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Open notebook science as an emerging epistemic culture within the Open Science movement

Open Notebook Science, une culture épistémique émergente au sein du mouvement de l'Open Science

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Résumés

English Français
The paper addresses the concepts and practices of "open notebook science" (Bradley, 2006) as an innovation within the contemporary Open Science movement. Our research points out that open notebook science is not an

incremental improvement, but it is a new "literary technology" (Shapin, Shaffer, 1985) and main element of a complex open collaboration ecosystem that fosters a new epistemic culture (Knorr-Cetina, 1999). This innovation aimed to move from a "science based on trust" to a science based on transparency and data provenance - a shift that recognizes the ability of scientists in performing experiments, but mostly, values their capacity of documenting properly what they say they have done. The theoretical framework was built with the notion of epistemic culture (Knorr-Cetina, 1999) and the "three technologies" perspective used by Shapin and Shaffer (1985) to describe the construction by natural philosophers of "matter of fact" as "variety of knowledge" so powerful that became synonymous of science itself. Empirically, we entered the "open lab" through a netnography that led us to understand that the epistemic culture being engendered by its practitioners is based on a "matter of proof".

Cet article traite des concepts et des pratiques d'« open notebook science » (science des cahiers ouverts) (Bradley, 2006) comme une innovation dans le contexte du mouvement de la Science Ouverte. Notre recherche indique que la science des cahiers ouverts n'est pas une amélioration incrémentale, mais une nouvelle technologie littéraire (Shapin, Shaffer, 1985) et le principal élément d'un écosystème complexe de collaboration ouverte qui encourage une nouvelle culture épistémique (Knorr-Cetina, 1999). L'innovation de la science des cahiers ouverts part d'une science basée sur la confiance à une science basée sur la transparence et la vérification de l'origine des données – un changement qui reconnaît l'habilité des chercheurs dans l'expérience, mais surtout qui valorise leur habilité de documenter de manière adéquate ce qu'ils disent avoir fait. Le cadre théorique a été construit à partir de la notion de culture épistémique (Knorr-Cetina, 1999) et la perspective des « trois technologies » utilisée par Shapin et Shaffer (1985) dans la description de la construction, par les philosophes naturalistes du « matter of fact » comme une « variation de connaissance » si forte que ce concept est devenu le synonyme de la Science elle-même. Empiriquement, nous avons exploré les laboratoires ouverts (open labs) par une netnographie, qui nous a aidés à comprendre que la culture épistémique forgée par les pratiquants est basée sur une « matter of proof ».

Entrées d'index

Keywords : Open notebook science, Open Science, Jean-Claude Bradley, epistemic culture, matter of proof

Texte intégral

Introduction

1 This article presents the results of a research project[1] that sought to understand both at a theoretical and an empirical level the proposal of an "open notebook science", as part of the innovations and of the epistemic culture (Knorr-Cetina, 1999) that are being generated within the scope of the contemporary[2] movement for Open Science. This innovation as well as the earliest experimentations in this field were conceived by Jean-Claude Bradley[3], a Chemistry professor and

researcher at Drexel University in the United States who aimed to promote a vigorous debate on open collaboration in science (Bradley; Lang; Koch; Neylon, 2011, p. 427). Bradley is acknowledged by other "evangelists" of Open Science as "one of the most influent open scientists of our time".[4]

2 This paper adopts two theoretical-methodological axes: Knorr-Cetina's (1999) notion of epistemic culture and Shapin and Shaffer's (1985) three technologies. On the one hand, it mobilises the notion of epistemic culture understood as "cultures that create and warrant knowledge" (Knorr-Cetina, 1999, p. 8); or else "those amalgams of arrangements and mechanisms-bonded through affinity, necessity, and historical coincidence – which, in a given field, make up how we know what we know" (Knorr-Cetina, 1999, p. 1). This concept operationalises our research to the extent in which: it defines knowledge as practice and not merely as an intellectual or technological product; it makes evident the fragmentation of science into different "independent epistemic monopolies"; and it goes against the idea of oneness and uniformity of scientific practices, including within the natural sciences. Thus, the paper analyses open notebook science as "entire conjunctions of conventions and devices that are organized, dynamic, thought about (at least partially), but not governed by single actors" (Knorr-Cetina, 1999, p. 11). On the other hand, it presents a characterisation of the emerging epistemic culture using the method adopted by Shapin and Shaffer (1985) to describe the process of legitimation of a new epistemic culture arising at the dawn of Modern Science as "*foundation of proper knowledge*".

3 Besides the bibliographical survey that laid the foundation for the development of this theoretical-methodological framework, this paper is also based on the survey and analysis of extensive documentation[5] produced and shared on an open mode, online and on real time, of the experiments with open notebook by its main enthusiast[6]. Starting from Bradley's premise that open notebook science, in its ideal form, would eliminate the asymmetry of information between researchers and the rest of the world, we made use of a netnography[7] as a means of getting into his "open lab" and of identifying the elements that make up this new epistemic culture[8].

4 Besides this introduction, the article is structured into five sections. The first one presents the state of the art of literary technologies and both models of scientific communication (diffusion and translation). Subsequently, we describe what open notebook science is, its origins and the three technologies (material, literary and social) that compose its epistemic culture. Then, we discuss the innovations of this scientific communication strategy in section four and, finally, we present our conclusions that open notebook science is part of a new epistemic culture that we have called "matter of proof" in contrast with "matter of fact" of Modern Science.

The state of the art of literary technologies and their models of communication: from diffusion to translation

5 Modern Science — that we address as Science (in the singular) due to its dominance in our collective imagination — was set up by treating scientific facts as results of an unusual type of work, carried out within the walls of a lab by a small group of "builders of facts", the "the blessed few", whose exceptional understanding of nature allowed them the privilege of "discovering" something that had been hidden and that was then skillfully revealed. Its main innovation consisted in the setting up of a new "variety of knowledge", the "matter of fact", in such a robust way that this new epistemic and social category became synonymous of science itself. Its main literary technology is the blind peer-reviewed scientific article, published in scientific journals. The scientific article dominates over other forms of communication, that is, of sharing new knowledge, and is presented as "ready science". This way of doing science adopts a "model of diffusion" (Latour, 2000), that presents research results in coherent narratives that modulate assertions to produce a truth effect with the purpose of persuading others of the "discovery" of a scientific fact.

6 According to Shapin and Shaffer (1985), the origins of this literary technology go back to the *experimental essays* of Robert Boyle and of naturalist philosophers, directed to the communication of phenomena produced within the private space of laboratories to those who did not witness the experiment first hand. Its function was to create virtual witnesses, promoting public interest in general and the adherence of new practitioners. Given its importance, a number of stylistic characteristics were prescribed for the composition of these reports, so that they might project the simultaneity of the execution of the experiment onto the minds of readers. This operation is "supported visually" by the graphic representation of scientific objects or processes in order to fill up gaps in the imagination.

7 The authors point out that this literary technology is articulated with: a) the material technology of scientific instruments that makes visible the hidden elements in nature and that seeks to eliminate human interference, as well as the lab itself as a space reserved for the execution of experiments; b) the social technology of conventions that, based on the (direct or virtual) witness of experiments, validates a particular piece of knowledge as legitimate, determining who is allowed to produce it and how one should deal with controversy.

8 In opposition to the diffusion model and its literary technology that seeks to shape the scientific article into a coherent narrative elaborated to persuade readers, open notebook science adopts the

translation model of scientific communication (Latour, 2000). It is a literary technology intentionally designed to make visible, to varying degrees, the strategies used by “fact builders” to enlist and keep under control the huge number of necessary associations between humans (scientists, engineers, financiers, public administrators, citizens, etc.) and nonhumans (specialised literature, laboratory, machines, among others) in the production of “until their stabilization as a “black box” — “that which is not considered problematic and functions as an automaton” (Latour, 2000, p.140), a matter of fact.

9 By making such changes, this innovation could not be considered an incremental improvement on laboratory notebooks that had prevailed since the emergence of Modern Science. It is, in fact, a new literary technology that opens up the totality of research records to foster the collective and collaborative production of knowledge, to broaden participation in science, to improve the quality of circulating information and to restructure the peer review evaluation process.

Open notebook science: what it is, its origins and key issues

10 According to Bradley (Sept, 26, 2006), open notebook science refers to “a way of doing science in which — as best as you can — you make all your research freely available to the public and in real time”. It claims for a new form of formal communication between scientists, enriched by the early opening of information and results. It demands a new practice: making available in real time the totality of scientists’ laboratory notebooks on online platforms, as well as free licenses that make possible the access, reuse and redistribution of content by any person or automated system. This innovation does not only include raw data and information about positive results of a given piece of scientific research; it also disseminates partial status, weaknesses and challenges at a stage when they have not yet been solved by scientists. Sharing the “backstage” of science, its intermediate stages, doubts and difficulties is part of Bradley’s strategy aimed at promoting a “faster science, better science” and at attracting collaborators and resources in order to solve scientific questions challenging him.

11 Bradley defined open notebook science in the following way:

> […] I will use the term Open Notebook Science, which has not yet suffered meme mutation. By this I mean that there is a URL to a laboratory notebook (like this) that is freely available and indexed on common search engines. It does not necessarily have to look like a paper notebook but it is essential that all of the information available to the researchers to make their conclusions is equally available to the rest of the world. Basically, no insider information. (Bradley, Sept, 26, 2006)

12 Open notebook science's origin is situated at the junction of new forms of collaboration in digital environments and the emergence of a free digital culture. Its first practices were carried out in the context of the UsefulChem project, launched in 2005[9], to fulfill Bradley's personal objective of "making a useful contribution to society" because "In thinking about what has meaning for me as a scientist, I realized that the work I was doing wasn't having the kind of impact that I would like it to have, and it was not benefitting mankind in the way I would have hoped. I concluded that this was partly a consequence of secrecy" (Bradley, Sep 2010).

13 The author acknowledged the Open Source Software as a source of inspiration:

> In Open Source Software, the code is made available to anyone to modify and repurpose. What we have been trying to do with UsefulChem is to provide the analogous entity for chemical research, which is raw experimental data along with the researcher's interpretation in a format that anyone can easily re-analyze, reinterpret and re-purpose. A good example of repurposing is using some results and observations from a failed experiment in a way that was never intended by the original researcher. This just doesn't happen regularly in science because failed experiments are almost never included in publications. (Bradley, 26, Sept 2006)

14 Another motivation was the perception of the internet as a technological opportunity that would alter the whole cycle of scientific production. To Bradley, peer review is a mechanism that avoids wasting time with sources of information whose return is not clear or guarantee (Bradley, Feb, 13, 2006). As the Internet would facilitate access to information, new processes and criteria of peer review should be established[10]. In his perspective, the dominant model negatively affects scientific research by being "a cost-effective way to maintain the quality and focus of journal" (Bradley, Aug, 20, 2012). To him, the dominant format of peer evaluation mainly caters for particular interests: those of the editor, who analyses adherence of manuscripts to the editorial profile of the publication; those of the author who seeks public recognition for his contribution; and those of the reviewers who analyse works without having to replicate experiments (Bradley, Aug, 20, 2012).

15 According to Bradley (2012), scientific articles report in highly condensed manner the working-out of an experiment, offering generic descriptions insufficient for its replication. Besides, he estimated that 87% of his own scientific production would never go beyond the walls of his lab because it consisted of experiments that had failed to achieve the "expected results", being therefore considered as "failures" by gatekeepers (reviewers and editors) who define what is to be published in scientific journals. To him, science is made up not only of "success", but also by "failures":

> There is also a tremendous amount of useful information in reactions or reaction attempts that is never shared. Regardless of whether or not a reaction is 'successful', if its execution is carefully recorded it can provide valuable information. Some excellent tools and standards exist that allow for easy semantic tagging of chemical reactions and properties so that an experiment can be available for discovery as soon as it is started. (Bradley, Apr, 18, 2013)

Also:

> […] Any chemistry grad student can tell you that there is tremendous value in discussing failed experiments with others who are equally or more knowledgeable. However, this discussion is usually limited to lab co-workers. By recording ongoing experiments in blogs, I can help you just by knowing what you are trying to do, even if you have not yet succeeded. (Bradley, Feb, 9, 2006)

16 Bradley questioned the quality of scientific journals, including the most renowned ones, for their limited capacity of evaluation – restricted to anonymous evaluators who deal with gaps in information and whose voluntary work is precarious given the shortage of time to issue an opinion and the impossibility of replicating experiments. From this perspective, the open notebook would operate as a platform of open peer review and would broaden the scale of the process, as:

> The only people truly qualified to judge a piece of research are those who have actually looked at the raw data to see if everything adds up and that takes time, assuming they have access to it. It is unlikely than anyone will do that without being properly motivated – generally only other researchers trying to reproduce the experiment for their own purposes will have a good reason to invest the time. (Bradley, Oct, 04, 2007)

17 The author pointed out that open notebook science sets up a dialogue with the transition from a culture of "*trust in an authority"* to a culture of "*mistrust of everything and everybody",* even though both consider unacceptable that a researcher should publish results without providing experimental evidence. By stating that "Science is about mistrust", Bradley (Oct, 4, 2007) sought to promote the transition from trust to proof, using as a starting point practices based on transparency, on the quality of evidence and on the preservation of data provenance. That is, on the history of the set of data that allows its origins to be traced, the transformations it has undergone as well as the analyses and interpretations issuing from it.

> A major flaw in the current scientific publication system is that there is still too much trust. Readers are expected to trust editors to choose appropriate anonymous peers to review submissions. Reviewers trust primary authors when reporting the summarizing of their research results. Primary authors trust their collaborators, students and postdocs to give them accurate

> information when writing papers. If we make the laboratory notebook and all associated raw data public we can significantly reduce the amount of trust required to keep this house of cards standing. (Bradley, Oct, 4, 2007)

18 The availability of research data would greatly increase possibilities of scrutiny, correction, refutation, complementation, collaboration, validation and learning by a broad audience because “There is no gatekeeper to convince in this system. No software to download. No server to set up. Almost no learning curve. Anyone doing science is free to replicate in their field of interest. Fully democratic science” (Bradley, Feb, 9, 2006). The open notebook would also counteract the *trusted source cascade* effect*,* as “once in print, it is very hard to correct these errors, if they are eventually found out” (Bradley, Oct, 4, 2007). That is why he was vehemently opposed to the habit of considering as valid a piece of information because it had been published in a scientific journal and he categorically stated that “there is no *trusted source”.*

19 According to Bradley, the illusion that trustworthy sources do exist contributes towards disseminating the indiscriminate use of research results. As a result, he advocated a model of communication that adopts open curatorship practices to make explicit the procedures that generated the data, allowing the researcher to evaluate the relevance of assertions and the quality of the data by accessing their source. When commenting on the contributions of his students through their lab notebooks, he stressed that: “If you want to use a number, use it, but know what it means. (...) In an open notebook environment, you have the log page that describes what the student did. You can trust or not in this number by the details he or she gives you” (Bradley, Mar, 15, 2010). The author believed that it is the most productive way of dealing with the ambiguity inherent to scientific practice which can thus be reduced, albeit not completely eliminated. From this perspective, the open notebook would favour science based on evidence obtained through the – open and continuous – sharing of experiments, whatever their status (ongoing, finished, discarded) or result (partial or final; favourable or ambiguous).

20 According to Bradley’s understanding, the “matter of fact” is a problematic notion that distorts the communication among scientists by generating the perception that to display ambiguous or contradictory data is harmful to the researcher. With the statement “There are no facts in science, just evidences embedded in assumptions” (Bradley, Oct, 26 ,2008), the author pointed out that data produced by experiments should not be treated as irrefutable facts, but that, in the best of circumstances, they are evidence upon which scientists work with a degree of uncertainty and about which many suppositions are elaborated in their interpretation.

The Open Notebook Science and its three technologies

21 We now describe the three technologies of open notebook science as a practice which, when articulated, promote a new epistemic culture we have called “matter of proof”.

The material technology

22 Bradley’s laboratory, as many other Chemistry laboratories, was equipped with scientific instruments, chemical substances and other necessary input to the working out of experiments. It had computers employed for open notebook practices, among other activities; plus, equipment for the production of podcasts with the content of lessons and images of experiments.

23 Just as with other research units, access to the laboratory was controlled; nevertheless, it was also made accessible to non-members of the research team. The easiest way of “entering” the lab was obviously through its open notebooks. That is why, during the early years of its implementation, Bradley made considerable investments in the development of infrastructure and services aimed at recovering information such as the automatic indexation of contents through non-specialized search engines such as Google as well as RSS solutions that informed collaborators about updates.

24 In practice, his “open lab” connected a small and decentralised scientific community that brought together complementary expertise and gathered professional experts, amateurs, students, technicians, not-for-profit organisations and commercial enterprises[11] and boots, creating an “open collaboration ecosystem” that expanded the material infrastructure of the research because “now we're not just one lab doing research, but a network of labs collaborating” (Bradley, Jan, 09, 2008).

25 Bradley also shared material technology that expanded the possibilities of open research on antimalarial agents: for example, he donated samples of chemical compounds to other research units or carried out experiments thought out by third parties as long as the experimental plan had been approved by his team. From this perspective, Bradley’s Open Chemistry was not limited to Open Data, to Open Source and to Open Peer Review. Among many successful collaborations[12], the first “Open Science loop” in May 2007 stands out “where hypothesis formation, docking, synthesis, and assay results were performed openly in real time” (Bradley; Lang; Koch; Neylon, 2011, p. 430).[13]

The literary technology

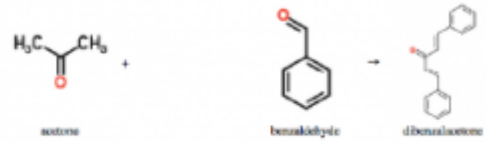
26 The earliest practices of open notebook used the Blogger proprietary platform to record research activities because its functionalities covered the initial expectations of publishing posts, setting up a dialogue with collaborators through comments box and of offering functionalities such as search engines and RSS feed to readers. Soon, the author realised that the blog's functionalities were limited, because open collaboration required more than commenting, suggesting or criticising. It was necessary to edit contents directly, to rewrite, to remake without the need of requesting a login and password from the platform's administrator. The UsefulChem Project became adopted the configuration of a "bliki" (blog plus wiki), in which the blog registers the status of the research project for a broader audience while the wiki records the working out of the experiments.

27 The standardisation of the "page of experiment" into a structured format whose completion becomes mandatory was aimed at ensuring the quality of the entry and of making it possible its re-use by information services (Bradley, Feb, 13, 2006). The page (figure 1) was made up of nine sections: 1) the number of the experiment; 2) the graphic representation of the experiment, 3) the name of the researcher; 4) the objective; 5) procedures; 6) results; 7) discussion; 8) conclusion and 9) log.

Figure 1. Experiment n. 269, done by the student Matthew McBride

EXP269 (/EXP269)

Editar | 0 (/EXP269#discussion) | 11 (/page/history/EXP269) | ... (/page/menu/EXP269)



Researcher

Matthew McBride

Objective

To synthesize trans-dibenzalacetone from benzaldehyde and acetone.**[link to procedure followed JCB]**

Procedure

Add ethanol to a 10% potassium hydroxide solution and a 20% potassium hydroxide solution in separate 500mL Erlenmeyer flasks. Ethanol will be added to each of these solutions. Benzaldehyde (0.43M in approximately 550 mL of reaction mixture and the limiting reagent) will be added to each solution and then acetone will be slowly added to each flask. The solutions will be stirred on the stir plate to allow the reaction to be completed. Orange crystals of trans-dibenzalacetone should form as the reaction proceeds. The trans-dibenzalacetone product will be separated from the solvent and recrystallized from ethanol to purify the product.

Results

No product was recovered in this experiment and will be repeated on a smaller scale.

Here is the spreadsheet that was used to prepare this reaction and to determine the amount of addition of the different reagents: Reaction Preparation Spreadsheet

Discussion

Trans-dibenzalacetone is a common compound synthesized in introduction organic chemistry labs. It has been used for many years by many different universities. However, little to no information is available regarding the solubility of trans-dibenzalacetone in different solvents. Since this product is used in many labs, it would be valuable to have an idea of the solubility of this product especially when a solvent must be chosen with which to purify the trans-dibenzalacetone. First, the product must be synthesized and that is the purpose of this experiment, but once the product is obtained, the solubility of the trans-dibenzalacetone will be measured in five organic solvents so that the Abraham model may be used to predict the solubility of trans-dibenzalacetone in many different solvents.

There are a few reasons that this experiment may have not obtained a product. For the future experiment, the KOH and water will be mixed together and the solid KOH will be completely dissolved in the solution before the ethanol is added. In a similar manner, the benzaldehyde will be thoroughly mixed into the solution prior to the addition of acetone to ensure that the acetone is reacting with the benzaldehyde.

Conclusion

The reaction likely failed because the benzaldehyde could not be fully solubilized with the amount of ethanol used relative to water. This synthesis was successfully completed in EXP279 with 1:1 ethanol/water, compared to only 1:6 ethanol/water used in this experiment.

Log

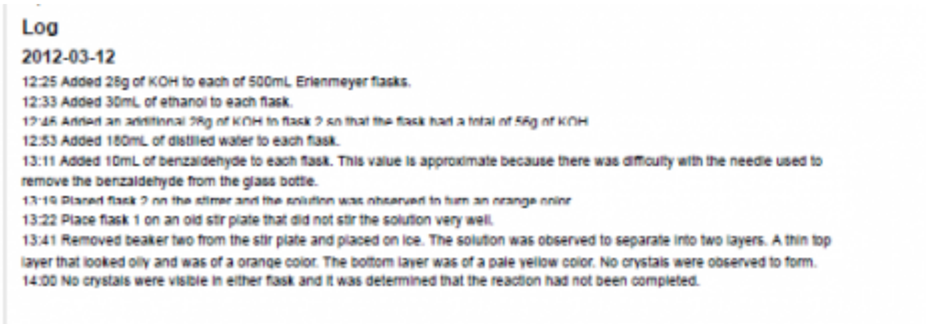
2012-03-12

12:25 Added 28g of KOH to each of 500mL Erlenmeyer flasks.
12:33 Added 30mL of ethanol to each flask.
12:46 Added an additional 28g of KOH to flask 2 so that the flask had a total of 56g of KOH.
12:53 Added 180mL of distilled water to each flask.
13:11 Added 10mL of benzaldehyde to each flask. This value is approximate because there was difficulty with the needle used to remove the benzaldehyde from the glass bottle.
13:19 Placed flask 2 on the stirrer and the solution was observed to turn an orange color.
13:22 Place flask 1 on an old stir plate that did not stir the solution very well.
13:41 Removed beaker two from the stir plate and placed on ice. The solution was observed to separate into two layers. A thin top layer that looked oily and was of a orange color. The bottom layer was of a pale yellow color. No crystals were observed to form.
14:00 No crystals were visible in either flask and it was determined that the reaction had not been completed.

28 Source: Open Notebook Science Challenge[14]

29 According to Bradley, the *log* (figure 2) is the most important section as, in an ideal mode, it records the experiment while it is being worked out – a fact that would ensure the precision and wealth of details. The recording of information adopts an objective style, without flourish, in which the researcher describes who did what, where, how, when and the partial results obtained. This format does away with the elaboration of a narrative, a requirement of scientific articles and it builds the *storyless experiment* (Bradley, Aug, 13 2007) which places value on partial results (*result-centric)*.

Figure 2 : Experiment n. 269 page detail – the log section



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Source: Open Notebook Science Challenge[15]

30 This understanding is radically different from practices adopted by scientific journals that privilege the communication of experiments *(experiment-centric)* or the obtainment of a molecule *(molecule-centric)*. Its major advantage is that “By focusing on each result independently, it no longer matters if the objective of the experiment was reached or if the experiment was aborted at a later point” (UsefulChem, 2012). Thus, it is possible to get rid of the binary criterion for classifying an experiment as “successful” or “unsuccessful” based on the achievement (or not) of a particular result.

31 Bradley intended to stimulate excellence throughout the scientific process and to promote discussions that are more consistent with science. In the collection “Reactions Attempt” efforts to work out reactions were made available, in which the gaps in the information were perceived as an invitation to establish collaboration among researchers who had an interest in the same reactions. From this perspective, open notebook could operate as a platform for social networking to the extent that collaboration networks become noticeable and can be monitored through the interaction of users[16].

32 Besides new file formats, the practices of open notebook require infrastructure. This must be user friendly, it must adopt open formats and offer functionalities so that its contents can be referable and recoverable by search engines, both generic and specialized in order to create an “ecosystem of collaboration” (Bradley, Lang, Koch, Neylon, 2011, p. 431).

33 From the legal point-of-view, Bradley adopted the Creative Commons Share Alike 2.5 license and the maximum degree of procedural opening, making available in its totality the content produced by his lab in real time, indicated by the logo “All Content – Immediate release” (Bradley, Feb, 24 2009)[17]. From the technical point-of-view, his experience with proprietary information management systems in laboratories[18] indicated that the need to learn to operate a new software discourages potential collaborators. As a result, Bradley adopted free web tools, already widely in use by the scientific community[19]. This option was also advantageous given the automatic and real-time indexation of content by search engines such as

Google[20], whose functionalities were personalized to meet the demands of collaborators in Google Custom Search for Open Notebook Science (Bradley, May, 15, 2008). The content became “easily found with no additional formatting work” because “as we approach 200 experiments it is becoming clear that the ability to retrieve information is just as important as doing the experiments” (Bradley, April, 27, 2008).

34 The community of adopters of the open notebook also invested in the indexation of the contents in specialized data banks, such as ChemSpider and X-Ray Crystal Structure Repository because “in a world of Open Distributed Science, redundancy is information's best friend” (Bradley, June, 07, 2008). In both cases, the representation of the information adopted *machine-readable* formats, by using the identifiers InCh and InChKeys[21]. However, the indexation of content solved only half of the problem as it was also necessary to elaborate *queries* to recover *result centric* contents as well as visualization tools. Rajashi Guha and Andrew Lang developed interfaces that compare *duplicate runs* visually (Bradley, Nov, 06, 2008) while Bradley experimented with the online game Second Life as a tool for 3D visualization of molecules for his students.

35 Motivated by the idea of “faster science, better science”, Bradley perceived in automation the possibility of diminishing the incidence of human error and of fostering a more analytical profile in researchers. To this end, he sought to create an automated workflow that would integrate repositories, blogs, wikis, data banks, search engines and applications to increase the accuracy of records, preserve the sources of data and avoid loss of information. In lab notebooks, automated logs could improve the quality of records because, as Bradley puts it, if you “Take a look at the lab notebooks in a typical organic chemistry lab – can you really reproduce all those experiments without talking to the researcher?” (Bradley, Jan, 03, 2008)

The social technology

36 The meaning of “being a scientist” or, in other words, of being a specialist, has been resignified in different senses. In the first place, the lowering of entry barriers by abandoning the requirement of previous formal certification confers the condition of peer upon any person (or automated system) capable of producing relevant contributions. In Bradley’s words, “I don’t care whether [the contributions] come from a Nobel laureate, from a precocious 14-year-old or from a bot” (Bradley, Dec, 12, 2006)

37 Formal interchange among researchers is no longer limited to the communication of scientific facts through articles, but it has become more diverse, both quantitatively and qualitatively. The *storyless experiments* format exempts researchers from the role of author of

coherent narratives about his/her research, promoting the move from a type of communication focused on scientific articles that report experiments or the obtainment of molecules to an approach focused on partial results, independent of their status (ongoing, finished, discarded) or final results (favourable or ambiguous). The adoption of open licenses allows researchers to be authors of contributions without becoming owners of the information. Combining these characteristics, open notebook science would favour the transition from the "all or nothing" of the culture of secrecy to an economy of microcredits that would acknowledge different types of collaboration and that would record the timestamp of whoever has made an independent contribution, whenever, wherever and however it was made.

38 To Bradley, any experiment well documented in an open notebook should be considered a contribution to science. For this reason, he advocated the early sharing of data in opposition to scientists' tendency to procrastinate, fostered exactly by the expectation of constructing the scientific fact. In the opposite direction to this tendency, the continuous opening of laboratory notebooks would establish a continuous process of open peer review, whereby, at any moment, collaborators act as testers. They access the documentation of an experiment and verify its adequacy as they try to obtain the same set of evidence the original author states he has produced. Thus, there is a move from a model based on reliable sources to a model of transparency about the source of data according to which "the whole truth is more valuable than a subset of the truth presented in a way that might be conveniently misleading" (Bradley, Feb, 28,2010).

39 Finally, the emergence of new patterns of discovery with the use of data-driven intelligence tools creates new professional profiles. In Chemistry, for example, the Cheminformatics professionals extract meaning from abundant data bases and their professional relevance lies on the capacity to manipulate information and to ask unprecedented and meaningful questions.

Discussion

40 Open notebook science is, maybe, the less known practice of the open science movement – an umbrella term encompassing several initiatives[22] and perspectives. Even though there is no consensus about the open science modus operandi, its extent and its political and social meaning (Albagli, 2015), its early adopters agree on at least three points: the first one is the understanding that dominant means of scientific production and communication are inadequate as they do not avail themselves of current possibilities of collaboration and sharing of information and knowledge. Secondly, the identification of digital technologies, particularly the Internet, as a "technological

opportunity" to promote the spirit of a "true science". This vision was clearly expressed at the Budapest Open Access Initiative (BOAI, 2002) that advocates the recovery of the "ancient tradition" and the "willingness of scientists and scholars to publish the outcome of their research with no remuneration, in the name of the transparency and democratization of knowledge". The third point of agreement is the adoption of the paradigm of open knowledge as conceived by the Open Knowledge Foundation (2005) as "any type of content, information or data that people are free to use, re-use and re-distribute with no legal, technological or social restriction". With open notebook science, it is no different.

41 Several arguments are put forward in favour of open science and its practices. It is alleged that most scientific research is financed by the State and, therefore, results cannot be privatised (Deng, 2008). Also, the role of knowledge in the defense of the "common good", in the strengthening of citizenship and in the construction of more equitable and sustainable societies is highlighted (Chan; Okune; Sambuli, 2015); but mostly, the possibility of maximising the advancement of science through both online and real time collaboration (Wilbanks; Boyle; Reynolds, 2006). The last argument was clearly adopted by Jean-Claude Bradley, summarized in his motto "faster science, better science". However, if this innovation shows great potential to increase the volume and quality of scientific information, Bradley didn't call attention to the fact that open notebook science can foster a new productivism in science without dealing with inequalities and contradictions in the actual scenery of the changing conditions of production and circulation of information and knowledge (Albagli, 2015).

42 Through the open notebook science concept and practice, Jean-Claude Bradley questioned the values supported and promoted by the dominant mode of science, advocating in favour of a new contract between science and society. In similarity to the Open Source movement that inspired him, he intended to create a method of developing science – open, robust and fast – to increase the capacity for innovation. He wondered if we could have "egoless science" (Bradley, April, 7, 2009) at experimentation level, in which scientists would not procrastinate to share relevant information because of the pride of appearing to run a perfect operation or the fear of doing certain experiments and not liking the outcome or that he/she might be proved wrong. In that sense, open notebook science fosters a "gift economy" where scientists should share information immediately, be less territorial regarding their production and benefit from the spontaneous contributions of third parties.

43 Operating now within the translation model, researchers' reputation would not be built through the positive evaluation of a "compiled version", "the article", but through the value of the "donated code", "the experiment" to an enlarged community of peers. In that sense,

open notebook science is a literary technology that can connect the well-established Open Access movement (to scientific articles published in peer reviewed journals) with Open Data efforts. This more recent movement is demanding the open share of the data that subsidises researchers' affirmations about their research findings which, in turn, is expected to be well recorded in laboratory notebooks. This innovation reclaims to share the entire research process, beyond favourable results of "successful experiments". Attempts and discontinuities are understood as the most promising opportunities for open collaboration because they are what is still to be done or accomplished.

44 It is worth calling attention to the fact that Bradley adopted the open paradigm with a certain degree of pragmatism. Like a *bricoleur*, he benefited from opportunities without giving up some of his principles. For example, he used online services that are not free tools, considering the cost-benefit of ubiquitous and easy-to-use platforms. This sense of opportunity was also present in his relationships to pharmaceutical labs and plants in the development of open antimalarial drugs. In this context, open licenses seem to be the mechanism that constitute a "win-win game" in which chemical and pharmaceutical industries can also be part of the solution to problems, as they can provide the input, the instruments and the investment for open research also, for their capacity of producing industrial-scale medicines. Licenses could operate as anti-property mechanisms that are meant to prevent that new monopolies of knowledge create barriers to stop scientific knowledge from reaching people.

45 Thus, the author sought to confront legal and technical questions necessary to the opening of knowledge, but he also made a heavy investment on a third aspect – the social – referred to in earlier definitions of open knowledge (Pollock, 2004) that stressed that access to knowledge should not be limited to the final version of works. This definition emphasizes the need to access the source code underlying the "raw material of knowledge" which allows us to verify and to modify the final products, to elaborate related works etc. To this end, it suggested "avoiding that information be kept under secret or forgotten in a drawer" (Pollock, 2004).

46 In that sense, open notebook science reclaims new practices that might operate on editorial, technical and legal obstacles to the circulation of knowledge. From the editorial point-of-view, Bradley was convinced that the blind peer review process, mediated by the action of scientific editors and anonymous evaluators, embodied excessive trust, perceiving it as a value intrinsic to science itself. This conception unfolded into a public perception that this type of evaluation is the locus of facts (not opinions), of full control of variables and protocols (without happy accidents), of writing (against orality) and of truth (and not misrepresentations). In the opposite direction, Bradley intended to promote excellence through mistrust – not to install a police state, but

in the attempt to clarify that scientific practice is very different from the images of stability, control and certainty of our collective imagination. Therefore, the open notebook science literary technology does not attempt to persuade readers or to close controversies at an early stage, but bets on the communication of scientific information without the previous control of an editorial board in an open process of peer review (open to everybody), transparent (seen by everybody), continuous (without an expiry date), interactive (allowing for replies and rejoinders) and dynamic (with new comments and corrections over time). It is an instrument of continuously open curation.

47 This innovation is the central element of an “open collaboration ecosystem” within which the production and communication of scientific knowledge work in a synchronous, integrated and automated way, creating continuity between open data and open access to scientific production once data provenance is preserved. This ecosystem is constituted by a set of tools that create an “architecture of attention” (Nielsen, 2012) at the service of a “projected serendipity”. Its objective was to “draw the attention of the right specialist to the right problem at the right time” (Nielsen, 2012, p. 24) so that the “latent micro expertise” responded just in time to a momentary question that blocked the development of research, enlarging collective intelligence. Within this approach, “faults”, gaps and ambiguity are not considered negative aspects of scientific practice, but fundamental characteristics of the production of new knowledge.

Conclusions: open notebook science and its new epistemic culture

Open notebook science is a very new concept, originally elaborated within the field of organic chemistry by a scientist with a particular teaching and researching experience at a university in the USA, and peculiar ties with the open knowledge movement. The initial conception developed by Bradley and early adopters has taken on new formats[23] and it is still under construction by new followers, particularly in Biology and Physics[24].

48 It is too early to evaluate the contributions of that approach to open science since it remains an alternative, non-mandatory practice, without relevant institutional support unlike the Open Access and the Open Data movements. We can mention some initiatives that adopt this approach, like Open Notebook Science Solubility Challenge, a crowdsourcing research project that collected more than 600 measurements of non-aqueous solubility of organic compounds and turned it into an open book. The accomplishment of the first open loop science in May 2007, in which all steps of a research, from “the

elaboration of hypotheses, docking, synthesis and analysis were performed openly". There is also the Open Source Malaria project (2011), coordinated by Matthew Todd, from Sydney University in partnership with Medicines for Malaria Venture (MMV), considered a very significant open notebook initiative, which is opening up the complex process of drug production with the ambitious objective of creating affordable treatments for a tropical disease neglected by the pharmaceutical industry.

49 Open notebook science was developed by Jean-Claude Bradley in order to deal with the false appearance of infallibility in science and the harmful effects of the "model based on trust" – to be replaced by transparency and the preservation of data provenance. The author acknowledged the problematic aspects of scientific practice, referring cases of fraud, plagiarism and corruption, but he invested on what he considers the system's structural faults: the concepts of "reliable source", the excessive confidence between peers and the notion of "scientific fact". When he stated that "There are no facts in science, just evidences embedded in assumptions" (Bradley, Oct, 26, 2008), he rejected the founding concept of Modern Science because he understood that, at best, measurements and experiments results can only be used as evidences, never as unchallengeable facts.

50 Given the characteristics of the open notebook science material, literary and social technologies described above, we conclude that open notebook science engenders a new epistemic culture that is not based on the construction of "matter of facts", but in we have called "matter of proof". It values the meticulous documentation of scientific practice above the making of scientific facts. It also favours the virtualization of testers since it is an open collaboration/curation platform where peers can question descriptions and results, point out omissions, suggest other ways of elaboration, repeat the experiment, suggest alterations, rectifications, and future developments. It may provide feedback and renew scientific research continuously.

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Notes

1 The article presents part of the results of the doctoral research “New laboratory notebooks and new epistemic cultures: between experiment policies and political experiment” approved by Post-Graduate Program in Information Science (PPGCI Ibict-UFRJ), supervised by Professor Sarita Albagli and co-supervised by Professor Antonio Lafuente, carried out with financial support of Fundação de Amparo à Pesquisa do Estado do Rio de Janeiro (Faperj) and Coordenação de Apoio ao Pessoal do Ensino Superior (Capes). The authors wish to thank Peter Murray Rust, Jenny Molloy and Cameron Neylon for their helpful comments.

2 Several scholars of science (Lafuente, Nielsen, Murray-Rust, David) have identified Modern Science as the “first open science revolution”, as the severe asymmetries of information between scientists and their sponsors resulting from the increased use of mathematics as well as from the proliferation of experimental practices required a control system with norms, incentives and organisational structures that reinforced the commitment of scientists to “the rapid diffusion of new knowledge” at the end of the 16th and the beginning of the 17th centuries. At this moment, the earliest scientific journals come into being as a way of propagating scientific knowledge and of constituting a shared body of knowledge and a long-term collective memory (David, 2011).

3 Professor Bradley coordinated *e-learning pr*ojects; he also taught the subject “Recovery of Information in Chemistry”. He was a member of the Blue Obelisk, an informal group created by Peter Murray-Rust in 2005 to promote open data, codes and standards for which he received an award in 2007.

4 Professor Bradley passed away in 2014; his legacy was the subject of the “Defining the Future for Open Notebook Science – A Memorial Symposium Celebrating the Work of Jean-Claude Bradley” that took place in July of the same year at the University of Cambridge.

5 The sources of information are the blogs UsefulChem and Drexel CoAS E-Learning; his open notebook “Open Notebook Science” (wiki), articles, chapters in books, interviews, shared talks in his Youtube channel, recordings of classes on the subject of “Recovery of information in Chemistry” and electronic presentations published on Slide Share.

6 We consider Bradley as the main “recruiter” of open notebook science by his special role in mobilising resources; but it is necessary to point out the support of Andrew Lang, Bill Hooker, Cameron Neylon, Rajarshi Guha, Steve Koch, Anthony Williams, Matthew Todd, Anthony Salvagno, Rajarshi Guha, Philip

Rosenthal Daniel Zaharevitz, among other early adopters and collaborators.

7 This term has been popularised by Robert Kozinets and it gives a name to ethnographically-inspired studies that describe a human group - interpersonal behaviour, beliefs, institutions, and material production – through objects of digital communication.

8 Although we acknowledge the existence of Computer Supported Collaborative Work movement and collaboratories on 1990s we haven´t implied that Bradley was affiliated with them at first. Since, our research adopts the perspective of the actor-network theory, we understand that actors aren't mere intermediaries that carry the effects of a wider social context without transforming it. Instead, they behave as mediators with the ability to "make other actors do unexpected things", making possible a certain state of things (Latour, 2005, p.187). In this sense, we have identified that Bradley had a previous experience designing digital technologies, such as the web-based laboratory management system Standard Modular Integrated Research Protocols (SMIRP) and that he was aware of collaboratories, but we considered it a minor reference since it was cited only once in all his public records, in a proposal draft named "CI Team: Using Cyberinfrastructure in Blogs, Wikis, and other RSS Technology to Promote Open Source Science in Higher Education and Workforce Development" written with Beth Lynne Ritter-Guth.

9 Starting from this objective, Bradley later on focused his work on the development of open antimalarial compounds.

10 Among those, quick online availability and the quality of the description of the experiments that had been performed.

11 In this case, companies adopted a CC license which is equivalent to a situation of public domain.

12 Other examples of successful collaboration are the Open Notebook Science Challenge and the Open Notebook Science Solubility Challenge, crowdsourcing research projects that collected measurements carried out by students who adopted the open notebook science.

13 The loop brought together docking analyses by Rajarshi Guha (Indiana University), syntheses of compounds in Bradley's lab, tests by Philip Rosenthal's group (University of California) and tests of antitumour activity offered Daniel Zaharevitz, head of the Information Technology Branch of the Developmental Therapeutics Program do National Cancer Institute (NCI).

14 Available at: http://onschallenge.wikispaces.com/EXP269 Accessed on: 10 Aug. 2015

15 Available at: http://onschallenge.wikispaces.com/EXP269 Accessed on: 10 Aug. 2015

16 Don Pellegrino, then PhD candidate, analysed the use of the collection Reactions Attempts, elaborated "maps between people and chemical [substances] as source of reliable and semantically unambiguous data" (ONS Challenge, 2010) and identified networks of collaboration based on the open notebooks. The post "Visualizing Social Networks in Open Notebooks" (Dec 20, 2010) says that they were experimenting network analysis, through automatic discovery of new connections in open scientific work, aiming to accelerate new collaborations. The open notebook science case integrates his thesis "Interactive visualization systems and data integration methods for supporting discovery in collections of scientific information" (2011).

17 In practice, the majority of early adopter notebooks are partially open or pseudo open. Four logos, developed in 2009, identify the degree of opening in terms of omissions or postponement of the publication of data and information.

18 Standard Modular Integrated Research Protocol (SMIRP), "a flexible modular collaborative tool that was originally designed to track and manage

the dynamic environment of a discovery-driven laboratory research operation" (Bradley, McEachron, 2003)

19 Bradley found inspiration in Open Dinosaur, the crowdsourcing Project for measuring bones that manages data with Google spreadsheets. (Bradley, Jan, 19, 2010)

20 "Google applications would prove to be key for other sophisticated search and retrieval tools that would evolve over time" (Bradley; Lang; Koch; Neylon, 2011).

21 Textual identifiers of chemical substances that facilitate their indexation.

22 Open Access, Open Data, Open Hardware, Citizen Science, Open Education, Open Peer Review, Open Curation are other initiatives that make up the range of practices of Open Science.

23 This notion has inspired, for example, Anthony Salvagno and Brian Glaz to organize the Open Notebook Science Network, created to remove technological barriers and make notebooks more accessible to researchers and the public. Similarly, the Open Edition platform created in 2009 by the Centre pour l'édition électronique ouverte (Cleo) has "a new space of experimental academic writings, direct communication between researchers, the construction of science" (Cleo, s/d), to encourage the practice of open blogs ("carnets") in Humanities and Social Sciences disciplines - currently with 2079 notebooks.

24 Our documental research has not uncovered any records indicating that Bradley intended to make open notebook science into a standard procedure in the field of chemistry, much less for other disciplines. However, researchers are opening their notebooks.

Table des illustrations

	**Titre**	**Figure 1. Experiment n. 269, done by the student Matthew McBride**
	URL	http://rfsic.revues.org/docannexe/image/3186/img-1.png
	Fichier	image/png, 67k
	**Titre**	Figure 2 : Experiment n. 269 page detail – the log section
	Crédits	Source: Open Notebook Science Challenge[15]
	URL	http://rfsic.revues.org/docannexe/image/3186/img-2.png
	Fichier	image/png, 15k

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