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Eurasia Journal of Mathematics, Science and Technology Education

Volume 1, Number 1, November 2005

SCIENTIFIC ARGUMENTATION IN PRE-SERVICE BIOLOGY TEACHER EDUCATION*

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ABSTRACT. This paper discusses the design of an instructional unit examining scientific argumentation with prospective biology teachers. Linguistics and philosophy of science have turned to argumentation as a relevant skill; its importance in science classes has also been highlighted by scholars. We define school scientific argumentation and analyse its components. We present the unit, directed to pre-service biology teachers, which includes different strategies; among them, we propose guided reading, analogies, debates, and discussion on historical episodes. We describe the activities, examining the nature-of-science topics addressed. The sequence relates to secondary science teaching; this may increase the meaningfulness of the nature of science in teacher education.

KEYWORDS. Argumentation, Biology, Components, Scientific Explanation, Nature of Science, Teacher Education.

INTRODUCTION

This paper discusses with some detail the design, and more briefly the implementation, of an instructional unit that aims at examining with prospective biology teachers the skill of scientific argumentation and its importance in science education. We are a team of teacher educators in charge of two consecutive one-semester courses, Didactics of Biology I and II. These compulsory courses are directed to students in the fifth and sixth years of the degree in biology teaching (these students would be more or less equivalent to biology graduates in a masters program in biology education).

We acknowledge the need to introduce contents of the nature of science in science teacher education, as a means to improve their teaching skills and metacognitive awareness (Matthews, 1994; McComas, 1998). We want our future teachers to be able to convey to their

ISSN: 1305-8223

* A preliminary version of this paper was presented at the Seventh International History, Philosophy and Science Teaching Conference (Winnipeg, Canada, July/August 2003).

own students a coherent view on science, its development, its evolution and its relations with society and culture. The ability to do so would comprise both an explicit teaching of nature-of-science models and the integration of these in the presentation of the scientific content.

Our aim is to prepare prospective teachers so that they are able to enhance, in their own students, cognitive abilities or skills that are strongly related to science, but that also belong to any 'rational' activity. In this sense, 'general' cognitive abilities would be those put into action in any rational human enterprise, and science, as a paradigm of this way of thinking, contributes both to the characterisation and to the learning of such abilities (Sanmartí, 2003). In our view, the development of 'scientific' cognitive skills would start from the selection and implementation of particular procedural contents that are able to support them, such as identifying problems, formulating hypotheses, contrasting models, providing evidence, etc.

Recent research on the nature of the scientific language in the classroom has led to identifying scientific argumentation as a topic of key importance in science teacher education (Ogborn et al., 1996; Driver, Newton and Osborne, 2000; Osborne, 2001; Duschl and Osborne, 2002). Argumentation and explanation would be at the very vertex of the 'scientific pyramid' (Duschl, 1990), being the most inclusive and elaborate scientific abilities, in which models are put into action in order to give meaning to the world. This perspective on the role of argumentation/explanation of course denotes the philosophical perspective to which we adhere, the cognitive model of science from the current semantic view (Giere, 1988; Izquierdo and Adúriz-Bravo, 2003).

A broad range of theoretical conceptions on the nature of scientific argumentation is currently available in the literature of science education; these conceptions are mostly derived from classical positions from the philosophy of science or linguistics (including rhetorics). Jonathan Osborne (2001) has thoroughly reviewed educational definitions of scientific argumentation and their epistemological foundations. Consequentely, it is not our intention to repeat such considerations; we rather want to present our own ideas on school scientific argumentation, which we have developed for our practice as science teacher educators.

SCHOOL SCIENTIFIC ARGUMENTATION

Considering science education as acquisition of cognitive skills is in tune with some influent contemporary views on the nature of science, which assume that doing science is not merely performing practical experiences, a position of strong inductivist or empiricist reminiscence, but also, and more importantly, talking and writing about such experiences with particular, and very elaborate, semiotic systems (the scientific lanaguages). Current philosophy of science has turned to argumentation as a skill of major relevance (Toulmin, 1958; Gross, 1990) and consequently the importance of argumentation in the science classes has been

highlighted in recent years (Driver et al., 2000; Osborne, 2001). Argumentation as a discursive tool is at the heart of the process of scientific explanation in the classroom.

In order to be able to construct operative models and explanations 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 when choosing between models. In the scientific community, such choice (usually referred to as 'scientific judgement') 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 elaborate kind of oral communication (Jiménez Aleixandre, 2003) and of text production (Sanmartí, 2003).

In our work, we identify to some extent the skills of explaining, justifying and arguing, though some authors from the field of linguistics make distinctions between them based on formal or pragmatic considerations (for instance, it is usually pointed out that arguing as a typical rhetorical procedure implies a strong will to convince). Those three skills have been labelled cognitive-linguistic abilities, since they reflect high-order cognitive capacities but at the same time imply the production of very elaborate oral and written texts (Sanmartí, 2003).

For our teacher education purposes, we define scientific argumentation as the production of a text in which a natural phenomenon is subsumed under a theoretical model by means of an analogical procedure1. Argumentation can therefore be considered as the 'textual' counterpart of scientific explanation.

In a 'complete' school scientific argumentation, we recognise the following elements, which we call 'components':

1. the theoretical element, meaning that there must be a theoretical model (Giere, 1988) as a reference, allowing to explain a phenomenon by its 'similarity' to the model;

2. the logical element, 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 element, meaning that arguments have convincing as an important aim (Osborne, 2001);

4. the pragmatic element, meaning that arguments are situated in a particular communication context from which they take meaning.

The next section of the paper is devoted to presenting a complete instructional sequence directed to pre-service biology teachers that was designed following the guidelines of a theoretical framework previously presented (Adúriz-Bravo and Izquierdo, 2001; Izquierdo and

Adúriz-Bravo, 2003). The sequence amounts to four hours and includes a variety of resources used in individual, small-group and plenary tasks. Among these resources we can mention dramatisation, debates, quizzes, historical episodes, analogies, text analysis, guided reading.

We provide an overview of the complete sequence, describing the different activities. We mention the nature-of-science topics addressed (among them, reasoning patterns and scientific discovery), and we show how these are materialised. An important feature of the sequence is that it always relates to science teaching in the secondary classroom; this increases the potential meaningfulness of the nature-of-science content that is taught to prospective science teachers.

THE INSTRUCTIONAL UNIT

Our instructional unit is structured in three activities, as described below. The activities comprise a series of individual paper-and-pencil tasks followed by small-group and plenary discussion.

Introductory activity: focusing on the problem of argumentation

This activity intends to highlight the relative vagueness that, in natural language, the terms 'describe' and 'explain' have. With this aim, student teachers are presented with an unknown sub-microscopic sample: it is an electronic-microscope image of chromosome crossing-over during prophase I of cell meiosis. The overhead image presented to them has no identification labels on it.

A student is then asked to describe what he/she sees. As the student performs what he/she considers a description, notes are taken on the blackboard. After that, another student is asked to explain what he/she sees. As in the previous step, notes of this 'explanation' are taken on the blackboard.

Then comes a moment of conceptualisation of the task. The notes taken during the previous steps of the activity somehow show that the verbs 'describe' and 'explain' have an ambiguous meaning in natural language. Students required to describe, for instance, usually employ theoretical terms (such as 'chromosome', 'allele', 'meiosis') and introduce hypotheses or other inferences. Students required to explain, on the other hand, usually resort to causal, functional or transdictive2 inferences, or sometimes enumerate sheer characteristics of the image (colour, shape, size).

Other aspects of the problem of describing and explaining in the science classroom are then examined with the class. On the one hand, we distinguish between cognitive and linguistic procedures involved in description and explanation. Subjects need to know how to construct a

description or an explanation in their minds but they also need to enact such procedure in a coherent text. We also focus our students' attention on the fact that both abilities pose clearly different intellectual demands, description being much simpler than explanation.

On the other hand, the activity suggests that, when teaching in secondary science classes, it is necessary to make explicit and to share the meaning of these competences, which are often required in the science classes. Therefore, it is necessary to transform them into explicit objects of instruction.

Theoretical activity: examining scientific argumentation

The importance of learning to talk and write science has been receiving increasing attention in the literature of science education (Lemke, 1990; Sutton, 1992). Many authors within this line work from a neo-vygotskian perspective, regarding languages as systems of resources that enable subjects to construct meaning. Accordingly, the natural language is considered to play a central role both in the transmission and in the generation of science.

Neus Sanmartí (2003) uses the label 'cognitive-linguistic abilities' to characterise any one of a set of complex intellectual skills extensively used in the classroom. Such abilities can be associated to different text typologies ('genres') and resort to diverse semiotic registers (speech, writing, figures, images, scale models, gesture...).

A great number of cognitive-linguistic abilities can be identified (describing, summarising, defining, explaining, justifying, warranting, arguing...), even though the precise meaning of each of them cannot be totally ascertained. We classify those in first-order abilities (such as describe, define, narrate, summarise) and second-order abilities (such as justify, hypothesise, refute, explain, argue), suggesting that the latter involve structuring and organising a number of the former.

Arguing has a central role amongst cognitive-linguistic abilities. Given the relevance of scientific argumentation, we think it is important that science teachers teach their own students to elaborate argumentative texts and to identify their components.

Adúriz-Bravo (2004) offers an instructional proposal that aims at working this nature-of-science content using a French film on the life of Madame Curie and what we call the 'invention' of radium3. Student teachers see a sequence of the film in which Marie explains to Georgette, nanny to her little daughter Irčne, the problem she has encountered when trying to account for the irregular radioactivity of pitchblende. Student teachers are required to identify the (oral) texts in which an argumentation takes place and to give examples in which different 'languages' (speech, text on the blackboard, images, gesture) are used in correspondence to the four constitutive components of the argument (theoretical, logical, pragmatic and rhetorical).

Metacognitive activity: reflecting on school scientific argumentation

Initially, we aim at acquainting our students (future biology teachers) with current research on school scientific argumentation. For this purpose, recent investigations by Richard Duschl, Marilar Jiménez Aleixandre, Jonathan Osborne, John Ogborn and other authors are discussed.

We then turn to the role of argumentation in assessment/evaluation. Science teachers often use the formulation 'justify' in their written evaluations with little conscience of its broadness and complexity. As an example to reflect upon, we present our student teachers with actual answers (collected during a previous investigation: Meinardi and Adúriz-Bravo, 2002) to a simulated 'evaluation task': arguing why lice become resistant to 'Nopucid' (an old-fashioned Argentine shampoo against lice). A careful analysis of extremely different answers conveys the idea that the formulation is flawed when argumentation is not clarified, taught and practised beforehand.

The last task of the unit involves working around instructional activities for school scientific argumentation. Student teachers in small groups design an activity, on any biology topic, which would demand from their own hypothetical secondary students the ability of argumentation. Whole-class discussion of the proposed designs asks 'arguing on argumentation': student teachers are required to support their designs referring to the contents covered in the unit. During discussion, 'good' pre-existing examples of the use of argumentation in the secondary classroom are presented and analysed (for instance, Duschl, 1990; Duschl and Osborne, 2002).

The discussion promoted during the set of three activities briefly described above acquaints prospective teachers with some ideas on the nature of science, such as scientific explanation, controversy, pragmatics and abduction. But these ideas are examined through the lens of didactics of science (i.e. science teaching methodology). The aim is to explore the possible usefulness of the nature of science in science teachers' actual professional practice.

FUTURE

Our instructional sequence has recently been put into practice on three occasions with 30 student teachers each time. We have had some informal feeback on its robustness. The proposal has also been adapted for, and implemented with, prospective physics and chemistry teachers. In all these occasions, no systematic data on the pedagogical success of our design has been collected.

Data collection is now being done within a small research project that has just begun. We aim to identify, by means of surveys and interviews, possible substantive changes in teachers' nature-of-sciences conceptions helped by the exposition to the unit.

For this reason, this paper only concentrates on the design of the unit and its coherence with the theoretical framework of reference (Izquierdo and Adúriz-Bravo, 2003). Another important aim is presenting to the science education community our own developments on the idea of school scientific argumentation: definition, classification amongst other abilities and identification of components.

NOTES

1. Many English-speaking authors in philosophy of science and science education (cf. Osborne, 2001) add as a requirement for an argumentation the existence of some form of debate in which two or more opposite views on the phenomenon are confronted and defended. These authors consequently emphasise the rhetorical component of argumentation. In English, the verb 'argue' conveys some idea of confrontation, whereas in Spanish, the corresponding verb 'argumentar' relates more to the idea of providing reasons for the phenomenon, i.e. it somehow implies the production of a reasoning pattern. Thus, in our tradition (stemming more directly from the Latin verb 'arguere', 'to make clear') the logical component is emphasised.

2. By 'transdiction' we mean an explanation which resorts to entities and functions situated at the organisation levels below that of the phenomenon. For instance, we would say that explaining the behaviour of ideal gases in terms of the kinetic-molecular theory is a case of transdiction.

3. The film is Claude Pinoteau's Les palmes de Monsieur Schutz, released in 1997. A version with English subtitles is available on DVD from Fox Pathé Europa.

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