Acta Scientiarum
http://periodicos.uem.br/ojs/acta
ISSN on-line: 2178-5201
Doi: 10.4025/actascieduc.v42i1.45389

Cantor's dilemma: approximations between experimentation, literature and natural sciences teaching

Fábio Peres Gonçalves[1] and Elisa Prestes Massena[2*]

[1]Universidade Federal de Santa Catarina, Florianópolis, Santa Catarina, Brasil. [2]Universidade Estadual de Santa Cruz, Rodovia Jorge Amado, km 16, Ilhéus, Bahia, Brasil.*Corresponding author. E-mail: elisapmassena@gmail.com

ABSTRACT. Research indicates the potential of literary works to be used in teaching natural sciences. This text deals with Carl Djerassi's *Cantor's dilemma* (1991), a material that portrait intrigues from the academic world in the form of fiction. The objective of the present study was to investigate the potential of this work for the approach of experimentation in training natural sciences teachers from various fields. The work was analyzed according to the procedures of the discursive textual analysis and two emergent categories were constructed: 'epistemological issues associated to experimentation' and 'the laboratory diary in scientific activity'. The analysis pointed out the potential of the work to favor the debate regarding: the function of experimentation in the refutation/confirmation of hypotheses and their social nature; the non-reduction of the work with experiments to the action in the laboratory; the association between experimentation and error; and writing in laboratory journals and related aspects.

Keywords: experimentation; literature; teacher training.

O Dilema de Cantor: aproximações entre experimentação, literatura e ensino de ciências da natureza

RESUMO. Pesquisas sinalizam o potencial de obras literárias para serem utilizadas no ensino de ciências da natureza. O texto em questão trata da obra *O dilema de cantor* de Carl Djerassi (1991) que trata, em forma de ficção, de intrigas do mundo acadêmico. O objetivo do trabalho foi investigar o potencial dessa obra para a abordagem da experimentação na formação de professores da área de ciências da natureza. A obra foi analisada de acordo com os procedimentos da análise textual discursiva e foram construídas duas categorias emergentes denominadas 'questões epistemológicas associadas à experimentação' e 'o diário de laboratório na atividade científica'. A análise apontou o potencial da obra para favorecer o debate em relação: à função da experimentação na refutação/confirmação de hipóteses e à sua natureza social; a não redução do trabalho com experimentos à ação no laboratório; à associação entre experimentação e erro; e à escrita em diários de laboratório e a aspectos a ela vinculados.

Palavras-chave: experimentação; literatura; formação de professores.

El dilema de cantor: aproximaciones entre experimentación, literatura y enseñanza de las ciencias naturales

RESUMEN. Investigaciones señalan el potencial de obras literarias para ser utilizadas en la enseñanza de las ciencias naturales. El texto en cuestión trata de la obra *El dilema de cantor* de Carl Djerassi (1991) que trata, en forma de ficción, de intrigas del mundo académico. El objetivo del trabajo fue investigar el potencial de esta obra para el abordaje de la experimentación en la formación de profesores del área de las ciencias naturales. La obra fue analizada de acuerdo con los procedimientos del análisis textual discursivo y se construyeron dos categorías emergentes denominadas 'cuestiones epistemológicas asociadas a la experimentación' y 'el diario de laboratorio en la actividad científica'. El análisis apuntó el potencial de la obra para favorecer el debate en relación: a la función de la experimentación en la refutación/confirmación de hipótesis y a su naturaleza social; a la no reducción del trabajo con experimentos a la acción en el laboratorio; a la asociación entre experimentación y error; y a la escritura en diarios de laboratorio y a aspectos vinculados a ella.

Palabras-clave: experimentación; literatura; formación de profesores.

Received on November 5, 2018.
Accepted on September 12, 2019

Introduction

The possibility of using literary works in teaching natural sciences has been mentioned in several works. Guerra and Braga (2014), for instance have pointed to Umberto Eco's well-known work *The name of the Rose*, as a resource by which discussions can be developed about the nature of science, more specifically about the birth of modern science. Other noteworthy works, such as *The periodic table* by the writer Primo Levi (Levi, 1994), have also been the object of researchers' analysis on the teaching of natural sciences. Regarding this work Osório, Tiedemann, and Porto (2007) and Gonçalves (2014) highlighted its potential to be explored in the teaching of chemistry, as well as to favor discussions regarding experimentation in chemistry teachers-training.

A lot of research on experimentation in the field of teaching natural sciences was developed over the last decades. Important collections have been published, such as those organized by Wellington (1998) and by Psillos and Niedderer (2002). Many articles have drawn attention to the need to overcome visions of experimental activities supported by thesis of empirical-inductive understanding of science, including Hodson (1994), Gil Pérez, et al. (1999), Hirvonen and Viiri (2002) and Hofstein, Navon, Kipnis, and Naaman-Mamlok (2005).

In light of this, in the search to characterize other literary works with similar potential to *The periodic table* (Levi, 1994), the authors recommend the book *Cantor's dilemma* (1991) from the famous scientist Carl Djerassi (1923-2015). Therewith, the objective of the present study was to analyze the potential of *Cantor's dilemma* (Djerassi, 1991) for the approach of experimentation in training natural sciences teachers. The thesis is that experimentation is part of the education of natural sciences teachers and not only a 'methodological resource' to collaborate in the learning of specific natural sciences contents. Teachers must learn about experimentation, including how to best develop experimental activities.

The aspects pointed out by Gonçalves (2014) stand out in what does not constitute this work. In other words, this is not a work articulated with studies of literary theory. It is rather an indication of the potential of the work that could assist in science teachers training. It is known that interpretations of other areas of knowledge about the book under discussion are necessary and important. It should be noted that the scientific content of the reviewed book has not been equally examined or commented upon.

It is understood that when explored in educational processes, literary works with the potential to favor the approach of experimentation can contribute in a way that natural sciences teachers can play their role as language teachers, as appointed long ago by Sutton (2002). Similarly and Zanetic (2005) argues in favor of the idea that every teacher, regardless of the content they teach (be it mother tongue, foreign language, chemistry, physics, history, etc.) constitutes a reading teacher. It is evaluated that the defense favorable to a reading teacher runs through the fomentation of something redundant that is the formation of a reader teacher. This argument has been shared not only in the teaching of natural sciences but in other areas of the school curriculum (Hernandes & Souza, 2016).

The following are comments on the work *Cantor's dilemma* (Djerassi, 1991). After, the methodological detail for the analysis of the book is presented, as well as the results of its examination in order to emphasize its potentiality to discuss the experimentation in natural sciences teachers training.

Canto's dilemma: brief overview

Carl Djerassi's *Cantor's dilemma* (1991) exposes a fiction involving intrigues from the academic world. The author was a chemistry professor at Stanford University, and wrote a text with situations lived in this profession based on his own experience, mixing personalities of the world of science with figures of the fictional plane. The book is about a scientist (I. Cantor - I.C.) and his initial pupil (Jeremiah Stafford - Jerry) who may be nominated for the Nobel Prize due to an article published on *Nature* (*Cantor's dilemma,*1991), when conducting an experiment about tumors. Other characters are Kurt Krauss, an oncologist who defies Cantor's ideas and Celestine Price, J. Stafford's girlfriend.

The book introduces questions from the academic world, – such as the subtle relationships between renowned researchers in this field – involving the understanding of science and how they go through the constitution of groups of reference in research, who have to fight to gain recognition from their peers.

The first version of the work was published as a short story in the Hudson Review in 1986, been published in book format just in 1989. The short story was initially called *Castor's dilemma* but in the book publication the title became *Cantor's dilemma* (Garfield, 1989).

Carl Djerassi presents a considerable work of fiction literature, in which he portrays the aspects experienced in his university teaching career.

Methodological considerations

The book *Cantor's dilemma* was submitted to the procedures of discursive textual analysis (Moraes & Galiazzi, 2007) constituted by the stages of unitarization, categorization and communication. In the unitarization, based on the reading of the book, the units of meaning – excerpts associated with the objectives of the research – were extracted. Then, in the categorization, the units were grouped according to semantic criteria in emergent categories – those constructed from the units of meaning –, unlike the previously defined *a priori* categories from a theoretical framework. As the analytical choice was by means of emergent categories, a section with a previously defined theoretical framework that would guide the definition of *a priori* categories was not included. Finally, in the communication, descriptive and interpretive texts were elaborated about constructed categories, namely: epistemological issues associated to experimentation; and the laboratory diary in scientific activity.

The categories of articulation with theoretical interlocutors that support the discussion are discussed thereafter.

Epistemological questions associated to experimentation

Herein are presented the arguments regarding the potential of the analyzed work in favoring discussions about epistemological questions linked to experimentation in science. The questions refer to the role of experimentation in refuting/confirming hypothesis, to the collective dimension of experimental works, to experimentation beyond the activities performed in the laboratory and the relationship between experimentation and error.

The book sheds light on the idea that experimentation contributes to the confirmation of a hypothesis and also to the fact that a theory cannot be definitively confirmed. The following quotes are extensive but necessary to the analysis:

> 'So? You have a way to test it?' Kraus had immediately put his finger on the man's weakness. Cantor had not yet come up with any experiment that might demonstrate the correctness of his hypothesis, and a hypothesis without proof is sometimes worse than useless – it can be dangerous. A man can spend the rest of his experimental life chasing after a rainbow.
> [...]. Originally, he'd been apprehensive about how his hypothesis would hold up to one of Krauss's notorious critiques – the man could be merciless even to his friends – but after this morning's brainstorm on the toilet. Cantor felt supremely confident. He was not going to mention his flash of insight – the experiment that would convert hypothesis into unassailable fact – to Krauss or anyone else at Harvard. That would have to wait until the experiment was done. But he was convinced it would work. He felt intuitively that it was too beautiful not to (Djerassi, 1991, p. 6)[1].
> A scientific theory cannot be proved but only disproved. In other words, it must be tested experimentally (Djerassi, 1991, p. 197).

The first quote presented above encourages discussions on the possible comprehension of the role of experimentation in terms of 'confirming' hypothesis. This comprehension may favor the limited appropriation regarding the use of experimentation in science. As argued by French (2009), there are experimental works that originated from theories, as well as theories that are associated to experiments which until then did not find theoretical support that would explain the results.

The second quote shows a positioning with a certain distance from what was initially explained when affirming that experimentation 'would convert the hypothesis in undeniable fact'. This strongly dogmatic vision contradicts more contemporary discussions regarding the role of experimentation. Popper (1975) for instance, claimed that a theory cannot be conclusively confirmed by an experiment but it can be refuted by it. Popper's positioning goes against the empiric-inductive vision that favors verification of a specific

[1] Edition published by Penguin Books in 1991. However, the first edition as a book was in 1989.

knowledge by way of experimentation as a means to explain the truth. Similar to Popper (1975), Lakatos (1999) agrees with the impossibility of a definite confirmation of a theory by means of experimentation. However, he disagrees with Popper (1975) when it comes to the understanding that an experiment can conclusively refute a theory, signaling the historical dimensions of the so-called crucial experiments.

In light of the above, there is another quote from the book that deserves attention:

> In the, the second experiment – Cantor's independent test of his tumorigenesis theory – came out precisely as the professor had hoped: the changes in the structure of the incriminating protein were mirrored perfectly in the composition of the protein's template, the ribonucleic acid. He had vindicated earlier optimism: first a sweet theory, and now un even sweeter experiment (Djerassi, 1991, p. 114).

The understanding that the role of experimentation is to test a previously conceived theory is a contradiction to the empiric-inductive vision. The latter understands that the safe creation of knowledge comes from the sensitive experience. Chalmers (1993) classifies the understanding that scientific theories are originated from experimental data obtained through observation and experimentation as a common sense vision in science. On the other hand, the author affirms that the idea of scientific knowledge as proven knowledge can also be characterized as a common sense vision in science.

The idea regarding the collective dimension of experimental work contradicts the common sense about the works in the laboratory:

> When Cantor began to sketch the plan for his experiment on the Blackboard, however, something was different, and Stafford sensed it. The professor finished writing and Stafford stopped scribbling on the pad in his lap. Cantor, in his white lab coat – affectation that most superstars (outside of hospitals) did not share – had returned to his desk. He'd started playing with some paper clips, slipping one into another to form a chain. It was long enough for a bracelet when he finally looked up. 'Jerry', he said and then stopped. He lengthened the bracelet to a choker. 'I must ask you something that will probably surprise you. I don't want you to talk about this project with anybody, even in my lab. You do understand why I want this to be kept quiet, don't, you Jerry?' Cantor almost seemed to be pleading as he leaned forward. The paper clip chain jingled faintly as it hung from his hand. 'This is not the usual 'if' experiment: 'If it doesn't work we'll do this, and if it does, then we'll do that.' This' – pointed to the blackboard – 'has got to work, and when it's done, it's finished. Jerry' – Cantor gripped the side of his desk – 'this experiment will be in all the textbooks, it's the sort you do once in a lifetime. Look how lucky you are: you aren't even twenty-eight years old, while I [...] (Djerassi, 1991, p. 38-39, grifo do autor).

Kosminsky and Giordan (2002) have investigated the understanding among Brazilian high school students regarding what science is and who scientists are. One of the common understandings identified was that this profession deals exclusively with the activities and works inside the laboratory. It is common to find references in natural sciences teaching pointing that, for instance, television can contribute to the dissemination of the understanding about natural sciences among the students through documentaries and news (García-Carmona, Vásquez Alonso, & Manassero Mas, 2012). Works developed by Resnik, Massarani, Ramalho, & Amorim (2014), who analyzed the coverage of science and technology by a Brazilian news program, seem to corroborate with the above to a certain extent, considering that a significant part of the news showcased by a specific part of the program show scientists working inside of laboratories. However, there was a larger number of news and cases in which scientists would appear in offices or conducting field work. Considering all above, it is clear that fiction literature can contribute to battle certain common sense visions about scientific work when challenging the image of scientists as people who work alone and independently inside of a laboratory.

Social dimension consideration also appears in certain parts of the book referring to socializing results obtained by experimental work.

> Stafford quickly led Cantor through the key data – especially the scintillation counts associated with the radioactively tagged proteins. The professor was jubilant. 'We're going to write this up for Nature.'
> 'Not PNAS?' Stafford was surprised.
> 'No, I'd like to string this out a bit. Just a preliminary communication first, without the experimental details, so that nobody can jump on the bandwagon right away. Nature is just fine for that.' It was true; Nature a weekly, was one of the two most widely read journals in the world for preliminary communications on biologically related subjects. Watson ad Crick's first announcement of the double helix model for DNA had occupied a single page in Nature.
> 'In that case, why not Science? Why send the manuscript all the way to London? It'll take only a day to reach Washington.'

> 'Come to my office.' Cantor allowed himself a rare gesture of physical intimacy: he put his arm around Stafford's shoulder. Jerry, you know I'm not a secretive man. But in this instance, I'd like to have as little advance notice as possible. I want ... fireworks: a sudden explosion! Do you know how hard that is to bring off? I'm absolutely certain that, if we submit this to Science, Krauss will be one of the referees. If I were the editor, I'd certainly seek his advice. I'd like to surprise Kurt – after all, he's heard the theory, he as much challenged me to test it experimentally. We did it in less than three months!
> 'What's the matter with you, Jerry? Cantor smiled at his student. You ought to be jumping with joy. Instead you just sit there and mope.'
> 'I guess I'm just bushed, I. C. You do know how hard I worked.'
> 'Of course, Jerry. Of course. You get a good night's sleep and, tomorrow, prepare the two tables summarizing the radioactivity and nuclear magnetic resonance data. I'll write the paper myself tonight. Then we'll go over the final text together' (Djerassi, 1991, p. 57-58).

There is an explicit positioning towards the relationship between the process of socializing scientific knowledge in scientific epistemology – and which involves working with experimentation. Kuhn (2011) has discussed the importance of socialization for the validation process of what is produced by scientists – and that cannot be limited to the knowledge originating from experimentation. In the context of natural sciences teaching, Sutton (2002) emphasized that a few students seem to believe that scientists conduct experiments and discoveries, and language seems to be used solely for the purpose of socializing what was 'discovered'. The author believes that this is an incomplete and deceitful understanding regarding scientific work, especially because it neglects the role of language in the creation of new knowledge. Sutton (2002) adds that scientists must persuade themselves and their peers, as well as engage in negotiations about what should be the focus of investigation, and that these aspects must be addressed in education, in such a way that it enables natural sciences teachers to be equally seen as language teachers. Socializing experimental results reinforces the understanding that the work inside the laboratory is articulated with other activities that stretch beyond this space. There is another part of the book that supports this understanding:

> He wondered whether his old professor would have approached him under such circumstances. Probably not. But then Stafford was an exception – even among his own students. During the past couple of years, Jerry had practically become his younger alter ego. When Cantor resumed, his voice had recovered it customary briskness, business as usual. 'Jerry, you know what's at stake here. It can't take longer than three months – not if you drop everything and start right away. Better head for the library the now – and look into who else has used that Maeda technique. It's the usual density-gradient differential centrifugation but with a clever twist: he alternates between a stepwise and a continuous gradient. It ought to help you locate our protein in cellular plasma membranes. If I were you, I'd start with the Citation Index. You should thank God for it. When I was your age, all we had was Index Medicus or Chemical Abstracts.'
> It was true, the Citation Index simplified life. In contrast to all of the other bibliographic aids that searched the literature backward, this one did it forward. Maeda's original paper had been published in 1983. The Citation Index would list all publications since 1983 citing Maeda paper and thus would lead Stafford quickly to other workers who had used the same method. It would save Stafford hours, but he knew all that, and Cantor knew that Jerry knew. Even though he suspected that the younger man would be irritated, Cantor could never resist the temptation to point out how much tougher research had been in the old days (Djerassi, 1991, p. 39-40).

Sutton (2002) reinforces that writing is just as important for science as handling delicate equipment inside of a laboratory – which has already been acknowledged by the quote above. Moreover, reading is equally fundamental for the development of scientific work and for experimentation in the laboratory itself. The author insists that aspects as such must be taught to students and suggests that the natural sciences teachers should educate their students to read while tracking the 'ideas' and 'evidences' used by scientists in order to understand how knowledge and language transform in the context of natural sciences. Gonçalves (2014) has also identified the reference that work as experimentation is not limited to the laboratory in the book *The periodic table* by the Italian writer Primo Levi. The author presents his work as a resource to be used in the initial formation of chemistry teachers to favor the learning of experimentation while contributing to a broader cultural education of these students.

Cantor's dilemma can still contribute to reflections on the epistemological nature of the relationship between experimentation and error:

> 'You mean what Stafford did was wrong?'
> 'No!' Cantor said sharply. 'It doesn't mean that at all. You put it too black and white. It could mean that,

> unknowingly, he has neglected to mention some crucial detail, Or Krauss's man neglected to follow one. I had that experience in my own graduate work as a chemist. I carried out a reaction, called a 'decarboxylation,' which involved heating a substance in a glass tube above its melting point. The first time, it worked beautifully, but later I had very erratic results. It took me a long time to figure out the explanation: initially, I'd used soft glass, which is slightly alkaline, while later I'd picked Pyrex. It turned out that the reaction was promoted by traces of alkali.' (Djerassi, 1991, p. 110, grifo do autor).

The french epistemologist Gaston Bachelard has made a relevant contribution to the discussion about error in science. The type of error that Bachelard (1996) refers to is not the one associated with the lack of information or distractions. It is the type of error from which researchers struggle to distance themselves at first. It is the type of error in the epistemological sense resulting from what the author called epistemological obstacles. Considering that developing scientific knowledge is related to the overcoming of the epistemological obstacles from an epistemological point of view, it is possible to affirm that error is the starting point for scientific progress. In other words, 'truth comes from error'. In the quote further above, there are indications that the type of error to which the character of Cantor refers to is the one that could be easily overcome by the scientist. Nevertheless, it is important to remember that Bachelard (1996, p. 126) stated that "[...] the first demanding experiment is the experiment that fails". This discussion links experimentation and error, and contributes to create a distance from the wrong vision that understands the role of experimentation solely for the purpose of confirming hypothesis and theories.

In summary, the book *Cantor's dilemma* shows characteristics that suggest that the reading and understanding of it favors discussions on the epistemological nature linked to experimentation. This could be a way to teach more about experimentation in science, for the sake of satisfying an old claim from the literature, in which teaching natural sciences should lead to the development of an approach that stretches beyond the products of science.

The laboratory diary in scientific activity

This category discusses aspects regarding the importance of a written record in activity diaries in the laboratory. The matter about the importance of record is emphasized in the work and it is explicitly stated that sometimes the lack of these records can put a certain activity performed in the laboratory in check. Here follows an example:

> The data were all ready for the professor's. In fact, so many papers and graphs were piled up on the desk that Cantor never even asked to see Stafford's laboratory notebook. The overflowing desk with its disorganized pile of papers and printouts and Xerox copies of journals articles ('Students don't read anymore these days in the library,' Cantor complained periodically, 'they just photocopy') was in striking contrast to the immaculate laboratory bench (Djerassi, 1991, p. 57, grifo do autor).

Making records into the diary is essential as it "[...] enables the researcher to recover past events with precision [...]" (Vieira, 2002, p. 93), and may become an instrument for future further analyses into the research data, as well as for further new questions. The written record has been carried out by scientists through the entire history of science (Chassot, 2004). However, it is necessary to explain how each scientist relates to writing. Silva and Trancoso (2015) stated that there are various types of documents created by scientists and one of them is their notebooks. According to the authors, such notebooks – or laboratory diaries – are used to avoid the loss of records and for grouping a set of information regarding the research such as comments, calculations, positioning about other articles etc. Along the same lines, Lima (1997) has emphasized the unsurmountable documentary value of written records for the understanding of all the aspects of a research study. The importance of the diary is also emphasized by other authors, such as Do Ó (2004).

The book questions the type of writing that should go into a laboratory diary and the exercise of carrying it out. Questioned about what he would write about the performed experiment, the character of Jerry Stafford says:

> What I've got to write isn't some exquisitely concise letter to the editor. I've got to produce the equivalent of cookbook: style doesn't count and brevity is frowned upon. And it has to be exact: nor just 'add a few drops of Tabasco, season to taste, and cook until done.' I.C. wants a description of everything I did those three months and in enough detail so they can repeat it at Harvard the precise amount of Tabasco, was it added dropwise or in one portion, the temperature and the time the dish cooked... (Djerassi, 1991, p. 84-85).

The quote above explains the understanding that the character has about what written records in the diary should look like: precise and detailed. These aspects can be linked to a scientific view in which all data must be 'reliable' and 'replicable'. However, as stated by French (2009), the relationship between theory and data should not be 'top down', provided that the experiment could have a 'life of its own'.

Following the quote further above, since the diary was never ready and Jerry Stafford kept coming with excuses, Cantor opts for the shortcut mentioned below:

> Cantor decided on a sloppy but simple shortcut; He would photocopy all the appropriate pages from Stafford's laboratory notebook and send these to Harvard with a brief explanatory latter.
> There was nothing improper in copying Stafford's notebook. A scientist's laboratory journal is not a personal diary; its whole reason for existence is to be produced on demand for inspection by others. Invariably, such notebooks are the kind one can buy at larger stationers, solidly bound, with page numbers already stamped in the upper corners. Entries reflect this solid, orderly façade: all are written down chronologically, completely, conscientiously, as a guide for others to follow. Just a Everest expedition leaders insist in maddening detail on seemingly trivial discipline, Cantor behaved in such a manner when it came to laboratory notebooks. Everything had to be entered in indelible ink, not pencil; even trivial calculations had to be in first-year graduated student got the same speech: 'You can't put too much into your notebook, but you can write too little. You never know which details may turn out to be crucial.' When the students departed from Cantor's laboratory, the notebooks had to say behind. A locked bookcase in the professor's spacious office contained over two hundred such books, carefully catalogued – the evidence of more than a quarter of a century's experimental work (Djerassi, 1991, p. 86).

The quote above shows the importance of a detailed record of experimental procedures. The written record is important for the understanding of what happened in the laboratory and also favors the understanding of the context in which an experiment took place.

The discussion regarding the laboratory diary is extended throughout the work and can be observed in another discussion between Jerry and Cantor:

> 'It's strange. You've always preached to us about keeping proper records, but I never saw yours while I worked with you. When you sent the Xeroxed pages to Krauss – don't get me wrong, I.C., but it looked a bit like a student sending his notes to the professor – and When Krauss gave the to me, I was almost touched, I say 'almost' because, frankly, I resented the fact that I learned about the details of your work through Krauss rather than directly from you.'
> Cantor displayed no emotion.
> 'here isn't much more to say. Your notes were clear and concise. And you know, I got some awfully good training in your lab. I breezed through your experiment the first time though' (Djerassi, 1991, p. 221).

Based on the quote above, it is possible to approach the association between writing and success in science, as if the detailing of recorded information could not lead to knowledge that can be historically overcome. In sum, there seems to be a linear relationship between detailing records and the success creating knowledge. The idea is that a type of science consolidated on the scientists' success with the omission of mistakes can be subjacent to that, when in fact the error is often linked to the epistemological truth (Vallverdú & Izquierdo, 2010).

Therefore, *Cantor's dilemma* also presents the potential for a discussion about the aspects associated to the laboratory diary, so as to strengthen the discussion mentioned in the previous category regarding the importance of writing for scientists.

Final considerations

The analysis of the book *Cantor's dilemma* (Djerassi, 1991) suggests its potential to be explored in education processes with the objective of discussing the epistemological dimension in experimentation and the characteristics of laboratory diaries. Among the possible debates that can be stimulated by the book, there are those concerning: the function of experimentation and error; and the written records in laboratory diaries and the aspects linked to it. It has been assessed that discussions regarding these aspects can contribute to natural sciences learning while also contributing to broader students' cultural education through the access to literary works. Studies encouraging reflections regarding the epistemological nature of experimentation during natural sciences teachers training are frequent. Exploring the literary works to ease engaging in such reflections can represent an alternative.

It is important not to ignore the fact that the work with literary studies is associated to the teachers' and the students' understanding of the act of reading. The way the teacher conducts the process of reading with

students will have direct implications in their learning. Recognizing that reading is not a neutral process requires the awareness that the readers' understanding about the role of experimentation in natural sciences can influence their reading and understanding of the book *Cantor's dilemma*. The authors share the vision of Freire (2008), who believes that reading the world precedes the reading of words. Thus, a common sense vision regarding experimentation can determine the way high school students read the world when taught by natural sciences teachers exposed to the reading of *Cantor's dilemma*. The reading of the world must be learned appropriately by the teacher and taken into consideration during the reading of words – based on the contributions of contemporary epistemology regarding experimentation.

The study of experimentation in the analyzed book can also encourage the discussion on what is called the 'scientist with literary aspiration'. Carl Djerassi was a well-known scientist whose works were not limited to 'creating science'. In addition to *Cantor's dilemma*, the author has also published other works, including studies in collaboration with another also well-known scientist: Roald Hoffman (awarded the Nobel Prize in Chemistry). These scientists have written *Oxygen* (Djerassi & Hoffmann, 2001). The reading of literary works produced by important scientists can support in demystifying common-sense visions that place the virtues of people dedicated to the natural sciences and people dedicated to literature and other arts, human and social sciences etc, against one another.

Still in the context of teacher education, it is necessary to recognize the importance of acknowledging teacher's understanding about the use of literature in science teaching. Particularly regarding the popular science literature, Strack, Loguércio, and Del Pino (2009) investigated higher education chemistry teachers perception regarding the use of this literature in their classes. The authors pointed out that the teachers did not envisage the use of scientific literature in their classes, which may be due to the context of these professionals' performance and their educational trajectories. Thus, the results are in line with the argument that the use of literature in science education needs to be constituted as a content of teacher training processes in all different levels. It is understood as a theme of expanding research the articulation between literature, teacher training and natural sciences teaching, so that one can seek understanding of issues such as: a) how natural science teachers explore the literature in their classes? How do teacher trainers approach the use of literature in natural science classes as a content of their practice? What are the educational processes that articulate literature and science teaching contributions for the submitted subjects? Publications in recent years, such as Gonçalves and Brito (2014), suggest that the articulation between literature and science teaching may be present in educational processes. In this authors' work it is proposed an activity of reading and analysis of excerpts from Primo Levi's *Periodic table* for teaching about experimental activities for undergraduate chemistry students.

Regarding the context of basic education, which was not the focus of the present study – therefore, beyond the teachers training – it is important to recognize the necessity of exploring the book *Cantor's dilemma* within the discussion with other knowledge areas and not limiting its understanding to the natural sciences. Therewith, the authors would like to state that although the focus of the discussion herein was on experimentation, there is no disrespect, for instance, to the poetic license of the present work, especially due to the understanding that it is the study of the work in the interaction with teachers of other knowledge areas that can enrich its study in school.

Henceforth, the potentials of the work *Cantor's dilemma* can extend beyond the approach of experimentation, in the quality of education content for natural sciences teachers.

References

Bachelard, G. (1996). *A formação do espírito científico: contribuição para uma psicanálise do conhecimento*. Rio de Janeiro, RJ: Contraponto.

Chalmers, A. F. (1993). *O que é ciência afinal?* São Paulo, SP: Brasiliense.

Chassot, A. (2004). *A ciência através dos tempos*. São Paulo, SP: Moderna.

Djerassi, C. (1991). *The cantor's dilemma*. New York, NY: Penguin Books.

Djerassi, C., & Hoffmann, R. (2001). *Oxygen*. Weinheim, DE: Wiley-VCH.

Do Ó, A. A. (2004). Thomas Lindley: um viajante fala de doenças e dos seus enfrentamentos, no início do século XIX. *História, Ciências, Saúde-Manguinhos, 11*(1), 13-31. Doi: 10.1590/S0104-59702004000100002

Freire, P. (2008). *A importância do ato de ler: em três artigos que se complementam*. São Paulo, SP: Cortez.

French, S. (2009). *Ciência: conceito-chave em filosofia*. Porto Alegre, RS: Artmed.

García-Carmona, A., Vásquez Alonso, À., & Manassero Mas, M. A. (2012). Comprensión de los estudiantes sobre naturaleza de la ciencia: análisis del estado actual de la cuestión y perspectivas. *Enseñanza de las Ciencias, 30*(1), 23-34. Doi: 10.5565/rev/ec/v30n1.442

Garfield, E. (1989). Current comments. *Current Contents, 12*(1), 300-304. Retrieved from http://www.garfield.library.upenn.edu/essays/v12p330y1989.pdf

Gil Pérez, D., Furió Más, C., Valdés, P., Salinas, J., Martínez-Torregrosa, J., Guisola, J., & Carvalho, A. M. P. (1999) ¿Tiene sentido seguir distinguiendo entre aprendizaje de conceptos, resolución de problemas de lápiz y papel y realización de prácticas de laboratorio? *Enseñanza de las Ciencias, 17*(2), 311-320.

Gonçalves, F. P. (2014). Experimentação e literatura: contribuições para a formação de professores de Química. *Química Nova na Escola, 36*(2), 93-100. Doi:10.5935/0104-8899.20140011

Gonçalves, F. P., & Brito, M. A. (2014). *Experimentação na educação em química*: fundamento propostas e reflexões. Florianópolis, SC: Editora da UFSC.

Guerra, A., & Braga, M. (2014). *The name of the Rose*: a path to discuss the birth of modern science. *Science & Education, 23*(3), 643-654. Doi: 10.1007/s11191-012-9543-8

Hernandes, E. D. K., & Souza, R. J. (2016). The initial formation of the reader teacher. *Creative Education, 7*(8), 1175-1180. Doi: 10.4236/ce.2016.78122

Hirvonen, P. E., & Viiri, J. (2002) Physics student teachers' ideas about the objectives of practical work. *Science & Education, 11*(3), 305-316. Doi: 10.1023/A:1015216725459

Hodson, D. (1994) Hacia un enfoque más crítico del trabajo de laboratorio. *Enseñanza de las Ciencias, 12*(3), 299 -313.

Hofstein, A., Navon, O., Kipnis, M., & Naaman-Mamlok, R. (2005). Developing student' ability to ask more and better questions resulting from inquiri-type chemistry laboratories. *Journal of Research in Science Teaching, 42*(7), 791-806. Doi: 10.1002/tea.20072

Kosminsky, L., & Giordan, M. (2002). Visões de ciência e sobre cientistas entre estudantes do ensino médio. *Química Nova na Escola, 15*(1), 11-18.

Kuhn, T. S. (2011). *A estrutura das revoluções científicas*. São Paulo, SP: Perspectiva.

Lakatos, I. (1999). *Falsificação e metodologia dos programas de investigação científica*. Lisboa, PT: Edições 70.

Levi, P. (1994). *A tabela periódica* (Luiz Sérgio Henriques, trad.). Rio de Janeiro, RJ: Relume-Dumará.

Lima, A. L. G. S. de. (1997). A bordo do República: diário pessoal da expedição de Oswaldo Cruz aos portos marítimos e fluviais do Brasil. *História, Ciências, Saúde-Manguinhos, 4*(1), 159-167. Doi: 10.1590/S0104-59701997000100008

Moraes, R., & Galiazzi, M. do C. (2007). *Análise textual discursiva*. Ijuí, RS: Unijuí.

Osório, V. K. L., Tiedemann, P. W., & Porto, P. A. (2007). Primo Levi and *The periodic table*: teaching chemistry using a literary text. *Journal of Chemical Education*, 84(5), 775-778. Doi: 10.1021/ed084p775

Popper, K. (1975). *A lógica da pesquisa científica*. São Paulo, SP: Editora Cultrix.

Psillos, D., & Niedderer, H. (Org.). (2002). *Teaching and learning in the science laboratory*. Dordrecht, NL: Kluwer Academic Publishers.

Resnik, G., Massarani, L., Ramalho, M., & Amorim, L. (2014). Ciência na televisão pública: uma análise do telejornal Repórter Brasil. *Alexandria: Revista de Educação em Ciência e Tecnologia, 7*(1), 157-178. Doi: 10.5007/%25x

Silva, M. C. S. de M., & Trancoso, M. C. D. (2015). Produção documental de cientistas e a história da ciência: estudo tipológico em arquivos pessoais. *História, Ciências, Saúde-Manguinhos, 22*(3), 849-861. Doi: 10.1590/S0104-59702015000300011

Strack, R., Loguércio R., & Del Pino, J. C. (2009). Percepções de professores de ensino superior sobre a literatura d divulgação científica. *Ciência & Educação, 15*(2), 425-442. Doi: 10.1590/S1516-73132009000200012

Sutton, C. (2002). Los profesores de ciencias como profesores de lenguaje. *Enseñanza de las Ciencias, 21*(1), 21-25.

Vallverdú, J., & Izquierdo, M. (2010). Error y conocimiento: un modelo filosófico para la didáctica de la ciencia. *Enseñanza de las Ciencias, 28*(1), 47-60.

Vieira, J. A. (2002). O uso do diário em pesquisa qualitativa. *Cadernos de Linguagem e Sociedade, 5*(1), 93-104. Doi: 10.26512/les.v5i0.6518

Wellington, J. (Org.). (1998) *Practical work in school science: which way now?* London, UK: Routledge.

Zanetic, J. (2005). Física e cultura. *Ciência e Cultura, 57*(3), 21-24.

INFORMATION ABOUT THE AUTHORS

Fábio Peres Gonçalves: Graduated in Chemistry (2002) from Federal University of Rio Grande, Master in Science Education and Tecnology (2005) and PhD in Science Education and Tecnology (2009) from the Federal University of Santa Catarina. He is a professor at the Federal University of Santa Catarina (UFSC), Departament of Chemistry, and is a member of the Editorial Board of the journal Alexandria (2013-current). He has experience in the field of Education, working in research and teaching in the following themes: Teacher Training, Teaching and Learning.
ORCID: https://orcid.org/0000-0003-0172-2411
E-mail: fabio.pg@ufsc.br

Elisa Prestes Massena: Graduated in Chemistry (1999), Master in Science (2003) and PhD in Education (2010) from the Federal University of Rio de Janeiro. She conducted pos-doctoral studies in Education in the University of Vale do Rio dos Sinos (2013). She is a professor at the State University of Santa Cruz (UESC), Departament of Science and Tecnology, and is a coordinator of PPGEC/UESC (2018-2020). Vice president of Brazilian Society of Chemistry Teaching. Coordinator of Research Group GPeCFEC/Cnpq/UESC. She has experience in the field of Education, working in research and teaching in the following themes: Teacher Training, Curriculum and University Teaching.
ORCID: https://orcid.org/0000-0002-7670-0201
E-mail: elisapmassena@gmail.com

NOTE:
The authors were responsible for the conception, data analysis and interpretation; writing and critical review of the manuscript, and also the approval of the final version to be published.