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Secondary science teachers' use of discourse moves to work with student ideas in classroom discussions

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ABSTRACT

We investigated 10 secondary science teachers' facilitation of classroom discussions to examine how they went beyond eliciting student ideas to working with student ideas to support sensemaking. We qualitatively analysed video records of instruction and focussed our analysis on discussions stemming from formative assessments embedded in learning progression-based curricular units. We found that discussions could be placed on a quality continuum from recitation, to emergent, to transitional, to productive based on the degree to which teachers went beyond eliciting student ideas. We also found that discussion quality reflected the type and distribution of discourse moves teachers employed. In the highest quality (or productive) discussions, teachers used a concerted array of discourse moves to elicit, mark, and build on student ideas, including pressing students for reasoning, highlighting similarities and differences among the ideas and reasonings presented, and connecting student ideas to the learning progression. Teachers used these discourse moves relatively evenly throughout productive discussions. This study contributes to the growing body of literature on ways teachers can effectively support student sensemaking. It illustrates how science teachers' use of discourse moves can shape the quality of discussions and points to the potential of learning progressions as a tool to facilitate productive discussions.

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Productive discussions; learning progressions; discourse moves; secondary science teachers

Introduction

Teachers' attention to student thinking is an integral part of effective science instruction and plays a central role in models of ambitious science teaching that promote rigorous and equitable learning for all students (McDonald et al., 2013; Stroupe & Windschitl, 2015; Thompson et al., 2016; Windschitl et al., 2018). As opposed to more traditional ways of teaching, where teachers deliver knowledge to students, ambitious teaching involves continuously working on and with students' emerging science ideas to move student thinking

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forward. High quality, or productive, discussions are a crucial medium for eliciting and working with student ideas (Michaels & O'Connor, 2012; Mortimer & Scott, 2003; Windschitl et al., 2018). Productive discussions provide opportunities for students to generate ideas, clarify their thinking and reasoning, and make their ideas public to the teacher and other students in the service of helping students make sense of phenomena and scientific concepts.

The discourse moves teachers use to facilitate discussions can play an important role in fostering productive student talk and sensemaking (Bansal, 2018; Chin, 2006, 2007; Colley & Windschitl, 2016; Kawalkar & Vijapurkar, 2013; Thompson et al., 2016). In particular, the moves that teachers use to respond to student ideas elicited by initiating questions are important for moving student thinking forward (Bansal, 2018; Chin, 2006; Thompson et al., 2016). Yet, teachers often struggle to use discourse moves that go beyond eliciting student ideas to further probe and develop student thinking (Furtak, 2012; Harris et al., 2012; Thompson et al., 2016). More research is needed to understand the types and distribution of discourse moves integral to productive discussions to better support teachers in orchestrating these opportunities for student sensemaking.

To help address this need, in this study, we investigated how 10 secondary science teachers went beyond eliciting student ideas to working with student ideas in the moment-by-moment interactions of classroom discussions. We specifically analysed teachers' facilitation of discussions stemming from formative assessments embedded in learning progression-based curricular units. We considered these discussions to be a generative context to examine if and how teachers went beyond eliciting student ideas since both formative assessment and learning progressions are instructional strategies that focus on attending to student ideas. With the process of formative assessment, student understanding is elicited so both teachers and students can take action to move toward learning goals (Bell & Cowie, 2001). Learning progressions (LPs) are descriptions of student thinking about disciplinary-specific ideas and practices that increase in coherence and sophistication over time; teachers can use LPs to identify their students' current thinking and then appropriately intervene to guide students to more sophisticated levels of understanding (Corcoron et al., 2009). LPs specific to the concepts of water cycling and carbon cycling were developed for the curricular units implemented by the teachers in our study (see Figures 1 and 2). These LPs were based on a general progression of student thinking from simple force-dynamic accounts of scientific phenomena to coherent, model-based scientific accounts.

We sought to identify how these discussions varied in quality and to determine the types and distribution of discourse moves teachers used in high versus low quality discussions. Our purpose in conducting this study was to contribute additional insight into how teachers can effectively engage their students in productive, sensemaking discussions. The following research questions guided our investigation and analysis:

- How did the quality of disc ussions vary based on the degree to which teachers went beyond eliciting student ideas to working with student ideas?
- What specific discourse moves did teachers use and how did these discourse moves vary by discussion quality? In particular, what discourse moves did teacher use to work with student ideas?

	Progress Variables		
Levels of Achievement	*Connections across systems cluster*	*Surface water cluster*	*Soil/groundwater cluster*
Level 4 Qualitative model-based accounts	Traces water through connected systems along multiple pathways at multiple scales Identifies driving forces and constraining factors		
Level 3 School science accounts	Tells school science stories of water moving through multiple steps and along multiple pathways without accounting for driving forces and constraining factors. Is aware of atomic-molecular and landscape scales, but provides accounts at macroscopic scale		
Level 2 Force-dynamic accounts with mechanisms	Recognizes water can move or flow to connected places and identifies mechanisms for water movement Uses force-dynamic language that invokes inanimate enablers, proximity, or special circumstances to move water		
Level 1 Force-dynamic accounts	Focuses on human-centric actions and concerns Focuses on immediate and visible world Water can appear or disappear (e.g., evaporated means gone) Does not connect water in different locations		

Figure 1. Learning progression for water cycling.

	Progress Variables
Levels of Achievement	
Level 4 Qualitative model-based accounts	Students recognize that the mass of plants comes mostly from carbon dioxide in the air, rather than from water and soil nutrients. Students recognizes carbon cycling as a single cycle where matter and energy are conserved and in which carbon moves from atmospheric carbon dioxide to organic carbon and back again.
Level 3 School science accounts	Students recognize that the mass of plants has to come from somewhere. Students view water and soil nutrients as the "ingredients" plants use to make mass and that plants use sunlight for energy and carbon dioxide for breathing.
Level 2 Force-dynamic accounts with mechanisms	Students think that plants make their own mass using sunlight, water, air, and minerals or nutrients in the soil. Students think that plants use sunlight and soil nutrients for energy, and students think that plants drink by soaking water through their roots and breath in carbon dioxide and breath out oxygen.
Level 1 Force-dynamic accounts	Students focus on human-centric actions and concerns as well as on the immediate and visible world.

Figure 2. Learning progression for carbon cycling.

Background

High quality, or productive, discussions

Our focus on classroom discussions stems from recognition of the centrality of discourse in the teaching and learning of science. Learning science involves learning the language unique to science disciplines and how to use that language to express ideas and build understanding (Lemke, 1990). As such, students need opportunities to produce and use the language of science through talk and writing. Talk is particularly important for learners as it is central to meaning making, where an individual's ideas can be rehearsed, made public, and worked upon (Mortimer & Scott, 2003). Talk in the classroom is academically productive when it allows students to make intellectual progress and deepens student understanding of and reasoning about complex material (Engle & Conant, 2002; Michaels & O'Connor, 2012; Windschitl et al., 2018). In productive discussions, student ideas need to be surfaced and then worked on or with to help students make sense of phenomena and scientific concepts (Campbell et al., 2016; Windschitl et al., 2018). Through productive discussions, students can expand and clarify their thinking, gain a sense of what they do and do not understand, and respond to and take up others' ideas.

Teacher discourse moves to promote productive discussions

Academically productive talk is important for student learning, yet it is complex for teachers to facilitate. The types of discourse moves that teachers employ play an important role in promoting productive student talk. For example, the kinds of questions teachers ask and how they follow up with student responses have been found to influence the nature of student talk (Bansal, 2018; Chin, 2006, 2007; Colley & Windschitl, 2016; Kawalkar & Vijapurkar, 2013; Thompson et al., 2016). Indeed, sets of explicit guidelines have been developed to help teachers implement discourse moves to facilitate productive discussions in science classrooms (Michaels & O'Connor, 2012; Windschitl et al., 2018).

Studies focussed on teacher questioning provide some insight into how teacher moves influence productive student talk (Chin, 2007; Kawalkar & Vijapurkar, 2013). Chin (2007) examined episodes of productive discussions to investigate the relationship between teacher questions and students' responses. She found that in productive discussions, the predominant patterns and strategies of teacher questioning could be characterised into four broad approaches with specific questioning strategies within each approach. Kawalkar and Vijapurkar (2013) compared teacher questioning strategies between inquiry-based and traditional science classrooms. They found differences in the types of questions asked and patterns of questioning between the different classrooms. In traditional classrooms, teachers tended to ask questions about what students already knew, whereas in inquiry classrooms, teachers asked questions in a sequential pattern to make student thinking explicit and move students toward conceptual understanding.

Studies by Colley and Windschitl (2016) and Bansal (2018) went beyond teacher questioning to investigate the broader strategies or moves teachers used to successfully facilitate productive talk. Colley and Windschitl (2016) examined the co-occurrence of certain teacher-mediated conditions associated with different levels of rigour of student talk during whole class discussions. They characterised rigour as the levels of intellectual work students engage in during discussions, particularly associated with constructing evidence-based explanations. They found that discussions with the most rigorous student talk were associated with certain teacher discourse moves and scaffolds that were used in combination, including asking open-ended questions, prompting students to elaborate on ideas, referencing an activity or representation, using prediscussion tasks, and inviting students to comment on each other's ideas. Similarly, Bansal (2018) conducted a case study of two secondary science teachers who were observed to consistently engage students in dialogic discourse, as opposed to teacher-centered monologic discourse. Bansal characterised the moves these teachers used into three categories: foundational moves aimed at developing norms for and a culture of discourse in the classroom, initiation moves to elicit multiple student perspectives, and perpetuation moves to promote the active exchange of ideas among students. These perpetuation moves were particularly important. As Bansal found, eliciting student ideas is not enough to facilitate productive teacher-student dialogue; teachers need to keep the dialogue moving, which includes using strategies to press students for reasoning or to support arguments with evidence.

Indeed, other researchers have found that the ways teachers respond to student ideas elicited during discussions play an important role in fostering productive talk. For example, Chin (2006) specifically investigated the "follow-up" phase of teacher-student exchanges in the initiation—response—follow-up pattern. Chin found that certain discourse moves in this phase were important in promoting productive student talk, including avoiding explicit evaluations or put-downs of student responses, restating student responses, and posing subsequent questions to build on student responses. As another example, Tytler and Aranda (2015) inductively categorised the discourse moves that expert primary school teachers used to respond to student inputs during science discussions. They found that beyond elicitation moves, teachers used clarifying and extending moves to help students refine their ideas.

Challenges in moving beyond eliciting students' ideas

Several studies illustrate the struggles teachers can have with moving beyond eliciting students' ideas and responding to those ideas. For example, Thompson et al. (2016) investigated the link between teachers' responsiveness to student ideas and the level of explanatory rigour of student talk (similar to Colley & Windschitl, 2016). Thompson et al. found that high levels of rigour were associated with high levels of teachers' responsiveness to student ideas and that teachers were responsive in three general ways: building on students' science ideas, attending to students' participation in the learning community, and connecting to students' lived experiences. However, out of the 222 lessons they observed, only about 6% actually exhibited high responsiveness and high rigour. As a second example, Harris et al. (2012) examined how three teachers elicited, revoiced, connected, and/or built upon students' ideas and questions while implementing a curriculum that emphasized opportunities for teachers to elicit and work with student ideas and questions as a source for student-led investigations. They found that all three teachers readily elicited student ideas and questions and did so using similar instructional moves. However, they also found that teachers struggled with being responsive to student contributions: Teachers varied in how often and in what ways they went beyond eliciting to further develop student ideas and questions. As a third example, Furtak (2012) examined the use of an LP to support biology teachers' implementation of a formative assessment and found that teachers often identified and interpreted student ideas during whole class discussions about the assessment. However, teachers were more likely to repeat or clarify what students said rather than make explicit inferences about their ideas. Further, in those instances where teachers made explicit inferences, some teachers helped students think through their own ideas while others told students their ideas were wrong.

As the above corpus of studies indicates, certain types of teacher discourse moves are associated with promoting productive sensemaking talk from students; however, teachers often struggle to implement these moves so that they are able to go beyond eliciting student ideas to further working with them. Our study builds from and extends this previous work by investigating a generative but rarely researched curricular context supportive of eliciting and working with student ideas: formative assessments embedded in LP-based lessons (for other exceptions, see Furtak, 2012; Furtak et al., 2018; Jin et al., 2017). In particular, compared to previous studies of teacher discourse moves, we performed a fine-grained analysis of teacher-student talk both to track more specific discourse moves and to determine the ways these moves were (or were not) used in concert—to better understand teachers' successes and struggles in engaging their students in sensemaking.

Research design and method

Study context

Project overview

This case study (Merriam, 1998) was conducted during the final year of a five-year environmental science research and professional development project for secondary science teachers, termed here as Pathways. Pathways was a partnership among four environmental science research institutes situated in diverse geographic, demographic, and institutional settings in the United States: East Coast, Great Lakes, Mountain, and West Coast.

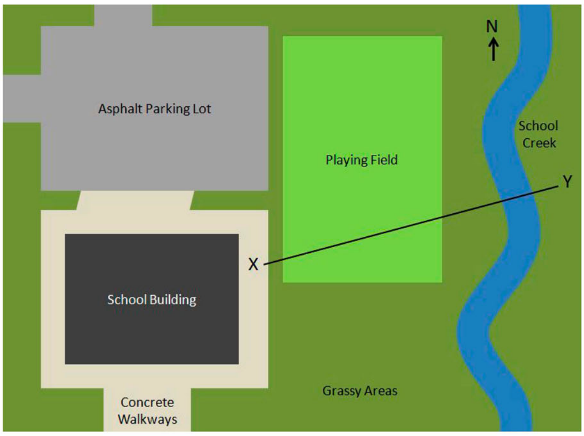
Across the four sites, there were three stages of project development (see Jin et al., 2017). First, LPs for the strands of water cycling and carbon cycling were constructed and iteratively revised using teacher and student assessment data (Gunckel et al., 2012; Jin & Anderson, 2012). Second, each LP was then used to develop a related curricular unit, called a Teaching Experiment, or TE. As stated in the Introduction, formative assessments aligned with the LPs were embedded in each TE—what Shavelson et al. (2008) termed formal formative assessments. Third, LP-based instructional supports and professional development materials were designed and sustained multi-year professional development opportunities for secondary science teachers were provided at each of the four sites. The professional development opportunities focussed on using LPs to understand student thinking and reasoning in the contexts of each TE. Although attending and responding to student thinking was a main theme of the professional development, facilitating productive discussions with specific discourse moves was not a primary focus.

Pathways LPs and TEs

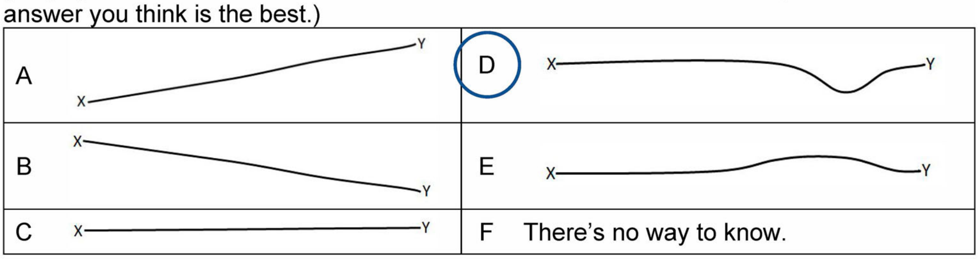
As introduced above, Pathways project members developed research-based LPs for water cycling and carbon cycling (see again Figures 1 and 2). The TEs were then constructed from each LP. The water cycling TE, *School Water Pathways*, engages students in scientific practices to study the water cycle as it occurs at their school. In total, this TE includes eight lessons and four formal formative assessments. An example of a water cycling formative assessment is shown in Figure 3. Each formal formative assessment includes a detailed explanation for teachers about how various student responses and reasonings connect to the four levels of the water cycling LP. The carbon cycling TE, *Plant Growth and Gas Exchange,* engages students in exploring two questions related to the carbon cycle: Where does dry plant matter come from? What is the main component of plant matter? In total, the TE includes 11 lessons and seven formal formative assessments. An example of a carbon cycling formative assessment is shown in Figure 4. Again,

School Map Formative Assessment

Below is a map of a school campus.



1. If you were looking from the side instead of from above, what would the shape (height) of the land be like across the distance from Point X to Point Y? (Circle the answer you think is the best.)



Explain your reasons for your answer.

Playing fields are usually pretty level and in D, the land starts out level from X. A creek has to be lower than the land around it because water flows down. In option D, the land dips down where the creek is.

2. Circle which direction you think School Creek is flowing:

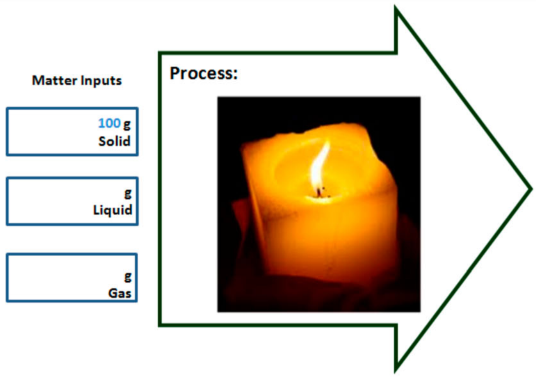
a. North b. South c. You can't tell from the map

Explain how you know.

Sometimes you can tell direction of water from a map, but not here. There are no tributaries, topographic lines, or other clues to suggest elevation and direction.

Figure 3. Formative assessment from water cycling TE.

Formative Check: While your students are working with the process tools, circulate to see if they are using the idea that some of the masses are leaving the system (candle, baking powder), either in an unspecified way or as energy. Remind them that they must explicitly conserve mass when using the tool, and that matter cannot be converted to energy, or vice versa.



Candle burning

What did you observe happening to the mass and CO_2 concentration as the candle was burning? Should show an increase in concentrations of CO_2, and a decrease in mass.

Explain what you think happened to the mass of the candle as it burned?
Some of the solid wax (and oxygen) was converted to carbon dioxide and water.

Figure 4. Formative assessment from carbon cycling TE.

these formative assessments provide guidance to teachers on how student responses and reasonings connect to the LP.

Study participants

Ten secondary science teachers participated in this case study. They were selected from the approximately 160 teachers involved in the Pathways project during the 2012–2013 academic year by members of the professional development teams. Four selection criteria were used: Teachers participants (1) had been involved in the project for a minimum of two years, (2) had implemented one or more of the TEs in previous years, (3) were distributed across the four sites, and (4) included both middle school and high school teachers. A summary of teacher and school information is included in the supplemental online material.

Data collection and analysis

We observed and video recorded five consecutive days of classroom instruction during each teacher's implementation of one TE in one class. We recorded field notes on a classroom observation checklist and used two video cameras to capture both whole class and small group interactions. In total, 50 class sessions were video recorded; the average length of each video was 58 min.

To focus on how teachers worked with student ideas during discussions, we looked specifically at discussions stemming from the formal formative assessments in the curriculum. Given that these assessments were focussed on student ideas and tied to LPs, we thought these discussions would provide a generative context for examining if and how teachers went beyond eliciting student ideas to working with them. We first identified all video recorded instances where teachers implemented a formal formative assessment and then determined which of these instances included a teacher-facilitated discussion of the assessment. A discussion was defined as a sustained interaction about content between the teacher and two or more students in either a whole class or small group context. Across the 50 video-recorded class sessions, we identified 22 instances of a discussion stemming from a formal formative assessment. We then created verbatim transcripts of each discussion.

Next, to characterise the overall quality of a particular discussion, we examined the transcripts and inductively developed four descriptive codes (Saldaña, 2016) to document the degree to which teachers went beyond eliciting student ideas to working with them. From low to high quality, these codes were recitation, emergent, transitional, and productive. We considered a discussion as recitation if it was dominated by teacher talk, with the teacher only occasionally eliciting student ideas about the substance of the formative assessment, and thus providing limited opportunities to work with student ideas. Most student responses in recitation instances were brief and did not reveal much of their thinking or sensemaking. A discussion was deemed emergent if a teacher consistently elicited student ideas about the substance of the formative assessment but did not further discuss or address these ideas by following up on student responses or pressing students further (i.e. did not work with student ideas). Again, most student responses were brief; students presented their ideas but were given limited opportunities to reveal the thinking behind their ideas or their sensemaking. A transitional discussion was one where a teacher consistently elicited student ideas about the substance of the formative assessment and occasionally went beyond elicitation to work with these ideas. In transitional instances, at least some student responses revealed their thinking and sensemaking. Finally, we considered a discussion productive when a teacher both consistently elicited student ideas and consistently moved beyond elicitation to follow up on student responses or press students further. In productive instances, students' thinking and sensemaking were often visible. Five researchers coded the quality of each of the 22 discussion transcripts individually and met collectively to resolve discrepancies through discussion until consensus was reached.

We then performed a finer grained analysis of teacher discourse moves to better understand differences in discussion quality, specifically, to determine how teachers worked with student ideas. We considered discourse moves as specific turns of teacher talk used to facilitate student talk and achieve discussion goals (Windschitl et al., 2018). As such, we constructed a set of codes to capture teachers' varied discourse moves: We began with a provisional set of codes drawn from the literature (e.g. Michaels & O'Connor, 2012; Windschitl et al., 2018), then iteratively refined these codes and added additional ones derived from the data themselves (Saldaña, 2016). We organised these codes into four types of moves: eliciting moves, marking moves, building moves, and other. The final set of nine codes and four types is shown in Table 1.

Table 1. Teacher Discourse Moves Used in Discussions.

Teacher Discourse Move	Description	Similar Move(s) in Literature
Eliciting Moves		
Eliciting student ideas	Teacher asks students to share their responses to a formative assessment question or to a follow up question.	Probing (Windschitl et al., 2018); New question (Tytler & Aranda, 2015)
Determining range of student responses	Teacher gauges range of student ideas and/or reasoning by eliciting responses from several students or groups of students, or by asking for different kinds of responses.	Eliciting Further Responses & Canvassing Opinion (Tytler & Aranda, 2015)
Marking Moves		
Repeating a student response	Teacher repeats part or all of what students stated.	Marking (Tytler & Aranda, 2015)
Revoicing in more scientific terms	Teacher uses scientific terms or concepts to restate or elaborate on student responses.	Revoicing (Tytler & Aranda, 2015; Windschitl et al., 2018)
Highlighting similarities and/or differences in student responses	Teacher draws attention to similarities and/or differences in two or more students' ideas or reasoning.	Agree/disagree and why (Michaels & O'Connor, 2012)
Building Moves		
Eliciting student reasoning	Teacher asks students to explain their reasoning.	Asking for evidence or reasoning (Michaels & O'Connor, 2012); Pressing (Windschitl et al., 2018)
Connecting to the LP	Teacher connects language or ideas from the LP to student responses and/or questions students to consider additional LP elements.	
Asking for clarification or an example	Teacher follows up response by asking students to clarify what they said or to provide a representative example.	Say more (Michaels & O'Connor, 2012); Pressing (Windschitl et al., 2018); Requesting clarification/elaboration (Tytler & Aranda, 2015)
Other		
Providing information	Teacher explicitly conveys content information to students.	

For each transcript, we coded at the level of teacher turn. A teacher turn was defined as one or more questions, statements, exclamations, and/or confirmatory responses a teacher made between two student responses. For each teacher turn, more than one discourse move could be assigned. At times, a discourse move was implied from the context—what came discursively before and/or after. Once the coding scheme was finalised, three researchers individually coded each transcript for discourse moves and met to resolve discrepancies until consensus was reached. We then calculated the percentage of teacher turns coded with each discourse move for each of the quality categories of recitation, emergent, transitional, and productive discussions. Finally, we compared the relative use and distribution of discourse moves by quality category.

We ensured the trustworthiness (Brenner, 2006) of our analysis in five ways. One, we used the video records and field notes as overlapping data sources to ensure all discussions of formal formative assessments captured during recording were identified. Two, we assigned one researcher to create a given transcript and then a second to check the transcript against its original recording. Three, for each cycle of coding, a minimum of three researchers collectively designed the coding scheme, applied it to a sample of the data, made modifications, and practiced coding with additional samples until consistency was reached. Then, the researchers independently applied the coding scheme to each piece of data and resolved differences through discussion. Four, for our coding of discourse moves, to ensure consistency of coding, the team of three researchers individually re-coded and collectively discussed half of the 22 transcripts after all transcripts had been coded and adjudicated once. Finally, we tracked all analytic decisions made using a detailed audit trail (Guest et al., 2012).

Findings

The quality of discussions

As stated in the Methods section, we identified 22 discussions stemming from formal formative assessments. Using our coding criteria based on the degree to which teachers went beyond eliciting student ideas, we categorised these discussions on a continuum from low to high quality. We identified three of the 22 discussions as recitation; seven, emergent; six, transitional; and six, productive. Example transcripts from and detailed comparisons across emergent, transitional, and productive discussions are included in the next Findings section on teacher discourse moves (see Tables 3–6).

Teacher discourse moves

To better understand differences in the quality of discussions—to determine how teachers went beyond eliciting student ideas to working with student ideas—we focussed on teacher discourse moves. Across the 22 discussions, we found that teachers routinely used nine discourse moves organised into four types of moves (see again Table 1). As shown in Table 2, we calculated the percentage of teacher turns coded with each discourse move for each of the quality categories (recitation, emergent, transitional, productive). Since a given teacher turn could be coded for more than one discourse move, the sum of percentages of turns coded for each discourse move does not total to 100 for a given category of discussion. We then compared the relative type and distribution of teacher discourse moves across quality categories.

As expected, since we examined discussions stemming from formal formative assessments, *eliciting student ideas* was a common discourse move in all quality categories. As shown in Table 2, *eliciting student ideas* was the most common discourse move in emergent, transitional, and productive discussions—included in 77%, 72%, and 55% of teacher turns respectively. It was also prominent in recitation discussions, constituting

Table 2. Percentage of Teacher Turns Coded With Each Discourse Move by Discussion Quality Category.

	Recitation	Emergent	Transitional	Productive
Eliciting Moves				
Eliciting ideas	44%	77%	72%	55%
Determining range	11%	22%	10%	24%
Marking Moves				
Repeating	6%	14%	33%	25%
Revoicing	0%	15%	8%	17%
Highlighting similarities and/or differences	0%	1%	1%	13%
Building Moves				
Eliciting reasoning	0%	3%	9%	29%
Connecting to LP	0%	2%	12%	15%
Asking for clarification/example	8%	9%	21%	15%
Other				
Providing information	64%	21%	9%	4%

Table 3. Transcript Excerpt and Teacher Discourse Moves From Ms. S's Productive Discussion.

Transcript Excerpt	Discourse Moves
Ms. S: So today's lab is going to help you investigate this question [When you add water to a sponge, does it gain mass? Explain your answer]. What do you think right now? Student 1, what do you think? If I take this sponge … and I add water to it, is it going to gain weight?	*Eliciting ideas; eliciting reasoning*
S1: Yes, technically yes, but no.	
Ms. S: Technically yes, but no. What do you mean?	*Repeating; eliciting reasoning; asking for clarification*
S1: The water may be inside the sponge, but the water is not technically merging with the sponge.	
Ms. S: So if I weigh the wet sponge, is it going to be heavier?	*Eliciting ideas; asking for clarification*
S1: Yes.	
Ms. S: So why are you saying no then?	*Eliciting reasoning*
S1: Because there is still water in the sponge, it's just mixed in.//	
Ms. S: Okay, I'm going to ask … Student 2.	*Eliciting ideas; eliciting reasoning; determining range of responses*
S2: I said I think it does because the water has its own mass but so does the sponge and if you add those two it combines to be bigger.//	
Ms. S: Okay, any other ideas? Yep, what did you say, Student 3?	*Eliciting ideas; eliciting reasoning; determining range of responses*
S3: I am going to agree with Student 1, but also, when you put that water in the sponge, it's actually like filling up that empty space on the inside, which kind of gives it more mass.	
Ms. S: Which kind of gives it more mass. So you're saying that there are empty spaces in this sponge and we're going to stick water in those empty spaces, which is going to give it more mass.	*Revoicing*
S3: Yes.	
Ms. S: Okay, Student 4, what do you think?	*Eliciting ideas; eliciting reasoning; determining range of responses*
S4: I say yes, the mass is going to get greater, but going back to what Student 1 said about how they are different things. With what we are doing with the plants, the soil, the plants, and the water are all different things, but when we combine them together, we can get the mass of all of them.	
Ms. S: Okay, so if we look at the mass of whole system then, what do you think will happen?	*Eliciting ideas; asking for clarification*
S4: They'll get larger.	
Ms. S: They'll get larger. But then you're going to agree with Student 1 that that's not really part of the sponge?	*Repeating; highlighting similarities and/or differences in responses*
S4: Yes.	
Ms. S: Okay. How many of you agree with Student 2? (Some students raise their hands.) Ms. S: How many of you agree with Student 1? (Some students raise their hands.)	*Eliciting ideas; determining range of responses; highlighting similarities and/or differences in responses*

the second most common discourse move for this quality category and included in 44% of teacher turns.

Looking across the quality categories, we found differences in the type and distribution of discourse moves used. More specifically, recitation discussions predominately featured the discourse move of *providing information* (64%). This finding is consistent with our initial categorisation of recitation discussions as largely consisting of teacher talk. Although teachers did *elicit student ideas* in recitation discussions, teachers mainly provided content information and used fewer of the other discourse moves to mark or build on student ideas. In emergent discussions, *eliciting student ideas* accounted for the highest percentage of teacher turns (77%), and although the move of *providing information* was used (21%), it accounted for a lower percentage

Table 4. Transcript Excerpt and Teacher Discourse Moves From Mr. J's Productive Discussion.

Transcript Excerpt	Discourse Moves
Mr. J: What drives the flow of water?	*Eliciting ideas; connecting to LP*
S1: Gravity.	
Mr. J: Gravity. And for gravity to work, does gravity necessarily move water on a flat plane?	*Repeating; eliciting ideas; connecting to LP*
Ss: No.	
Mr. J: It needs some slope, right? If we look back at this picture, and we'll go to number one [item 1 about the shape of the land from Point X to Point Y], it's identifying a cross-section from here to here. Which one of those is likely not an answer? For that cross-section of earth (points to map projected on the screen)? Student 1?	*Revoicing; eliciting ideas; connecting to LP*
S2: A.	
Mr. J: Because?	*Eliciting reasoning*
S2: Because water needs to go in a slope, goes down on a slope, so I think if it slopes up, then the river can't be there.	
Mr. J: So this river suggests that that has to be lower than this plane, right? Otherwise, water would be flowing this way, and the river wouldn't be going north-south. I'd agree with that. Student 3, take another one, and either say support it or challenge it.	*Revoicing; eliciting ideas; determining range; connecting to LP; eliciting reasoning*
S3: E. I'm against it because, that would be where the water would be right at that bump. So the water would go somewhere else.	
Mr. J: So you're saying that's a ridgeline, and so the river wouldn't be there because of that?	*Revoicing; eliciting ideas; asking for clarification*
S3: Yes.	
Mr. J: You see that? Some people making some sense of it now? Somebody else take one of those letters and either challenge it or support it. Yes, Student 4.	*Eliciting reasoning; determining range*
S4: B. I support it because it flows downhill, water flows downhill, that's downward slope.	
Mr. J: Okay, and so that means the river would be roughly right here (points to Point Y on answer B on the screen). Okay, I'd agree with some of that. I think there's maybe a challenge. Student 5?	*Revoicing; eliciting reasoning; determining range; connecting to LP*

of teacher turns than in recitation discussions. Further, compared to recitation discussions, a higher percentage of teacher turns in emergent discussions involved the marking moves of *revoicing student responses in more scientific terms* (15%) and *repeating student responses* (14%), as well as the eliciting move of *determining the range of student ideas* (22%),. In transitional discussions, *eliciting student ideas* was still predominant (72%); however, the marking move of *repeating student responses* (33%), and the building moves of *asking for clarification or an example* (21%), and *connecting to the LP* (12%), were more prominent in transitional than in recitation or emergent discussions.

In productive discussions, a lower percentage of teacher turns were coded as *eliciting student ideas* (55%) compared to emergent and transitional discussions. However, the percentages of certain marking and building moves were higher than in the other quality categories, including the marking moves of *revoicing* (17%) and *highlighting similarities and/or differences between responses* (13%), and the building moves of *eliciting reasoning* (29%) and *connecting to the LP* (15%)., For example, the discourse move of *eliciting reasoning* was included in 29% of teacher turns in productive discussions but was minimally used in the other quality categories (i.e. 0% in recitation, 3% in emergent, and 9% in transitional). In addition, as illustrated in Figure 5, the percentages of teacher turns coded for each move in productive discussions were more even in their distribution compared to the distribution of moves in recitation, emergent, and transitional discussions.

Table 5. Transcript Excerpt and Teacher Discourse Moves From Mr. A's Transitional Discussion.

Transcript Excerpt	Discourse Moves
Mr. A: Now the next question. Since you mentioned all these things [that plants need to grow] (pointing to the list he had written on the whiteboard from students' responses to question 1), I'm going to ask each group now. How do you know that plants need this? How do you know that plants use water for growth?	*Eliciting reasoning*
S1: Because the plants are a living thing and we are a living thing. So we need those things to live, so plants need them too.	
Mr. A: Wow, good answer, right. Plants are living things and we are living things. We need water, so do plants. So tell me, go ahead, this group, tell me what is the difference between living and nonliving? How do you say plants are living?	*Repeating; eliciting ideas; eliciting reasoning*
S2: With non-living things, they never die. They always exist … living things die …	
Mr. A: So nonliving things don't die and living things die, okay. Any other characteristics of living things?	*Repeating; eliciting ideas; determining range of ideas (same for next two teacher turns)*
S3: Living things grow.	
Mr. A: Living things grow. What else?	
S4: Reproduce.	
Mr. A: Reproduce. Living things?	
S5: Think.	
Mr. A: Living things think.	*Repeating*
S5: Not a lot.	
S6: Have cells.	
Mr. A: Living things have cells, correct. And what is the most important thing that living things have to maintain?	*Repeating; eliciting ideas*
S7: Homeostasis.	
S8: Homeostasis.	
Mr. A: Homeostasis, right. So back to this, so living things have all those characterisations. Now do plants have all those things? Do plants have cells?	*Repeating; providing information; eliciting ideas*
Ss: Yes.	
Mr. A: Do plants grow?	*Eliciting ideas*
Ss: Yes.	
Mr. A: Do plants maintain homeostasis?	*Eliciting ideas*
Ss: Yes.	
Mr. A: Right. Now, going back to this one, how do you know that plants need water? How do you know they use water to grow?	*Eliciting reasoning*
S9: If you don't give them water, then they die.	

Table 6. Transcript Excerpt and Teacher Discourse Moves From Ms. E's Emergent Discussion.

Transcript Excerpt	Discourse Moves
Ms. E: So, we know that with the candle burning, what do we have? Do we have liquid that results from the burning? S1, what do you think? Do we have liquid from the candle burning that results?	*Eliciting ideas*
S1: Yeah, there is wax.	
Ms. E: Okay, the wax is liquid, but that kind of re-solidifies and stays with the mass of the solid.	*Revoicing*
S1: Oh no, but there's …	
Ms. E: But what else was happening as it flamed? What do you notice is coming out of the candle as it burns?	*Eliciting ideas*
S1: Um, gas.	
Ms. E: Right. Smoke. So we have gas. So how much gas do we have here coming out? If this was 10.52 and this was 10.48, what does this have to be to be equal?	*Revoicing; eliciting ideas*
S2: .04 grams.	

To further illustrate the differences in the use and distribution of teacher discourse moves by quality of discussions and how teachers worked with student ideas, we turn to examples from individual transcripts. We begin with excerpts from productive

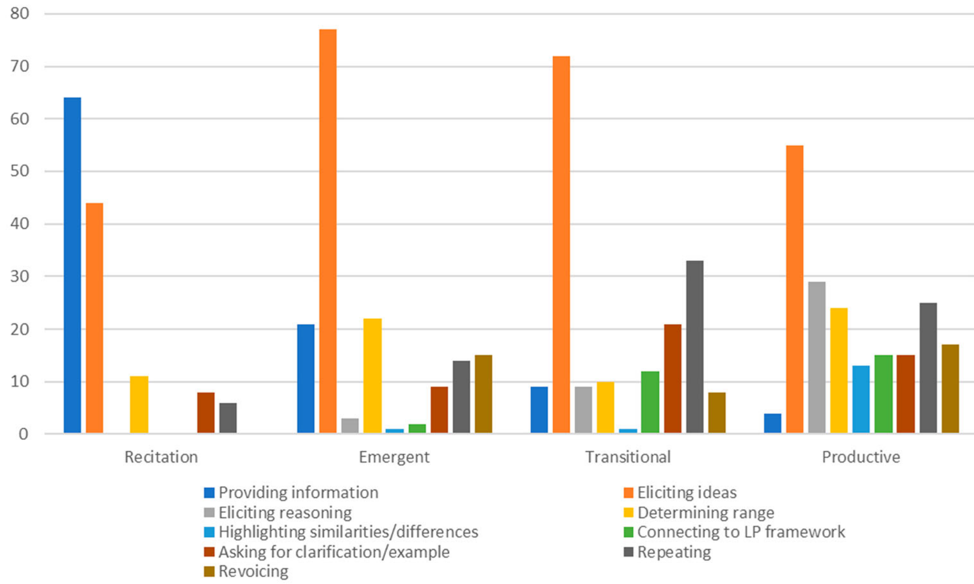


Figure 5. Distribution of discourse moves by discussion quality.

discussions and then compare them to transitional and emergent instances. One example of a productive discussion came from Ms. S as she implemented a formative assessment from the carbon cycling TE that asks students to consider what it means to gain mass in three different contexts, including adding water to a sponge. The purpose of this formative assessment is to help students begin to consider the difference between plants gaining temporary mass from water and permanent mass from carbon. An excerpt with discourse moves from this productive discussion is shown in Table 3.

Overall, in this excerpt, Ms. S used several discourse moves in concert with one another in a sustained effort to engage students in making sense of their ideas about whether or not a sponge gains mass. More specifically, Ms. S consistently employed the building move of *eliciting student reasoning*. She asked students multiple times to present both their answer and their reasoning stemming from the formative assessment prompt. She further pressed students for reasoning by asking: 'What do you mean?' 'So why are you saying no then?' Ms. S also used the marking move of *highlighting similarities and/or differences in student responses* when posing a series of questions to determine which of two students' responses others agreed with. Further, Ms. S used the moves of *asking for clarification, revoicing in more scientific terms, repeating a student response*, and *determining the range of student responses*. In sum, Ms. S went beyond eliciting students' yes/no responses and worked with students' ideas by continually eliciting students' reasoning behind their responses and highlighting differences between two students' responses and then having all students consider whose response they agreed with.

A second example of a productive discussion came from Mr. J's implementation of the School Map Formative Assessment for the water cycling TE (see again Figure 3). Mr. J focussed this discussion on item 1 that asks for the shape of the land between Points X and Y. An excerpt of this discussion with discourse moves is shown in Table 4.

In this excerpt, Mr. J began with a question that connected to the curricular LP: 'What drives the flow of water?' (see again Figure 1 for the LP). He then continued to use the building move of *connecting to the LP*: He reminded students that gravity is a driving force of water flow and encouraged students to use this central concept from the LP to support or challenge any of the six possible answers to item 1. In addition, Mr. J consistently used the building move of *eliciting student reasoning*. He did not solely ask students for what they thought was the correct answer, but rather to pick a response option and to support or challenge the appropriateness of that option as an answer. As with Ms. S, he also used the moves of *asking for clarification, revoicing in more scientific terms*, *repeating student responses,* and *determining the range of student responses*.

As a comparison to these productive discussions, an example of a transitional discussion came from Mr. A as he implemented a formal formative assessment from the carbon cycling TE. During this whole class discussion, Mr. A asked students two of the three primary questions included as part of this assessment: (1) What do plants need to grow? (2) How do students know that plants need those things for growth? An excerpt from this discussion with discourse moves is shown in Table 5.

Although Mr. A began and ended this discussion with the building move of *eliciting student reasoning*, he did not probe student reasoning as consistently as Ms. S or Mr. J. Rather, Mr. A repeatedly used the moves of *eliciting student ideas* and *repeating student responses* when asking two series of factual questions, first about the differences between living and nonliving organisms and then about the characteristics of plants, without following up with other moves. As such, students had fewer opportunities to elaborate on their reasoning, draw connections to the LP, or explain how their ideas or reasoning resonated with or contradicted those of their classmates. In this transitional discussion, Mr. A did not have as sustained an effort to engage students in sensemaking as Ms. S or Mr. J did in the productive discussion examples above.

Finally, an example of an emergent discussion came from Ms. E, who also implemented a formative assessment from the carbon cycling TE. For this assessment (see again Figure 4), students first watched Ms. E perform a demonstration of a candle burning in a sealed chamber with a probe that measured carbon dioxide levels. The students then completed a graphic organiser to record the mass of the candle before and after it burned. The purpose was to check if students understood that some of the candle's mass was converted into CO_2 and that mass could not be converted into energy. An excerpt from this emergent discussion with discourse moves is presented in Table 6.

In this brief excerpt, Ms. E queried students about their observations of the candle burning and their calculations about the candle's change in mass. She employed the discourse moves of *eliciting student ideas* and *revoicing in more scientific terms*. However, except for the marking move of revoicing, she never went beyond elicitation to engage students with their ideas about why such a mass difference might exist or how it connected to key ideas about the cycling of carbon in the LP.

Discussion

Attention to student ideas is an integral part of effective and equitable science instruction (McDonald et al., 2013; Stroupe & Windschitl, 2015; Thompson et al., 2016; Windschitl et al., 2018). Teachers' facilitation of high quality, or productive, classroom discussions is an important pedagogical strategy to elicit and work with student ideas. Several previous studies have found that certain types of teacher discourse moves are associated with promoting productive sensemaking talk from students (Bansal, 2018; Chin, 2006, 2007; Colley & Windschitl, 2016; Kawalkar & Vijapurkar, 2013). However, other studies highlight the challenges teachers face with facilitating productive discussions (Harris et al., 2012; Thompson et al., 2016). In our study, then, to contribute to the knowledge base on how science teachers can effectively engage students in sensemaking through productive classroom discussions, we investigated 10 classrooms where teachers facilitated discussions stemming from formal formative assessments embedded in two LP-based curricular units. Specifically, we characterised these discussions along a quality continuum based on the degree to which teachers went beyond eliciting student ideas to working with student ideas (i.e. how productive the discussions were). We then analysed the discourse moves teachers used during discussions of varying quality to better understand how teachers worked with student ideas.

We found differences in the type and distribution of discourse moves in discussions along the continuum. Overall, marking and building moves were more prominent in transitional and productive discussions than in recitation or emergent discussions. *Eliciting student ideas* was a prominent discourse move in all discussion quality categories. This was expected given that we focussed on discussions stemming from formal formative assessments designed to surface student ideas. However, in recitation discussions, teachers did little to work with student ideas through marking or building discourse moves. These discussions largely consisted of teacher talk and the primary discourse move teachers used was *providing information*. In emergent discussions, teachers used the move of *providing information* but used other moves as well, notably the eliciting move of *determining the range of student responses* and the marking moves of *repeating student responses* and *revoicing student responses in more scientific terms*. In these emergent discussions, although teachers were less often pushing or probing student thinking, they were seeking a broader range of ideas as well as marking student ideas as important and making connections to academic language through repeating and revoicing (Tytler & Aranda, 2015; Windschitl et al., 2018). In transitional discussions, teachers used the building moves of *connecting to the LP* and *asking for clarification/examples* to work with students' elicited ideas. Through these two moves, teachers connected student ideas to key ideas or language of the curricular LPs and probed students to clarify what they meant and/or to provide a representative example.

In productive discussions, teachers used an array of discourse moves to respond to and work with ideas elicited from students. In particular, the building move of *eliciting reasoning* accounted for a higher percentage of teacher turns in productive discussions than in the other quality categories. In other words, teachers tended to go beyond eliciting answers to further press students to explain their reasoning. Other researchers have also identified *eliciting reasoning* as important for facilitating productive discussions in science classrooms (Bansal, 2018; Michaels & O'Connor, 2012; Windschitl et al., 2018). The marking move of *highlighting similarities and/or differences across responses* also accounted for a higher percentage of teacher turns in productive discussions compared to the other quality categories. With this move, teachers worked with ideas by drawing attention to commonalities and discrepancies between ideas or reasoning presented by students. This move resonates with Michaels and O'Connor's (2012) talk move of *agree/disagree and why*, which they considered an important move to help students take up and respond to the ideas and reasoning of others. The building move of *connecting to the LP* accounted for a similar percentage of teacher turns in transitional and productive instances (12% and 15%, respectively). Thus, as in transitional discussions, another way teachers worked with student ideas in productive discussions was by making connections between student ideas and the key ideas or language of the LPs. Finally, teachers also used the moves of *determining the range of student responses*, *repeating student responses*, and *revoicing* in productive discussions. Again, through these eliciting and marking moves, teachers surfaced multiple ideas, marked ideas as important, and made connections to academic language.

As shown, teachers used an array of discourse moves to respond to and work with student ideas in productive discussions and they used these moves relatively evenly (see again Figure 5). In other words, in productive discussions, teachers tended to use a range of discourse moves with similar frequency rather than to concentrate on just a few. This suggests that attention to the distribution of discourse moves within a discussion is important. In particular, as shown with the transcript examples in the Findings section, teachers tended to use moves, such as *eliciting student reasoning* and *connecting to the LP*, consistently and in conjunction with other moves throughout productive instances. In line with Colley and Windschitl (2016) and Windschitl et al. (2018), we recommend more careful attention to how discourse moves should be coordinated with one another to move student thinking forward.

Our research points to the promise of using LPs as a tool for facilitating productive classroom discussions. In the two highest quality categories of discussions (transitional and productive), we found that teachers used the building move of *connecting to the LP*, where they connected student responses to key ideas or language from the LPs provided in the curriculum. This move may help address the dilemma Thompson et al. (2016) found of teachers valuing canonical scientific knowledge versus student ideas. In their study, they found that a majority of teachers elicited a wide range of student ideas but then focussed on the correct science ideas and thus did little to support student sensemaking. In contrast, they found that the few teachers who promoted highly rigorous student talk focussed on students making progress with ideas and attended to the classrooms' emerging understanding of canonical knowledge. LPs are tools to promote the progress of student understanding as it unfolds and builds over time (Corcoron et al., 2009). Thus, LPs can be a tool for classroom discussions with which teachers take student ideas, connect to the language of the LP, and help progress student thinking toward more sophisticated understandings of canonical knowledge. Indeed, as a tool for discussions, an LP can be understood to serve as a macroscript, providing a clear intellectual goal that helps teachers balance guiding the overall discussion with allowing students to traverse a series of byways in articulating their ideas and reasoning (Resnick, 2010).

We think our finding related to the generative nature of LPs in productive discussions particularly important, as previous research on the usefulness of LPs to understand and support classroom interactions is mixed (Furtak, 2012; Furtak et al., 2018). Despite concerns about the limitations of LPs (Hammer & Sikorski, 2015), our findings point to the potential of LPs as a resource for teachers to facilitate productive discussions.

Conclusion

Our study informs science teachers, teacher educators, and professional developers about how to engage students in productive discussions—about how teachers can move beyond simply eliciting student ideas to working with these ideas. As with all studies, it has a number of limitations, in particular, we did not examine other important factors that may have contributed to discussion quality and the discourse moves used by teachers. Researchers have found that establishing classroom norms for discussion is an important component of productive student talk (Bansal, 2018; Michaels & O'Connor, 2012; Thompson et al., 2016). We focussed on the discourse moves that teachers used in specific examples of discussions, but we did not examine broader ways that teachers may have established or promoted classroom norms for discussion. Other researchers have found that additional factors, like time, discussion goals, teacher beliefs, and teacher content knowledge (Pimentel & McNeill, 2013; Sabel et al., 2016), can also contribute to variations in discussion quality and the use of discourse moves. Further, as Furtak et al. (2018) found, long-term professional development with a focus on LPs can help teachers facilitate more productive discussions. Although the teachers in our study did participate in a professional development experience focussed on LPs, we did not analyse how factors related to the professional development influenced their use of LPs and/or facilitation of discussions; it was beyond the scope of this paper. The role of professional development is important to consider in future research on facilitating productive discussions, in general, and on using LPs to facilitate discussions, more specifically.

Facilitating productive discussions is certainly complex work. Teachers need to attend to the discourse moves they are using and the ways they are using discourse moves in concert with one another. As indicated by our findings, to facilitate productive discussions, teachers should be encouraged to work with student ideas by using building and marking moves such as *eliciting student reasoning*, *connecting student ideas to the LP* (if an LP is available), and *highlighting similarities and/or differences across student ideas and reasoning*. Further, teachers should be encouraged to use these and other discourse moves consistently and in concert with one another throughout a discussion.

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