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Fostering Model-Based School Scientific Argumentation Among Prospective Science Teachers*

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The paper aims both to foster and to assess "school scientific argumentation" among secondary science teachers during their pre-service education. For these purposes, the paper uses the meta-scientific construct of "theoretical model" (proposed by the so-called semantic view of scientific theories from contemporary philosophy of science) in three different and complementary conceptual levels. Firstly, the paper suggests teachers to argue using theoretical models (as opposed to propositional items) from science as a key component of their arguments. Secondly, the paper tries to scaffold teachers' argumentation practices modeling them with paradigmatic exemplars (which the author calls "epitomes"). And thirdly, the paper uses a four-component model of school scientific argumentation as an analytical tool to inspect how science teachers argue. The teachers' argumentative texts that are discussed in the paper arise from their participation in teaching-learning sequences designed to improve their argumentation skills via three synergic model-based operations: analyzing epitomes of arguments, (co-)constructing new arguments, and meta-theoretically reflecting upon them.

Keywords: school scientific argumentation, model-based approach, epitomes, four-component analysis, science teacher education

Introduction

Argumentation is recognised as a key feature of science (as cited in Toulmin, 1958), and as a major component in a high-quality science education for all (as cited in Osborne, 2005). There are several approaches to the study of scientific argumentation in the classroom, related to the different theoretical frameworks used, and to the practical aims sought (as cited in Duschl, 1990; Driver, Newton, & Osborne, 2000; Osborne, 2001; Duschl & Osborne, 2002; Sanmartí, 2003; Adúriz Bravo, Bonan, González Galli, Revel Chion, & Meinardi, 2005; Revel Chion et al., 2005; Erduran & Jiménez Aleixandre, 2008).

The approach of this paper to argumentation for science teacher education is tuned with the theoretical framework from didactics of science (i.e., science education as an academic discipline) called "cognitive model of school science", proposed by scholars at the Universitat Autònoma de Barcelona in Spain (as cited in Izquierdo Aymerich & Adúriz Bravo, 2003). Such framework has been analogically devised using as a starting point the so-called "semantic view of scientific theories" coming from contemporary philosophy of science; in

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particular, it resorts to Ronald Giere's (1988) cognitive model of science, with his specific conceptualisation of "theoretical models". Within this framework for this paper, "school scientific arguments" are discursive tools that permit to make meaningful connections between the realm of facts in the world and the theoretical models that can give meaning to them (Izquierdo Aymerich, Aliberas, & Adúriz Bravo, 2004; Adúriz Bravo, 2005b).

The aims of the research and intervention discussed here are both to foster and to assess school scientific argumentation in secondary science teachers during their pre-service education. This paper uses the meta-scientific construct of "theoretical model" in three different and complementary conceptual levels:

(1) Proposing teachers to argue using theoretical models from science as a key component of their argument, as opposed to a theory-based approach, where propositional items (such as principles and laws) are used. Thus, school scientific argumentation is presented to teachers as the process of construction of a very elaborate text in which a fact is subsumed under a model of reference;

(2) Proposing to scaffold teachers' argumentation practices via modelling processes: Teachers are presented with "epitomes" (i.e., paradigmatic examples) of good school scientific argumentation, and their own productions are then mapped onto a highly stylised, abstracted structure, which arises from what is perceived as "common" between the different epitomes. The agreed-on structure that is used is a matrix that is presented below;

(3) Using a four-component model of school scientific argumentation, complementary to TAP (Toulmin's argumentation pattern) (Toulmin, 1958) as an analytical tool to inspect how science teachers argue.

Theoretical Framework

For the purpose of pre-service secondary science teacher education, the researcher defines school scientific argumentation as the production of a text in which a natural phenomenon (or a set of phenomena) is subsumed under a theoretical model—"candidate" to explaining it—by means of an abductive and analogical procedure. This subsumption is done due to the fact that a Wittgensteinian "family resemblance" is perceived between the fact of the world to be explained and the model, considered as an epitome or abstract exemplar of a whole class (Adúriz Bravo, 2005b). Argumentation could then be considered here as the "textual" counterpart of the cognitive process of scientific explanation.

The researcher also uses an analytical tool that recognises that different structural components are always adequately mastered (that is, introduced, combined and balanced) in a complete and robust school scientific argument: (1) The theoretical component, meaning that there must be a theoretical model (Giere, 1988) as a reference, allowing explaining a phenomenon by its "similarity" to the 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, etc.) (Adúriz Bravo, 2005b); (3) The rhetorical component, meaning that arguments have been convinced as an important aim (Osborne, 2001); and (4) The pragmatic component, meaning that arguments are sensitive to the particular communicative context in which they are situated and from which they take meaning (Izquierdo Aymerich & Adúriz Bravo, 2005).

These four structural components can be used as: (1) Pillars for the design of didactical activities (i.e., teaching-learning sequences) to foster processes of school scientific argumentation; (2) Key entities in order to model "good" school scientific arguments in such processes; and (3) Categories for the analysis of the scientific arguments produced therein.

A matrix (see Table 1), comprising the four structural components presented above and their corresponding indicators, serves both the purpose of analysing arguments through categories and the purpose of

fostering/scaffolding arguments through entities. Such matrix, in the version presented in Table 1, is introduced via didactical activities in science teacher education. A slightly more "theoretical" version is used to assess the quality of argumentative texts.

Table 1
Matrix of Components and Indicators of a "Good" School Scientific Argumentation Used With the Teachers in This Study

Components (What should we pay attention to?)	Indicators (What should we be able to perform?)
Theoretical component: in argumentation, the theoretical model gives meaning to the intervention that we perform on phenomena following specific aims	We need to identify a school theoretical model (which includes the aims and values of the intervention); We need to select, "theory-load" and inferentially relate the facts using the model; We need to construct evidences projecting the model onto the facts
Logical component: in argumentation, we explain through a complex text that draws conclusions from theoretical foundations	We need to structure a complex, rich and dense text using the adequate connectors (hence, therefore, because of, due to, etc.); We need to clearly identify the premises and conclusions, and to show the relationship between them; We need to use powerful reasoning patterns (abductive, analogical, deductive, etc.)
Pragmatic component: in argumentation, we use language that is suited to the audience	We need to use rational and reasonable contexts; We need to connect with previous knowledge of the audience (misconceptions, background, culture, etc.); We need to give meaning to the scientific language used (using analogies, paraphrases, instances, etc.)
Rhetorical component: in argumentation, we try to convince the audience so that they see the facts as we see them	We need to stress the robustness, power and parsimony of the proposed explanation; We need to connect with the interests and motivations of the audience; We need to "humanise" the explanation (illuminating it with the history and philosophy of science, showing the values involved, appealing to its inventive and provisional nature, etc.)

Intervention and Results

The interventions reported here were done in two compulsory undergraduate courses (Didactics of Physics and Philosophy of Physics) within a degree in science teaching, directed to prospective physics teachers for secondary education (students aged 12-18). In these courses, the researcher used a set of three didactical activities aimed at indentifying, evaluating, fostering, scaffolding and explicitly reflecting (from a meta-level) on school scientific argumentation. The activities were designed by the research group GEHyD (Grupo de Epistemología, Historia y Didáctica de las Ciencias Naturales, i.e., History and Philosophy of Science and Science Teaching Group) (as cited in Adúriz Bravo, 2005b; Adúriz Bravo et al., 2005; Revel Chion et al., 2005).

The first activity sets argumentation in motion by requiring teachers to argue around socioscientific issues (cloning, eugenics, clinical trials, nuclear energy, scientific fraud, gender issues in science...). The second didactical activity scaffolds teachers' argumentation processes by accompanying them through the various steps of the process; teachers are asked to state a thesis, to provide reasons for and against it, and to back up what they are sustaining by means of evidence construction and resource to a theoretical corpus. Teachers are also required to adjust their written arguments to different audiences (experts, students, lay people, etc.) and to use different linguistic devices to convince. The third activity proposes that teachers meta-cognitively reflect on the very nature of scientific argumentation, understood as a key element of the scientific enterprise (as cited in Duschl, 1990; McComas, 1998; Sanmartí, 2003).

The four-component theoretical schema presented above serves, at the same time, as foundation for the design of these three activities, as "model" of good scientific argumentation and as analytical tool to follow

changes in pre-service teachers' argumentative abilities.

During the courses, the researcher has collected several written productions from the science teachers involved, which they were required to produce during the performance of the activities. In those productions, which could be considered converging "attempts" at school scientific argumentation, the researcher analysed the presence, combination and balance of the four structural components.

As an example, Table 2 presents three short excerpts from teachers' texts. Teachers read "El guiso fantasmagórico/The ghastly stew" (Adúriz-Bravo, 2005a), a short narrative on George de Hevesy's mythical invention of the radioactive tracers as a solution to a domestic conundrum. They are then asked to write a dialogue, at the market, between the landlady at the boarding house where de Hevesy lodged (whose concoctions with food leftovers endangered the guests' health) and a female friend of hers. The dialogue is required to have an explanation of de Hevesy's plot to unmask the fraudulent landlady.

Table 2

Excerpts of Teachers' Written Argumentative Productions in the Early Stages of the Didactical Activities

(1) You know that Hevesy has been clever enough to find out that the food was not fresh. Imagine it: He put radioactive substances in his dessert and left it behind. Hevesy was prepared; with an electroscope, he detected the presence of the radioactive substance and revealed my secret.
(2) Do you know about radioactivity? I know now. They are substances that permit to follow others. This Hevese guy, using one of these radioactive substances, put it in the leftovers of his lunch and, when he found them the next day, he shoved it in my face.
(3) It is as if you painted the stew with an inerasable felt-tip pen and then you discover the mark.

Note. In these early examples of argumentation, three groups of teachers attempt at "adapting" the model for a wider audience, but many model-related elements remain hidden. The differences in register (vocabulary) between the examples are notorious. The structure of the texts is mainly narrative, with linear connectors. More complex connectors explicitly indicating the subsumption process (therefore, due to this, as a cause, hence, as a consequence...) are missing.

In order to assess the quality of teachers' arguments, the researcher followed Adúriz-Bravo et al.'s (2005) and Revel Chion et al.'s (2005) proposals of characterisation of the obtained texts as:

(1) Proto-arguments, where the theoretical model is still weak, difficult to recognise; teachers still resort to their own alternative conceptions of common-sense knowledge;

(2) Quasi-arguments, where there is a distinct model and a robust syntax, but the pragmatic and rhetorical resources are still poorly mastered;

(3) Pseudo-arguments, where there are important logical faults under a seemingly complex, entangled syntactic structure.

The main results of this study can be summarised as follows:

(1) As for the theoretical component, most secondary teachers activate and use "accepted" scientific models to argue around a particular problem. Therefore, proto-arguments seem not to be usual at this level. The mastery of contents is greatly helped by working in small collaborative groups;

(2) As for the logical component, analysis with the schema shows formal problems in their early argumentation, which are slowly and progressively corrected while prospective teachers engage in the "scaffolding" activities. Pseudo-arguments and non-complex, linear arguments are usual with this target population. We can see a narrative and sequential structure (following a "temporal" logic) with an abusive use of the connector "(and) then";

(3) As for the rhetorical component, some of the issues discussed prompt teachers in a "neutral" style of argumentation, while other issues require them to use a broader spectrum of linguistic resources. The mastery

of these different rhetorical "toolboxes" is uneven. Some contexts activate quasi-arguments with an "academic" style, mainly modelled on standard textbook explanations;

(4) As for the pragmatic component, some of the "exercises" suggested in the activities (writing letters, doing scientific popularisation, engaging in dramatisations, etc.) are initially tackled as a mere "re-textualisation", without taking into account the strong need to adjust scientific language to the audiences involved. Quasi-arguments prevail. Along with the different activities, teachers become aware of this major difficulty in "sound" argumentation.

Conclusions

The researcher starts with the recognition that pre-service science teachers need to learn the basics of school scientific argumentation, since they are required to teach at school at least three pieces of content related to it:

(1) How to scientifically argue in the classroom, as a major competence that should subsequently be transferred to the exercise of citizenship;

(2) Major scientific arguments (historical and current), as epitomes of "good", sound connection between claims and evidence;

(3) The nature of scientific argumentation, undoubtedly as a key feature of contemporary science (as cited in McComas, 1998).

Therefore, there is an urgent necessity to design good pedagogy around this content. The researcher's efforts are aligned with the production of theoretical foundations, practical proposals and empirical results that provide insights into this issue. Along with this line, the researcher thinks that the ideas discussed in this paper contribute to:

(1) Going deeper into model-based science education research and innovation practices, making links between valuable contemporary philosophy of science and science classrooms of all the educational levels (as cited in Develaki, 2007);

(2) Providing complementary perspectives to the "standard" analysis of arguments in school science using Toulmin's argumentation pattern;

(3) Showing examples of the use of rationales or guidelines to design teaching-learning sequences that are informed by research in didactics of science (as cited in Millar, 2002; Méheut & Psillos, 2004).

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