The Role of Dialogue in Science Epistemic Practices

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Abstract

Science as a field of study is defined by epistemic practices of questioning, inquiry, argumentation and legitimising scientific knowledge. These epistemic practices shape the kinds of talk in the classroom as scientific knowledge is "talked into being". The question that we aim to answer with this chapter is "What is the unique function and role of dialogue in learning science epistemic practices?" Discourse analysis is a means to analyse scientific talk to review the mechanisms and patterns through which scientific knowledge is learnt. As such, to develop our argument, we first delve into the theoretical underpinnings based on a sociocultural perspective of dialogue in science education. This is followed by a review of empirical studies in science education that focusses on talk in four key science epistemic practices of questioning, science inquiry, argumentation and legitimising conceptual knowledge. The review provides evidence of dialogue as fundamental to both the enactment and learning of science epistemic practices by scientists and science students. We included a discussion about the way forward for dialogue in science and STEM education research.

Introduction

Dialogue serves as a means by which the business of everyday transaction takes place. Through verbal exchanges between individuals, ideas, concepts, agreements and disagreements come into being. Teaching and learning are largely accomplished via verbal exchanges. Teachers and students interact with one another to exchange ideas, discuss alternatives, explore solutions to reach consensus. Resources such as language, hand gestures and written texts facilitate these interactions. As such, studying the dialogues that occur during teaching and learning events will illuminate the "consciousness of individuals" within the social setting of the classroom (Kubli, 2005).

The theory of dialogue (Bakhtin, 1981), known as dialogism, was developed by Mikhail Bakhtin and when combined with Vygotsky's (1962) idea of thought and language, provides a convincing frame to examine interactions in classrooms. The focus of dialogism allows us to make sense of speakers' intentions and thoughts through analysing their utterances together with the context in which the utterances are made. This is the "consciousness of the individual" as described by Kubli (2005, p. 504). Dialogue is about engagement of individuals or groups within a social space using available communicative resources to encourage, facilitate and develop their abilities to critique and interpret with the aim of deepening understanding (Bound, Tan, Choy, Wang & Chuen, 2017). For Bakhtin, expression and creation of meaning in dialogue is never complete, never closed and always oriented toward the future. Similarly, the fact that language is used as a tool to enable teachers and students to exchange ideas during interaction forms the fundamental basis for adopting a sociocultural perspective to examine classroom interactions since language systems are social and cultural artefacts.

The role of dialogue in supporting science teaching and learning is well acknowledged within the science education research community (Kelly, 2007). Research in this area has over the years examined how dialogue was used by teachers to construct and maintain various types of activity in science classrooms, and revealed the rules and dynamics involved in the teaching and learning of science (e.g., Lemke, 1990; Mortimer & Scott, 2003; Wells, 1999). Increasingly, there is recognition that dialogue is not only central to the teaching and learning process, but also fundamental to the epistemological nature of science itself. Science is a discipline that aims to build knowledge about the world we live in. It is an enterprise that relies heavily on groups of individuals (scientists) engaged in the epistemic practices of hypothesising, experimentation, collecting and making sense of evidence, and developing plausible explanations based on available evidence. These epistemic practices rely on consensus and agreements within the community of scientists to legitimatise knowledge and “have been developed through a historical process, including, for instance, conferences which have institutionalised certain language or conceptual systems in order to facilitate further discussions” (Kubli, p. 523). Science learning in schools mimics the way scientists work to recover the knowledge that scientists discover. In order to understand science and how science can be learnt, it is logical to focus on (1) the context in which ideas are generated, (2) the way in which ideas are represented and communicated between individuals and the community, and (3) the role of language in describing the concepts in science.

In this chapter, we review several empirical studies in science education that focus on dialogue in questioning, inquiry, argumentation and legitimising conceptual knowledge. The purpose of this review is to find out how science education researchers have examined the relationship between dialogue and science epistemic practices as well as the conclusions they have drawn from the various methods employed in their studies. From the review, we aim to answer in this chapter “What is the unique function and role of dialogue in learning science epistemic practices?”

Theoretical Justification

Role of Dialogue in Science Learning

Vygotsky (1981) argues that language plays a key role, providing the means both for coordinating action and for thinking together. It is generally believed that language is derived from social context rather than having a basic unchanging nature. As such dialogic representations are necessary not only to support forms of collaborative interactions, they are necessary for the production of cultural artefacts, many of which are largely socially constituted (Tomasello et al, 2005). Indeed, as Lave and Wenger (1991) proposed, language is the “tool of tools” that is needful for development of both the individuals’ abilities to participate effectively as members of their communities and simultaneously in the development of those communities through their members’ participation.

In the sense-making process, language can manifest itself in a monologic or dialogic manner. Lotman (1988) explained the role of monologic discourse “to convey meanings adequately” (p. 34). As such, monologic function is important for passing on cultural meanings, “providing a common memory for the group” (p.35), to facilitate the preservation of continuity and stability of beliefs and values within a culture. Monologic function is hence, by nature authoritative, not open to question or alternative perspectives. In this transmissonary model of communication, although intersubjectivity is assumed, it cannot be guaranteed, because there is no opportunity for misunderstandings or misinterpretations by the receiver(s) to be corrected. Even with this limitation of monologic interaction, there is still a role for monologic interactions and direct instruction in school (Wells, 1998) to enable teachers to “pass on” fundamental knowledge and instructions to students. But monologic instruction alone is limiting. Students need to be given opportunities to engage in clarifying dialogue to reach desired intersubjectivity. Opportunities and space for explorations and dialogic interactions are hence necessary.

Explorations of classrooms by researchers typically focus- on the sequential organisation of the discourse and of the functions that teachers’ and students’ utterances performed in the co-construction of meaning (Wells & Arausz, 2006). In understanding dialogic interactions in the classroom, research has typically emphasised on the third move of triadic dialogue to take account of various different ways in which a teacher might follow up on a students’ answer to a teacher’s initiating question (Wells, 1993). Wells and Arausz (2006) found that interaction became more dialogic when the class was engaged in activities such as planning, interpreting, or reviewing student inquiries. The researchers also found low frequencies of “true” discussion. They found dialogic interactions that were teacher-led enabled participants to systematically explore an issue and work toward some form of conclusion. Adopting an exploratory orientation does make dialogue more likely to occur. It was concluded that the single most important action a teacher could take to shift the interaction from monologic to dialogic is to ask questions to which there were multiple possible answers and encourage the students who wish to answer to respond to, and build upon, each other’s contributions. It is commonly assumed that students are more interested in learning when they actively participate in the learning process and know that their contributions are able to influence the final outcome of the problem solving process. However, in science, students are involved in learning more abstract and impersonal concepts where they have less control over the final knowledge that is crafted. As such, Wells and Arausz, (2006) suggested that dialogic interactions be orchestrated such that the students are "invested in the outcome of the discourse and, second, that the outcome is not predetermined in advance." (p. 415).

Along the same vein of how dialogue in the science classroom can be promoted to sustain students' interest in learning science, Bereiter (1994) suggested the construct of "progressive discourse". From his research, progressive discourse supports science learning as it encourages participants to be willing to revise their own ideas and conceptions as they consider the ideas, proposals and arguments by others with whom they interact. The resultant understanding created from discussions and dialogic interactions is likely to be superior in terms of complexity of logic and accuracy when compared with initial ideas the individual students had at first. As such, dialogic interactions in classrooms is appropriate for learning of fundamental science concepts that need not necessarily be controversial in nature. The progress in knowledge from students' everyday understanding to a change in conceptual understanding upon being exposed to scientific evidence and reasoning reflects a characteristic of science epistemic practice as scientific knowledge "is created through dialogue between alternative points of view, supported by arguments from evidence, and subject to revision in the light of further evidence." (Wells & Arausz, 2006, p. 417). Given that dialogue provides a platform for science ideas to be discussed openly and critically, science teachers can seize occasions that spontaneously arise to encourage students to express alternative points of view, to learn how to provide supporting arguments for their own perspective and to listen respectfully to, and attempt to understand, the perspectives and arguments of others. As such, the development of skills related to dialogue is as important for science learning as learning the content of science.

Epistemic Practices of Science

Science is a way of knowing the world around us that relies heavily on curiosity, theories, laws, and empirical evidence. Some of the activities that scientists are involved in include raising questions about the world around us, conducting investigations to gather data, connecting the data to plausible explanations and building a strong argument to convince peers that the evidence and explanations are valid. To make sense of data, transform them into evidence and to link evidence to explanations, scientists make inferences. All inferences in science hold true on condition that the laws of nature are constant and is applied the same way to all matter across time and space. This Uniformity of Nature Principle assumption applies to all scientific knowledge (Wenning, 2006). According to Wenning (2006), the inferential process to craft scientific knowledge can either take the stance of rationalism, reliabilism, coherentism, or empiricism. Regardless of the stance taken, it is clear that scientists engage in some form of discussion and justification to convince the scientific community that the relationship between specific evidences and explanations are valid. To enculture science learners with the practices of scientists, students can be exposed to the epistemic practices of questioning, inquiry, argumentation and legitimising conceptual knowledge.

According to Kelly and Licona (2018, p. 140), "epistemic practices are the socially organised and interactionally accomplished ways that members of a group propose, communicate, evaluate, and legitimise knowledge claims." Each of the epistemic practice in science (questioning, inquiry, argumentation, legitimising conceptual knowledge) all require the use of discourses, whether spoken, written or symbolic. Discourse refers to the language used and includes both verbal and non-verbal communications and the use of signs, and symbols. The reliance on language in the knowledge construction process implies a need to examine language use in classrooms in order to understand how scientific knowledge is communicated, taught and learnt.

It is important to point out that the boundaries of these four epistemic practices are not distinct as scientific practices are in reality messy in nature (Mody, 2015). Thus, summarising the range of epistemic practices in science in terms of questioning, inquiry, argumentation, and legitimising conceptual knowledge is a simplification of the field. Nevertheless, for the purpose of this chapter, the discussion and organisation in terms of these four epistemic practices provide a useful way to highlight the role of dialogue across a range of characteristic activities of how scientists conduct their work. The four practices are also a reflection of the literature in how science education researchers have positioned their work in the research topics of questioning, inquiry, argumentation and legitimising conceptual knowledge.

Review of Studies involving Dialogue and Science Epistemic Practices

Questioning

The process of building scientific knowledge typically begins with a question. In the investigation of natural phenomena, scientists raise questions about how and why things work. These questions form the basis for the design of experiments, data to be collected, and interpretation and discussion of evidence. Since questions form the core of science epistemic practice, it should also form the stem of the science learning process (Chin & Osborne, 2008). Research in the role of dialogue on questioning generally falls into two categories focusing on either teacher questioning or student questioning. Both are necessary as instructional supports to help students learn how to ask and make sense of scientific questions.

For teacher questioning, many studies look into the interaction pattern between teachers and students, given that what is a question must be contextualised to an interaction exchange or adjacency pair (Schegloff & Sacks, 1973). A common observation from almost every study was the limited IRE (Initiate-Response-Evaluate) exchange that framed the way most teachers ask questions (Sinclair & Coulthard, 1975). To promote science learning, many researchers have looked for ways to modify the IRE structure to make classroom talk more engaging and dialogic (e.g., Mortimer & Scott, 2003; Roth, 1996; Wells, 1999). In the context of science classroom talk, Mortimer and Scott (2003) made a distinction between dialogic talk that is opened to multiple points of view (heteroglossic voices; Bakhtin, 1981) and authoritative talk that is confined to one hegemonic point of view. An IRE exchange, even though it involves two or more people in the conversation, is a form of authoritative (or monologic) talk because the teacher is only eliciting and evaluating a narrow range of answers from a scientific perspective. A dialogic talk, by contrast, involves a wider range of perspectives, not necessarily aligned with an authoritative (i.e. scientific) point of view.

A key to dialogic talk is for teachers to ask more open-ended questions and make the last move in the IRE triadic exchange less evaluative and more of an extended "follow up" (F), thus turning the interaction into what Mortimer and Scott (2003) call an IRF-RF- chain of questioning. Along this line of research, science teachers are encouraged to use various discursive strategies, such as Socrative questioning (Hogan & Pressley, 1997), reflective toss (van Zee & Minstrell, 1997), revoicing (O'Connor & Michaels, 1993), constructive challenge (Chin, 2006), and meta-discoursing (Rappa & Tang, 2018) to help students consider alternative views in their discussions and thinking. These dialogic characteristics are an important part of scientific questioning that are being exemplified through effective teacher questioning.

While teacher questioning, particularly of a dialogic nature, provides a model for students to learn how to ask good scientific questions, student questioning is also crucial for meaningful learning and inquiry (Chin & Osborne, 2008). The ability of students to pose appropriate scientifically-oriented questions to guide their thinking and discussions with others is an important skill to acquire (Kuhn, 2009). In the science learning process, students should be able to work with others to “ask questions that would help them become aware of what they do not understand, compare the strengths and weaknesses of competing ideas, recognise any inconsistency or faulty reasoning, formulate and test hypotheses, evaluate the evidence that supports or refutes the hypotheses, and generate alternative explanations or ideas that are more viable.” (Chin & Osborne, 2010, p. 235). Such student-to-student questioning in small group discussions is one of the defining features of what Mercer, Dawes, Wegerif, and Sams (2004) call Exploratory Talk as it mirrors the ways of reasoning among scientists.

Inquiry

Science inquiry generally refers to the activities and processes scientists engage in to study the natural world through experimentation and negotiation of meanings from their observation or experimentation (Crawford, 2000). Contrary to the popular myth of a solitary scientist working alone, in reality, collaboration is the norm in science inquiry as scientists typically work in teams and operate within a community of practice (Lave & Wenger, 1991). In this sense, the scientific study of the world is inseparable from the networking and consensus building activities among scientists (Latour, 1987). Therefore, to be involved in science inquiry requires a participatory and interactional process that occurs through the negotiation of the sociocultural practices in scientific communities (Lemke, 2001).

Two major strands of research are carried out in science education with respect to science inquiry and dialogic instruction. The first strand focuses on what is uttered in class to understand the learning of science content through engagement in science investigations and exhibitions (e.g., Ash, 2003; Moje, Collazo, Carrillo, & Marx, 2001; Tang & Putra, 2018). For instance, in Kaartinen and Kumpulainen's (2002) study which focused on collaborative inquiry in chemistry learning, they examined the discourse and content learning involved in a group investigation task. With the view that the key elements of collaborative inquiry included experimentation, social negotiation and explanation-building, they developed an analytical tool for highlighting processes of explanation-building in collaborative inquiry, focusing on four parallel analytic frames, namely discourse moves, logical processes, nature of explanation, and cognitive strategies. Analysis of the discourse moves in the students' discussions revealed six conceptual themes related to the learning of solubility. Each conceptual theme usually started from the initiation move and led to several conversational moves in the form of continuing or extending the discussion. Complex topics and explanations that occurred within one conceptual theme often took several conversational turns to build up. Kaartinen and Kumpulainen's (2002, p.208) study suggests that collaborative inquiry requires several dialogic processes in order for negotiation of various perspectives, interpretations and attitudes to take place.

Recognising the important role of language competencies in enabling students to participate in science inquiry processes, the second strand of research focuses on strategies that foreground the learning of English language for science learning, particularly for students from diverse language background. Fradd and Lee (1999) argued for the need to look at science inquiry from a language and cultural perspective in the sense of recognising that the dialogue in language diverse science classrooms typically involves elements of different students' family and cultural background. There is value therefore in examining the emergence and roles of these different dialogic interactions to enable more meaningful science inquiry processes, such as raising questions, crafting explanations and communicating ideas. Based on this premise, a number of studies integrated specific literacy instruction (e.g., text-based investigations, read-alouds) to complement the hands-on investigations required in science inquiry lessons. For instance, a class of fourth grade English language learners (ELLs) in Haneda and Wells's (2010) project was involved in a science project that built their understanding of the physics of motion and the inquiry skills involved in the project. A key feature in their approach was the use of writing and reading of science journals to enrich the ELLs' discussion of their practical investigations. The study shows that engagement with science ideas through multimodal connections across action, talk and text are an important consideration when designing science inquiry lessons for diverse language learners.

Argumentation

In justifying and connecting claims to scientific evidence, scientists engage in argumentation. By argumentation, we refer to the "verbal, social, and rational activity aimed at convincing a reasonable critic of the acceptability of a standpoint by putting forward a constellation of propositions justifying or refuting the proposition expressed in the standpoint" (van Emerson & Grootendorst, 2004, p.1). As such, argumentation always involves a dialogic event between two or more individuals. Scientific argumentation, however, is a special case where the dialogue also involves the coordination between theory and empirical evidence to put forward a claim, prediction or explanation (Duschl & Osborne, 2002). Historical and sociological studies of science have shown that the development of science frequently occurs through dispute and debate around competing theories that provide explanations of natural phenomena (Kuhn, 1962; Latour, 1987).

In learning this epistemic practice of science, students need to learn argumentation as a form of discourse through a range of explicit instruction, modelling and pedagogical activities (Erduran, Simon, & Osborne, 2004). There has been a number of approaches taken by researchers in this area. One common approach focuses on the language structure of an argument based on Toulmin's (1958) model of argument (Cavagnetto, 2010). Studies that adopt this approach reported on students learning the claim-evidence-reasoning structure of an argumentative discourse and applying it to generate explanations of a phenomenon as well as evaluate competing explanations (Erduran et al., 2004; Pimentel & McNeill, 2013; Sampson & Clark, 2008). For instance, in Erduran et al.'s (2004) project, the researchers collaborated with science teachers to develop argumentation lessons as part of their instruction. A key emphasis in the study was the development of a tool based on Toulmin's argument pattern to trace the quality of argumentation in the analysis of discourse from whole-class and small-group discussions among secondary school students. They maintained that since scientific argumentation engages learners in a dialogical conversation based on claims and rebuttals, the presence of rebuttals can be treated as a measure of sustained engagement in argumentation discourse. On this basis, they examined transcripts of talk from 43 discussion groups in 23 lessons to identify episodes of opposition and dialogical argument, and found an increase in the level of argumentation over 2 years.

A different approach to argumentation focuses on the dialogical relations between two interlocutors instead of examining the language structure of an argument (Ford & Forman, 2006). This approach emphasises the process of argumentation at a collective level rather than the product of argumentation achieved by an individual. Based on Bakhtin's (1981) view that there are always different ideas confronting each other in a dialogue, Roth (2013) asserts that argumentation does not belong to individuals, but is inherently a collective phenomenon that emerges in and through the relations between speaker and hearer. In an analysis of two children talking about their ideas as they observed an experiment, Kim and Roth (2014) show how the conversational turn pair between both speakers must be considered as the minimum analytic unit for argumentation to take place. As Kim and Roth (2014, p.4) put it, "A claim becomes a claim only when it is stated and responded to by the recipient". Importantly, it is the turn pair that drives the interplay of contradiction and resolution which simultaneously move the conversation ahead as well as lead to the development and progression of ideas.

Legitimizing Conceptual Knowledge

The process of legitimizing conceptual knowledge in science is often perceived to be the end goal of scientific pursuit, which is to build a coherent and rational understanding of the world we live in. Experiments are set up, data are collected and analysed, explanations are crafted and reports are generated with the purpose of generating a body of scientific knowledge to inform the community. According to Foucault's (1972) analysis, the body of scientific knowledge comprises the formation of an apparatus of concepts, which emerge as a set of rules for determining what are meaningful statements within a discipline. Thus, what is a concept in any discipline is dependent on a "discursive formation" that is derived from all the talk spoken by members of a discourse community, rather than a mental concept that resides in the mind or consciousness of an individual (Foucault, 1972).

Just as the pursuit of science has been the development of scientific knowledge, the goal of science learning has been for a long time the development of conceptual understanding, with the assumption that scientific knowledge development in individuals mirrors the complex process of theory change in the history of science (Posner, Strike, Hewson, & Gertzog, 1982). Traditionally, research in conceptual understanding in science is dominated by the notion of conceptual change which is marked by a change of an individual's understanding from a naïve mental view (or misconception) to a scientifically accepted view. However, there has been a gradual shift from this perspective to a social and discursive view, beginning with a study from Roschelle (1992) who applied conversational analysis and pragmatics to examine how "convergent" conceptual change between two physics students was achieved through their collaborative discourse. Another study by Duit, Roth, Komorek, and Withers (1998) combined conceptual change research with a discourse analysis perspective. Based on the view of "language as a form of highly flexible situated action rather than a window onto individuals' underlying cognitive representations that are expressed in talk" (Duit et al., p.1061), they conducted a microanalysis of how a group of students participated in a particular "language game" of integrating talk and concepts to understand a natural phenomenon.

The relationship between classroom talk and the process of legitimising conceptual knowledge is further illuminated by studies that use a linguistic analysis on discourse. A common approach is the application of Halliday's (1978) systemic functional linguistic (SFL) to understand how students learn science content through classroom discourse (e.g., Fang, 2005; Lemke, 1990; Seah, Clarke, & Hart, 2011). Based on this perspective, Lemke (1990) analysed the content of science in classroom talk from the semantic relationships among the uttered words made by the teachers and students. He found that talking science consists of "an actual pattern of meaningful action, using semiotic resources, that is repeatedly performed and recognised in a community; a formation is a sort of "institutionalised" way of talking, or gesturing, or behaving" (Lemke, 1990, p.194). In other words, what science educators often call a "concept" is really a construct for a canonical and recognisable assemblage of semantic relationships of texts according to the discourse practices of the scientific community. While there are certainly unique ways in which individuals think and talk about a particular concept, every utterance and action largely conforms to repeatable social patterns that are more or less the same across different settings within the educational community.

In more recent years, several studies have extended science classroom talk to include other multimodal resources that are frequently drawn upon to make scientific meanings in the classrooms (e.g., Givry & Roth, 2006; Kress, Jewitt, Ogborn, & Tsatsarelis, 2001; Lemke, 1998; Tang, Tan, & Yeo, 2011). After all, scientific concepts are seldom composed of a single mode of representation, but are "semiotic hybrids that are simultaneously verbal, mathematical, visual-graphical, and actional-operational" (Lemke, 1998, p.87). Based on this view, Tang et al. (2011) used a multimodal discourse analysis to examine how a group of high school students understand the concept of energy through their collaborative talk, and found that their meaning-making of the concept can only be achieved through a particular way of combining words, symbols, images and gestures. Similarly, based on an interaction analysis of students' talk and gestures, Givry and Roth (2006) proposed a redefinition of the nature of conception to consist of a dialectical unit that includes all semiotic resources (e.g., talk, gesture, setting) that are made available to a speaker.

Discussion

Based on the review, we can make a number of implications concerning the role of dialogue in learning science epistemic practices. We discuss the implications in terms of the conceptual, methodological and pedagogical issues related to the role of dialogue.

Conceptually, the studies provide evidence of dialogue as an integral component of science epistemic practices as well as illustrate how the mechanics of dialogue through which scientific knowledge is proposed, communicated, evaluated and legitimised (Kelly & Lincona, 2018). The heteroglossic and intertextual nature of dialogue, the joint interactions enabled by dialogue, and the semiotics of language and representations mediated through dialogue all form the fundamental basis on which all the four epistemic practices are enacted. In this sense, scientific questioning, inquiry, argumentation and legitimatising conceptual knowledge are essentially dialogic events between two or more individuals within the scientific community.

In addition, each epistemic practice has specific requirement that taps on the affordance of dialogue. For questioning, the context of a question is dependent on the interaction exchange it is embedded. Conversely, the authoritativeness or dialogic nature of the exchange rests on the close or open-endedness of the question, both of which are necessary for the process of building scientific knowledge (Mortimer & Scott, 2003). For inquiry, dialogic processes are necessary for the social negotiation of perspectives, interpretations and attitudes in order to build robust explanations arising from observation or experimentation. Furthermore, the explanations are proposed in a social space through dialogue where critique and dispute of competitive theories could take place, which is the essence of scientific argumentation. Critique is also an important form of knowledge evaluation and legitimatisation of knowledge against the backdrop of normative knowledge agreed upon by scientists. Finally, the knowledge constructed by scientists are institutionalised and added to the conceptual canons of science through a discursive formation (Foucault, 1972) of repeated and recognisable ways of talking and acting by scientists who operate within their discourse communities.

Methodologically, the studies we reviewed also show how the epistemic practices of science can be analysed through a dialogic lens. First, it was evident that the analysis of epistemic practices cannot be separated from the dialogue they are embedded. For instance, what is regarded as a question or claim can only be determined by a response in a turn-taking adjacency pair. As such, the conversational turn pair between two speakers or voices in a dialogue must be considered as the minimum analytic unit for the analysis of questioning and argumentation (Kim & Roth, 2014). The analysis of dialogue is not limited to interactions (e.g., discourse moves, turn-taking) but also includes meaning-making elements that are determined by the semantic and intertextual relationships of the words uttered in the dialogue (Lemke, 1990). While research in the dialogue of science education has emphasised the importance of oral discourse, there is increasingly more studies that include and foreground other modes of representation, particularly gestures and images, that are equally central to science epistemic practices. The attention to multimodal resources in the role of dialogue represents the forefront of current research in science education.

In terms of the pedagogical implications, as the role of dialogue is fundamental to the epistemic practices of the scientific community, the attention to dialogue in the science classroom will facilitate student learning of science. For example, the discursive features of teacher and student questioning are essential bases for the type of dialogic and exploratory talk to take place, which are necessary for students to develop critical thinking and deep understanding in science (Chin & Osborne, 2008; Mercer et al., 2004). Dialogic interaction also enables meaningful science inquiry processes that involve experimentation and collaboration. Engagement with science ideas through this process has shown to be beneficial for science students, especially for students from diverse language background (e.g., Haneda & Wells, 2010). In making scientific claims, the learning of argumentation is best taught and practiced as a form of dialogue between two person having diverging results or interpretations. Instructional tasks that promote such dialogue around competing theories and alternative explanations not only aid students to improve their argumentation skills, but also gain a deeper conceptual understanding in science (e.g., Erduran, 2004).

The Way Forward

The role of dialogue as discussed in current science education literature is central to students' ability to engage in the epistemic practices of science. As one of the discipline goals of science is the ongoing pursuit to understand and construct models to represent the natural world, new vocabularies, new ways of thinking and communication, would continue to evolve in sync with new discoveries. The epistemic practices of questioning, inquiry, argumentation, and legitimising conceptual knowledge provide the normative practices on which new understandings of the natural world are built. To better appreciate the effects of new discoveries and scientific knowledge on the communicative demands of learners, in-depth analysis of classroom talk and interactions can be carried out in learning situations from classical scientific knowledge (for example Newton Laws) to more contemporary and modern knowledge (for example quantum physics).

As learning moves towards a more integrated form, the call for science learning to take a cross-disciplinary and integrated approach has become louder. The progress towards Science, Technology, Engineering and Mathematics (STEM) education appears inevitable. With an integrated approach, hybrid epistemic practices adopting characteristics of the different domains would result. For instance, beyond learning scientific concepts, the role of dialogue in STEM classrooms would also extend to sense-making and decision-making in socioscientific issues. The penetration of science into our everyday lives demands that learners of science be scientifically literate to be informed consumers of science to participate in a democracy. The epistemic focus of socioscientific issues require learners to be engaged in understanding multiple perspectives including moral, religious, and personal in the construction of a coherent reasoning to support a specific position relating to controversial issues (Kelly & Licona, 2018). In applying scientific knowledge to make sense of complex socioscientific issues, dialogue forms the fundamental means in enabling persuasion during argumentation. Coherent lines of arguments in proposing solutions to socioscientific issues can only be achieved through the use of scientific vocabularies, knowledge and inquiry process. This implies that generic everyday discourse is limited in the scientific sense-making process. Consequently, it is needful for pedagogical practices in science to explicitly include ways to enable learners to engage in formulating productive discussions, since "conceptual, epistemic, and social goals all entail the use of discourses (spoken, written, symbolic) and pose communicative demands of students." (Kelly & Licona, 2018, p. 5). Along the same vein, the inclusion of engineering thinking in STEM education demands that learners be engaged in understanding the concepts of optimisation of systems and be involved in the crafting of criteria to evaluate success of systems. These engineering epistemic practices, when amalgamated with conceptual knowledge and models in science learning, would require and result in different ways of dialoguing and interaction in the classrooms. Of importance and interest would be for researchers to empirically examine the similarities and differences in dialogic interactions in science and STEM classrooms to enable greater clarity on the two forms of learning.

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