Observatories, Laboratories and Experiments in Geographical Information Science

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Abstract Geographical information science (GIScience) has, as a young and interdisciplinary field in information science, demands different than the one's in other disciplines. Other fields have observatories and laboratories to solve their specific problems, but GIScience has not. The concept of observatories cannot be transferred to GIScience without further modifications. We discuss the function of observatories, laboratories and experiments in scientific evolution and their implications on scientific evolution to conclude, based on the specific demands, how laboratories in GIScience may look like. We propose, amongst others, data journals and second-order laboratories. The proposed view of a laboratory may lead to stronger collaborations within GIScience, a much faster evolving field of science, as well as formal laws and theories in the long term.

Keywords: data journal, preprint server, second-order laboratory, scientific revolution, paradigm shift, traceability, reproducibility, pooling of resources, cybernetics, philosophy of science

1 Observatories and Laboratories

Experiments have been discussed in the context of science, e. g. by Hacking [6, 18]. They play an important role in the formation of theories: observations lead to hypotheses, and repeated observation as well as experiments, i. e. observations of arranged setups, are used to validate these hypotheses. The execution of observations and experiments has, in many fields of research, been institutionalized in form of *observatories* and *laboratories*.

Observatories are build to observe a subject matter, e. g. stars in astronomy, when we cannot control the setup of the observed matter. Laboratories, in contrast, usually allow to control the setup, which opens the possibility to choose which processes are observed, and thus to validate a hypothesis on a, more or less, isolated environment. Laboratories often contain the examined matter, e. g. chemicals, whereas observatories do not. Both, observatories and laboratories, are present in many fields of research.

Natural and Earth Sciences. Many examples of laboratories exist in natural sciences, e. g. in physics, chemistry, biology, medicine and engineering. In astronomy and many earth sciences, e. g. in meteorology, geodesy, volcanology, oceanography and geology, observatories exist, because processes in astronomic and geographical scales are hard to impossible to influence. Computer clusters are, besides traditional observatories and laboratories, increasingly used in these disciplines.

Mathematics and Philosophy. Laboratories in mathematics and philosophy are very different from the ones in natural sciences. The examined matter is, in case of modern mathematics, completely determined by axioms. These axioms are chosen by the scientist, and hypotheses can, based on the axioms, be validated by formal proofs, which are performed in the mind and formally represented on paper. Theorems and their proofs take the place of laboratories in mathematics. Thought experiments play a similar role in philosophy, because they are also carried out in the mind.

Humanities. Experiments in the humanities usually involve only previous data and knowledge but no material tools. Libraries, archives, linguistic corpora and media laboratories are examples of observatory like institutions. They are characterized by a collection of data sets, which are used by a group of scientists.

The boundaries between observatories and laboratories become increasingly blurred, and many non-typical examples of observatories and laboratories exist. We will, in the following, use the term laboratory to refer to both, observatories and laboratories.

2 The Function of Laboratories

Laboratories can be characterized by their function in the formation of theories:

Traceability and Reproducibility. Experiments only deliver valuable results if other scientists can retrace the experiment and reproduce its results [13]. Laboratories can ensure, e. g. by the traditional use of laboratory notebooks, that information about the experiment is archived and, by providing a controlled environment, that experiments can be reproduced [16, 17].

Communication of Knowledge. Reuse of scientific knowledge assumes that scientists know about the knowledge collected by other scientists and can communicate their own. Most contemporary laboratories are operated by a collaboration of scientists, amongst others to stimulate the collection and communication of knowledge.

Pooling of Resources. Observations and experiments become increasingly complex. Laboratories are, in many cases, used to pool resources and scientists due to several reasons: experiments can be very expensive, a high number of scientists may be involved, examined assets are unique, etc. The pooling affects experimental setups and the execution of the experiments.

Experiments and laboratories have different roles in the formation of theories: experiments are used to find hypotheses and validate them, whereas laboratories coordinate the use of experiments and provide methodological assistance. We will, in the next section, examine how laboratories facilitate the evolution of science by their function in the formation of theories.

3 Laboratories Influence the Evolution of Science

Scientific knowledge is evolving, theories are developed and discarded, implicit knowledge changes and technical methods are improving over time. Many descriptions exist of how science works and how it evolves [2, 10]. We provide a short overview of some of these descriptions and discuss the influence of laboratories on the evolution of science.

Scientific Revolution and Paradigm Shifts. Kuhn describes the evolution of science by various phases. After a *pre-paradigm phase*, the phase of *normal science* begins: theories are developed and advanced by the use of experiments, and scientific practise, including the use of laboratories, is subject to the predominant paradigm. When experiments are in conflict to the paradigm and the resulting *crisis* cannot be resolved within the context of normal science, a *scientific revolution* may follow. The revolution is closely connected to a *paradigm shift* that forms in a *post-revolutionary phase* an incommensurable new paradigm. This paradigm can lead to a new phase of normal science. Theories in the context of the new paradigm are expected to overcome some issues of the previous paradigm, and crises are, in consequence, necessary for the advancement of science.

Experiments play an important role in scientific evolution [10]. As laboratories are institutions that are build for the purpose of facilitating experiments, they play an important role in the evolution of science – for scientific practise in the context of normal science as well as for the emergence of crises.

Science as a Cybernetic System. Scientific and technical knowledge as well as the predominant paradigm influence how laboratories are build and which function they have in the evolution of science [1, 7, 14]. Laboratories in turn influence the knowledge and predominant paradigms by the results they produce [9]. This feedback loop includes the "observer" in the domain of science [4, 5]; laboratories can be understood as observers in this context. The understanding of understanding, i. e. the understanding of how we conduct research and conclude knowledge, is required, according to von Foerster, to successfully conduct transdisciplinary research [4]. The phenomenon of understanding of understanding is examined in *second-order cybernetics*.

Based on the specific demands of each field of science, laboratories fulfil different functions and influence the evolution of science in different ways. In the next section, we discuss, based on these considerations, how a laboratory in the field of GIScience may look like.

4 Laboratories in Geographical Information Science

GIScience is a young and interdisciplinary field in information science. The long term goal of formulating theories and laws is simple to achieve when science is executed at a conceptual level. The grounding of formal theories [15], however, makes the formulation of theories and laws in GIScience much more demanding, because many exceptions and irregularities have to be considered. The evolution of GIScience and paradigm shifts may help to overcome this problem and lead to theories and laws in GIScience in the long term.

Laboratories facilitate the evolution of science, because they support traceability and reproducibility, and they afford the communication of knowledge and the pooling of resources. Besides these classical problems of science, GIScience faces additional ones: data is, in many cases, quickly changing when it is collected by computers; ontology merging is hard because of the multitude of involved data sources and disciplines; data is in many cases not shared, or it is published under unclear licenses; and incommensurable methods from different disciplines are used.

Based on these manifold demands, laboratories in GIScience can be expected to be different from existing ones. They may, for example, be more complex and consist of various, closely related parts. We can expect many laboratories to be centred around a data centre, because the processing of data is an important aspect in GIScience. As information has, in contrast to conventional experiments, no location and no material intervention is needed[1], a laboratory has no location either and can be expected to be centred around groups of scientists. We will, in the following, discuss how a laboratory in GIScience may look like in order to meet the discussed demands. This vision of a laboratory does not raise the claim to be complete nor, the only meaningful option.

Data Journal. A laboratory should collect data, because data and information are central to an information science. The collected data should be published in a peer-reviewed journal, which is part of the laboratory. Each publication should contain a data set, a description of the data, and references to conference and journal papers which use the data. The data should be open access, licenses should be disclosed, information about the source of the data should be reported, and ontologies of how to interpret the data should be provided.

Such a data journal provides several opportunities: various researchers can use the same data sets; existing results can be reproduced; theories can be tested on a more extensive number of available data sets; and published data can properly be cited, giving more credit to the author of the data publication.

[1]Experiments without material intervention have been discussed controversially [11, 12, 19]. The view of a laboratory, as proposed in this article, is based on the exploration of information. As the information is gained by observations of the world and only the exploration is executed without material intervention, the controversy does not apply to this view of a laboratory.

Collection of Services. Research has to be documented in order to be communicated to the community. Existing publications contain, in many cases, only parts of the algorithms. A laboratory should provide the possibility to store algorithms, their documentation and references to external publications, to review and run algorithms, to visualize their results, and to access all the stored data. This makes existing research more reusable.

When algorithms are stored as *services*, they can be executed by the data centre: each service has clear interfaces for the type of the input and the output of the algorithm, and the algorithm can be executed on the server infrastructure without the need to download data nor code. The algorithms may be stored in different, appropriate programming languages, but services may either be executed in a graphical user interface or be combined by a simple script language.

Preprint Server. The evolution of science relies on the ability to reproduce existing results, and on communicating which ideas failed and why they failed. Today's practise, however, supports these aims only in parts, and the resulting negative effects can, for example, be observed in medical research [8]. Data journals and collections of services are useful in this context, but many results are worth to be discussed and shared before publishing. The laboratory should facilitate such a sharing of data, algorithms and papers before they are published, much like preprint servers, e. g. arxiv.org, do.

A Laboratory Affording Paradigm Changes. When a crisis occurs, it can be important to change the predominant paradigm. Laboratories are affected by paradigms, and we can try to open the laboratory to multiple paradigms. This can, for example, be achieved by having no or only very little requirements to the used data types and the interfaces of the services. It is an open question in how far laboratories can afford paradigm changes, amongst others because it is important to do computations in the semantic domain, not only in the logical one [3].

Second-Order Laboratory[2]. We can observe how other scientists work, when preprint results are stored; data about how we conduct research, e. g. records of experiments which do not confirm the hypothesis; and reflections about why we conduct research the way we do. This ability turns the laboratory in a *second-order laboratory*, which is of high importance for conducting research in transdisciplinary research.

The challenge of handling the heterogeneity and the high number of methods in transdisciplinary research can be compared to the challenge of examining waste amounts of heterogenous data. While laboratories may be able to solve

[2]The term *second-order laboratory* has, as far as I know, not been used in literature before. I would like to coin this term to describe the role of a laboratory in the context of *second-order cybernetics*.

the challenge of big data, second-order laboratories may be able to solve the challenges of transdisciplinary science[3].

Laboratories in GIScience differ from the ones in other fields. They have, however, much in common with other laboratories: they have an inventory, afford experiments, archive the results and afford a pooling of resources.

5 Outlook

We discussed the function of observatories and laboratories. Based on the scientific demands, we concluded how a laboratory in the field of GIScience may look like.

A laboratory is a social construct, and acceptance in the community is crucial. Scientists have to learn how to collaborate and share research results before they are published. In the fields of mathematics and physics, this is common due to the existence of preprint servers, but in other fields of science such practises are not yet established. It remains an open question whether a laboratory, like proposed in this article, would be accepted by the scientific community.

It is not clear what the ongoing efforts to build second-order laboratories can achieve. Will we be able to make the shift to a true transdisciplinary GIScience by overcoming incommensurable methods, which assumes a much higher degree of reflection about how we conduct research?

An important challenge is to separate an experiment from its environment. This is possible in natural sciences but demanding in the field of GIScience. It remains an open question in how far we are able to find solutions to this problematics, and whether we are able to build true laboratories rather than observatories.

[3] The term *big science* could be used to describe this phenomenon but has been used with a different meaning in literature before.

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