Method

This study is based on three groups of high school students (10th grade, 15–18-year-olds) enrolled at a public school in Venezuela. One group (n = 33) was randomly designated as the control and the other two as Experimental Group A (n = 33) and Experimental Group B (n = 38), respectively. The number of students on some test items varies as all the students registered in the course did not attend class on that day. All three groups were taught by the same instructor (second author of this study). Following is a summary of the activities in which the three groups participated:

First week: All three groups received instruction in the traditional expository manner on the following aspects of the topic on atomic structure: Thomson, Rutherford, and Bohr models of the atom and the Millikan oil drop experiment for determining the elementary electrical charge. This presentation was based on the textbook by Caballero and Ramos (2001), which follows the traditional approach characterized as 'rhetoric of conclusions' (Schwab 1974); namely, students were not allowed to reason and understand the underlying arguments. Most of the time during this week was spent on emphasizing (based on the textbook approach) experimental details (Thomson, Rutherford, Millikan and in the case of Bohr experimental evidence related to hydrogen line spectra) and ignoring the rationale of why and how the scientist was doing his work. At the end of the week, students were asked to draw a concept map based on how they perceived the development of scientific knowledge. Students had received instruction on the elaboration of concept maps in a previous course based on the work of J. Novak (Ausubel et al. 1991; Novak and Gowin 1988; Novak 1990).

Second week: All three groups responded to a 3-item Pretest (presented later in this section). Experimental Groups A and B were provided a Study Guide based on the scientific method and the Millikan–Ehrenhaft controversy with respect to the determination of the elementary electrical charge (see Study Guide, Appendix). Students were asked to read the Study Guide over the weekend and prepare for discussing it the next week. During this week, Control Group students continued to discuss the atomic models of Thomson, Rutherford, and Bohr. On the other hand,

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Experimental Group students were asked to read the Study Guide, followed by a question–answer session dealing with various aspects of the Millikan–Ehrenhaft controversy.

Third week: Experimental Group students (A and B) were subdivided into small groups and asked to present and discuss what they considered to be the principal ideas in the Study Guide. The instructor acted as a moderator and clarified issues. Discussion of the Study Guide generated considerable discussion and following are some of the salient features: (a) How could Millikan discard data and not report it in his published paper? (b) It is not clear how Ehrenhaft followed the scientific method and still lost support of the scientific community? and (c) Do all scientists work like Millikan and Ehrenhaft? After this interactive session, students were asked to draw another concept map based on what they considered to be the most important aspects of scientific development. During this period, the Control Group students were provided instruction with respect to the atomic structure based on the traditional methodology. For example, simple problems based on electronic transitions (Balmer formula) were solved.

Fourth week: Both Control and Experimental Group (A and B) students responded to a 5-item Posttest. Besides this, all groups received instruction with respect to a simple version of the wave mechanical model of the atom, uncertainty principle, quantum numbers, and electron configurations of chemical elements.

During the next month, 17 students from the Experimental Groups (A and B) and 11 from the Control Group were selected randomly for a semi-structured interview, which was conducted by the second author. All interviews were audiotaped and then transcribed. Each interview lasted about 30 min, and the instructor showed the students their responses to items from the Pretest and Posttest and requested clarification or any additional comments. Items in the Pretest and Posttest were elaborated by consulting the science education research literature and three investigators working in history and philosophy of science at our university.

Pretest

1. What in your opinion was Millikan's major contribution in the oil drop experiment? Did Millikan develop his experiment without receiving any contribution from other scientists?
2. After the scientists have developed a theory (for example atomic theory), does the theory ever change? Rutherford completely changed Thomson's model, and Bohr changed Rutherford's model. Do you think that these scientists made mistakes while doing the experiments?
3. How does scientific knowledge develop? Explain.

Posttest

1. Scientists have a unique method (scientific method) for carrying out their experiments; that is, there exists only one way of doing science. Can a diversity of methods exist for developing scientific knowledge? Explain.
2. Some astrophysicists believe that the universe is expanding, whereas others believe that it is in a static state with no expansion or reduction. How are these

different conclusions possible if all of these scientists have done the same experiments and have the same experimental data?
3. Scientists do experiments in order to collect evidence to find answers to the hypotheses they have proposed. What is the importance of experimental data for scientists?
4. In your opinion, during the development of the experiments, does controversy with other scientists and creativity can help in the development of science?
5. In your opinion, what are the most important aspects of scientific development?

Item 2 of the Pretest and Items 1 and 2 of the Posttest are adapted from Lederman et al. (2002) as part of their *VNOS-Form B* (p. 505). With respect to the scientific method, these authors stated: 'The myth of the scientific method is regularly manifested in the belief that there is a recipe like stepwise procedure that all scientists follow when they do science' (Lederman et al. 2002, p. 501). At this stage, it is important to note an important difference between items in the Pretest and Posttest of this study and those in *VNOS-Form B.* All items in this study are context specific or in other words have a domain-specific background. For example, Items 1 and 2 of the Pretest specifically refer to Millikan's oil drop experiment, Thomson, Rutherford, and Bohr's models of the atom—all these formed part of the students' chemistry course and were included in the textbook they followed (Caballero and Ramos 2001). This textbook formed part of a study that reported the evaluation of atomic structure in Venezuelan high school chemistry textbooks within a history and philosophy of science framework (Páez et al. 2004). Similarly, the textbook by Caballero and Ramos (2001) also formed part of a study that evaluated the oil drop experiment in Venezuelan high school chemistry textbooks (cf. López 2006). In the case of the Posttest, Item 2 refers to the work of the astrophysicists, whereas the other four items refer to the oil drop experiment.

Validation of Students' Responses on Items in Pretest and Posttest

In all items of the Pretest and Posttest, students were provided the opportunity to express their views, opinions, reasons, understandings, and of course epistemological beliefs. At no stage in this study, we have claimed that students' responses (both Control and Experimental Groups) were fully representative and exhaustive of their thinking at a particular point during the evaluation. Students were at liberty to express their views to the extent that they considered necessary and essential. Furthermore, it is important to note that the format of these items is very different from multiple choice evaluations. Responses on all items in the Pretest and the Posttest were classified as: conceptual, rhetorical, and no response. Most of the criteria for classification were the same as used by Niaz et al. (2002) and Niaz and

Luiggi (2014). In general, a conceptual response showed an understanding of the underlying issues, whereas a rhetorical response simply reiterated the information provided (quite similar to what Schwab 1974 has referred to as a 'rhetoric of conclusions'). In general, conceptual responses provided plausible reasons that supported a particular stance/understanding of the issues being explored and were based on reflections and not memorization. On the other hand, rhetorical responses were generally prescriptive with little attempt to present arguments/reasons for adopting a particular position. Furthermore, rhetorical responses at times reiterated memorized textbook presentations related to theories and models, which consider that if a theory/model is replaced it means that the previous formulation was erroneous. According to current history and philosophy of science, theories/models are not right or wrong but differ in their heuristic or explanatory power (cf. Lakatos 1970). Examples of both types of responses are provided in the next section. Responses of 4 students from the Control Group and 8 from the Experimental Groups (A & B) were classified by both authors. There was a coincidence of 76 % on the Pretest and 70 % on the Posttest. Disagreements were discussed in various meetings and both authors presented arguments and finally a consensus was achieved. Remaining responses were then classified by the second author, and in the case of further disagreements, both authors discussed and resolved the differences.

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