

## Open hardware as an experimental innovation platform: preliminary research questions and findings

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### ABSTRACT

In this article, we explore the concept of Open Hardware (OH) as an experimental innovation platform to take a first step in the study of the institutional and sociotechnical conditions for fostering and advancing Free and Open Source projects at the European Organization for Nuclear Research, CERN. For our purposes, OH will be described as a highly adaptable platform for present and future research infrastructures. As part of the contemporary movement for “Open Science,” OH will be examined with respect to its actual and potential contributions to the development of common tools and infrastructures for large-scale scientific collaborations. The primary data we use was gathered by the CERN Knowledge Transfer group in October 2016 through an online survey in addition to face-to-face interviews. Our preliminary findings point to the need for establishing different modes of institutional support beyond CERN and outside the hobbyist market to help advance cultures of collaborative hardware development in the sciences.

Keywords: *open hardware; experimental innovation platform; knowledge infrastructure; dissemination*

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### INTRODUCTION

Innovation studies have been radically transformed in the past three decades with the identification of the key role played by user-led innovation for advancing the state-of-the-art in many professional and scientific fields (von Hippel, 1988, 2004, Hyysalo et al., 2016). Questions of openness have been equally important in the study of innovation across distributed professional networks (Chesbrough, 2003, Chesbrough et al., 2017) and organised publics for Internet commons-based peer production (Benkler, 2006, Kelty, 2008, Fish et al., 2011). In this fairly recent but expanding research domain, Open Hardware (OH)<sup>1</sup> constitutes an important object of inquiry for creating new intra- and inter-organisational dynamics with higher degrees of openness to public participation.

In this article, we explore the notion of OH as an experimental innovation platform to take a first step in the study of the sociotechnical conditions for fostering and advancing Free and Open Source (FOS) projects at CERN. For our purposes, OH will be described as a highly adaptable platform to integrate present and future “knowledge infrastructures,” which represent “robust networks of [scientists], artefacts, and institutions that generate, share, and maintain specific knowledge” in various professional and academic fields (Edwards, 2010). As an integral part of the contemporary movement for “Open Science” (Fecher and Friesike, 2014, Albagli et

al., 2015) OH will be examined with respect to its actual and potential contributions to the development of common tools and infrastructures for large-scale scientific collaborations.

First, we will address OH as one of the mechanisms for knowledge transfer at CERN. Then, we will describe how OH is perceived by its practitioners based on a preliminary survey and a collection of interviews. Our primary quantitative and qualitative data were gathered by the CERN “Knowledge Transfer Group” (CERN-KT) in October 2016. It contains responses from community members, engineers, hobbyists, company executives as well as CERN engineers, managers, procurement officers, and legal experts. The preliminary study we describe here was conceived independently by CERN-KT as a first step to establish a more robust empirical foundation for future OH initiatives, exploring the interface between large-scale scientific organisations and “innovation communities,” conceived here as “nodes consisting of individuals or firms interconnected by information transfer links” (von Hippel, 2004, p. 96).

For our purposes in this article, experimentation is defined in two complementary ways. First, we assume it to be one of the key organisational and strategic dimensions of “hybrid forums” (Callon and Lascoumes, 2011) for debate regarding research and innovation as FOS technologies are mandated by the European Commission. Experiments in technical democracy shape

open innovation policies through the promotion of expert/lay-expert forms of engagement in “hybrid collectives” (Callon and Lascoumes, 2011) which are dedicated to create alternatives to IP-based research and innovation. In addition to broader policy-level debates on innovation, we call “internal”<sup>2</sup> the experimental dimension defined in historical and ethnographic studies of “experimental systems” (Rheinberger, 1997) as experimental set-ups, which allow for operationalising research questions, manipulating objects of inquiry, and exploring (and extending) the limits of what can be done in research settings. Reflecting upon the role of theory, research instruments, and experimental practices, we find this definition particularly useful to frame our studies of OH as one of the promising means for building scientific instruments and research infrastructures.

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## OPEN HARDWARE AT CERN

Introduced in 2009, OH was embraced as a knowledge transfer mechanism through the creation of the “Open Hardware Repository” (OHR) at CERN. Created to facilitate exchange among hardware designers, the OHR currently hosts more than 100 projects and more than 1200 units have been produced for more than 100 end-users (Nilsen and Anelli, 2016). In our estimates, the lead expert user and designer community around CERN OH projects consists of a little over 200 members with varying degrees of involvement.

To create a specific OH license at CERN, existing licenses were benchmarked and a public online channel was created to consult with the community. Subsequently, the “Tucson Amateur Packet Radio” license (TAPR) was used as the basis for drafting the “CERN Open Hardware License” (CERN OHL) published in 2011 (Ayass and Serrano, 2012, Powell, 2012, 2015).

In its experimental quality, OH has the capacity to bridge institutional spaces, disciplinary fields, and connect technoscientific experts through collaborative practices, shared tools, and protocols. This capacity to be adopted and adapted across expert domains is well known: many OH initiatives within and beyond the sciences have been directly or indirectly inspired by FOSS development models, tools, and values (Ackerman, 2008, Serrano, 2016). In parallel with FOSS, OH encompasses a wide range of moral, legal, technical and economic forms, which carry the potential for alternative productive arrangements, as well as hard barriers of field expertise for increased public participation. Many projects have been built on OH as a platform, such as the Arduino and Lilypad for interactive design (Buechley and Hill, 2010, Baker, 2014, Faugel and Bobkov, 2013), the RepRap 3D printing community (Söderberg, 2013) and the Berkeley Mote sensor project (Ruiz-Sandoval et al., 2006), among several others.

Despite positive experiences reported by OH designers, manufacturers, and users, the “coopetitive”

dynamics across highly heterogeneous domains of commercial and non-commercial activity remain understudied and unknown to a large extent. In order to help advance OH research, we started a collaboration at CERN to pursue the following research question through a series of case studies, combined with ethnographic studies of development practices and community dynamics: *What are the conditions for creating, maintaining, and scaling an OH platform for the sciences?* This is the overarching question from which we derive the one we address in this article: *What is the profile, perception, and experience of OH practitioners regarding the sociotechnical dynamics of OH?*

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## CERN OPEN HARDWARE SURVEY

In total, 149 cases were collected with an online survey for the “Impact of CERN Open Hardware study” and, after data clean-up of replicates and empty responses, the final dataset contained 146 respondents. For the analytic purposes, basic descriptive statistics were generated (Table 1 and Figure 1). Questions of evaluation and perception were not quantified but visualised using a Likert scale (Figure 2).

There are caveats with respect to the scope of the “Impact of CERN Open Hardware study.” First, the survey was meant as an exploratory device of limited depth and breadth, which is not to be taken as representative of the broader OH community. Since the goal was to learn initially about the basic profile and practical experiences of community members around CERN, target groups were initially categorised according to their self-declared role as “supporters,” “procurement,” “legal & administrative personnel,” and “firms.” Key CERN OH supporters were interviewed at first and several contacts were obtained. Interviewees were also identified through the OSHWA mailing-list after the survey was collected by CERN-KT.

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## RESULTS FROM THE EXPLORATORY SURVEY

In terms of the respondents’ basic profile, most participants are young professionals (in their 30’s and 40’s), male-identified with post-graduate degrees. The majority have technical backgrounds, followed by scientific and management training. Occupations range from company employee to academic researcher and a less than 20% of the respondents occupy top management positions. Interestingly, respondents are divided in two major groups of professionals in non-profit (55%) and for-profit sectors (45%). Younger age groups and gender disparity represent patterns, which have been observed in many surveys conducted with members of OH and FOSS communities (OSHW Community Survey 2012, 2013, Ghosh, 2005, Nafus et al., 2006). There is a concentration of respondents in their 20’s, 30’s, and 40’s. The well-

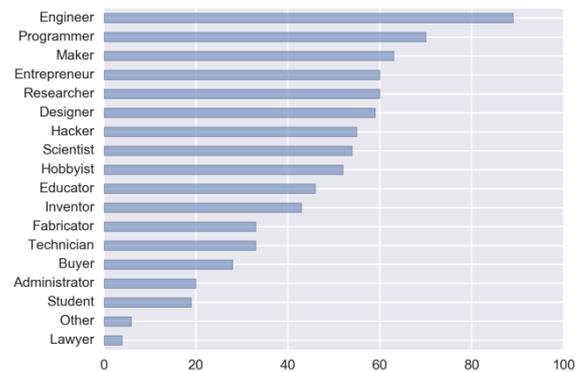
known abyss between a majority of men *vis-à-vis* women-identified and other gender minorities in FOSS is very present as well (Nafus, 2012). Levels of education express yet another parallel with previous OSHWA and FOSS surveys: most respondents have academic education but the biggest number has post-graduate-level education.

**Table 1:** Respondents' basic profiles

Age	%
18 – 24	3
25 – 34	39
35 – 44	35
45 – 54	17
55 – 64	5
65 or older	1
Location	%
Europe	49
North America	12
Latin America	7
Asia	4
Africa	1
Not-Available	27
Education	%
Ph.D.	31
Masters	40
Bachelors	21
Other	8
Gender	%
Men	89
Women	8
Other gender identifications	3
Job Title	%
Employee	29
Scholar	21
Entrepreneur	20
Manager	12
C Level Executive	10
Director, Vice-President	8
Job Function	%
Technical	59
Academic	19
Management	15
Administrative	5
Marketing	1
Sector	%
Non-profit	55
For-profit	45

In terms of reported roles in the OH community, most respondents self-identified as technologists (engineers and programmers) with popular identities, such as

“maker”, “entrepreneur”, “hacker” as well as established ones, such as “researcher” and “designer.” The second half of the respondents identified mostly as educators, inventors, fabricators, and hobbyists. The lowest concentration of responses reflects more peripheral and therefore less active positions, involving procurement officers, managers, legal experts, and students.



**Fig. 1:** Reported roles in the OH community

OH practitioners report a wide range of social and technical experiences. For generating the graph above, respondents described themselves in various categories at once. The broader community encompasses a much larger constituency of electronics amateurs, academics, mechanical and electronics engineers, and smaller groups of interaction designers and artists. According to the OSHWA surveys of 2012 and 2013, the majority participates in the condition of hobbyists using OH for self-education and personal projects (80% on average).

Many participants report having downloaded CERN OHL-licensed designs (63%) but fewer have released their own projects (30%) or contributed to CERN OHL-licensed projects (34%). Many respondents have reacted positively to the question of “CERN-OHL marketing value.” These initial observations suggest the need for further empirical work on license preference and adoption. Based on previous ethnographic research conducted among OH developers at community centres of the Pacific Rim, Murillo observed a predominance of flexible copyright licensing, such as Creative Commons, despite on-going debate about their inadequacy for hardware projects. This observation is corroborated by the OSHWA surveys which report on a majority of designers and engineers to use FOSS licenses (around 50% on average for 2012 and 2013 respectively), Creative Commons licenses (34.4% and 37.5%), and public domain for hardware documentation (25.3% and 26.6%). Counterintuitively, most respondents in OSHWA surveys report not having attached licensing information to their design files (49% and 47%). There is evidence of change in this trend with the wider circulation of the CERN OHL, whereas for the years of 2012 and 2013 its adoption was still relatively small (2.1% and 6.5% respectively). Despite higher-than-average understanding of licensing

models and issues among OH enthusiasts in general, little consensus has been reached regarding the existing alternatives for OH licensing, ranging from copyleft-inspired, such as TAPR and CERN-OHL, to permissive licenses, such as Solderpad. One of the most important historical reasons for the unprecedented level of public understanding of IP issues among FOSS and OH practitioners has to do with the political usage of flexible licenses as circumvention mechanisms to build alternative moral economies (Kelty 2008; Leach 2009). Licenses have, in their cultural sense, being used as a means not as ends for the purposes of collective organisation to build pools of public resources in various areas of academic, professional, educational, and artistic endeavour.

To advance an understanding of the CERN OH community, survey questions were dedicated to respondents' perceptions of social, economic, and legal dynamics (Figure 2). An overwhelming majority defended that “OH advances knowledge transfer” (Question 1). Strong agreement was also expressed with the observation that “OH is a personal reputation building channel” (Question 17) but not for companies (Question 16). Equally majoritarian was the affirmation that overall research and technology development costs are reduced (Question 10 and 22), development efforts are sped up (Question 5) and shared among various organisations (Question 24), and highly customisable products are made possible (Question 20) despite their small production batches. Documentation accuracy is more of a controversial topic (Question 21) and “openness” is considered responsible for increasing companies' “competitive advantage” (Question 4).

In contrast to the survey results, the interview material allowed us to move beyond the surface of opinions, giving access to much more nuanced understandings of the controversies and challenges surrounding OH as a platform for research and innovation. The debate about “lock-in mechanisms,” for example, was framed by the interviewees with industry experience in terms of independence from suppliers: whereas most responded positively, few companies reported the existence of new dependency ties with designers of OH products. Respondents have also observed that, in their experience, companies might not make the R&D investment to take up an existent design, shouldering the responsibility for manufacturing it. In various areas of non-critical application, such as in the hobbyist market, prices are driven down in a “race to the bottom” due to accelerated turnover coupled with the absence of quality control. For a group of industrial engineers working with scientific instrumentation, “when you order the same [OH] product based on the same schematics, the results can be dramatically different from one company to another.”

Respondents were divided around questions of market size and the possibility of revenue-generation based on OH services. Respondents hesitated when asked if they had experiences with legal disputes to evaluate the OH potential for reducing legal costs. Similar uncertainty and

doubt was observed with respect to license enforcement (Question 15).

The issue of “coopetition” surfaced many times in the qualitative dataset, whereas the majority of respondents agreed in the survey that “OHSW requires companies to innovate fast” (Question 9). This position was corroborated by an early OH entrepreneur who affirmed his company has to “run on a much faster clock speed,” which means keeping an accelerated inventory update to guarantee he is ahead of “cloners.” His company pushes new open hardware products to the market every twelve weeks on average.

Some of the key differences we observed in the responses to the survey and the interviews when comparing and contrasting OH and FOSS development models have to do with: 1) marginal costs of manufacturing; 2) value chain; 3) supply chain, including complex hardware supplier management; and 4) regulations as hardware is subject to more complex (consumer-protecting) regulations, including complex IP licensing issues.

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## **DISCUSSION: PRELIMINARY RESULTS AND OPEN QUESTIONS FOR FUTURE STUDIES**

From the preliminary results of the “Impact of CERN Open Hardware Study” we identified several open issues for further research. With respect to the participants' profiles, we observed the entrance of new but hesitant contributors: companies with expertise to provide OH services which are reluctant to make the initial investment. From the interviews, we gathered that traditional companies, entering the market to manufacture OH designs, do not want to be held responsible for the design itself. There are also complaints about hidden costs: design modifications generate R&D overhead depending on the complexity of the project at hand.

While some infrastructural elements of OH as an innovation platform have been worked out—for example through the CERN OHL and OHR—, there still remain many unexplored areas for improving documentation. This is a key question which relates directly to the issue of openness and accessibility. Despite overall positive perceptions of OH documentation, respondents with scientific hardware expertise described feeling frustrated with lack of sufficient documentation. Respondents also emphasised the fact that openness is not guaranteed with OH licenses.

Another pressing issue has to do with the need for clarifying the similarities and differences between OH and FOSS development methods and business models: whereas the former is more entangled in complex licensing arrangements (potentially involving several forms of IP protection), it demands a wider range of fields of expertise plus commercial involvement in various development phases. The confusion between the two has led to the unreflexive borrowing of FOSS development approaches without their proper transposition to the

domain of hardware. Difficulties in the process of transposition include the difficulty of identifying the basic elements of hardware documentation to render a particular project truly open. Last but not least, FOSS and OH have overlapping but distinct “hybrid collectives,” whereas the novelty of OH seems to be an attractive force to enrol new contributors to FOS development more generally.

Based on responses to the question of “how to track OH projects,” we identified the need for advancing the study of development trajectories with a focus on dissemination, adoption, and adaptation. In order to establish OH as an innovation platform, we gathered from OH practitioners it is fundamental to diversify the institutional support for further improvement of basic development tools for design, testing, simulation, and versioning (see: Serrano 2016 for further discussion of this topic). Innovation laboratories such as CERN IdeaSquare may serve as accelerators to facilitate experimental innovation based on OH technologies (both as tools and infrastructures). Following the example of IdeaSquare as a “hybrid collective” for experimental innovation, OH has the potential to connect a much larger support network across educational, non-profit, and for-profit organisations. This process of diversification will allow for new development trajectories that are conducive for unlocking the real potential of OH as a platform for experimental innovation.

The case of OH at CERN remains central for advancing our understanding of technical, legal, and socioeconomic dynamics of OH in institutional settings. In the context of emergent global research infrastructures for experimental innovation, the specificities we identified and described serve to compare and contrast across OH cases. The experimental character of OH as an innovation platform presents itself, albeit in its earliest stage, in the form of novel collaborative and productive arrangements. For future studies, it is necessary to specify these new collaborative dynamics in detail *vis-à-vis* frictions and tensions in the on-going dispute with traditional IP-based and other forms of technology transfer.

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## SUPPLEMENTARY MATERIAL

We included as part of this paper a supplementary data analysis report: “Impact of CERN Open Hardware Study (v.0.6).”

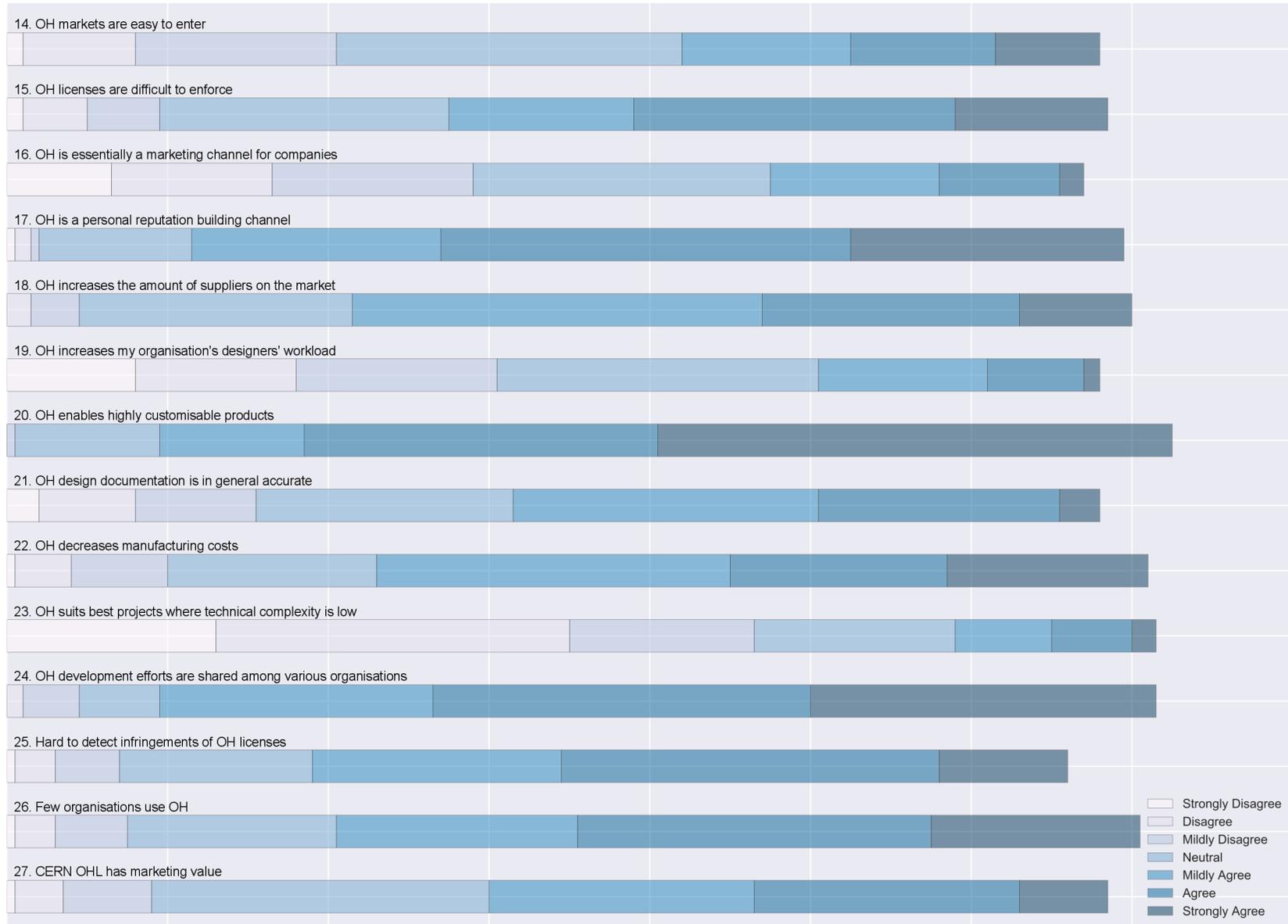
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**Figure 2b:** Respondents' perceptions of common open hardware issues

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<sup>1</sup> According to the community-vetted Open Source Hardware Definition: "Open source hardware is hardware whose design is made publicly available so that anyone can study, modify, distribute, make, and sell the design or hardware based on that design. The hardware's source, the design from which it is made, is available in the preferred format for making modifications to it. Ideally, open source hardware uses readily-available components and materials, standard processes, open infrastructure, unrestricted content, and open-source design tools to maximize the ability of individuals to make and use hardware. Open source hardware gives people the freedom to control their technology while sharing knowledge and encouraging commerce through the open exchange of designs."

(source: Open Source Hardware Association  
<https://www.oshwa.org/definition/>)

<sup>2</sup>According to the historian of science Hans-Jörg Rheinberger (1997, p. 37) "experimental systems give laboratories their special character as particular cultural settings: as places where strategies of material signification are generated. It is not, in the end, the scientific or the broader culture that determines 'from the outside' what it means to be a laboratory, a manufactory of epistemic things becoming transformed, sooner or later, into technical things, and vice versa. It is 'inside' the laboratory that those master signifiers are generated and regenerated".