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Exploring the Form and the Function: a Review of Science Discourse Frameworks in the Service of Research and Practice

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Abstract
The importance of how classroom discourse can be used to support science learning has gained national attention with respect to both science teaching and research across K12 and higher education. In this review article, we examine a commonly referenced set of nine frameworks for use in *science* classrooms. Specifically, we examine the ways in which various frameworks emphasize the structure (i.e., *form*) or practical use (i.e., *function*) of language across classroom settings, and the impact of such an emphasis on the facilitation and analysis of science classroom discourse. The findings from this review should help researchers investigate and educators facilitate classroom discourse in ways that ensure that all students can participate in and demonstrate their scientific understanding.

Keywords Science classroom discourse · Discourse frameworks · Science education

> Whether the vessel is a legal document or a rap song, language is often chosen to exclude. To use a scholarly phrase, "discourse communities" are often gated, so it's the good writer's job to offer readers a set of keys. -Roy Peter Clark.[1]

Introduction

Cameron (2001) has suggested that *discourse* can be defined in two different but complementary ways: as "language above the sentence level" (p. 10), the *formalist* interpretation, and as

[1]Clark, R.P. (2011). The glamour of grammar: A guide to the magic and mystery of practical English. New York: Little, Brown Spark. (Quote is found on p. 45)

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"language in use" (p. 13), the *functionalist* characterization. The formalist description focuses on the structure of language; the functionalist depiction emphasizes the way language is put into practice. Both are useful lenses for those trying to analyze (researchers) and those trying to apply (practitioners) discourse in different settings. However, if one lens is employed to the full exclusion of the other, then there will always be something missing from an understanding of how discourse is operating in a given context.

While the study of discourse has been a longstanding intellectual tradition, the examination of its use in the particular context of *science classrooms* gained momentum with the publication of Lemke's (1990) seminal work *Talking Science*. Among the insights Lemke's book provided is that the structure of science classroom discourse served as a tool to allow the teacher to maintain control over how learning unfolded, often to elevate the transmission of facts over other outcomes. In other words, Lemke's analysis showed that there were formal features of science classroom discourse that limited the functional use of that discourse by students. Drawing a connection to Clark's quote above, science teachers were not providing the keys to allow students to be full members of the classroom discourse community, much less the broader scientific discourse community.

Perhaps spurred by the findings presented in Lemke's book, the *National Science Education Standards* (National Research Council 1996) delineated a significant role for discourse in the teaching and learning of science. Engaging students in public discourse related to scientific concerns was one of the four goals laid out in the introduction, and two of the teaching standards (B and E) listed skills related to structuring and orchestrating discourse. This concern continued in *A Framework for K-12 Science Education* (National Research Council 2012), which stated: "Standards and performance expectations that are aligned to the framework must take into account that students cannot fully understand scientific and engineering ideas without engaging in the practices of inquiry and the discourses by which such ideas are developed and refined" (p. 218). Furthermore, in Appendix D (*All Standards*, *All Students*) of the *Next Generation Science Standards* (*National Reseatch Council* 2013), it is noted that engagement in the science and engineering practices is "language intensive and requires students to participate in classroom science discourse … They speak and listen as they present their ideas or engage in reasoned argumentation with others to refine their ideas and reach shared conclusions" (p. 5). Though these standards highlight the goals of science classroom discourse, they do not specify how these might be achieved.

Concomitant with this concern for discourse in national standards has been an emphasis on discourse in science education research. The specific foci of the publications in this realm from 1990 onward range from a general interest in improving the quality of science classroom discourse, to a specific concern with teacher questioning, to productive engagement in scientific argumentation, to influence on student identities, and to the establishment of classroom discourse communities. Our goal in this paper is to review one specific slice of that expansive literature: *discourse frameworks that provide guidance to both researchers and teachers for studying and supporting productive science classroom talk*.

We want to frame this review by again referencing the opening quote by Clark. It is critical that both researchers and teachers find ways to provide the "keys" to science classroom discourse communities to all students. Jurow and Creighton (2005) have said, "Discourse...is an important resource teachers use for organizing students' participation and through which students can display their understandings" (p. 277). The goal of this paper will be to review frameworks that would help researchers analyze and teachers facilitate classroom discourse in ways that ensure that all students can participate in and demonstrate their scientific understanding through such discourse.

Methods

To ensure the broadest coverage of scholarly works, multiple searches using keywords DISCOURSE, FRAMEWORK, MODEL, and SCIENCE (in various combinations) were used in Google Scholar to identify frameworks for review. The details of the selection methodology are described in the Supplementary Materials. Briefly, we required that selected publications must have *developed* frameworks that (1) are built off a set of discernible assumptions, (2) represent a collection of interconnected ideas, and (3) provide guidance for practice, for both researchers studying discourse and teachers facilitating discourse. While numerous articles have *applied* discourse frameworks for study, just fourteen meet all of the criteria laid out above. Nine of these publications were chosen for discussion in this review so as to most broadly represent different perspectives on discourse (i.e., *formalist* and *functionalist*), journals, and ideas from several countries.

Examining Nine Discourse Frameworks

The sequence of frameworks presented in this section will be based on the *functionalist–formalist* dichotomy: We will begin with frameworks that are more functionalist in nature and move towards frameworks that are more formalist in emphasis. It should be noted, however, that all frameworks give attention to both the use and structure of discourse, so the sequence was based on our interpretation of where the focus lay. Table 1 summarizes the frameworks, including the key information expanded upon below.

Bereiter's (1994) *progressive discourse* framework builds off the premise that science is not the search for objective truth, but instead for knowledge that is seen as constantly improving (i.e., progressive). The framework Bereiter presents for progressive discourse indicates that his concern is for the long-range outcomes of talk in the science classroom- that the knowledge a group of science learners generates today will be more sophisticated than it was yesterday. Thus, his unit of analysis is discourse spanning multiple days of learning. Bereiter's focus on the nature of the use of classroom talk was represented by the four epistemological commitments necessary to ensure that the discourse was progressive: *mutual understanding*—a commitment to work towards common understanding satisfactory to all, *empirical testability*—a commitment to frame questions and propositions in ways that allow evidence to be brought to bear on them, *expansion*—a commitment to expand the body of collectively valid propositions, and *openness*—a commitment to allow any belief to be subjected to criticism if it will advance the discourse (p. 7). Bereiter notes that it is the adherence to such commitments that "define[s] [the] cultural practice" of science (p. 7). The implication is that observance to these commitments should define the cultural practices of science classrooms.

Bereiter gave significant attention to the use of the progressive discourse framework within science classrooms in his original article (1994). For instance, he suggested that discourse in science classrooms can still be progressive even though students are not generating novel scientific knowledge, so long as students realize that their new understandings are superior to the previous ones. Bereiter also indicated that teachers should only directly confront misconceptions when these ideas "impede the progress of the discourse" (p. 9). Bereiter and his colleagues applied progressive discourse to their work on knowledge-building communities (Hewitt and Scardamalia 1998) and to elementary science classrooms (Bereiter et al. 1997), showing in both cases what kind of educational outcomes can be achieved when such a framework is used. Criswell and Rushton (2014) utilized progressive discourse as an analytical

Table 1 Discourse frameworks examined

Framework	Key ideas	Unit of analysis	Functionalist or formalist	What counts as quality discourse
Progressive discourse (Bereiter 1994)	The progressive nature of knowledge construction in science is key and proceeds through commitments of mutual understanding, empirical testability, expansion, and openness.	Stretches of student–student and student–teacher discourse over multiple class periods	Functionalist	Progress in community understanding
Consensually driven explanation (Meyer and Woodruff 1997)	Consensus-building is a critical component of the advancement of scientific understanding; knowledge-building within a community provides space for reconciling conflicting personal understandings and scientific explanations.	Group discussion around a single task	Functionalist	Progress in community understanding through convergence and coherence
Transformative communication (Polman and Pea 2001)	Productive scientific inquiry requires that teachers scaffold activities with a series of moves while maintaining students' active involvement.	Set of exchanges between student(s) and teacher	Functionalist	Transformation in both the students' and teachers' understanding
Improvisational science discourse (Jurow and Creighton 2005)	Students should have the freedom to think flexibly and creatively in science classrooms; pedagogical approaches should acknowledge students' (often unexpected) ideas and use these as resources for promoting learning.	Exchanges between teacher and student(s) about an idea or task	Functionalist	Innovation and improvisation that value students' experiences
Productive disciplinary engagement (Engle and Conant 2002)	Student engagement, the core of productive learning, requires that learning environments are designed to allow students to problematize, maintain authority, hold students accountable to classroom and disciplinary norms, and provide them with sufficient resources to engage in these ways.	Group discussion around a single task	Functionalist	Intellectual progress (e.g., identifying the source of confusion, connecting ideas across topics)
Meaning-making (Mortimer 2003)	Understanding meaning-making within science classroom discourse through five aspects of analysis: (1) teaching purposes, (2) content of the classroom interactions, (3) communicative approach, (4) patterns of discourse, and (5) teacher interventions.	Entire episodes of classroom discourse that allow for analysis in terms of all five aspects.	Functionalist/formalist	Capacity for students to engage in productive meaning-making
Toulmin's argumentation pattern (Erduran et al. 2004)	Argumentation drives scientific progress in both the enterprise of science and in science classrooms; high-quality argumentation includes rebuttals.	Individual utterances by students and teachers	Formalist	Realization of the strongest scientific argument
Evidence-based reasoning (Brown et al. 2010a, b)	Scientific reasoning involves (i) the practice of science to produce rules and (ii) the application of these rules within a general framework of argumentation.	Complete statements (e.g., subject with predicate) and surrounding statements	Formalist	Realization of the strongest scientific argument
Productive science discourse (Grimes et al., 2019)	Charting progress towards conceptual convergence in an open-ended discourse involves the analytical integration of sensemaking and transactivity with argumentation.	Episodes of classroom discourse that explore patterns in student utterances	Formalist	Convergent, normative discourse with minimal instructor input

tool to examine the way five chemistry teachers implemented a problem-solving activity with their students. The most significant finding was that the use of codes organized around the commitments of progressive discourse allowed the authors to identify two different activity structures (Polman 2004) in which differential emphasis was given to the *expansion* and *openness* commitments, a finding that offers both researchers and teachers a different lens for studying and designing learning experiences.

Meyer and Woodruff (1997) developed a largely functionalist framework which they labeled as *consensually driven explanation,* and then studied its impact on learning in science classrooms (Woodruff and Meyer 1997). They indicated the influence of *progressive discourse* on their epistemological stance and therefore on their framework. In Meyer and Woodruff (1997), the authors identified the six elements of their pedagogical approach to consensually driven explanation, which included two that are germane to the current discussion: (a) sociogenerative contexts and (b) a delay of the public explanations until groups have generated a locally stable explanation (p. 175). A critical finding is that there were three mechanisms, strongly supported by the two highlighted elements of the pedagogical approach, which make the achievement of consensually driven explanation possible: (1) mutual knowledge, (2) convergence, and (3) coherency. Clearly, the first of those mechanisms was influenced by Bereiter's (1994) *mutual understanding* commitment. However, it is the other two mechanisms that were more central to the learning outcomes they envisioned: "...when the group achieves convergent understanding, we expect consensus to be further demonstrated through discourse concerning issues of coherence…the "fit" of an explanation to related conditions" (p. 189).

In both Meyer and Woodruff (1997) and Woodruff and Meyer (1997), the authors examine what it looks like when this framework is applied to middle school science classrooms. In the former article, they suggest that their concerns for *convergence* and *coherence* represent a unique contribution to research and practice, and have significant implications for learning. Specifically, they suggest that these components of their framework assist students in gaining an appreciation for scientific knowledge and in navigating challenging scientific ideas. Schwarz et al. (2003) focus on the two different types of discourse Meyer and Woodruff had distinguished when comparing intra- with inter-group talk: constructive/generative—typical of small (intra) group talk, and dialectic/persuasive—more prominent in large (inter) group talk. The interplay between these two types of discourse is a focus of the Schwarz et al. study. A key finding is that "many reasons initially expressed by individuals [were] abandoned in collective outcomes but some reappear further in the individual" (p. 240). This suggests that researchers and teachers need to pay attention to the emergence and disappearance of students' ideas during inquiry and the role that the discourse plays in these events.

Polman and Pea (2001) ground their functionalist framework[2] of *transformative communication* in sociocultural principles. These authors cite Rogoff's (1994) criticism of *unguided discovery* and her championing of a community-of-learners approach as a key influence. They also draw on Vygotsky's ideas about the transfer of understanding from the *inter*mental to the *intra*mental plane, and the importance of analyzing the zone of proximal development (ZPD) to determine when such transfer is likely to occur. Transformative communication is engendered by a set of discourse actions and thus is analyzed at the level of a set of exchanges

[2] Our labeling of Polman and Pea's work as *functionalist* is based on the fact that even though it does lay out the *structure* of an exchange, their focus is much more on the use of transformative communication in supporting scientific thinking.

between interlocutors. The level of detail of their analysis of such exchanges, however, would not approach that “afforded by, for instance, conversation analysis” (p. 229); Polman and Pea were interested in the more macro-level effects on students’ ability to engage productively in project-based learning and the teacher’s ability to scaffold such learning (Polman 2000). They present the sequence of actions that results in meaningful effects on those two actors: (1) Students make a research-related move constrained by their current knowledge; (2) the teacher does not expect the move, but recognizes its affordances beyond what students intended; (3) the teacher reinterprets the move and helps the students see its additional potential; and (4) the meaning of the original move is transformed as the students appropriate the teacher’s reinterpretation (p. 227). It is important to emphasize that this discourse framework anticipates transformation for all participants. Students have had their specific move and their more general understanding of the research process transformed, and teachers have had their awareness of the students’ capacities to engage in project-based learning within their ZPDs transformed.

Polman and Pea highlighted their “theory behind transformative communication” as a useful aspect of their framework for researchers and their explication of the discourse sequence of this type of communication as a “powerful cultural tool for use in other inquiry science settings” by teachers (p. 236). They did, however, recognize a need for future research to explore where and how breakdowns occur in transformative communication (p. 236). These authors also indicated the need for such dialogic structures to be examined in additional contexts and types of conversations (p. 236). Tabak and Baumgartner (2004) undertook such an application by exploring the nature of interactions in a high school biology class focused on learning about evolution through inquiry; thus, there was much more of a content goal to the learning than the process-focused goals in the Polman and Pea study. They were able to establish a set of conditions that expanded the discourse pattern of transformative communication into the participant structure they labeled as *teacher as partner* (p. 393). Their analysis of classroom episodes allowed them to generate a table (1, p. 403) that demonstrated how the teacher–student relationship and discourse pattern, along with other factors, produced the teacher-as-partner participant structure.

Jurow and Creighton’s (2005) framework of *improvisational science discourse* represents the paragon example of a concern for function over form. As they note early in their article, “Improvisation, in music and in social life, involves creatively using the resources at hand to devise an action or response that allows one to develop new possibilities for participation and understanding” (pp. 275–276). Not only does this passage indicate the authors’ philosophical stance, but also it implies their unit of analysis: the participation frameworks of science classrooms. To provide a vision of what improvisational science discourse would look like in the classroom, Jurow and Creighton define the critical pedagogical acts of *orchestrating* and *improvising*: orchestrating involves coordinating the educational goals with decisions about who will speak, what ideas will be explored, and how much time is devoted to such explorations; improvising means innovating around the foundational tools provided by established routines, students’ funds of knowledge, and classroom resources. While recognizing the tension that exists between “innovation and structure” (p. 276), these authors assert that the framework for improvisational science discourse could open third spaces for generating transformative communication.

In applying their framework to a study of science teaching in elementary classrooms, Jurow and Creighton identify two discourse practices that support the enactment of improvisational science discourse: (1) positioning students-as-scientists and (2) expanding scientific repertoires. The first of these is significant because of the link to positioning theory (Harré and Van Langenhove 1998) and the implications of this link for the impact discourse can have on students' science identities (Olitsky et al. 2010). The second is compelling because the authors pinpoint a sequence of actions that made possible the expanding repertoires and that paralleled the actions that Polman and Pea (2001) recognized as critical to transformative communication. Harlow (2014) extracted the idea of emergent instruction (p. 280) from Jurow and Creighton's (2005) framework and used it as one of four categories of practice into which she coded the teaching occurring within elementary science lessons. Harlow produced an intriguing flow chart for determining key events for further analysis, using the presence/absence of improvisation and emergence as key decision points. What is most interesting about Harlow's work is that she applied the findings to making suggestions for how to design and structure professional development for teachers in ways that would increase their flexibility when using curriculum in different contexts.

Engle and Conant (2002) introduced the concept of *productive disciplinary engagement* (PDE) and proposed that discourse in science learning environments should mirror that of scientists engaged in the professional act of constructing scientific knowledge. By engagement, the authors pointed to specific behavioral markers of participation by the learners, including the number and proportion involved in the conversation, eye gaze and body positioning, and the length of time during which the discourse episodes unfold. By productive, the authors argued that the learners show intellectual progress over time, which is characterized by increasing sophistication in student thinking, recognizing inconsistencies in ideas, raising new questions not previously asked, and making connections between concepts. Engle and Conant identified a set of four guiding principles to produce PDE: (1) problematizing science content; (2) giving students authority to play an active role in defining, addressing, and resolving authentic problems; (3) emphasizing accountability to the norms of scientific practice; and (4) providing adequate time and resources aligned to the expectations placed on the learners. The critical balance to strike in productive engagement is between student agency in the structure and nature of the discourse while maintaining a connection to and respect of others' ideas, including those of the teacher and scientific experts. The inherent collaborative and collective nature of scientific knowledge is captured by this principle, as the authors promoted the idea that constructing understanding cannot happen by ignoring the contributions of others in the process.

Principles from Engle and Conant's work have been used to study knowledge-building within problem-based learning environments for medical students (Hmelo-Silver and Barrows 2008), developing collective responsibility for elementary students studying optics (Zhang et al. 2009) and species survival (Engle 2006), and to explore sensemaking and persuasion for middle school students studying ecosystems (Berland and Reiser 2011). Windschitl and his colleagues (Windschitl et al. 2008) introduced *heuristics for progressive disciplinary discourse* (*HPDD*) and studied how they could help support the development of ambitious science teaching practices, and several recent studies have considered how teachers navigate challenges associated with model-based instructional approaches, where classroom discourse is central to achieving the learning goals (Colley and Windschitl 2016).

Of all the frameworks that will be examined, Mortimer's (2003) *meaning-making* framework is the most complex and comprehensive. Grounded heavily in the sociocultural principles of Vygotsky (1978) and Bakhtin (1934, 1953), this framework represents a balance of the formalist and functionalist perspectives; the authors themselves imply this: "… we are interested in finding out more about the *speech genre* of school science and the ways in which that pattern of language use supports development of the school science *social language*" (*it. original*, p. 24). Mortimer and Scott achieved this balance through highlighting five aspects of science classroom discourse grouped within three domains of teaching considerations: FOCUS—teaching purposes and content of the classroom interactions, APPROACH—communicative approach, and ACTION—patterns of discourse and teacher interventions. Teaching purposes (i.e, the goal of the learning activity) and content (categorized as *every-day–scientific*, *description–explanation–generalization*, and *empirical–theoretical*) denote the functional aspects of the framework. Patterns of discourse and teacher interventions designate the formalist aspects of the framework. The communicative approach aspect, which the authors noted "lies at the heart of the framework" (p. 27), serves to bridge the two perspectives. Representing "the ways in which the teacher works with the students to address the different ideas that emerge during the lesson" (p. 27), communicative approach is represented by two dimensions: *dialogic–authoritative* and *interactive–non-interactive* (pp. 33–34). Different combinations of these two dimensions produce four classes of communicative approach, which allow researchers to analyze how meaning-making is achieved or teachers to plan more productive meaning-making experiences.

Many of the examples where this framework is considered are situated within secondary learning environments, including 2006 and 2010 studies from the original authors (Aguiar et al. 2010; Scott et al. 2006). In the 2006 study, Scott, Mortimer, and Aguiar investigated how teacher–student discourse shifted between authoritative and dialogic, and proposed that although both are needed, they are often in tension with each other. In the 2010 paper, the authors considered how student questions influenced the form of ongoing discourse in Brazilian secondary schools, and concluded that teachers' explanatory structure was contested, elaborated upon, or continued when responding to their queries. Later, Ford (2012) used the framework to probe the idea of dialogic understanding of natural selection in high school biology classrooms, arguing for dialogic framing as an alternative to argumentation for achieving the learning goals.

Erduran et al. (2004) developed Toulmin's argumentation pattern (TAP) as a framework to evaluate argumentation in science classrooms based on the foundational work of Stephen Toulmin (1958). Argumentation plays a central role in the practice of science, and it is through arguments about the interpretation of data, fitness of methodological approaches, and validity of scientific claims that science progresses (Kuhn 1962). From a cognitive perspective, argumentation requires the externalization of thinking to the intramental plane (Vygotsky 1978), promoting the development of knowledge, beliefs, and values, and allows learners to become enculturated into the practice of scientific discourse. TAP is formalist in nature and characterizes five major components of an argument—claim, data, warrant, backing, and rebuttal—as they relate to the quality of discourse in classroom settings. The framework is applied at the level of individual utterances/sub-utterances to code the components of (co-)constructed arguments by students and teachers. Erduran et al. (2004) demonstrated the use of this framework to capture argumentation patterns in the discourse of year 8 students. They generated argumentation profiles at the level of each teacher and lesson to visually evaluate the robustness of whole-class argumentation. Furthermore, the authors developed a scheme for quantifying the levels of students' dialogical argumentation in small groups, particularly as it relates to the nature of rebuttals. They argue for the requirement of rebuttals to high-quality argumentation, contending that students who engage in discourse without rebuttals remain epistemically unchallenged. The developed scheme quantifies episodes of student argumentation around a single topic from level one to five, with level one argumentation consisting of simple claim versus claim or counter-claim utterances, and level five argumentation displaying extended arguments with more than one rebuttal. The authors demonstrated the utility of this scheme by comparing the frequency distribution of the argumentation levels of small-group, student discourse at the beginning and at the end of the academic year. TAP has been used in a variety of studies of science classroom discourse. In K12 settings, the framework has been used to evaluate the impact of explicit instruction on argumentation on students' argumentation skills (Venville and Dawson 2010) and to explore the argumentation patterns of pre-service and in-service educators (Gray and Kang 2014). At the undergraduate level, researchers have applied TAP towards the quantitative analysis of small-group argumentation in cooperative learning settings as it relates to meaningful learning (Shah et al. 2018) and to the characterization of the strength of student argumentation as a function of instructor discursive moves (Moon et al. 2016).

Like TAP, the evidence-based reasoning (EBR) framework (Brown, Furtak et al. 2010) is another formalist framework based on the centrality of evidence-based arguments to the enterprise of science. EBR was primarily developed in response to the cited difficulties of using TAP, a framework for evaluating *general* argumentation patterns, to reliably identify the elements of *scientific* argumentation. EBR combines TAP with Duschl's (2003) framework for assessing student inquiry to produce a framework that describes scientific reasoning as a two-step process: (1) the scientific approach of collecting and analyzing data which yields *rules* (e.g., theories, laws, relationships) (2) and the application of these rules within a more general framework of argumentation. The framework highlights five elements (i.e., premise, claim, rules, evidence, data) and three processes (i.e., application, interpretation, analysis) that contribute to both the structure and justification of an argument. The absence of various elements and/or processes yields a hierarchy of incomplete arguments, ranging from those with an unsubstantiated claim to those that represent overgeneralizations, which can be used to evaluate the quality of an argument. The framework is designed to be applied to both written and classroom discourses at the level of an individual statement (with a subject and predicate) and its surrounding statements, and can be used to generate diagrams capturing student debate to facilitate the visual evaluation of competing arguments.

Hardy et al. (2010) used the EBR framework to analyze the quality of students' scientific reasoning in elementary and middle school classrooms, noting correlations between students' demonstrated conceptual understanding and level of reasoning. Brown and coworkers (Brown et al. 2010a, b) used the framework to develop highly scaffolded assessment items to investigate middle and high school students' use of evidence in their reasoning about the topic of buoyancy. Furtak et al. (2010) report an adaption of EBR that can be used to evaluate the quality of student reasoning during whole-class discussions, and to capture the teacher's role in the co-construction of reasoning in these settings.

Grimes et al. (2019) developed the productive science discourse framework as another attempt to expand the utility of TAP in science research and teaching. In a study examining how pre-service science teachers (PSTs) collaborated in small groups to explain a scientific phenomenon, the authors initially attempted to code the data using elements in Toulmin's argumentation pattern. However, they noted that "large chunks of discourse we considered crucial to PDE [productive disciplinary engagement] did not lend themselves well to this kind of analysis" (p. 15). To overcome this limitation, Grimes et al. added two elements inspired by the sensemaking framework of Kapon (2017): *prompts*, which represent talk that aids the flow of discourse, and *clarifications*, which indicate discourse that reduces the ambiguity of ideas. Furthermore, they included the component of *transactivity* to their integrated argumentation–

sensemaking framework. Adapted from the work of Kruger and Tomasello (1986), transactivity indicates both the nature and the orientation of the speaker's talk: the authors captured the nature of transactivity by the type of transaction (statement, question, response) and its orientation (self-oriented or other-oriented). Grimes et al. applied these components of their *productive science discourse* framework, which combines features of argumentation, sensemaking, and transactivity, to the PSTs' explanations of scientific phenomenon at the micro (individual utterances), meso (episodes within the full discourse), and macro (overall discursive event) levels.

The authors assert that combining the different components and attending to the three levels described above allowed them to understand "how a group of P[S]Ts went from generative discourse…toward a shared convergent form of argumentation that is close to normative discourse with minimal input from the instructors" (p. 25). There is a clear implication that both analyzing how authentic science classroom discourse such as this evolves—the purview of researchers—and supporting this kind of discourse to promote scientific understanding—the purview of teachers—demands expanding the analytical and pedagogical lenses beyond just argumentation—or sensemaking for that matter. They further suggest that providing opportunities for discourse that can meaningfully integrate argumentation and sensemaking allows science learners to "both engage in scientific practices and make significant progress towards conceptual convergence" (p. 25). Because of the recency of this publication, there were no additional studies that had utilized it in further contexts.

Discussion

Insights from Attending to the Functionalist–Formalist Dichotomy

As noted in the "Introduction," a great deal of attention has been given to discourse in the realm of science education. Standards emphasize the important role it plays in helping students learn science and think scientifically. Teachers endeavor to support more productive discourse so that their students can engage meaningfully with content. Researchers create and apply discourse frameworks to better understand the extent to which students are emulating scientific discourse communities and help teachers better facilitate discourse. What has not existed in the literature is a systematic examination of that last domain: the frameworks designed by (science) education researchers to explore and support the use of discourse in science classrooms. This paper has strived to fill that gap.

The functionalist–formalist distinction was used as a lens to examine the frameworks being reviewed; its use allowed the authors to gain fresh perspectives on these frameworks. For instance, while all the authors had read Mortimer (2003) book, the formalist–functionalist dichotomy allowed us to understand the relationships between the five aspects of their framework differently. Particularly powerful was the insight that the communicative approach, which Mortimer and Scott themselves considered to be "central to the framework" (p. 33), effectively served to create a bridge between the formalist (patterns of discourse and teacher interventions) and the functionalist (teaching purposes and content of the classroom interactions) aspects of their framework. This suggests that it may be valuable for researchers who are developing or evaluating frameworks to determine what each component represents in terms of the formalist–functionalist dichotomy and consider whether balancing such components might allow their frameworks to more holistically serve the intents for which they are designed.

There is a second critical insight generated by applying the formalist–functionalist lens that relates to the unit of analysis. Those frameworks that more heavily emphasized functionalist considerations tended to have a broader-grained unit of analysis—at the level of entire discursive episodes or even multiple learning experiences (e.g., Bereiter 1994), whereas those favoring formalist concerns tended to have finer-grained units of analysis—largely focused on the level of the speaker turn. This is not surprising, given the fact that focusing on the structure of talk does require one to zoom into the words speakers use and the way they are put together. However, what is interesting is that the authors of the one framework that initially had a formalist focus and then added functionalist considerations (Grimes et al. 2019) noted the need to zoom out to the meso level (of talk episodes) to properly assign the formal features of the discourse. It seems likely that all discourse frameworks should lend themselves to this zooming in and out to different levels of analysis in order to more fully explicate the why and the how of science classroom talk.

The Emergence of Other Dichotomies

Using the formalist–functionalist lens also helped to make other significant dichotomies visible during the examination of the discourse frameworks. One is between *convergence* and *divergence* of ideas through the discourse. During the discussion of Meyer and Woodruff's (1997) *consensually driven explanation* framework, it was noted that one of the two mechanisms they identified for achieving this discursive outcome was convergence of reasoning through the discourse. Both the EBR (Brown et al. 2010a, b) and the TAP (Erduran et al. 2004) frameworks attach importance to converging on the argument with the strongest reasoning and evidence, and Grimes et al. (2019) recognize the significance of explanations that achieve conceptual convergence. By comparison, Jurow and Creighton's (2005) *improvisational science discourse* framework, with its emphasis on supporting students in "see[ing] new relations, and develop[ing] new possibilities for science" (p. 291), values divergence in the discourse. Likewise, Polman and Pea's (2001) *transformative communication* framework championed discourse in which both students and teachers "f[ind] new and unexpected meanings" (p. 235) through their interactions.

Bereiter's *progressive discourse* framework balanced the convergence–divergence dichotomy with different components: *openness* and the critique on which it relies produces convergence, while *expansion* and its directive to broaden "the body of collectively valid propositions" (p. 7) engender divergence. It has been shown that both convergent and divergent thinking support creative problem-solving by scientists (Brophy 2001). Moreover, it has been demonstrated that creativity in (science) classrooms is enhanced by scaffolding both convergent and divergent thinking. As such, it seems that there would be utility to having discourse frameworks that promote the structure and use of discourse that can produce both convergence and divergence at appropriate points within the discursive activity. Researchers should examine how the use of a discourse framework relates to the manifestation of the convergence–divergence dichotomy, and teachers should consider whether the use of a particular framework might emphasize one pole at the expense of the other.

A related dichotomy is that between *sensemaking* and *argumentation*. The framework of Grimes et al. (2019) brought this dichotomy to the fore, as they recognized that just coding the PSTs' discourse for argumentation failed to capture much of the richness of that dialog; adding codes associated with sensemaking filled in the gap. Recently, Odden and Russ (2019) chose to explore the relationship—and differences—between these two constructs. They suggest that, “argumentation extends well beyond sensemaking…Argumentation can also take place once students have already made sense of an idea—that is, they have already fully constructed their explanation” (p. 199). This distinction bears similarities to Ford’s (2008) notion that the social practice of science is undergirded by the processes of *construction* and *critique*. From a discursive standpoint, one would expect a potentially complex interplay between sensemaking and argumentation, and construction and critique, but the study by Grimes et al. (2019) is one of the few to explore science talk from such a perspective.

The final dichotomy surfaced through a point made in the Polman and Pea (2001) article: They acknowledge that, “Examining in detail when and how breakdowns occur in getting from one step to the next is beyond the scope of this article, but such research would be valuable” (p. 236). This suggests a dichotomy between *fluency* and *disruption* of discourse. The emphasis in all of the frameworks reviewed was on describing what an ideal instantiation of that structure or that use of the discourse would look/sound like (i.e., when the discourse is fluent). There are limited references to ways in which the discourse might be disrupted, either in form or in function. However, none of the articles gives significant attention to the nature, causes, or impact of such disruptions. This is not the case in other areas of research into discourse. In fact, in a book dedicated to exploring the relationship between human activity and repair of discourse, Hayashi et al. (2011), after noting that “hitches” or “errors” are common in discursive activities, state that, “these phenomena- and participants’ efforts to contend with them- are so ubiquitous that very few approaches within the human and social sciences have avoided commenting on, or contending with them, in some way” (p. 1).

The insights from the use of the formalist–functionalist dichotomy and the recognition of the three other dichotomies associated with these frameworks were critical findings produced by this review. However, all of these individual insights were pointing towards a broader issue at the heart of classroom discourse, which we discuss in the conclusion.

Conclusion

We draw on ideas from Pirsig (1999) *Zen and the Art of Motorcycle Maintenance* to build a bridge between the individual insights discussed in the last section and the broader issue to be broached in this section.[3] Pirsig’s book centered on a metaphysical journey to discover a resolution to the tensions caused by the dichotomy between *subjective* and *objective*. Pirsig’s concern was that this dichotomy produced two different criteria for determining “quality.” He proposed the notion that quality preceded any objective or subjective analysis.[3] As such, subjective and objective analyses should not lead to two opposing views of quality, but quality should be manifested in complementary subjective and objective forms (Sobel 2020). Given the primacy of quality in human experience, Pirsig suggested that human endeavors should first and foremost focus on the exploration of quality. In the end, an exhaustive search produces a sense of quality that most enriches the endeavor to which we are applying it and overcomes the appearance of incompatible dichotomies.

[3] The ideas overviewed in this paragraph are part of Pirsig’s *Metaphysics of Quality* (MOQ). See https://en.wikipedia.org/wiki/Pirsig's_Metaphysics_of_Quality for additional details of this theory of reality.

Each of the reviewed frameworks offers the developers' sense of what constitutes quality in science classroom discourse (Table 1). Bereiter (1994) holds up the attainment of *progress* in understanding as his view of quality. One can even see evidence of an evolution in the view of quality discourse within a group of the frameworks. Meyer and Woodruff (1997) also value progress as an aspect of quality discourse, but add to this the stance that a movement towards *coherence/convergence* is a critical aspect of progress. For Grimes et al. (2019), progress is produced through an interweaving of sensemaking and argumentation, and leads participants to a conceptual convergence.

Polman and Pea's (2001) transformative communication and Jurow and Creighton's (2005) improvisational science discourse frameworks both entailed more functionalist perspectives and emphasized divergence of ideas. By comparison, Erduran et al.'s (2004) TAP and Brown et al. (2010a, b) EBR frameworks both adopted more formalist perspectives and underscore convergence of ideas. It seems as if these two pairs of frameworks represent very dichotomous views of discourse and therefore different senses of quality classroom discourse. Quality to Jurow and Creighton is *improvisation* and to Polman and Pea is *transformation*; these seem fundamentally different from quality as understood by the other two frameworks, which is realization of the strongest scientific argument. As a field, science education should be considering the implications of these differences in what quality represents in different frameworks and, more importantly, find ways to ensure that the sense of quality across various frameworks produces complementary dialectics rather than oppositional dichotomies. As such, future work should examine the dichotomies noted in the "Discussion" section and identify ways to transform them into dialectics.

Placing primacy on quality in science classroom discourse in the broadest sense might also allow both researchers and teachers to integrate the most powerful parts of different frameworks. For instance, there would seem to be great value in combining the capacity to produce transformations in both students' and teachers' thinking as envisioned in Polman and Pea's (2001) framework, with the support of critical thinking enabled by the discursive structure of scientific argumentation laid out in the EBR framework. Through attention to these concerns related to quality in science classroom discourse and the different expressions of it in the discourse frameworks developed, enacted, and studied by the science education community, it seems much more likely that our researchers and teachers will be able to provide the keys of scientific discourse communities to students.

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