Towards improving science discussions:
A framework to guide instructional decision making

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Introduction

Although much has been written about the nature of productive discussion and teacher moves that can support such talk, we argue that there is insufficient guidance for teachers' instructional decision-making for conducting discussions. Rather, guidelines often operate at a level of generality which is not helpful to the enactment of meaningful talk. For instance, Alexander argues that discussion should be collective, reciprocal, supportive, cumulative, and purposeful (Alexander, 2005, 2020)and, whilst true, in and of themselves such criteria do not help the practitioner with detailed recommendations for how to act. Likewise, Resnick, Michaels and O'Connor argue that talk should be accountable to standards of reasoning, accountable to knowledge and accountable to the learning community – yet another set of general, non-specific criteria (Resnick, Michaels, & O'Connor, 2010). Such standards, while welcome, do not distinguish types of dialogue, and most importantly, their pedagogical purpose. We contend that helping teachers to have a clearer sense of the *types* of discourse and the *purposes* of discussion in science will help them to enact more productive talk. Fundamentally all discursive deliberations seek to make epistemic progress (Golding, 2013). Epistemic progress requires epistemic work (Manz & Renga, 2017) and being clearer about the goal enables clarity both in evaluating the value of the discussion and how to improve its effectiveness. In short, we need a classificatory system that enables teachers to identify the goals of classroom discourse. In this paper we offer a two-part framework that would both enable teachers to identify the intent of discourse and to interrogate its value.

Background and Rationale

During the past 20 years there has been increasing emphasis on the potential contribution of oral discussion, dialogue, and argumentation to the learning of science. This focus has been justified by several lines of theoretical and empirical research: 1) students need practice to appropriate the language of science (Driver, Newton, & Osborne, 2000; Fang, Lamme, & Pringle, 2010; Lemke, 1990); 2) argumentation is central to the nature of science and helps students to make sense of complex scientific phenomena (Driver et al., 2000; Erduran & Jiménex-Aleixandre, 2008; National Research Council, 2012; Osborne, 2010); and 3) learning gains are greatest when students engage in interactive dialogue (Alexander, 2020; Chi, 2009; Kim & Wilkinson, 2019). Building on this research base, recent work has positioned facilitating sensemaking discussions as a core practice for novice science teachers (Kloser et al., 2019).

Despite the demonstrated value of classroom talk for learning (Chi, 2009), discussion and argumentation are rare in science (Newton, Driver, & Osborne, 1999; Weiss, Pasley, Sean Smith, Banilower, & Heck, 2003). In science, as in many disciplines, talk is dominated by the familiar Initiation-Response-Evaluation (I-R-E) format. Such talk has at its heart a notion of performativity, requiring students to display knowledge while reserving evaluation for the teacher. In contrast, dialogue where students share ideas is more challenging for teachers to enact. First, given its contingent and improvisational nature teachers must relinquish a degree of control to students. Second, the teacher must interpret students' ideas in the moment and decide which contributions to build upon – both of which require an expertise in the domain (Bennett & Turner-Bisset, 1993; Turner-Bissett, 1999). And finally, they must position students' ideas in relationship to one another to build toward the learning goal of the lesson.

A large body of research has explored the ways that teachers can support dialogue and discussion in their science classes. Teachers can, for instance, set up the epistemic conditions to support dialogue by problematizing content and giving students authority to evaluate claims (Engle & Conant, 2002). Focal questions and activities can be designed to have multiple plausible solutions so that students can consider and compare different ideas (Berland & Reiser, 2011; Jiménez-Aleixandre, Bugallo Rodríguez, & Duschl, 2000). Finally, the teacher can assume different roles (Chen, Hand, & Norton-Meier, 2017) and use particular questioning techniques (Chin & Osborne, 2008; Dillon, 1994; King, 1995) to help students to develop their ideas and facilitate group discussion. In particular, talk moves are "tools" that have been taken up by teachers as a way of initiating and supporting dialogue (Michaels & O'Connor, 2015). Many strategies have also been developed to support such dialogue such as talk and turn, listening triads, argument lines, four corners, concept cartoons and concept mapping (Osborne, Donovan, Henderson, MacPherson, & Wild, 2016). Thus, there is a rich repertoire of strategies to support and enact discussion – but to what end?

A limitation of this work is that it often treats productive dialogue as a monolithic entity and give little attention to the goal of the dialogue. Experts in the field agree that science talk can be used for a wide range of purposes (Grossman, Dean, Kavanagh, & Herrmann, 2019), be they *pedagogical* (e.g., eliciting background knowledge, review) or *disciplinary* (e.g., designing an investigation, constructing a scientific explanation). Although some practitioner resources have presented frameworks for types of discussions (e.g., (Michaels & O'Connor, 2015; Osborne et al., 2016; Windschitl, Thompson, & Braaten, 2018), the specific purpose of discussions is not often explicitly recognized; rather, there is a tacit assumption that discussion per se is a good thing. The lack of clarity about the purpose leads to confusion about what kind of talk will best support the teacher's intended outcomes. If the function of a classroom discussion is simply to elicit student ideas about a phenomenon e.g., "Is a seed alive?", then the epistemic work needed is simply the space in which students are encouraged through non-evaluative questioning to offer elaborated reasons for what they think. If, in contrast, it is to come to a consensus about the criteria for what makes something to be judged to be alive, then this is insufficient. Rather, students will have to engage in argument from evidence about the ideas the initial discussion elicits.

Research on teacher facilitation of discussion often presents generic talk moves (e.g. Michaels & O'Connor, 2015), many of which are discipline agnostic (e.g. "What's your evidence" and "Does anyone disagree?"). While these tools are useful starting points for teachers to facilitate discussion with students, they are rarely sufficient to achieve a specific disciplinary purpose for discussion. In addition, research has shown that these formulaic moves often result in a performative type of discourse termed "pseudoargumentation," in which students adopt the superficial features of argument and dialogue without actually considering the ideas of their peers or coming to a deeper understanding of the scientific concepts and practices(Berland & Reiser, 2011; McNeill & Knight, 2013) (Berland & Reiser, 2011; McNeill & Knight, 2013).

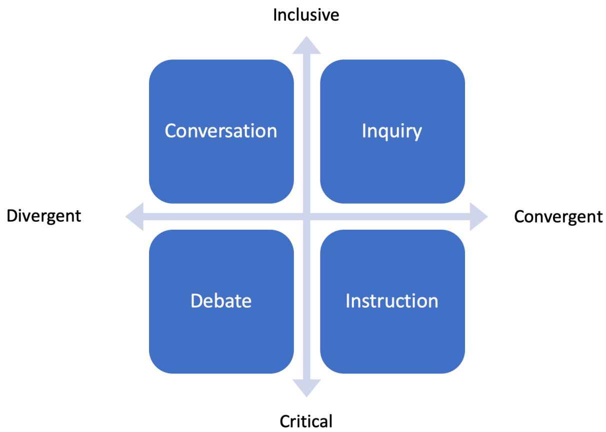
Towards a Framework for Clarifying the Nature of Dialogue in Science Learning

Given the limitations of current research, we offer two preliminary frameworks on *types of dialogue* and *the disciplinary purposes for discussion in science*. We view these two parameters of discussion as interrelated, but important to distinguish. We draw from examples from our research on science discussion in elementary science classrooms to describe how these frameworks can be used as tools to support teachers' instructional decision making, including articulating the goals of a discussion, writing a focus question, and enacting talk moves.

Types of Dialogue. In developing our framework for the *Types of Dialogue*, we draw from the categories of dialogue proposed by Burbules (1993). Burbules argued that skilled teachers work from a repertoire of dialogues that can be arranged in two dimensions: divergent-convergent and inclusive-critical (Fig 1). Divergent dialogue is traced to Bakhtin's notion of heteroglossia (1981), which acknowledges that speakers use language differently to communicate ideas based on their own interpretations and experiences. As a result, talk tends to multiply possible interpretations. Conversely, convergent dialogue seeks to narrow interpretations to build consensus towards a single account. The inclusive-critical dimension reflects attitudes towards one's partner in dialogue. An inclusive orientation entails granting "potential plausibility" to what one's partner says and seeking clarification on what led that person to their position (p. 111). On the other hand, a critical orientation is more skeptical and questioning and involves testing ideas against "evidence, consistency, and logic" (p. 111).

These two dimensions result in four types of dialogue. Conversation is an inclusive-divergent type of dialogue that seeks mutual understanding rather than reconciliation of differences. Inquiry is an inclusive-convergent type of dialogue that aims at answering a specific question by producing an outcome that is agreeable to all. Its goal is the achievement of consensus which is a fundamental goal of science. Debate is a critical-divergent type of dialogue that has a skeptical spirit but relies on value judgements and does not necessarily seek to reconcile differences. Instruction is a critical-convergent type of dialogue that seeks to move a discussion towards a definite conclusion and is often monologic. This type of dialogue represents a highly directive form of teaching that asks students to make conceptual connections guided by closed teacher questioning. We argue that all four types of dialogue can be beneficial and that distinguishing which one best serves the instructional goals is a key pedagogical skill.

Figure 1: Types of Dialogue



When students are introduced to a new scientific phenomenon or concept, instruction often begins with dialogue as conversation (inclusive-divergent). This approach aligns with the view that science learning can be viewed as a conversation based on the creation of difference (Ogborn, Kress, Martins, & McGillicuddy, 1996). The teacher may ask the students "how they see the world" by drawing on phenomena, artifacts, and other multi-modal forms of communication or their existing "funds of knowledge" (González, Moll, &

Amanti, 2006). Through eliciting divergent ideas, the teacher may be able to open up a perceived gap or conflict in knowledge that can motivate sensemaking (Odden & Russ, 2019). For example, teachers might show a picture of a tanker car imploding and ask students why they think it happened (Windschitl et al., 2018). In this type of discussion, teachers would seek to uncover what students already know and how they know it, as well as to highlight any potential differences or inconsistencies in the explanatory hypotheses proffered. In such a discussion, the teacher might explicitly specify that the goal is to brainstorm a wide range of ideas and, consequently, might not expect students to take a skeptical or critical stance.

Later in an instructional sequence, teachers might specify a particular question that students can collect evidence to answer that may result in dialogue as inquiry (inclusive-convergent). Although such a dialogue might begin with a period of conversation (inclusive-divergent) in which different ideas are generated, the ultimate purpose is to gather ideas for further dialogue in which they are supported, compared, and, eventually, evaluated. For this type of discussion, shared experiences that are accessible to all members of the class provide one basis for the evidence to assess any claims advanced. Another source is the ideas introduced by the teacher, who might offer aspects of the consensually agreed-upon scientific model. The epistemic work that is being done here is at the lower levels of Manz's framework of "Noticings", "Public Attributes" or "Data Collection" (Manz, 2016). Such work is important in evaluating which of identifying salient features, and then evaluating which should be attended to in building an explanatory hypothesis.

Fundamentally, however, the goal of such dialogue is inclusive-convergent. Its aim is to build an explanatory hypothesis for why the tanker car implodes so dramatically. Such dialogue requires contributions which are synergistic, identifying relevant and irrelevant evidence and then generating new understandings by the process of building upon one another's ideas. This type of dialogue may also have an aspect of questioning "not with the critical purpose of rejecting these alternatives, but towards determining the reasons, evidence, and experience that underlie different ideas as a means of understanding them and assessing them more accurately" (Burbules, 1993, p. 116). An example of this type of dialogue might be interpreting the results of pressure-volume experiments in order to determine key relationships that might explain the tanker car implosion. In some cases, there may be several answers to a question or approaches to a problem. For example, students might generate their own models of the implosion that would have different features. This would still constitute inquiry, given that the alternatives seek to answer the same question, but its goal is fundamentally convergent as it seeks to achieve consensus about the best model. Epistemic progress must then be judged by whether alternative hypotheses have been considered and flaws identified.

In contrast, dialogue as debate does not necessarily seek consensus. Instead, it identifies the significant issues that must be considered in coming to a decision and seeks to evaluate their competing merits. In the context of science, such dialogues involve applications of science or socio-scientific issues. In an era when we are confronted by the issues of environmental degradation, climate change and pandemics, they are inescapable. Should we, for instance, lock down all households in response to the coronavirus? The primary function of such a debate is to identify the divergence of views, evaluate their strengths and enable us to identify the validity and value of the different positions e.g., the protection of the elderly versus the economic harm. While it is perfectly possible that a consensus may emerge – there is no certainty that it will be achieved, and it is not the primary goal. Such debates in the context of science education have value as they illuminate the issue of whom we should trust in science and why (Oreskes, 2019; Oreskes & Conway, 2010) bringing to the fore how we judge expertise, the role of peer review and the importance of consensus in science (Höttecke & Allchin, 2020). For the teacher, it is important to recognize that such dialogues do not require resolution. Rather, their function is to put the science in a meaningful context, identify the relevant issues, and surface the relevant values at play.

Finally, there are instructional dialogues – dominated by I-R-E. Their primary function is to communicate key ideas and concepts from the discipline and make this knowledge available to the group. Thus, I-R-E functions as a means of establishing a degree intersubjectivity and common understanding (Wells & Arauz, 2006). However, its failing is that the discourse structure does not afford sufficient opportunities to check for student understanding and pedagogically can be very ineffective (Chi, 2009; Hake, 1998).

As we have discussed, each of the forms of dialogue can have educational value when they serve the overall goals of the lesson. We argue that for pedagogy to be efficient and effective, it is critical for teachers to be aware of their instructional goals and the type of dialogue that will best serve them. Furthermore, knowing the goal there are specific types of discursive moves to support each of these forms of dialogue. Examples of each are shown in Table 1.

Table 1: Types of Dialogue

Types of Dialogue	Goals	Related Teacher Probes
Conversation	Eliciting different ideas	Why do you think that happens? How do you know that? What does that remind you of? Are there any other possible reasons that might happen?
Inquiry	Building, comparing, and evaluating ideas based on evidence	How many different ideas are on the table? Do we have more evidence for A or for B? Which evidence is the strongest? What are the flaws in that argument?
Debate	Arguing value-based positions	Who would that solution help? What are the tradeoffs? What do you value more, A or B? Why should we trust this expert? How can we judge whether this website is to be trusted?
Instructional	Communicating key disciplinary ideas and concepts	What is the name for…? What principle/law does that relate to? What is the term we use to describe? How are A and B different? How do we explain…?

Disciplinary Purposes of Science Discussion. A second consideration in considering the value of any dialogue, though, is its pedagogical and epistemic purpose for learning science. Of the four types of dialogue, inquiry holds particular prominence in science classrooms. Inquiry dialogues in science focus on finding the most reasonable answer to a question or the most efficient solution to a problem. Yet, knowing that the dialogue might be inclusive and aim for convergence – that is the type of dialogue – is, in and of itself, not sufficient to help teachers identify a focus question or enact the moves that might orient students towards disciplinary ways of knowing.

Therefore, to help teachers understand the different types of purposes that can be addressed through inquiry dialogue, we propose the following framework for *Disciplinary Purposes of Discussion* in science learning. These types of discussions are drawn from a range of practitioner facing resources ((Michaels & O'Connor, 2012; Osborne et al., 2016; Windschitl et al., 2018), and are also informed by the discussions we have observed in our work in elementary classrooms. The purposes we have identified are: 1) to build a common understanding of a definition/concept; 2) to explore causal hypotheses to explain phenomena; 3) to consider the strength and weaknesses of explanatory models; 4) to consider the design of an experiment; 5) to interpret data; 6) to engage in probabilistic thinking; or 7) to evaluate the likelihood of an event. For each of these, we consider exemplar focal questions and appropriate teacher probes that would support the dialogue. Examples for two of these are shown in Table 2.

Table 2: Disciplinary Purposes of Discussion, Supporting Questions and Teacher Probes

	Purpose	Sample Focal Questions	Related Teacher Probes
1	To build a common understanding of a concept or category	Is a seed alive? Is an orca a dolphin or a whale? Is a whale a fish or a mammal? Is Pluto a planet or not? Is X a decomposer?	What is the difference between A and B? How are A and B similar?
2	To explore models and causal hypotheses to explain phenomena	Why do you get an onshore breeze during the day and an offshore breeze at night? Why does a tile floor feel colder than a wood floor? What causes day and night? How does the smell from this bottle of perfume cross the room? Why did the tanker car implode? Which model of light best explains the diffraction of light? What's wrong with the Bohr model of the atom?	-How can we represent that on our model? -What is the relationship between those factors? -What evidence are you drawing from? -What does our model predict in that situation? - How is that represented on our model? - How would our model explain that observation? Is this relationship causal or just a correlation? What are alternative explanations for these findings?

			Which of these is the most likely explanation?
3	To consider a design of an experiment or investigation of a phenomenon	Is this a good way to determine how fast sugar dissolves in water? How can we best measure how pulse rate varies with breath rate? Where do woodlice live? How much of an apple is water?	-Which variable should we keep constant? -Which variables should we vary? -How many measurements should we take? -What are the limitations of this design?
4	To interpret data	What patterns are there in this data set of dinosaurs/air pollution/location of earthquakes etc? What is the best summary of this set of data of how the length of a rubber band varies with the force on it/how the height of grass varies with its distance from a hedge/the amount of sugar dissolves with temperature?	-What is the best way to represent this data? -How confident can we be in this finding? -Do all the data points fit the pattern? -Are there any alternative interpretations? -How is this data being misrepresented?
5	To engage in probabilistic thinking, to evaluate the likelihood of an event	What is the chance of two brown-eyed parents having a blue-eyed child? In this data set, which ones are likely to be outliers that we can discount? If your grandmother is 95 and smokes 20 cigarettes a day, is that good evidence that smoking is not harmful? If your parents have had 3 boys, is it very likely that their next child will be a boy?	- Is this part of a normal distribution or an outlier? -Why do you think that point falls outside the pattern? What is the likelihood that this happened by chance? What is the chance of this event?

		Given 3 measurements of the boiling point of water/the width of a piece of paper/the acceleration due to gravity etc, what is the best answer? What are the limits to our confidence in that answer	

Such dialogues are necessary because disciplinary inquiry in the sciences has the goal of answering one or more of three key questions. These are:

1. What exists?
2. Why does it happen?
3. How do we know?

To answer these questions, the sciences use 6 distinct types of reasoning (Kind & Osborne, 2017).

While they are not all unique to the sciences, successful developments of new science use one or more of these styles of reasoning. Establishing what exists is an a priori requirement requiring a process of categorization and classification and discussions that address our first purpose. Until this achieved there is nothing to discuss (Bowker & Leigh Star, 1999). Typically, then students will explore what it means to be alive, what is the difference between mass and weight, or the distinction between physical and chemical change – the first of our purposes for discussion.

Once, the entities that exist and their interactions and interrelationships have been established, the sciences move to exploring the second question – why does this happen? This requires addressing the 2nd purpose of building explanatory models either by using hypothetico-deductions from the model e.g., Newton's derivation of the Law of Gravity or by inference to the best possible explanation e.g, Darwin's explanation for the divergence in Finches on the Galapagos. However, models require evaluation by comparison with the evidence. Hence our third types of discussion are devoted to considering which models offer the most promise of achieving explanatory coherence (Thagard, 2008). Two types of evidence are commonly available – either that collected by observation or field work or that obtained from experimental investigation. Experimental investigation requires careful design and reasoning to ensure that the evidence is both reliable and valid – hence the third focus of discussion – what is the best design of an experiment to collect such evidence. Experiments naturally yield data. However, such data is open to interpretation, editing and different modes of presentation. This has been very clear in the past year with the multiple forms of data about Covid-19 and its effect. Resolving differences in interpretation requires our 4th form of discussion to evaluate what meaning can be extracted from the data. Finally, both interpreting data and models require students to engage in probabilistic thinking – how likely is this finding? How does chance affect the outcome? given the uncertainty in measurement, what is the result we can have most confidence in? How can we minimize uncertainty and improve the precision and accuracy of our data? This is our 5th goal of deliberative discussion. Identifying such patterns then returns us to the search for explanatory hypotheses and our second type of discussion. What are the possible explanations of the relationship between incidence of skin cancer and latitude (Osborne & Young, 1998) or the number of storks and the birth rate (Bergstrom & West, 2020). Is this finding causal or is it correlational?

Debate Dialogues

Debate dialogues have the primary purpose of offering an opportunity to consider a contextualized socio-scientific issues. As a type of discussion, it is critical divergent. They do not seek closure but offer an opportunity to consider and evaluate the merits of different views weighing scientific information with economic and ethical concerns. In that context, we see two primary purposes

Table 3: Purposes of Socio-Scientific Discussions, Focal Questions and Related Probes.

Purpose	Sample Focal Questions	Related Teacher Probes
To explore the use of science in the context of a body of values and economic interests.	Should we all be vegans? Should all children be vaccinated? Should we keep animals in zoos?	Who would that benefit? What value are you prioritizing? What are the arguments for and against?
To consider whom we should trust when science is questioned	Should we believe people who say that vaccinations are harmful? Should we believe in (fund?) homeopathy? Should we believe people who claim that the earth is flat?	How do we know they are an expert? What's the scientific consensus? Does this fit with previous research? Does this person stand to benefit or make money?

Significance Implications for Classroom Practice

Schools are one of societies' primary means of sustaining and transmitting its extant culture and knowledge. Teachers of a discipline have responsibility for facilitating and providing experiences that will support and enable learning. Designing such experiences is helped by clarity about the learning goal and a deep understanding of how a specific pedagogic pathway might facilitate it. Asking teachers and their students to engage in deliberative discussion without a clear sense of its pedagogic and disciplinary purpose is akin to riding a train with blacked out windows. You know you are going somewhere but only the train driver knows where. If there is greater clarity about the intent and purpose both teachers and students are in a position to evaluate the different contributions, their import, and how they might advance. Without such a perspective, there is distinct likelihood that students might meander across the scientific landscape unable to identify what are its major features, how we know and why we know.

Existing frameworks for discussions have failed to resolve the different types of dialogue that might support learning and consider what is the pedagogical purpose of the discussion within that disciplinary context. Knowledge of the types of discussion and their features can help teachers to have greater success in this difficult and complex form of pedagogy. And success matters. For, only if the teacher has the feeling that this activity is productive, will they then convince themselves that they can teach dialogically and use this form of pedagogy as a regular feature of their pedagogic repertoire. Secondly, being clearer about the nature of the activity and its purpose will help more students to participate. Lefstein and Snell (2014) identify that there is often uneven participation by students in dialogic events. Those who participate are familiar with the cultural assumptions embedded in such dialogic events and its goals and purposes. Helping to make these explicit to *all* students will enable more to participate in what we would argue are important learning events.

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