone) associated with the rest of DNA structure was not explored in the same level of depth for each teacher. Mrs. Cooper simply provided the analogy to her students to help them perceive the structure:

> Mrs. Cooper It has lines in between. Okay. I'd always thought it kind of looks like a twisted ladder.

Mr. Evans took this analogy one step further by elaborating on the composition of DNA:

> Mr. Evans Now the sides of the ladder. You can think of this as a ladder that's been twisted... They're made of sugar, and phosphorous. It's called the sugar phosphate backbone. There's two of them. If you're looking at the model, there's two of these backbones, and in between them are the rungs. The rungs of the ladder are nitrogen bases, and we saw the shape, the double helix.

From these examples, we also see how Mr. Evans attempted to connect the physical model of a twisted ladder to the conceptual model of DNA and more closely relate this model to DNA's actual structure by describing the sugar phosphate backbone. Additionally, this connection between the physical and conceptual model was strengthened by Mr. Evan's explanation of base-pairing between nucleotides of DNA, as he alluded to the twisted ladder model of DNA. He provided analogies (such as certain base-pairs being friends which enables them to bond) to further help their students understand the structure of DNA at a molecular level—which was not reflected in the explanations by Mrs. Cooper. However, this level of detail (e.g., phosphate backbone and nitrogen bases) was not required in the unit, so it was not necessary that Mrs. Cooper add these details to her scientific explanations. This simply reflects how Mr. Evans added more detail to his scientific explanations of DNA structure, to better suit his audience.

Similar differences were also seen when the teachers explained the DNA extraction activity. Briefly, students were first supposed to lyse cells, either from strawberries or wheat germ, and then extract the DNA through the addition of a detergent and alcohol solution. Mrs. Cooper explained the procedure to her class (e.g., smash the strawberries and then add the solution), but did not provide a scientific rationale for each step in the procedure. In contrast, Mr. Evans went into extensive detail on why the students used each chemical and related these chemicals to the structure and function of the cell and DNA. The following example illustrates Mr. Evans explanation of why a detergent was used in this exercise, using physical models (i.e., balloons) and authentic analogies:

> Mr. Evans: The membrane, the balloon part of the nucleus and the balloon part that makes the cell. They're primarily made up of fats and protein. That's it, that's just what

> they're made of, lipids they're called. Kind of a fancy science term for fat. All cell membranes are made of mostly fat. We have to think about how can we get through or remove or separate fat from the cell… The soap removes grease, that's why we use soap. The soap that you put in this stirred mixture of cells is going to actually start pulling on the fats that surround the nucleus and the membrane, or the membrane that surrounds the cell and the nucleus.

Mr. Evans spent time with his students to not only describe the reasoning behind the solutions used but to also provided authentic analogies to assist students in understanding these concepts and related the science content to their everyday lives.

Mrs. Cooper also used analogies in her explanation of this procedure, but the purpose of the analogy in this instance was different. In the following quote, Mrs. Cooper describes why students add alcohol to their mixture to precipitate the DNA out of the solution:

> Mrs. Cooper: Once you add that alcohol what you're doing is it's called precipitating the DNA out. You're taking the DNA. The DNA is going to not dissolve in that. It's coming out of the strawberry solution into the alcohol so you can see it. Think about when you dissolve salt in water, can you see the salt anymore? No, okay, so the DNA was dissolved, and then you add alcohol and all the sudden it's not dissolved, and you can see it.

Here, Mrs. Cooper describes how DNA is impossible to see unless you add something to precipitate it out of the solution. This is an accurate description of the purpose of the alcohol in this activity, but she does not provide a scientific rationale for why this solution works, such as the alcohol interacting with the DNA. Instead, she simply provided an example of why this solution works. In contrast, Mr. Evans provided examples through this analogy to lipids as fats, and thoroughly explained the importance of this analogy in this activity to lyse cells and extract DNA.

Taken together, while the two teachers Provided Information to their students in a similar amounts of classroom discourse and style, we observed distinct differences in how they provided explanations for the science content. Mr. Evans spent the most time on his explanations, and went into extensive depth on the topics and connected the science content to physical models and employed many analogies for his students to connect science concepts with everyday examples. Mrs. Cooper provided more succinct explanations that did not cover the level of depth as Mr. Evans, but served the purpose of what was required in the unit. Seeing as Mr. Evan's students were more advanced, as shown by the pretest scores, the depth in which he explained the science concept seemed appropriate. While the manner in which Mrs. Cooper delivered explanations to her class differed from Mr. Evans', it is important to note that this does not serve as a critique of her teaching. In fact, this direct style of teaching science content at the minimum level suggested in this unit may have been better suited to the demographics of her classroom (e.g., ELL and special education students), so her style of explanation was more appropriate for her audience.

Discussion

Using quantitative and qualitative analysis techniques, we examined classroom discourse that occurred in two science teachers' engineering design-based science unit. We also measured students' learning of identified science concepts within an engineering design context. This study supports and extends previous research on classroom discourse that points out that classroom discourse plays a central role in the complex activity of classroom instruction and teacher talk plays a particularly important role in scaffolding student understanding (Alozie et al. 2010; Christodoulou & Osborne 2014; Moje 1995; Oliveira 2010; Pauli & Reusser 2015; Pimentel & McNeill 2013; Puntambekar et al. 2007). However, we find that teachers use language in certain ways to meet their own pedagogical goals even though teachers enacted the same curriculum unit. In this study, both teachers attempted to engage students in productive classroom discussion about basic genetics concepts as students participated in science and engineering practices, but the structure and content of classroom discourse varied considerably. Teachers' talk overall highly focused on providing information about how to complete the classroom tasks and explanation of science content. In contrast to this similarity in teachers' talk with providing instruction, the differences between the two teachers' use of questioning strategies and presentation of new knowledge were clear. These differences in fact influenced the level of student involvement in classroom discourse and the richness and details of student contributions to the conversations.

We believe that teachers adapt curriculum materials in consideration of their students and resources available to them. In order to better meet the needs of the classroom context and classroom language demands, teachers make adaptations such as modifying the time spent on activities or the cognitive demand of the activities. In this study, we found that Mr. Evans demonstrated a larger focus on dialogic discourse, whereas a larger proportion of Mrs. Cooper's discourse was more triadic. In addition, Mr. Evans disseminated more content and explained the content using certain instructional strategies. Students in both classroom demonstrated significant learning gains, despite the differences in student demographics between the two classrooms. As mentioned previously, students were racially, ethnically, and linguistically diverse in Mrs. Cooper's classrooms. On the other hand, Mr. Evans' classes were more homogenous. Even with these differences in student population and other confounding factors, it was surprising to find that there were no such large differences in student learning gains in Mr. Evans and Mrs. Cooper's classrooms who indeed used different patterns of instructional practices and monologic discourse (Sinclair & Coulthard 1975; Lemke 1990) as they enacted the curriculum unit. This implies that the curriculum materials met the needs of students at a certain level, but Mrs. Cooper needed to use more instructional supports such as using prompts and guides, giving more examples during classroom discussions to better address her students' needs.

Using dialogic strategies, such as Launch, Launch-Extension, and Uptake questioning, help teachers promote collaborative dialogue in the classroom. In so doing, teachers promote student thinking and help students build scientific knowledge (Chin 2007). In our study, there was variation in questioning strategies among two teachers. Mr. Evan's questioning strategies consisted of less literal questions and more questions that required students to elaborate and deepen their answers. The one exception, however, was during the mathematics-focused lesson where Mr. Evans asked almost threefold more Literal questions than Mrs. Cooper. Students engaged in discourse during this lesson, but this finding suggests Mr. Evans may have resorted to using more Literal moves due to his lack of comfort compared to that seen in the science and engineering-focused lessons. Throughout the unit, however, we observed Mr. Evans further elaborated on student responses (Repeat), and followed up with more Uptake type questions which allowed for deeper discussions. He encouraged students to ask questions and actively engage in classroom discussion. In turn, active and sustained discussions occurred and students made their ideas and explanations explicit. The use of these specific strategies clearly shows Mr. Evans vision of learning as a social, collaborative, and communicative process, which aligns with the situated learning theory (Lave & Wenger 1991).

Students in Mrs. Cooper's classroom engaged in collaborative talk and reasoning as well; however, discussions were less exploratory and reasoning focused. The dialogic exchanges among the teachers and students did not challenge student understanding enough since most teacher questions simply required recall of facts. This finding suggests that questions posed by teachers have an important role in exploring students' critical thought and thinking, and guiding students' thinking (Chin 2007) because they provide a means for teachers to know students' needs and deeply evaluate students' understanding. Here, it is important to note that the curriculum materials teachers enacted included detailed lesson descriptions, but not specific supportive elements to increase dialogic discussions in science classrooms. This finding implies a need for more specific curricular supports and guidance to better employ dialogic strategies to promote effective classroom dialogue (Alozie et al. 2010). To promote this, curriculum may need to be written with more prompts for teachers to remind them to engage students in productive discourse, both with other students and with the teacher.

Teacher explanations are instrumental in shaping students' understanding of science, with some scientists proposing that the very purpose of science is to explain the workings of the world (Hill 1986; Kourany 1987; Nagel 1961). In the present study, we report the different approaches that each teacher took to explain the structure and function of DNA. These themes, more or less, contain abstract concepts and processes that cannot be observed without specialized technology. Our findings show that while each teacher was given the same unit to teach, they differed in their verbal explanations through their use of analogies, the depth of science content, and the connections made between physical and conceptual models. When we comparatively analyzed the verbal explanations given by each teacher, we found that each incorporated the use of analogies and science content differently in terms of both depth and quantity. Analogies are a useful tool that promotes conceptual change (Dagher 1994). As summarized by Dagher (1994), analogies "may provide students with the level of comfort and security that enables them to connect their world to the world of theories and abstractions." We found that Mr. Evans employed several analogies in this unit that explained the scientific content in a greater level of depth than Mrs. Cooper. This depth within the content not only includes analogies employed by Mr. Evans to effectively communicate the science content to his students but also in his traditional "lecture style" instruction. In contrast, Mrs. Cooper's lessons contained content appropriate for this unit, but we found few analogies used throughout the lesson to explain the science content and the depth of this content was very superficial. However, Mrs. Cooper may have purposefully employed this instructional strategy to support the needs of her classes (e.g., special education and ELL students).

Additionally, it was observed that the teacher's verbal explanations on the connections between physical and conceptual models differed in this study. Understanding how science is performed at a microscopic level is a difficult concept for students to fully comprehend. To enhance student understanding in this domain, it is suggested that the use of physical models can be utilized to construct explanations of science content (Geelan 2012). To more effectively scaffold these lessons, Mr. Evans was able to thoroughly explain the connections between the physical models to the conceptual models of the science content, and did so in a greater level of depth compared to Mrs. Cooper. As Mr. Evans' students were observed to have high scores on the posttest in this engineering design-based science unit; these findings collectively suggest that a teacher's use of verbal explanations that include a depth of knowledge in the content area, the appropriate use of analogies within this science content and connections made between physical and conceptual models of science are associated with learning gains in an integrated science unit. Taken together, we believe that the ability of a teacher to guide the transfer of relational information from a familiar domain of knowledge to a new domain of knowledge may contribute to the observed learning outcomes in this study.

In conclusion, the findings in this study demonstrated that although the teachers worked together to design the engineering design-based curriculum unit, they use different dialogic strategies, discussion patterns, and interactions with students. Along the same line, O'Donnell (2008) and McNeill et al. (2013) found that in curriculum enactment studies how teachers enact curriculum materials are more critical than how much of the curriculum materials teachers use or how much time they spend on the curriculum. In this study, we not only investigated how the engineering design-based curriculum unit shaped classroom discourse, but also how teachers enacted the curriculum in two different classroom contexts.

Limitations

The current study was limited to only two teachers and therefore provides some insights into the differences in student learning in their classes. While generalization of our findings is limited to our cases, we believe that several key ideas emerged from our study should be considered by other teachers to develop strategies for more dialogic classroom discourse. Another limitation of this study is that we have two separate populations of students with very different demographics. Mr. Evans' students came from a school which had a low percentage of students on free/reduced lunch. In contrast, most of the students from Mrs. Cooper's school were on free and reduced lunch. Previous meta-analysis has shown a correlation between student achievement and socioeconomic status (Sirin 2005). The inclusion of two separate student populations is also a strength since we were able to test the effectiveness of the curriculum unit with a diverse group of students.

Implications and Future Research

To date, most research on the implementation of new science and engineering standards addressed in NGSS (NGSS Lead States 2013) has focused on comparisons of student learning based on engineering design presence in science classrooms National Academy of Engineering and National Research Council 2014). Although this has offered promising results on the influences of engineering instruction in science classrooms, there has been little research on the classroom discourse occurred in engineering design-based science instruction. As such, the major contribution of this study was to identify structure and function of science talk occurred as teachers enact a science and engineering-focused unit and identify major factors that could account for variability in student learning. Based on the findings, we draw implications for science education and research, especially for reform-based science teaching. We argue that teachers should provide an environment where students express their ideas, ask questions, receive rich responses to their questions that foster them construct, or reconstruct their understanding. However, construction of effective classroom discourse is difficult for many teachers (Alozie et al. 2010; Christodoulou & Osborne 2014; Nassaji & Wells 2000) since this might require the re-alignment of teaching science in the classroom. If teachers do not perceive science learning as active and collective construction of knowledge it would be unrealistic to expect productive, effective, dialogic science talk in the class. Our work supports previous research that suggests that teachers need professional development and sustained support toward dialogic talk (Alozie et al. 2010).

Our findings suggest several areas for continued research with classroom discourse in engineering design-based science classrooms. Large-scale studies linking teacher talk, instructional strategies, and classroom talk to student outcomes are needed to better understand the role of teacher in the enactment of curriculum materials and its impact on student learning. Furthermore, additional research needs to study the process of curriculum adoption, specifically, the teachers' decision-making for higher level or lower level of adaptation and the impact of their beliefs and previous experiences in adapting curriculum materials. Consequently, future studies need to explore teacher learning of curriculum materials in the context of professional development and the impact of different features of professional development on teacher learning and the adaptations and enactment of curriculum materials.

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