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# Comparative analyses of discourse in specialized STEM school classes

Colby Tofel-Grehl[a], Carolyn M. Callahan[b], and Louis S. Nadelson[c]

[a]Department of Teacher Education and Leadership, Utah State University, Logan, Utah, USA; [b]Curry School of Education, University of Virginia, Charlottesville, Virginia, USA; [c]Department of Computer Science Mathematics and Statistics, Colorado Mesa University, Grand Junction, Colorado, USA

**ABSTRACT**
The authors detail the discourse patterns observed within mathematics and science classes at specialized STEM (science, technology, engineering, and mathematics) high schools. Analyses reveal that teachers in mathematics classes tended to engage their students in authoritative discourse while teachers in science classes tended to engage students in dialogic discourse. The authors examined variations in the type of discourse in relationship to the discipline being taught, the educational level of the teacher, and course requirements were also explored.

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The concerns that stakeholders in the United States hold about our national ability to prepare a qualified STEM (science, technology, engineering, mathematics) workforce motivated political leaders to propose an array of supports for K–12 STEM education (Augustine, 2005; Carnevale, Smith, & Strohl, 2010). For example, increased financial support for STEM high schools led to the relatively rapid expansion of the number of STEM schools—schools that are theoretically focused on STEM with the goal of increasing the numbers of graduates pursuing STEM careers (Subotnik, Tai, Rickoff, & Almarode, 2010). Several potential reasons these schools graduate higher numbers of STEM focused graduates exist, including selective student admissions processes that prescreen students for interest in STEM careers (Tofel-Grehl & Callahan, 2014). However, despite substantial government funding for these schools (U.S. Government Accountability Office, 2005), research on STEM school practices, differentiating features of STEM schools, and the effectiveness of STEM schools at increasing the number of students pursuing STEM careers. While some positive preliminary learning outcomes in STEM schools exist (Eisenhart et al, 2016), it remains unclear how much of students' success is due to the structure of STEM school, and the associated teaching rather than selective admissions processes that seek to admit students predisposed to STEM learning success (U.S. Government Accountability Office, 2005).

Classroom activities account for significantly more variance in student achievement than school-level activities (Louis, Dretzke, & Wahlstrom, 2010; Saunders, Goldenberg, & Gallimore, 2009) and may actually mediate the effects school cultures can have on student experiences and outcomes (Heck, 2010; Leithwood, Anderson, Mascall, & Strauss, 2010). Thus, a warrant exists for addressing the gap in empirical accounts of the teaching and learning activities in STEM schools. Our research addressed this gap through an empirical documentation of teacher-student discourse in STEM schools. To gain a deeper understanding of the teaching and learning conditions in STEM schools, we focused on documenting the classroom discourse within and across STEM schools to develop a deeper understanding of these instructional activities.

## *Discourse in mathematics and science instruction*

Engaging students in classroom discussions creates an opportunity for the learners to develop critical reasoning and argumentation skills (Duschl & Osborne, 2002). When effective questioning techniques are used in instruction, students tend to experience higher levels of achievement (Schoen, Cebulla, Finn, & Fi, 2003). However, STEM school teachers use of discourse tends to differ from the discourse process teachers use in traditional U.S. high schools (Lemke, 1990; Scott, Mortimer, & Aguiar, 2006). Thus, we seek to explore how discourse takes place within STEM schools and the corresponding influence on student learning.

Across both science and mathematics education, engaging students in open discourse provides an opportunity for students to experience increased learning and reasoning. Current research on science education discourse focuses primarily on meaning-making and the ability of students to develop discipline-appropriate arguments and explanation (Gee, 2000). Student discourse can facilitate development of deeper content understanding and stronger scientific argumentation skills (Erduran, 2007; Ritchie & Tobin, 2001; Sandoval, 2005).

Similarly, a substantial portion of mathematical discourse research indicates that students' learning improves when learners use consensus building to develop their conceptual understanding, and engage in learning environments that foster engagement and participation (Amit & Fried, 2005; Klein, 1997; Nathan, Eilam, & Kim, 2007; Yackel & Cobb, 1996). Students are more engaged in learning and report better understanding when participating in decentralized classroom conversations that emphasize developing understanding of mathematical concepts over achieving a correct

**CONTACT** Colby Tofel-Grehl colby.tg@usu.edu Department of Teacher Education and Leadership, Utah State University, 2805 Old Main, Logan, UT 84322-1400.

answer (Amit & Neria, 2008; Nathan et al., 2007). Given the potential benefits of discourse to student mathematics and science learning there is justification for investigating how discourse takes place in mathematics and science courses within STEM school. Rather than viewing classroom discussions as providing evidence of students' concept attainment, our research focused on the use of discussion to develop localized meaning and catalyze the attainment of deeper understanding (Driver, Newton, & Osborne, 2000; Duschl & Osborne, 2002; Forman, 1992).

### Styles of classroom discourse

Scott, Mortimer, and Aguiar (2006) identified two broad level discursive patterns for describing classroom discourse—authoritative and dialogic. Authoritative discourse revolves around the traditional classroom power structure in which a teacher retains the authority and control over classroom conversations. The power basis in authoritative discourse is reflective of differences in social structure position and knowledge between or among participants (e.g., teachers and students). In authoritative discourse the teacher is perceived as the source of knowledge, the holder of information, or confirmer of correctness, controlling participant access and input to the conversation.

In contrast, Scott, Mortimer, and Aguiar (2006) contended that in dialogic discourse the engagement of participants are more equally valued, with individuals of differing power levels sharing and taking part of the process of developing personal solutions or explanations. Thus, dialogic discourse provides opportunities for students to explore differing perspectives, theories, and opinions. Within schools, dialogic engagement refers to the ways in which both teachers and students collaborative share in the asking and answering of questions (Scott et al., 2006). Given the potential for differences in learning based on the form of discourse, there is justification for examining the nature of the discourse that teachers and students engage in during instruction in STEM schools.

### Teacher education level and discourse

Administrators in STEM school tend to argue that the greater level of education and the deeper STEM content knowledge of the teachers in their schools makes them more effective when compared to educators in traditional schools (Tofel-Grehl & Callahan, 2014). Many administrators in STEM schools actively recruit teachers holding terminal degrees in STEM fields arguing that a faculty composed of professional or highly educated scientists and mathematicians increases students learning outcomes. Higher levels of teacher content knowledge have been found to be associated with higher levels of student academic achievement and learning outcomes (e.g., Abell, 2007; Hill, Rowan, & Ball, 2005). Further, during discourse teachers with higher levels of content knowledge asked more meaningful questions (Roth, 1996), resulting in better student conceptual development and understanding of course content (Gess-Newsome, 1999; Talbert, McGlaughlin, & Rowan, 1993). With a link between strong content knowledge and teacher ability to drive meaningful discourse (Carlsen, 1996; Kennedy, 1998), a reasonable argument stands that advanced degree holders (who presumably have deep content knowledge) would be highly effective facilitators of discourse within classes specific to their discipline. We speculate that due to their deep content knowledge, teachers with advanced degrees in their discipline are more likely to engage students in discourse that is more dialogic in nature rather than authoritative. Thus, when examining the nature of discourse in classrooms there is justification for examining the level of content knowledge of the teacher.

### Required versus elective classes

To date there exists no comparative discourse analysis of elective and required classes. However, research indicates that standards-based learning associated with high stakes testing in required courses may limit teacher consideration of discourse and other nondidactic instructional approaches (Haney, 2000; Tofel-Grehl & Callahan, 2014). The perceived rigidity of teaching options in standards-based learning has been attributed to a reduction of opportunities to engage in more holistic approaches to curricula (Goodson & Foote, 2001; McNeil & Valenzuela, 2000). Comparisons of elective and required classes found instructional differences between the two. Teachers of the required classes tended to rely heavily on teaching approaches that emphasized rote-learning compared to teachers working in an elective class who engaged students with more projects, more frequently used class discussions, and relied on instructional practices that were vastly more ambitious (Gerwin & Visone, 2006).

Beyond teacher effects, student perceptions shift. Students enrolled in elective mathematics courses reported significantly lower levels of importance for pleasing the teacher compared to the perceptions of students in required mathematics courses (Greene, DeBacker, Ravindran, & Krows, 1999). Similarly, students in secondary science education evaluated the classroom environment of their advanced science electives significantly more positively than their required courses (Myers & Fouts, 1992).

## Research questions

Our goal was to analyze and understand the discourse questioning techniques of science and mathematics teachers while considering possible explanatory variable. With the unique nature of STEM schools as a context, we sought to examine how discussions and questions move students toward desired learning outcomes. Specifically we sought to explore the following:

- What types of discourse patterns are dominant in science and mathematics classrooms in STEM schools?
- How does discourse change based on discipline, the instructor's education, or elective/required class status?

## Method

Using a grounded theory approach for our cross case analysis study, we investigated the discourse patterns present in a sample of science and mathematics classes in STEM designated high schools. Data across six STEM designated schools, representing a diverse cross-section of school structures and geographic locations within the continental United States, provide the opportunity to analyze discourse instructional practices. We examined the classroom interactions between teachers and students through an iterative review of observational and interview transcript data and constant comparison of emergent themes across episodes. Once we identified the overall discourse instruction themes, we examined the differences in the application of those themes on the basis of discipline taught, instructor's level of education in the content taught, and the status of the class as elective or required.

## Participants

*Sampling.* We purposefully selected six schools from the nation's more than 350 self-identified STEM schools. We determined appropriateness for inclusion of schools based on diversity of school model type (e.g., fulltime nonresidential, fulltime residential, part-time pull-out, university affiliated), geographic region (e.g., Northeast, Southeast, Midwest, South, Southwest, Northwest), student enrollment (e.g., < 300, 300–599, 600–899, 900+), and admissions criteria (e.g., selective or open-admission).

We observed a total of 86 discrete classes in the six schools participating. From this corpus of 86 classes, we selected 12 classes for detailed discourse analysis. Classes were selected based on diversity of schools, content area, and the viability of the audio recorded during the observation period.

Site descriptions. As noted previously, we selected six schools to maximize diversity based on the criteria of geographic location, school model type, admissions criterion, and population size. Each school represented a different STEM school model type. A detailed explanation of the differences in model types and more in-depth descriptions of the sites can be found in Tofel-Grehl and Callahan (2014) and Thomas and Williams (2010).

Johnson Technical High School (JTHS) stands as one of the nation's first specialized STEM schools. Located in a large northeastern city, this full day magnet program determines admission based on student achievement on highly competitive city-wide exams.

A pull-out partial-day program model, the Academy for Science and Mathematics Education draws students from a small, rural, southeastern population. The school's competitive admissions criteria include a review and assessment of teacher recommendations, personal statements, grade point average, and standardized test scores.

The Engineering and Mathematics Day School (EMDS), an urban school in the Western United States, draws from both urban and suburban communities surrounding the school. EDMS is unique among other specialized STEM high schools due to its open admissions policies. Students are admitted into the school based solely on a random lottery draw. EDMS partners with a local university to provide students dual enrollment in high school and university classes, while sharing its space with another high school.

The Southern School for Gifted Science Students provides students with a school within a school model type experience within a large southwestern suburban community. The school has a highly selective admissions process based on criteria including test scores and prior academic achievement.

The Lockheed Academy for Science and Technology is a residential school located in a small suburban town outside of one the nation's largest Midwestern cities. The selective admissions criterion takes into consideration student test scores, prior academic achievement, and personal statements to select students with high academic capabilities and interests in STEM area careers.

The Technical Academy for Science and Mathematics (TASAM) is a small residential school that partners with the local state university to provide students with a highly accelerated academic program. Located in a rural location within a small southern state, TASAM draws students from the entire state, thus providing it with a much larger applicant pool than its rural location might otherwise provide.

## Procedure

At each site we interviewed the school administrators separately and conducted focus group interviews with teachers. We invited all STEM area teachers to participate in focus groups interviews that were conducted using semi-structured interview protocols. At five of the six sites we conducted focus group interviews with groups of students; scheduling conflicts prevented a student focus group at the final site. Students were selected for participation in the focus groups by teachers and administrators.

We observed as many STEM classes as possible over the course of our two-day site visits. To ensure consistency, both observers initially made observations within the same classrooms and then compared and discussed field notes. When our observation notes achieved sufficient consistency we conducted classroom observations independently. We observed a total of 86 classes across the six different sites. Of the 86 classes we observed, 72 were either science or mathematics courses. Audio quality necessitated the exclusion of ten classes from the corpus of 72 science and math classes. From that group of classes, we randomly selected one science class from each school for our analysis.

## Analysis

Because no current work exists to explain the dialogic interactions and their impacts on students we identified emergent discursive themes within the data consistent with a grounded theory approach to data analysis (Lincoln & Guba, 1985). Our data sources included audio recordings of the classes, field notes, focus group transcripts, and review of program documents. Our analysis of classroom discourse provided us with insights into the dynamics and practices within our sample of STEM school mathematics and science classrooms.

The initial macro level of coding used focused on the conceptual framework of authoritative versus dialogic discourse patterns set out by Scott, Mortimer, and Aguiar (2006). Broadly speaking, interactions were coded as authoritative when they were teacher dominated and driven. Dialogic discourse was coded when power and authority over the discourse was shared.

Our second level of coding looked at types of questions as an instructional technique. For example, teachers' use of questioning techniques is an effective tool to facilitate discourse and engage students and therefore is likely an effective indicator of how teachers instruct their students. Through our coding of discourse patterns we sought to document the nature of the questions asked by classroom participants (both teachers and students) and the nature of the responses (e.g., discourse) associated with the questions.

Third, we analyzed patterns in the use of questions with respect to the subject matter taught (science vs. mathematics), the degree held in the subject by the teacher (PhD vs. non-PhD), and the status of the observed class as required or elective.

### *Defining and coding of authoritative and dialogic discourse*

We defined authoritative discourse as a condition in which the teacher controls the conversation and the students' focus on directly answering teacher questions. Within authoritative discursive interactions emphasis is placed on using the discourse to demonstrate factual understanding. For example, we coded the exchange in Figure 1 as highly authoritative, as each question asked by the teacher had a specific answer and the student responses were evaluated for accuracy by the teacher.

In contrast, we defined dialogic discourse as conversation that involved collaboration and interaction between teacher and student with explicit attention toward deeper understanding and conceptual development. Thus, for our coding we considered dialogic discourse to be taking place when teachers guided student thinking with probing questions, but did not offer final validity to the student's response. In Figure 2 we present an interaction that we coded as strongly dialogic, as the questions asked by the teacher were focused on curricular goals, there was not a concrete right answer. Further, there exists a back-and-forth between the teacher and student focused on the reasoning with the teacher not presenting himself as the final authority on the validity of her answer.

## Findings

We found consistent patterns across STEM school sites within each of our two major areas of analysis: (a) authoritative versus dialogic discourse and (b) trends in discourse associated with class content (discipline), teacher preparation (attainment of terminal degree), and course status as required or elective.

### *Trends in authoritative and dialogic classroom discourse*

Our first research question focused on the nature of the discourse teachers used in their instruction. We found that while the level of dialogic versus authoritative conversation varied across classes teachers tended to maintain authority over classroom talk at all levels. Even when students acted as leaders during student presentations, teachers tended to used questions to drive classroom talk.

Classes where teachers maintained a more authoritative discourse pattern tended to have three commonly observed features. Within authoritative discourse classes the dominant format of instruction was lecture. Evaluation of student understanding occurred through closed-answer questions in a question-answer-evaluate (QAE) discourse pattern. In contrast courses where teachers facilitated more dialogic discussions, the prevalence of the QAE patterns diminished. Our analysis of dialogic discourse interactions revealed that students tended to provided their own justification for their answers rather than receiving evaluations of their responses from their teachers.

The second common feature that we observed in classrooms where there was notable authoritative discourse patterns was teachers spending less time answering student questions. We found that when teachers engaged in authoritative discourse they tended to offer short answers or often opted not to answer student questions. The third common feature for more authoritative discourse classrooms was the relatively low frequency of student engagement in dialog. Within authoritative discourse classrooms we found that students spoke less both in terms of frequency and length of time when compared to their peers in dialogic discourse classrooms.

**Teacher:** 27, so I have X + 3 is equal to 27, subtract X equals 24. So, the X intercept is 24 or another way of saying that and this is what I want you to think about, X = 24 is the X intercept. Or you could write it as a set of coordinates. What are my coordinates then?
**Student:** 24, 0.
**Teacher:** 24, 0, good. Let's do the same thing with the other one though, right? I want the Y intercept now, so what do I do (says student's name, 33:16). If I want the Y intercept, what do I do?
**Student:** Factor?
**Teacher:** No.
**Student:** Put zero in for X.
**Teacher:** Put zero in for what again?
**Student:** X.
**Teacher:** X, right on! That was what I was looking for.

Figure 1. **Teacher:** 27, so I have $X + 3$ is equal to 27, subtract X equals 24. So, the X intercept is 24 or another way of saying that and this is what I want you to think about, $X = 24$ is the X intercept. Or you could write it as a set of coordinates. What are my coordinates then? **Student:** 24, 0. **Teacher:** 24, 0, good. Let's do the same thing with the other one though, right? I want the Y intercept now, so what do I do (says student's name, 33:16). If I want the Y intercept, what do I do? **Student:** Factor? **Teacher:** No. **Student:** Put zero in for X. **Teacher:** Put zero in for what again? **Student:** X. **Teacher:** X, right on! That was what I was looking for.

**Teacher:** Abby, where shall we put this one kilo mass to make it balance?
**Abby:** I said eight inches
**Teacher:** And can you explain your logic that you went through to arrive at that?
**Abby:** Well I think that it was twice as much weight so it would be half as much distance.
**Teacher:** That sounds pretty simple and straight-forward. Do you want to come up here and try (on the model)? If I let go of this are you guys confident we will be ok?
**Abby:** No.
**Teacher:** No? Why not?
**Abby:** I am stalling for time to work it out. I was confident when I said it and put it as my answer but looking at it, it doesn't look right.
**Teacher:** Show of hands of how many people think it will balance.

Figure 2. **Teacher:** Abby, where shall we put this one kilo mass to make it balance? **Abby:** I said eight inches **Teacher:** And can you explain your logic that you went through to arrive at that? **Abby:** Well I think that it was twice as much weight so it would be half as much distance. **Teacher:** That sounds pretty simple and straight-forward. Do you want to come up here and try (on the model)? If I let go of this are you guys confident we will be ok? **Abby:** No. **Teacher:** No? Why not? **Abby:** I am stalling for time to work it out. I was confident when I said it and put it as my answer but looking at it, it doesn't look right. **Teacher:** Show of hands of how many people think it will balance.

Within classrooms that we coded as dialogic, we found two common themes. First we found that in classes where dialogic discourse patterns were prevalent, the instruction included a wide variety of approaches such as lectures, labs, round table discussions, and group work. Within dialogic classrooms, teachers tended to introduce the larger class to idea through a variety of methods such as a pair and share or jigsaw learning opportunity and provided students with substantial time to work in small groups before reconvening as a larger group. Students demonstrated greater autonomy leading class discussions and determining the topics for discussion. A second common condition we found to occur in dialogic discourse classroom was a high value of student opinion. We observed patterns of students sharing ideas and engaging with teachers in argumentation and discussion and appearing to be comfortable with the discourse dynamics. In dialogic discourse classes teachers frequently questioned students and students frequently responded with their own questions. In a situation in which the students in a class appeared to become disengaged from discussion teacher responded by sharing, "We cannot have a discussion without you all".

In looking specifically at questioning techniques across classrooms and disciplines we found that teachers tended to use different types of questions to achieve different goals within their classes. Teachers tended to use opening questions to focus student attention on the content of the day as well as to determine student prelesson understanding. Teachers tended to use follow-up questions to extend discussions, prompt elaborated answers from students, determine student understanding, and seek additional information from the students. Through the use of a combination of opening and follow-up questions, teachers retained control of the classroom discourse. The nature of many of the opening and follow-up questions engaged students in rather closed and rigid discussion patterns. We observed such a moment of questioning within a physics class (Figure 3), where the teacher used his or her questions to prepare students for the coming topic using the historic context and to determine their level of knowledge regarding the topic.

In mathematics classes, we found that teachers tended to use follow-up questions for the purpose of guiding students through the proper procedures for solving a problem or completing a lab, as shown in Figure 4. Additionally, teachers tended to use follow-up questions to further to present the additional information needed to explain content. While dominantly seen in mathematics classes, the phenomena was also observed to occasionally occur among science teachers who used questions as an instructional technique for guiding laboratory procedures (see Figure 4).

Teachers tended to use analytic and justification questions to provide students with an opportunity to explain their answers and thinking as well as precursors to applied reasoning questions. We found a direct correlation between the number of these types of questions teachers asked and observable instances of student abstract thinking such that fewer teacher generated questions seeking analysis from students was associated with the fewer instances of students abstract thinking. When teachers asked questions seeking analysis, justification, or applied reasoning from students, students were observed to spend more time talking. Further, we found that the analysis questions tended to precede small and large group discussions.

Often, the teacher' reasoning and justification questions prompted students to ask more questions of each other. When students responded to the analysis questions they were more likely to receive a question from a peer than they were when they responded to the rote knowledge opening or follow-up questions (see Figure 5).

### ***Trends in discursive differences associated with classroom characteristics***

*Subject matter.* Across all sites, teacher interview and classroom observation data yielded evidence of a high value on questions to support student reasoning. In all teacher focus groups, both mathematics and science teachers—regardless of degree attainment level—articulated a philosophy valuing student reasoning

**Teacher:** Think back 1000 years what happened?
**Students all call out:** Dinosaurs, Jesus, Ming Dynasty?
**Teacher:** What was the one big thing?
**Emily:** The Norman Invasion?
**Teacher:** Now fast forward 1000 years. What would you say is the big thing that happened between 1900-2000?”
**Jessie:** Space?
**Matt:** World War I?
**Evan:** World War II?
**Jose:** The Cold War ?
**Teacher:** All of those are good. But this guy made point that 1000 years from now they will make the point we went to the moon. That is the thing we will be remembered for. When did we first fly? In the 20th century, right? So we first flew this century and we got up in air and then to moon. And that is what we are going to talk about—the Apollo 13 mission. When did we land on the moon?
**Evan:** 1969
**Teacher:** The whole point was to get out into space and orbit the earth. Has anyone seen the movie ‘The Right Stuff’? When were the first people in space?
**Emily:** 1959
**Teacher:** And who was first?
**Emily:** Urie

**Figure 3.** **Teacher:** Think back 1000 years what happened? **Students all call out:** Dinosaurs, Jesus, Ming Dynasty? **Teacher:** What was the one big thing? **Emily:** The Norman Invasion? **Teacher:** Now fast forward 1000 years. What would you say is the big thing that happened between 1900-2000?” **Jessie:** Space? **Matt:** World War I? **Evan:** World War II? **Jose:** The Cold War? **Teacher:** All of those are good. But this guy made point that 1000 years from now they will make the point we went to the moon. That is the thing we will be remembered for. When did we first fly? In the 20th century, right? So we first flew this century and we got up in air and then to moon. And that is what we are going to talk about—the Apollo 13 mission. When did we land on the moon? **Evan:** 1969. **Teacher:** The whole point was to get out into space and orbit the earth. Has anyone seen the movie ‘The Right Stuff’? When were the first people in space? **Emily:** 1959. **Teacher:** And who was first? **Emily:** Urie.

and thinking. Furthermore, in response to follow-up questions relating to classroom observations, teachers noted that asking students to explain themselves provided an essential window into their thinking. As one teacher said, “We can’t know what they are thinking if we don’t ask.” However, despite articulating the same ethos valuing student reasoning, we observed differences between questioning and discourse techniques taking place in science and mathematics classes.

Within science classrooms, roughly 30% of teacher generated questions introduced a topic for discussion or fundamentally moved the area of discussion to a new topic. Follow-up questions, questions that directly flowed from an answer to a previous question, made up 40% of the questions asked by science teachers. Questions requiring participants to analyze, justify, or apply their reasoning made up an additional 15% of the questions asked by science teachers. The remaining 15% of teacher

**Teacher:** Do you remember the formula for finding the slope of a line?
**Student:** No.
**Teacher:** Y sub2 minus Ysub1 over x sub 2 minus x sub1. If I asked you to do that you could do that right?
**Student:** Yes
**Teacher:** Quickly give me the slope of y=2/3x -4
**Student:** 2/3
**Teacher:** From there we are moving into difference quotients. What does difference mathematically mean? What operation?
**Student:** Subtract.
**Teacher:** And quotient means?
**Student:** Divide.
**Teacher:** Correct. So this quotient (pointing at board) is the quotient of the differences.

**Figure 4.** **Teacher:** Do you remember the formula for finding the slope of a line? **Student:** No. **Teacher:** Y sub2 minus Ysub1 over x sub 2 minus x sub1. If I asked you to do that you could do that right? **Student:** Yes **Teacher:** Quickly give me the slope of $y = 2/3x–4$ **Student:** 2/3. **Teacher:** From there we are moving into difference quotients. What does difference mathematically mean? What operation? **Student:** Subtract. **Teacher:** And quotient means? **Student:** Divide. **Teacher:** Correct. So this quotient (pointing at board) is the quotient of the differences.

**Teacher:** So, if smog causes acid rain, what does the acid rain cause to happen?
**Student:** You mean other than it kills things?
**Teacher:** Yes. Think about it for a second. What does the acid rain affect?
**Carol:** Life.
**Teacher:** Ok, so it affects life. Well how do we decide to deal with the problem?
**Eddie:** When it affects people?
**Josh:** Not really.
**Teacher:** What do you mean, Josh, no?
**Josh:** It doesn't matter when it affects people. We only deal with problems when politician gets involved and they only care about rich people.
**Ashley:** That's not true. If it affects lots of people then that can cause people to deal with a problem. But there's lot of other reasons acid rain might not get dealt with. People don't always know about it. You can't just say it's because of money.
**Josh:** Look at California. There is tons of money there and so everyone dealt with the environmental problems like smog. But now the same thing is happening in New Mexico and no one is passing laws about it.
**Teacher:** That's an issue of correlation not causation, Josh.

**Figure 5.** **Teacher:** So, if smog causes acid rain, what does the acid rain cause to happen? **Student:** You mean other than it kills things? **Teacher:** Yes. Think about it for a second. What does the acid rain affect? **Carol:** Life. **Teacher:** Ok, so it affects life. Well how do we decide to deal with the problem? **Eddie:** When it affects people? **Josh:** Not really. **Teacher:** What do you mean, Josh, no? **Josh:** It doesn't matter when it affects people. We only deal with problems when politician gets involved and they only care about rich people. **Ashley:** That's not true. If it affects lots of people then that can cause people to deal with a problem. But there's lot of other reasons acid rain might not get dealt with. People don't always know about it. You can't just say it's because of money. **Josh:** Look at California. There is tons of money there and so everyone dealt with the environmental problems like smog. But now the same thing is happening in New Mexico and no one is passing laws about it. **Teacher:** That's an issue of correlation not causation, Josh.

generated questions were related to general classroom procedures, as they were focused on general classroom management

*Mathematics discourse.* In contrast, within mathematics classrooms, 25% of the teacher-generated questions were opening questions and over 52% were follow-up questions. Questions requiring analysis, justification or applied reasoning totaled 9%. As was the case in science classes, roughly 15% of the questions teachers asked the students were focused on general classroom procedures. Within mathematics classes, teacher instruction appeared more variable in approach and focused more on authoritative questioning patterns. In contrast, science teachers appeared to offer more uniform instructional approaches and greater discourse opportunities for students.

Some mathematics teachers seemed focused on students obtaining the correct mathematical answer, whereas others asked students to justify their answers and provide alternate explanations of their reasoning. Questioning techniques used by some teachers tended to be highly authoritative and seeking a specific response from a student to indicate accurate understanding of the content as presented, while other teachers used questions to provide students with opportunities to talk with peers and share ideas. Additionally, in classes dominated by an authoritative discourse pattern, teachers were more likely to answer their own questions. One teacher we observed used an authoritative and rapid-fire approach to engaging with his students (see Figure 6).

When asked about his instructional approach, the teacher stated that his questioning techniques and instruction were influenced by the Advanced Placement (AP) test. As he explained, "I focus on the AP, because that is what they expect of me. I don't waste time expecting them to think here. They think at home, and we work here." He justified his approach with the high AP test scores consistently achieved by his students. However, when pressed in a teacher focus group, the teacher acknowledged, "the kids in my math classes, they are going to be rock stars in math anywhere they go."

There was more variety among math classes with some being more dialogic. Students could see the difference in teacher approach. As one student explained:

> I loved Mr. Timpson, but he just grills us all day long. You learn a lot but you learn it all at home because you don't want to do badly. With Mrs. Rogers, she is a lot more willing to take her time and talk with us. We ask our questions and she tries really hard to answer them. Sometimes she will tell us she needs to think about it till tomorrow, but she always gets back to us. That just works better for me because I am not afraid I won't get it. I know she will help me.

The student identifies "talk" as that which was observed to be more dialogic with back-and-forth exchanges, while she refers to a teacher with a more authoritative style as "grill[ing]" students, implying a rigid teacher driven authoritative exchange.

**Teacher**: If you are having trouble there are plenty of smart people around you who know how to use the calculator.
**Student**: Is there any faster way to the smallest root?
**Teacher**: Which I never do. That's a new convention.
On to minimums. Goes from negative to positive, right?
It doesn't matter because the AP doesn't give it that way.
So where is Y increasing?
**Student**: 1.432
**Teacher**: Ok, so that is f PRIME; it is positive. Questions?
(teacher waits two seconds)
**Teacher**: Ok decreasing. Now lets see what you get for the answer.
**Student**: There is 0.
**Teacher**: Very good you picked up the zero. Don't forget the zero and the ten. No questions?

**Figure 6.** **Teacher**: If you are having trouble there are plenty of smart people around you who know how to use the calculator. **Student**: Is there any faster way to the smallest root? **Teacher**: Which I never do. That's a new convention. On to minimums. Goes from negative to positive, right? It doesn't matter because the AP doesn't give it that way. So where is Y increasing? **Student**: 1.432. **Teacher**: Ok, so that is f PRIME; it is positive. Questions? [Teacher waits 2 s.] **Teacher**: Ok decreasing. Now lets see what you get for the answer. **Student**: There is 0. **Teacher**: Very good you picked up the zero. Don't forget the zero and the 10. No questions?

Variations in discourse patterns observed within mathematics classrooms speak to differences in instructional styles and approaches. It is important to note that these differences do not necessarily link to differences in performance outcomes as measured in school or state standardized testing. However, there was some consistency between the stated goals of the classes and the discourse patterns within classes. More rigidly authoritative classes with fewer student opportunities for open discourse tended to emphasize standardized test outcomes. The teachers of these classes openly acknowledged the high value they personally, or the school community generally, placed on AP exam performance or state testing outcomes.

Alternately, teachers with a more dialogic approach stated more diffuse goals and were less focused on testing. These teachers argued that deep understanding of content was the primary goal for their students, often asserting that testing "gets in the way of real learning." Given that proponents of each discursive style seemed to focus on different goals for students, these styles can be assessed as different but not preferential.

*Science discourse patterns.* In science classes we observed much greater consistency of classroom discourse. Unlike mathematics classes, science classes were dominantly characterized by dialogic discourse. Regardless of class format, science teachers tended to provide students opportunities to talk as a group, share ideas, and ask questions. Even in the case illustrated in Figure 7, teacher talk time created a mechanism for further student engagement around the content rather than her disseminating factual information. It is apparent that she motivated her students to ask questions as well as identify areas of confusion.

Other observed patterns of discourse within science classrooms focused on motivating students to reason through issues and provide evidence of their ideas or position. Asking students to provide evidence for their reasoning was a practice that frequently took place within science classes. For example, in a physics class where the students and teacher were reviewing homework, the exchange in Figure 8 occurred.

Science classes appeared to focus more on the demonstration of reasoning. Discourse was an instructional tool teachers

**Teacher:** Ask the presenters to slow down and restate the long technical terms. You have got to tell them to slow down if that's what you need.
**Student**: Do lipopolysaccharides have the same things as the others?
**Student Presenter:** Yes because they are the same type of toxic molecules.
**Teacher**: Did we ever explain that acronym? Did we use that term? Maybe we should write it?
**Teacher**: Why do you think phenyl glycine is an example of it?
**Student**: Because it's only found on prokaryotes?
**Teacher**: Good, it's only found on the walls of prokaryotes and serves as a flag that says I am foreign? Was that was the panic was about? More questions?

**Figure 7.** **Teacher:** Ask the presenters to slow down and restate the long technical terms. You have got to tell them to slow down if that's what you need. **Student**: Do lipopolysaccharides have the same things as the others? **Student Presenter:** Yes because they are the same type of toxic molecules. **Teacher**: Did we ever explain that acronym? Did we use that term? Maybe we should write it? **Teacher**: Why do you think phenyl glycine is an example of it? **Student**: Because it's only found on prokaryotes? **Teacher**: Good, it's only found on the walls of prokaryotes and serves as a flag that says I am foreign? Was that was the panic was about? More questions?

**Teacher:** Here is moon and here it is rotating on its axis, and it takes it 27.3 days per rotation and they want to know the period. And in physics, the period equals the number of seconds, right?
**Student**: Would you just convert the days into seconds?
**Teacher**: What do you think? I need a brave volunteer to come up and do it. I need someone who does not know how to do it. Josh? So, come take problem as far as you can. Once you get stuck, you have a room full of people who will help you.
**Josh:** Ok (works on board).
**Teacher:** Can you explain what is going through your head as you're doing that?
**Josh:** I need help first**.**
**Teacher:** Ok, that's ok. So they are asking about period. What does period mean?
**Josh**: I don't think I know it.
**Teacher:** It's ok to phone a friend.
**Student** 2: The time it takes to rotate.
**Teacher:** So do you guys agree with that? So the time it takes to rotate, right? So that 27.3 days is the answer except they want it in seconds so you need to…
**Student 3:** So they just want us to convert it?
**Teacher:** You guys do it. Dazzle us with your conversion skills. Make sure you use the school's method.
**Student:** Ok**.**
**Teacher:** You guys ok with what he is doing so far? He is converting it to hours using the school method. Have we got everything in the right place? How do you know you did it right? That is part of the school method right there, going in and canceling out units. That is an essential part of the method. So now we have it at hours. Make sure you cross out the units to make sure you've got them in the right place. Someone with a calculator help us out?
**Student** 5: $2.4 \times 10^6$
**Teacher**: So 2.3 million. And does that do it for you? So does it match what we did here? It does. So we are right.

**Figure 8.** **Teacher:** Here is moon and here it is rotating on its axis, and it takes it 27.3 days per rotation and they want to know the period. And in physics, the period equals the number of seconds, right? **Student**: Would you just convert the days into seconds? **Teacher**: What do you think? I need a brave volunteer to come up and do it. I need someone who does not know how to do it. Josh? So, come take problem as far as you can. Once you get stuck, you have a room full of people who will help you. **Josh:** Ok [works on board]. **Teacher:** Can you explain what is going through your head as you're doing that? **Josh:** I need help first**. Teacher:** Ok, that's ok. So they are asking about period. What does period mean? **Josh**: I don't think I know it. **Teacher:** It's ok to phone a friend. **Student** 2: The time it takes to rotate. **Teacher:** So do you guys agree with that? So the time it takes to rotate, right? So that 27.3 days is the answer except they want it in seconds so you need to… **Student 3:** So they just want us to convert it? **Teacher:** You guys do it. Dazzle us with your conversion skills. Make sure you use the school's method. **Student:** Ok**. Teacher:** You guys ok with what he is doing so far? He is converting it to hours using the school method. Have we got everything in the right place? How do you know you did it right? That is part of the school method right there, going in and canceling out units. That is an essential part of the method. So now we have it at hours. Make sure you cross out the units to make sure you've got them in the right place. Someone with a calculator help us out? **Student** 5: $2.4\times10^6$. **Teacher**: So 2.3 million. And does that do it for you? So does it match what we did here? It does. So we are right.

use to provide students opportunities to clarify and demonstrate their thinking. Passivity on the part of students was not allowed; teachers mandated engagement. For example, an environmental science teacher stated, "I can't think for you. You are here to think and figure things out. Without you all this class won't work. I need your brains, not just your bodies." The teacher relied on the students' ideas to guide class content and instructional choices.

*Contrasts in science and mathematical discourse*. Mathematics and science classroom discourse differed along several dimensions. The closed nature of many of the mathematics teachers' questions and an overall more authoritative discourse pattern was accompanied by a general tendency by the students to be prepared to provide immediate responses. In one mathematics classroom, the teacher appeared to ask frequent closed-answer questions to maintain student focus and attention. As he said multiple times throughout the class, students needed to "pay attention because you never know when I will call on you next." Within his class, discursive engagement was a threat.

Another mathematics teacher used questions in her classroom to keep student attention as she moved rapidly through a series of questions (see Figure 9). Asking specific answer questions the teacher shaped the discourse of her class such that students attended closely to the details of the discussion without

**Teacher**: Pull your notebooks out please.
**Student**: Where was this assignment? What page?
**Teacher**: If you would get your notebooks out. Do you remember the formula for finding the slope of a line?
(Waits two seconds; no response)
Ok, this is how you do it.
(Draws answer on board)
If I asked you to do that you could do that, right?
**Teacher:** Difference mathematically means what operation?
**Student:** Subtract?
**Teacher:** And quotient means?
**Student:** Divide?
**Teacher:** So, this quotient is the quotient of differences. Friday we were talking bout functions. Refresh my memory, Madeline, what is a function?
**Student:** Well, umm….
**Teacher**: The answer will give you a relationship? Sandy, can you try to explain the relationship to a function?
**Student:** I am not really clear on that.
**Teacher:** How can I tell from a graph if it's a function?
**Student:** There is only one x value?
**Teacher**: So for each X value there is only one Y value. So how does that play out on a graph? Sierra, what does that mean? How can I look at this graph? What do we call that test on a graph?
**Student**: The line test?
**Teacher**: Which line test?
**Student:** The vertical line test.
**Teacher**: There we go.

Figure 9. **Teacher**: Pull your notebooks out please. **Student**: Where was this assignment? What page? **Teacher**: If you would get your notebooks out. Do you remember the formula for finding the slope of a line? [Waits 2 s; no response.] Ok, this is how you do it. [Draws answer on board.] If I asked you to do that you could do that, right? **Teacher:** Difference mathematically means what operation? **Student:** Subtract? **Teacher:** And *quotient* means? **Student:** Divide? **Teacher:** So, this quotient is the quotient of differences. Friday we were talking bout functions. Refresh my memory, Madeline, what is a function? **Student:** Well, umm. **Teacher**: The answer will give you a relationship? Sandy, can you try to explain the relationship to a function? **Student:** I am not really clear on that. **Teacher:** How can I tell from a graph if it's a function? **Student:** There is only one x value? **Teacher**: So for each X value there is only one Y value. So how does that play out on a graph? Sierra, what does that mean? How can I look at this graph? What do we call that test on a graph? **Student**: The line test? **Teacher**: Which line test? **Student:** The vertical line test. **Teacher**: There we go.

necessarily demonstrating conceptual understanding. Often when students stated that they lacked knowledge or understanding of the content, the teacher was observed either answering her own questions essentially ignoring students' requests for additional information or clarification.

However, heightened attention to the teacher or task did not mean students demonstrated higher engagement. Attentiveness and engagement were observed to be very different activities for students. Attentive students were observed to be involved in the physical act of paying attention to the teacher and conforming to the norms of the classroom. Engaged students were observed to demonstrate thinking about and grappling with content, which did not necessarily result in a solution. While students in some classes demonstrated being more alert to their teachers' questions, they were not necessarily more engaged in learning the concepts.

The contrast between the dialog taking place in mathematics and science classes was substantial. There was less teacher-led lecture time and substantially more group discussion in science classrooms. Students in science classes were asked more questions that lacked correct answers and required conceptual understanding. Science teachers tended to ask more questions that started with "why" or "what do you think would happen if" with expectations for multiple answers from many students. Frequently when teachers used the technique of soliciting multiple answers, the process resulted in dialogic discourse (see Figure 10). These discussions led to instances of students asking their own questions, both of their peers and their teacher. Student questioning was substantially more prevalent within science classrooms than mathematics classrooms.

When science students were engaged with the course content, they were observed to extrapolate on their answers and generated multiple solutions. Furthermore, in focus groups students shared that some classes, notably those with teachers they described as less "focused on students and more focused on tests" required them to be "on our toes." Student sentiment supported the observed phenomenon of students being attentive without being engaged with content within mathematics classrooms, which forced more authoritative discourse patterns. Students also noted a lack of enjoyment for many of these classes. When asked about their classes where teachers used authoritative discourse instruction the students were observed rolling their eyes, and many stated that although they excelled in the content, most notably mathematics, they had no intention of pursuing future classes in the area because they were "burned out" on these classes.

Students spoke with greater fondness and enthusiasm for the classes where teachers used dialogic discourse. Students identified these classes as mostly science classes. Many students

**Teacher**: When did it [the solution] turn pink**?**
**Student:** When it became more basic than acidic?
**Teacher:** When you added the first drop did the whole thing turn pink? Why did it go pink and then not go pink?
**Student:** That's because it's an acid and then it's basic and then it's an acid again. I work in a pool and it's the same
**Teacher:** This is sorta different. Without the swirling that one spot is basic. Why when I swirl is it not basic? Take two minutes and discuss. Erica will answer.
**(Group discussion)**
**Teacher**: Ok. Erica?
**Erica:** Because it wasn't very basic?
**Teacher:** And what happens?
**Erica:** The acid takes over the base
**Teacher:** Is this the zombie acid takes the brain out of the base? What is going on in the solution? What is the chemical reaction?
**Erica:** It's Fenalphayline. But we are getting water. An acid plus a base combine to water plus salt. So this is the generalized reaction. But, what about the pH?
**Teacher:** How many have taken foreign language? Are there irregular verbs? You learn to conjugate them normally and then they tell you bout irregulars. This is the same thing with the acid and bases.
**Student:** What happened to the sodium?
**Teacher:** I haven't dealt with it. What does the hexagon with double lines mean?
**Student**: It's a double bonded
**Teacher**: Correct, double bonded**.**

**Figure 10.** **Teacher**: When did it [the solution] turn pink? **Student:** When it became more basic than acidic? **Teacher:** When you added the first drop did the whole thing turn pink? Why did it go pink and then not go pink? **Student:** That's because it's an acid and then it's basic and then it's an acid again. I work in a pool and it's the same **Teacher:** This is sorta different. Without the swirling that one spot is basic. Why when I swirl is it not basic? Take two minutes and discuss. Erica will answer. **(Group discussion) Teacher**: Ok. Erica? **Erica:** Because it wasn't very basic? **Teacher:** And what happens? **Erica:** The acid takes over the base **Teacher:** Is this the zombie acid takes the brain out of the base? What is going on in the solution? What is the chemical reaction? **Erica:** It's fenalphayline. But we are getting water. An acid plus a base combine to water plus salt. So this is the generalized reaction. But, what about the pH? **Teacher:** How many have taken foreign language? Are there irregular verbs? You learn to conjugate them normally and then they tell you bout irregulars. This is the same thing with the acid and bases. **Student:** What happened to the sodium? **Teacher:** I haven't dealt with it. What does the hexagon with double lines mean? **Student**: It's a double bonded. **Teacher**: Correct, double bonded**.**

shared a sense of excitement and interest about these courses, stating that the classes were "easier to stay tuned into." Students noted that it was in these classes that they felt their opinions mattered most. As one student shared about his microbiology class, "We talk about ethics and things that matter. It's not just that we get to talk about it. It's that what we think matters." Even in the most intense science class observed, an honors physics class in which the teacher used clickers to require students to respond more rapidly to problems, the use of questions was observed to be different. For example, after asking students to solve a problem about the velocity with which a car would hit a wall, the teacher asked students to "take two minutes and turn to [the other students at] your table and see if you can figure out what variables would be different if we were now talking about two cars hitting each other." Following the small group discussion of the scenario, a student from each group shared what they discussed. Overall, the question "why?" was asked of students many more times in science classes than in mathematics classes.

*Teachers' educational background.* Because one of the factors allegedly unique to STEM schools is the level of education of faculty, there is potentially a relationship between differences in classroom discourse patterns and teachers' level of education.

In schools with a higher concentration of PhD-level teachers, there was consensus among faculty that their classes were run similarly to seminar-level college classes. The teachers stated that they believed their knowledge, along with the highly capable students, produced a classroom dynamic that was entirely unique. As one focus group participant stated, "You can't reproduce our school. We have highly gifted and motivated students. We are professors, not teachers here. Our classes are just entirely different than anything you'll see anywhere else." Many of the classes deemed elective were taught exclusively by the members of the faculty who held a PhD.

We found that there was little difference in the types of questions asked by PhD holders versus non-PhD holders with the exception of justification and reasoning questions. Teachers in five of the 11[1] classes used for this analysis held PhDs. PhD holders were found to ask authentic or originating questions 28% of the time whereas non-PhD holders asked those same types of questions 27% of the time. Follow-up questions were asked 42% of the time by PhD holders compared with 46% by non-PhD holders. Teachers

[1]One class was excluded from this sub analysis because the teacher on the day observed was a substitute for whom educational level was not available. Total *N* values have been changed to reflect this change to the data.

possessing a PhD were found to ask analysis, justification, or applied reasoning questions roughly 17% of the time while their non-PhD counterparts asked only 10% of those same questions. General classroom procedure questions were asked roughly 13% of the time by PhD holders compared to 16% of the time by non-PhD holders. Thus, our data suggest that the patterns of discourse somewhat varied between PhD and non-PhD teachers.

*Required versus elective classes.* Another possible explanation for shifts in discourse patterns may be due to whether classes were electives that students took by choice or a course that was mandated for graduation (by the school or state). We found that there was much more dialogic discourse taking place in elective classes compared to required classes. In elective classes the students were more engaged in classroom discussions and provide longer and more detailed answers to teacher asked questions. Additionally, students in elective classes were more likely to ask their own questions. The teachers within the elective classes asked the students more "how?" and "why?" questions. Many times when asking these questions, teachers would provide students with opportunities to participate in partner or group discussions. Alternately, in required classes the teachers appeared more content and standards driven, asking fewer open-ended questions, limiting students to providing short answers.

Within our sample, four of the 12 classes were electives. In these classes, 28% of the questions asked were opening questions compared with 26.5% in required classes. Elective classes demonstrated the lowest observed levels of follow-up questions with just 38% falling into the category compared to 50% of the questions asked in required classes. Within elective classes, justification, analysis, and applied reasoning questions received notably more time, taking up over 20% of the questions compared with 8% in required courses.

### Limitations

The first limitation of our study was the sample size, which was constrained to six schools. While we took efforts to be representative with our sample and gathered a range of data (e.g., observations, teacher and student interviews) we may not have effectively captured the discourse patterns that are commonly found in STEM schools. Additional research comparing the patterns of a greater range of STEM schools and non-STEM schools is a needed direction for future research.

The second limitation of our research is the possible influence of the researchers on the instruction and perceptions of the teachers. However, the consistency and alignment with research on teacher discourse patterns suggests that the teachers tended to be honest and not influenced by our presence. Longer term observation and additional interviews of STEM teachers in STEM schools is needed to corroborate our results.

The third limitation is the lack of knowledge of the developmental level of the students, classroom size, knowledge of the students, and other potential classroom and student level factors. However, our exploratory investigation has laid a foundation for future research that includes control for a wider range of potential influential students and classroom factors.

## Discussion

Our analysis revealed several differences between mathematics and science classes. Specifically, mathematics teachers within our sample asked significantly more fact or follow-up–type questions than science teachers. The use of follow-up questions is consistent with descriptions of teaching practices in mathematics classes in other research (Amit & Fried, 2005). Teacher use of follow-up questions is aligned with problem-based approach for mathematics education. Problem-based mathematics instruction requires teachers to use initial context problems as a starting point and then proceed with follow-up questions to scaffold both the procedural and declarative knowledge needed to further students' mathematical understanding.

The number of applied reasoning questions also differed across disciplines. We speculate that when mathematics teachers asked fewer questions that required students to apply their mathematical knowledge to different situations, students' mathematical thinking is likely to be constricted to the mathematics classroom and not applied across subjects. In contrast, much more of the discussion in science classrooms emphasized applications in new contexts, which we posit would enhance their ability to apply scientific thinking and the related concepts to a range of situations outside science classes.

The mission statements of many STEM schools include enhancing student development of higher order thinking and applied reasoning (Tofel-Grehl & Callahan, 2014). However, our observations of classroom discourse suggest that all teachers may not be embracing the mission. In many classrooms, particularly in mathematics, the teachers appear to be focused on students' skill acquisition to enhance their test achievement. Discourse focused on enhancing students' higher order skill and applied reasoning capacity tended to occur in science classrooms. We speculate that the differential use of discourse is due to the way that teachers perceive mathematics and science. While mathematics, at the K–12 level, is typified by finding the correct solution, science is more exploratory with experimentation and understanding of new discoveries. Thus, the nature of the disciplines likely determines how teachers perceive they are to teach and thus influences their questioning techniques and instructional use of discourse.

With regard to the difference we found in the number of applied reasoning questions between teachers with terminal degrees in their content area and those without, we speculate that the engagement in high level inquiry likely transforms how teachers think about learning and student engagement. Our explanation is supported by our finding that PhD holders were more likely to ask for and seek out examples of applied student reasoning, which suggests that teachers with terminal degrees tend to value dialogic discourse more than their peers who hold intermediate level degrees. However, our finding may be confounded by the class type; many of the teachers who held PhDs taught only elective classes, and we found more dialogic discourse occurred in elective classes regardless of the level of the teacher's degree. The potential conflation of elective course influence and teacher degree suggests that additional research is needed to determine why more dialogic discourse occurs in elective courses within STEM schools.

## Implications and conclusions

Given that teachers tend to teach in the style in which they themselves were taught (Lortie, 1975; Nettle, 1998) and that historically K–12 mathematics education has focused on static problem types and singular solution paths, it is unsurprising that even the highly educated mathematics teachers tended to use authoritative discourse instruction. More open-ended tasks in teacher education programs (particularly in mathematics education) may prepare teachers with understanding of approaches engaging students in more dialogic discourse learning. Preparing teachers to engage in dialogic discourse through professional development may be essential to their effective use of the instructional technique to enhance student engagement, learning, and critical thinking skill development.

Dialogic discourse can improve student learning in a variety of ways such as promoting critical thinking, connecting with prior knowledge, preventing and correcting private scientific conceptions, and developing disciplinarily appropriate argumentation (Driver et al., 2000; Duschl & Osborne, 2002). In the classes we observed, we found a dialogic discourse instructional approach most commonly occurred during science instruction provided by teachers with PhDs in elective classes. If novel classroom experiences are relatively limited to science classrooms, labs, and research experiences, it may be that STEM schools place higher value on students' science skill development. Thus, future researchers should explore the differential value placed on disciplines within STEM schools. Further, fruitful research is likely to be found in the exploration of the combination of factors representative of students' STEM school experiences and how these differ from experiences of students in traditional schools. Regardless, our research suggests that multiple interaction of factors in STEM schools provides students with an experience that enhances their persistence in studying STEM disciplines and preparation to join the STEM workforce.

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