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12. LANGUAGE, DISCOURSE, ARGUMENTATION, AND SCIENCE EDUCATION

INTRODUCTION

In didactics of science (i.e., science education understood as a scholarly discipline) as well as in other academic fields – such as the philosophy of science, cognitive science, or classroom ethnography – there is nowadays extended consensus around the recognition that scientific knowledge is "dependent inextricably on language and language is also central to our ability to think [scientifically]" (Evagorou & Osborne, 2010, p. 136).[1] Language constitutes a key element in science education: it can be seen as a tool that allows us to understand and apprehend the natural world, to shape and express our ideas and reasoning on it, and to develop, share, transmit and perpetuate scientific knowledge.

The paramount role of language in scaffolding and configuring science learning processes started to be widely acknowledged in the 1960s; such acknowledgment can be at least partially attributed to the seminal works of Jerome Bruner and the dissemination of Lev Vygotsky's ideas in the English-speaking academic community.[2] However, it was not until the late 1980s, and following conceptual developments in the philosophy of science, linguistics, and educational studies, that science education research began to pay consistent attention to the linguistic aspects inherent to science teaching and learning. As a consequence of this new focus, a very active and rapidly expanding research line has emerged and consolidated in the last two decades. Such line comprises several theoretical perspectives focussing on different aspects of the nature and use of the scientific language in the classroom (e.g., Lemke, 1990; Driver et al., 1994; Candela, 1995; Sutton, 1996; Sanmartí et al., 1998; Osborne, 2010), with studies looking into all educational levels, from Kindergarten to University.

Clive Sutton (1996), in his now classic paper "Beliefs about science and beliefs about language", portrays two distinct *epistemic* (i.e., knowledge-construction) functions that language can perform in science: language can serve as a *labelling* system, to tag and transmit established pieces of knowledge, or as an *interpretive* system, actively used to generate and consolidate new understandings. In his text, Sutton is advocating for a shift from the positivistic emphasis on language as a means of merely conveying conceptual information towards the constructivist idea of understanding language as a way of making and negotiating meanings. Adhering to this twofold characterisation of scientific language for the science classes would

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import that students need to be introduced, in a coordinated way, into the modes of reasoning and in the patterns of language that are deployed in the context of doing science. Along this line, Evagorou and Osborne (2010, p. 138) claim:

> [B]ecause reading and writing are activities that are constitutive of science, and because the language of science is complex and foreign to many students, we see teaching science as fundamentally a process of teaching a language – one in which the teacher has both to help students to interpret and construct meaning from scientific text and one in which they must provide opportunities to develop their fluency and capabilities with that language. In the classroom, three main forms of language are used as tools for understanding, communicating, and developing knowledge: talk, writing and reading.

In the same spirit of the previous paragraph, Jay Lemke (2001) argues that we could understand science education as a "second socialisation": an enculturation into a sub-community – science – that has its own representations, methods, ethos, and jargon. This theoretical approach should motivate us to examine how people learn to talk and write the language of science *while engaging in specific scientific activities*, such as observing, experimenting, hypothesising, debating, or publishing. In his renowned book *Talking science*, Lemke (1990) equates science learning – at least in some aspects – to learning to "talk science". This implies moving away from science lessons dominated by a "triadic dialogue" centred on teachers' authoritative talk – as in the classical IRF (initiation-response-feedback) sequences – towards designing and implementing classes in which students actively (re)construct language and flexibly use it to make sense of natural phenomena.

Lemke introduces a very suggestive idea: talking science could be considered a very elaborate and controlled social process; his description of this process is modelled on the metaphor that science is a foreign language that students have to learn. In his own words:

> Learning science means learning to talk science. It also means learning to use this specialized conceptual language in reading and writing, in reasoning and problem solving, in guiding practical action in the laboratory and in daily life. It means learning to communicate in the language of science and act as a member of the community of people who do so. "Talking science" means observing, describing, comparing, classifying, analyzing, discussing, hypothesizing, theorizing, questioning, challenging, arguing, designing experiments, following procedures, judging, evaluating, deciding, concluding, generalizing, reporting, writing, lecturing, teaching in and through the language of science. (Lemke, 1990, p. 1)

Lemke asserts that we learn to speak the language of science in much the same way in which we learn any other language: practicing it with people who master it and using it in a variety of *pragmatic* communicational situations, where it should be employed in its most frequent typologies, genres, and text formats. In accordance with this theoretical perspective, students must not only understand the main concepts implicated in the scientific theories and models, and grasp the scientific vocabulary, but they also have to be able to apply the necessary language structures and patterns, and use the most pertinent discursive tools and rhetorical strategies. Consequently, they must be able to identify and produce the different "acts of speech" that belong in science, such as descriptions, definitions, narratives, explanations, justifications, and argumentations.

In the specific case of the proficient use of scientific vocabulary, there is a crucial point about the meaning of words: science teachers should make bridges between the everyday meanings of terms and their meanings in distinct, recognisable scientific contexts. The ability to smoothly move from one context to another requires acknowledging that scientists use language in highly stylised and socially determined ways:

> Not only is there a specialist scientific vocabulary consisting of words which are recognizably unfamiliar but there are familiar words such as 'energy', 'power' and 'force' which must acquire new meanings. Moreover, the charts, symbols, diagrams and mathematics that science deploys to convey ideas, are essential to communicating meaning and students must learn to both recognize and understand their use. The challenge for the teacher then is to introduce and explain this new vocabulary; the challenge for the student is to construct new meanings from such a language. (Evagorou & Osborne, 2010, p. 136)

In science classes, teachers have to teach about a plethora of theoretical entities[3] that are hard for students to grasp, e.g., the cell membrane, a chemical bond, a tectonic plate, or the electric field. The teaching of entities such as those depends on the use of robust *representations*: for instance, it is usual to analogise a cell to a brick, to refer to electric currents in terms of water flow, or to depict atoms as tiny, moving balls (cf., Evagorou & Osborne, 2010). All of these representations are metaphoric, i.e., they involve *transfer* or *transport* of meaning between different contexts of use. According to the philosopher of science Rom Harré, new vocabulary is created within the existing structure of any given language through these metaphorical mechanisms, while securing the intelligibility of the terms in each of the new contexts through the whole process:

> We need to use metaphor to say what we mean – since in the course [of] scientific theorising we can conceive more that we can actually say. (Harré, 2004, p. 115)

Thus, analogies and metaphors can be utilised to construct and scaffold students' understandings in school science, since they are essential constituents of scientific theories and models (cf., Bailer-Jones, 2000). Models as abstract entities serve the purpose of providing plausible descriptions, explanations, and predictions about real systems in nature, but they are described and put into action through linguistic operations that students need to incorporate.

USING LANGUAGE TO LEARN SCIENCE

In the field of science education, recognition of the salient importance of language was mainly initiated by Rosalind Driver and her colleagues in the late 1980s, within the framework of a socio-constructivist paradigm for science education. This early shift to studying language issues in the science classes led to rapid growth of the number of papers in this line; since then, "talking science" has been allotted increasing space in the international forums and publications of didactics of science.

In addition, this corpus of didactical research has been "fecundated" by work done from other disciplines; for example, there are investigations centred on the relevance of writing within and across the disciplines that are in tune with what is being done in our own field. In didactics of language, it is pointed out that "school writing" is impoverished due to the chronic absence of instructional tasks that require writing for diverse audiences, making the teacher the almost exclusive recipient of the produced texts (cf., Charolles, 1986; Strange, 1986). This is a lesson to be learned for our science classes, where proposing "retextualisation" of knowledge aiming at a variety of targeted readers (experts and novices, in distinct communicational contexts) could be a powerful means to permit students show their theoretical understanding of natural phenomena.

Within the broad repertoire of discursive genres in which science teachers can engage their students, some appear to be more productive than others in terms of making scientific knowledge "live" in the classroom. Some research (e.g., Langer & Applebee, 1987) suggests that introducing extensive writing practices promotes more meaningful learning than instructional activities that only involve reading, since writing "presses" students to contemplate, in their own written productions, different kinds and sources of information.

The specialised literature also identifies different requirements and constraints in written formats: texts that define or describe seem to be more associated with memory processes and mechanistic learning than texts that demand explanation or argumentation. The latter typologies – since they solicit sophisticated pragmatic and rhetorical adjustments, the establishment of complex relationships, and the use of elaborate inferential mechanisms – constitute productions that "unveil" understanding processes in students while fulfilling nodal epistemic functions in science learning (cf., Kuhn, 2010; Navarro & Revel Chion, 2013). The importance accorded to writing school scientific explanations and arguments is related not only with the need for students to acquire cognitive and linguistic skills that warrant better learning outcomes, but also with fostering in those students meta-cognitive and self-regulation competencies, such as monitoring and control:

> Within the cognitivist perspective, writing has become much more than a graphic-motor activity in that it requires thinking processes, mainly reflection, not only before and during but also after the act of writing, when the text produced is revised. (Tynjälä et al., 2001, p. 9)

SCHOOL SCIENTIFIC ARGUMENTATION

Many scholars in didactics of science have converged in the recognition that the production of argumentative texts is particularly powerful for science education;[4] in addition, the function that mastery of argumentation has in different aspects of learning has been extensively investigated *outside* science education, and the results of such research have reinforced conviction within our community to adopt argumentation as a privileged strategy to teach science. For instance, Greg Kelly and Charles Bazerman (2003) – within the framing of ideas known as "writing across the curriculum" (WAC) – propose to engage students in instances in which they produce arguments in the scientific disciplines and beyond them. From these arguments, students learn to talk and write the language of the different academic fields.

In their proposal, these authors indicate that argumentative discourse would be one of the communicational functions *par excellence* in the development of scientific knowledge, and hence its importance in a science learning that seeks "authenticity". Basing on scientific models, students can construct a special kind of evidence-based explanation to make sense of the world around them; in this construction, we can help them identify that the sound connection between data (evidence) and conclusions (explanation) counts as argumentation:

> [S]tudents not only need to write in order to master the concepts and work of a field, but more particularly to develop competencies in the specific argumentative practices of their fields […]. In addition to the genre-specific writing competencies, with associated argumentative patterns, students must begin to gain a feel for the argumentative forums and dynamics of their fields. They must learn the kinds of claims people make [and] what kind of evidence is needed to warrant arguments […]. (Kelly & Bazerman, 2003, pp. 29–30)

Scientific argumentation demands a style of monitoring that enables student-writers, among other things, to: recognise the presence of adequately derived conclusions; revise the strong connection between these and the elements providing and justifying the *transition* from data – what Stephen Toulmin calls "warrants" and "backings" (cf., Erduran et al., 2004); and seek for strong structural coherence between propositions. The hybrid nature of argumentation – as a tight welding of the epistemic operations of *explaining* and *convincing* (cf., Kelly & Takao, 2002; Sampson & Clark, 2008) – provides both a "window" for the teachers to assess students' understandings, and an arena for the students to test their own appropriation of what they are learning.

As we have suggested, understanding science accomplishments as products *and* processes – i.e., what we know and how we know it – requires systematic discursive exploration of the intricate *interaction* between theoretical ideas and the evidence (empirical and other) that they rely on. In other words, students should become aware that scientific constructs divert in many aspects from common sense, and are often far from transparent; they should rather see those constructs as the laborious *inferential* products of one of the most intricate cognitive and social activities of humankind. All of this means sustained argumentative work in the science classroom.

Nowadays, a broad range of theoretical conceptions on the nature of scientific argumentation is available in the literature of didactics of science;[5] these conceptions are mostly imported from classical and renewed positions in linguistics (including here argumentation theory, dialectics, and rhetoric) and – to a lesser extent – in the philosophy of science. Conceiving argumentation as a "cognitive-linguistic ability"[6] that links phenomena, models, evidences and explanations through discourse would locate it – together with explanation – at the very vertex of the "scientific pyramid" (cf., Duschl, 1990): argumentation would be one of the most inclusive and elaborate scientific processes, in which models are put into action in order to give meaning to the world.

Didacticians of science Sibel Erduran and Marilar Jiménez-Aleixandre are amongst the most cogent advocates for the indispensability of school scientific argumentation:

> This competence is instrumental in the generation of knowledge about the natural world [and] plays a central role in the building of explanations, models and theories […] as scientists use arguments to relate the evidence they select to the claims they reach through use of warrants and backings. […] [A]rgumentation is a critically important discourse process in science, and […] it should be promoted in the science classroom. (Jiménez-Aleixandre & Erduran, 2007, p. 4)

These authors propose that there are at least five intertwined "potential contributions" that arise from the introduction of argumentation in the science classrooms (cf., Jiménez-Aleixandre & Erduran, 2007, p. 5):

1. Through arguing, students could get access to the cognitive and meta-cognitive processes characterising expert performance and enabling modelling.
2. They could develop the kind of communicative competencies that foster critical thinking.
3. Argumentation could support students' achievement of scientific literacy and their empowerment to talk and write the language of science.
4. Students could be introduced into the epistemic practices pertaining to the scientific culture and they could consequently construct epistemic criteria for knowledge evaluation.
5. Argumentation could accompany the development of scientific reasoning among students, particularly the choice between theories or positions based on rational criteria.

The research group LIEC (Llenguatge i Ensenyament de les Ciències/Language and Science Teaching, at the Universitat Autònoma de Barcelona in Spain) defines argumentation – following Dutch authors inscribed in the so-called "pragmadialectics" – as a social, intellectual, and verbal activity directed to support or rebut a claim. When arguing, in addition to the sheer content of the claim, its *purpose* and *recipients* are important: the "arguer" has to choose between explanations and to provide reasoned criteria to give validity to the most appropriate choices (Sanmartí, 2003). In order to be able to construct operative models about the natural world, students need, besides meaningfully learning the involved concepts, to be able to distinguish between different kinds of explanations and to apprehend criteria that enable critical evaluation. In the scientific community, such choice (usually referred to as "scientific judgment") occurs in a context of debate or controversy; in the classroom, argumentative dialogue is generally enacted through the presentation of opposing positions and the discussion of reasons and evidence supporting them. School scientific argumentation thus establishes a very specific and sophisticated kind of oral communication and of written text production.

In our own work, we identify to some extent the skills of explaining, justifying and arguing with one another, though some authors from the field of linguistics make sharper distinctions between them based on formal or pragmatic considerations (for instance, it is usually pointed out that arguing as a "rhetorical move" implies a strong will to make the audience *see* something in a particular way). In particular, we define school scientific argumentation as the production of a text in which a natural phenomenon is *subsumed* under a theoretical model by means of an analogical procedure (Adúriz-Bravo, 2011, 2014; Revel Chion & Adúriz-Bravo, 2014). Argumentation can therefore be considered as the "textual concretion" of a fully-deployed scientific explanation.

In a "complete" school scientific argumentation, we recognise the following overlapping dimensions, which we call *components*:

1. The *theoretical* component, meaning that there must be a scientific model (Giere, 1988) as a reference, allowing explanation of a phenomenon by its "similarity" to that model.
2. The *logical* component, meaning that arguments have a rich syntactic structure and can be formalised as reasoning patterns (for instance: deductive, abductive, analogical, relational, causal, functional…).
3. The *rhetorical* component, meaning that arguments have persuading and convincing as constitutive aims (Osborne, 2001).
4. The *pragmatic* component, meaning that arguments are situated in a particular communicational context that configures them and from which they take meaning.

We use this four-component analysis of school scientific argumentation with three purposes that support one another. In the first place, to guide the design and implementation of instructional activities aimed at teaching students how to argue (see Adúriz-Bravo, 2011). Then, to communicate to those students which are the key characteristics of good-quality argumentation. And finally, to perform evaluative analyses and give feedback on the texts they produce.

SUMMARY

In this chapter, we have examined the following key ideas:

1. Research on language in science teaching has consolidated in the last three decades, and it is undertaken from didactics of science and from other disciplinary approaches.
2. Language plays a fundamental role in science education due to its epistemic function of meaning-making. Such function is accomplished through the construction and re-signification of terms, the implementation of metaphors and analogies, and the utilisation of complex linguistic procedures such as explanation and argumentation.
3. Discourse (oral and written, in different genres and formats) permits teachers to look into students' science learning, and allows students to test their own understanding of scientific ideas.
4. Argumentation is a key act of speech in the development of science; thus, science teaching that seeks to convey clear messages on how science works should give prominence to this competency.

NOTES

[1] See Wellington and Osborne (2001) for a collection of references that attest the importance conceded to language in the science classrooms.

[2] See, for instance, Bruner (1966, 1990) and Vygotsky (1934/1962).

[3] This condition of being theoretical is independent of being "observable" or not in instrumental terms; it has to do with the conceptual "ladenness", and the hypothetical and inferential nature of these entities.

[4] See the literature compiled in Erduran and Jiménez-Aleixandre (2008).

[5] Jonathan Osborne (2001) has reviewed a number of educational definitions of scientific argumentation and examined their epistemological foundations.

[6] These abilities reflect high-order cognitive capacities but at the same time imply the production of very elaborate oral and written texts (Sanmartí, 2003).

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