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WHAT ABOUT “THE” SCIENTIFIC METHOD? A SURVEY APPLIED TO MIDDLE AND SECONDARY GEOSCIENCE TEACHERS

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Abstract

The debate over whether there is a single unifying scientific method or a variety of methods, each of which is applied to a different discipline of science, is still a difficult one. Popper idea of refutation was a criticism to the inductive method and claimed the need to submit theories to falsification. His thesis ended up being a demarcation of science and pseudoscience. But the question remains: do all sciences follow the same scientific method? Namely because discoveries in geology have to overcome time and space enormous scales, geologist have been called by Lord Kelvin as “stamp collectors”. Having started as a field science, and even having been denied by Hutton as an experimental science, modelling in geology only took place at the end of the 19th century by the hand of Sir James Hall. The need to mirror scientists' methods is a demand of inquiry-based teaching, but few geology teachers have correct knowledge about the method used by geologists. In the present study, a survey was undertaken online with the main objective of investigating what is teachers' knowledge about the (geo)scientific method. Participants were 108 geology middle and secondary teachers in Portugal. The majority of respondents were women (n=79; 73.1%) and the average age was 46 years old. All participants were graduated, but 51 (47.2%) had a master and 5 (4.6%) had a Ph.D. The results showed erroneous conceptions that are commonly reflected in inquiry-based teaching classrooms, namely regarding the scientific method but also about investigative competencies and geology as an experimental science. The majority of the teachers' said that there only exists one scientific method for all sciences (n=49; 45.4%) and that it has a fundamentally linear nature from observation to conclusion (n=54; 50.0%). The scientific method was claimed as needed to allow the confirmation of hypothesis by many teachers (n=44; 40.7%). Some participants referred Uniformitarianism as a principle that justifies the historical and interpretive reasoning of geologist (n=48; 44.4%), but not so many referred the analogic reasoning (n=28; 25.9%). Teachers also referred to critical and systemic thinking as scientific competencies (n=72; 66.7%) and gave less importance to others like observation and argumentation (n=27; 25.0%). Results analysis corroborate that an inquiry-base teaching methodology requires history of geology and an epistemological reflection to be integrated in teachers' initial training and professional development. The epistemology behind geology classes has to be taught to eradicate alternative conception about the scientific method.

Keywords: *Scientific-inquiry, scientific reasoning, investigative competencies, geology, teaching sciences.*

1. Introduction

Scientific method is still described in science texts as if it is a rigid, linear, and unique process. This discussion, whether it is a single unifying scientific method or if there are variety of methods applied to different disciplines of science, is well developed in educational literature. The present study specifically focuses on science teachers' views about scientific method and how they use the scientific inquiry in sciences (geology) classrooms. According to Lederman (2009) and Lederman and collaborators (2014), scientific inquiry is the processes of how scientists do their work and how the resulting scientific knowledge is generated and accepted, being the combination of general science process skills with traditional science content, creativity, and critical thinking to develop scientific knowledge. Inquiry-based teaching is claimed as the most preferable methodology to teach science aiming to develop students' knowledge and investigative competences. Inquiry-based teaching is defined as a pedagogical approach that models the scientific method. But to resort to that methodology, teachers need to have to have a clear understanding of the scientific method (or preferable named as scientific inquiry). Nevertheless, some critiques have already arisen regarding the use of the scientific inquiry in schools because it has been represented as an inflexible, rigid rendering of the actual processes of the scientific method (the scientific inquiry in science proper) leading learning to desocialization of knowledge (Emden, 2021). Within this theoretical framework the purpose of this study is to diagnose geology science teachers' knowledge of the geological scientific method and how they teach it in their inquiry-based classrooms.

2. Scientific method and models in geoscience research and teaching

At the beginning of textbooks, we regularly find accounts of scientific method designed to assist the beginner student in getting an idea of how scientific investigation may differ from inquiry in other areas (Blachowicz, 2009). These parts of the introduction to textbooks provide a relatively quick account of scientific method that is standardized, avoiding controversies, but also making no particular clarification regarding the scientific method and a particular discipline. The scientific method, as it has been portrayed in popular and introductory textbooks, has been declared a myth (Rowbottom & Aiston, 2006). According to Woodcock (2014) the use of the definite article 'The' implies that there is one and only one, a single and unique method. Nevertheless, historically there are at least two most influential views: inductivism and hypothetico-deductivism, that sometimes are both used in the same discipline. On the other hand, some authors claim the scientific method as having a fixed and linear number of steps, but no consensus is found in literature review about it. Woodcock (2014) mentions that beside no agreement being found in the number of steps, there is also no agreement in the starting point. For some authors the beginning is recognizing a problem (Marshak, 2022), for others it is by making observations (Bailey, 2021; Edmund, 2000; Pilar, 1979). For some authors the end is publishing (Edmund, 2000), but for many others it ends before reaching this point. This ambiguity among what is the scientific method may raise a question in middle and secondary teachers: What about the scientific method we have to teach in our science classrooms? Besides that, not yet well clarified issues, the geological method, and reasoning has many unique and singular particularities. Geology is a historical and interpretative science that has as its main principle the Uniformitarianism, popularized by Charles Lyell in the beginning of the 19th century. This principle reflects the assumption that the same natural laws and processes that operate in our present-day are the same that operated in the past and can be applied everywhere. Based on that methodological principle the geological scientific reasoning is not only historical an interpretive, but also resorts to analogies. Another problem that makes teaching the scientific and the nature of geology even more difficult, is the fact that it started as a field science and only in the middle of the 19th century was it also recognized as an experimental science. The use of models in geological research started by the hands of James Hall, but only after the death of James Hutton, a vigor's opponent to investigate geology in a laboratory mainly due to the enormous space and time scale geologists need to operate. The use of models in the classroom plays key roles in developing scientific understanding (Oh & Oh, 2011) of geological processes and are believed to support science instructions in eradicating students' alternative conceptions. Nevertheless, it is necessary for science teachers to understand the features of models used in geological research and in geological education before using them in inquiry-based classrooms.

3. Inquiry-based teaching

Scientific inquiry is one crucial component of scientific literacy and necessary for the science learning process (Chen, Pan, Hong, Weng & Lin, 2020). The term inquiry is generally used throughout the science education literature to describe approaches to science teaching. The inquiry-based teaching methodology sets knowledge and beliefs that guide the teaching of science (Abell & MCDonald, 2006). According to Deboer (2006), there is a tendency to treat inquiry-based teaching as if it is a new methodology and innovative, but in the middle of the nineteenth century it was already integrated in the educational landscape. In other words, it mirrors scientific inquiry by emphasizing investigative competences: questioning, observation, investigation, problem solving, and many others. Inquiry-based teaching uses the general processes of the scientific method as its teaching methodology. The aims of that methodology highlight the students' involvement in scientific questions, use of evidences in their answers, the establishment of explanations and the capacity to communicate and argue justifications (Lotter, Smiley, Thompson & Dickenson, 2016). It resorts to laboratory activities and to field work, but also to tasks in library to engage students to model the process by which scientists conduct their research. Wallace and Kang (2004) discovered that teachers' perceptions of good science learning were strongly linked to their perceptions of laboratory and inquiry implementation. Those teachers who believe that successful science teaching is deep conceptual understanding are more likely to use verification laboratories in their teaching, while teachers who believe that successful science teaching is to enculturate students into scientific thinking practices focused more on inquiry-based laboratories. Although being used since the middle of the nineteenth century, today natural science teachers (biologists and geologists) forget its essence and resort to textbook and lecture to teach science in primary and secondary schools (Capps & Crawford, 2013). These results, as often mentioned by teachers, are due to a lack of familiarity with inquiry-based learning (Harrison, 2014). However, according to research, the main issues include a lack of proper curriculum, a lack of resource resources, and a lack of professional development regarding assessment practices (Chen et al., 2020). Many teachers, according to Vhurumuku (2015), fail to educate about the nature of scientific inquiry because they either do not comprehend it or do not have the pedagogical abilities to do so. Explicit instruction, according to Abd-El-Khalick and Lederman (2000), is required for teachers to effectively educate about the nature of scientific inquiry.

4. Methodology

A survey resorting to a questionnaire was applied to 108 geology middle and secondary teachers in Portugal. Most respondents were women (n=79; 73.1%) and the average age was 46 years old. All participants were graduated, but 51 (47.2%) had a master and 5 (4.6%) had a Ph.D. The average years of service was 21 but ranging from 1 year to 48 years. The questionnaire (Appendix 1) had four demographic questions, nine multiple choice questions and one open question. Although the instrument was not timed, 6 minutes was the average time needed for the survey to be answered. The application was done online resorting to familiar teachers' websites and answers were collected for four months. The informed consent to use the gathered information in the investigation was explicitly written in the introduction of the questionnaire as well as the voluntary participation and the confidential treatment of data. The quantitative data were analyzed in the IBM SPSS Statistics version 27 and was mainly descriptive. The open question was subject to content analysis allowing its categorization and codification.

5. Results and discussion

A relevant number of the teachers' said that there only exists one scientific method to all sciences (n=49; 45.4%) and that it has a fundamentally linear nature from observation to conclusion (n=54; 50.0%). Only 16 teachers (14.8%) mentioned that each scientific area has a specific scientific method in accordance with its object of study. The scientific method was claimed as needed to allow the confirmation of hypothesis by many teachers (n=44; 40.7%), but most participants (n=51; 47.2%) referred that it is needed to ensure the replicability of the experiences. When specifically asked about the geological scientific method, participants referred that geology was just a field science (n=2; 1.9%), others that it is only an experimental science (n=1; 0.9%), the majority mentioned it was both a field and experimental science (n=103; 95.4%), and some that its method can never be used in the laboratory (n=2; 1.9%). Those answers were not expected since geology was first recognized as a field science and generally geology teachers do not realize that simulations can be done in the laboratory or that geology became an experimental science since the end of the 19^{th} century. However, more than 50% of the sample had a master or a Ph.D. and that specialization could have eliminated those erroneous conceptions. Nevertheless, many alternative conceptions emerged when asked about the experimental geology. As such, a huge number of participants considered Hutton as the father of experimental geology (n=38; 35.2%) when indeed he was its greatest opponent. Almost the same number of teachers referred that experimental geology started at the end of the 19^{th} century (n=37; 34.3%), or that it started with the work of the naturalist in the 17^{th} century (n=33; 30.6%). Regarding the use of models in geology only 2 participants (1.9%) referred to them as not accepted by the scientific community and many of the teachers claimed they are needed to discover new knowledge in geological research (n=63; 58.3%). When asked about the Uniformitarianism, 48 teachers (44.4%) referred that this principle justifies the historical and interpretive reasoning of geologist but not so many referred the analogic reasoning (n=28; 25.9%), nor the scientific (n=18; 16.7%). Teachers also referred to critical and systemic thinking as scientific competencies (n=72; 66.7%) and gave less importance to others like observation and argumentation (n=27; 25.0%). Regarding the open question and after a careful content analysis, researchers group them in four categories expressed in table 1. Many of these results are corroborated by other studies (Cigdemoglu & Köseoğlu, 2019) reflecting that the understanding of scientific inquiry is a critical element of teachers' professional development.

Table 1. Questions to be addressed about the scientific method and reasons.

Questions about the scientific method	Teachers' justifications
How can it be used in the classroom? Do not know the geological scientific method? What are models in geology? How can we build models to teach? How to promote innovation with inquiry-based approach?	Difficulty to understand some questions. Interest in knowing more about the theme. Not knowing how to teach the scientific method. Lack of information about that subject.

The results and the questions referred by teachers to be explored in teacher training or professional development, justifies a more profound intervention with epistemological and historical contents allowing the teacher to have more knowledge, and to use the inquiry-based teaching methodology in a more fruitful way. As teachers need to understand how to implement inquiry-based teaching, the scientific method and the nature of science justifies the need for developing, implementing, and sustaining more professional development activities.

6. Conclusion

The survey results showed teachers' erroneous conceptions that are commonly reflected in inquiry-based teaching classrooms, namely regarding the scientific method but also about investigative competencies and geology as an experimental science. Main conclusions indicate that the epistemology behind geology classes has to be taught to eradicate alternative conception about the scientific method. As such the inquiry-base teaching methodology requires history of geology and an epistemological reflection to be integrated in teachers initial training and professional development. If we learn from researchers, we may create learning experiences that are tailored to the requirements of teachers, resulting in improved instructional practice, and creating a mind-set of continuous professional development. If we do so we can discover about what professional development content is really needed to be approached so as to irradiate teachers' alternative conceptions about the scientific method.

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Appendix 1

SCIENTIFIC METHOD QUESTIONNAIRE

This questionnaire is intended to collect data for research, and it is aimed at middle and secondary school teachers of Natural Sciences and Biology and Geology. When answering it, you are giving your informed consent to let the researchers use the answers for the study being undertaken. The anonymity and confidentiality of the data collected are guaranteed. Please, voluntarily tick as many answers as you consider correct.

I. Personal data

Q1. Age (on 31st December 2021)
Q2. Sex
Q3. Area of expertise (e.g., geology, biology, among others)
Q4. Academic degree (the highest)

II. The scientific method

The scientific method is referred to by many scientists as the best contribution humanity has made to itself. So, we can refer that:

Q1. We consider that…
a) there is only the (unique) scientific method that applies the same in all areas of knowledge.
b) there is only the (unique) scientific method that is suited to the specificities of each area of knowledge.
c) each area of knowledge has its scientific method (not unique) defined according to the object of study.
d) each area of knowledge has its scientific method (not unique) defined according to the experimentation to be carried out.

Q2. The steps of the scientific method in geology are:
a) 1st Observe; 2nd Design a testable Forecast; 3rd Elaborate Hypothesis; 4th Experiment; 5th Conclude.
b) 1st Observe, 2nd Hypothesis, 3rd Draw a Testable Prediction, 4th Experiment, 5th Conclude.
c) 1st Observe; 2nd Elaborate Hypothesis; 3rd Experiment; 4th Conclude.
d) There is no linear sequence, the order of the steps is flexible.

Q3. The scientific method in geology must make it possible to obtain results that…
a) confirm the hypothesis.
b) are replicable.
c) reject the hypothesis.
d) are predictable.

Q4. The investigation method of geology is…
a) a field-only method.
b) an experimental method only.
c) a field and/or experimental method.
d) a method impossible to be carried out in the laboratory.

Q5. The experimental geology…
a) has existed since the time of the naturalists.
b) appears in the 19th century.
c) was advocated by Hutton.
d) It does not exist.

Q6. Models in geology are…
a) used only to monitor and predict geological processes in the laboratory.
b) fundamental to discovering new geological knowledge in the laboratory.
c) undeniably accepted in the scientific community.
d) recognized as not valid in the process of scientific discovery.

Q7. The principle of Uniformitarianism justifies geological reasoning to be…
a) scientific.
b) historical and interpretive.
c) by analogy.
d) None of the above.

Q8. If geology is an experimental science, this justifies geological reasoning being…
a) scientific.
b) historical and interpretive.
c) by analogy.
d) None of the above.

Q9. Inquiry-oriented teaching of geology requires the development of investigative skills, such as:
a) Scientific reasoning, critical thinking, and systems thinking.
b) Observe, measure, argue, and communicate.
c) Systems thinking and environmental insight.
d) Observation and systems thinking.

Q10. What questions about the geology scientific method would you like to be seen clarified?