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Exploratory Experimentation and Taxonomy of Experimentation

Abstract: *Transformation of the philosophy of science during the last three decades is largely based on the philosophers' insights in the experimental side of science. Central issues in this new field, such as classification of basic elements and types of experimentation, are still developing. Subject of this work will be one of these types, Steinle's „exploratory experimentation" (EE), and its place in taxonomy of experimentation. After presenting an array of historical cases of experimentation, I analyze Elliott's systematization of EE subtypes. I will claim that it does not represent development of Steinle's ideas, although it can be used to improve taxonomy of experimentation in general. Special attention will be dedicated to the development of this taxonomy and understanding forms of experimentation not focused on theory testing – specifically EE.*

1. Introduction

In recent decades, philosophy of science has turned its focus away from scientific theory. Since science started to be regarded as a historical phenomenon, and individual cases examined systematically, it quickly became clear that the experimental dimension of scientific practice is largely neglected. A standard view during twentieth century, from Duhem to Popper, understood experiment only as means of testing scientific theories. Turning attention to actual historical cases of experimentation brought the key insight that experiments are often carried out for other reasons than theory testing. Initiated by Hacking's work (1983, ch.9), this return to Baconian variety of relations between experiment and theory has pervasive consequences for the philosophy of science.

An increasing number of case studies in history of experimental science created significant and necessary material for understanding the actual role of experiment. The first classification of elements characteristic for experimentation was offered by Hacking himself (1988, 508-11). Although it does not purport to be definitive, this taxonomy is invaluable for philosophy of science, as it provides (at least tentative) framework for classifying the various forms of experimental practice. Here we will be using it in a form simplified by Galison (1988, 525), where experimentation comes down to the following four elements:

1) The objective of experimental research – questions about some specific topic (e.g. determining some specific correlations, calculation of some constant, choosing between rival theories...),
2) The establishment of knowledge prior to experimentation (background knowledge, fundamental theory, theory of instrumentation (i.e. experimental equipment), phenomenological (concrete, verifiable) hypotheses ...),
3) The experimental equipment (object being tested, devices interacting with object, detectors measuring the interference),
4) Data and data manipulation (data production, processing (assessment, reduction, analysis), and interpretation).

All these elements are highly plastic. For example, we can modify the question (1) in the middle of the experiment, data (4) can be selected or abandoned in many ways, and computer programs that commonly reduce and analyze data are very sensitive to modifications in the theory of instrumentation (2) (cf. Hacking, 1988, 512).Complex interplay patterns of these elements make a framework for classifying various types of experimentation. This paper will focus on the experimentation type known as "exploratory experimentation". It is investigated especially by Friedrich Steinle, and his opinions will be discussed in the third section. Kevin C. Elliott's development of Steinle's work, and my critical review on Elliot, will be subject in the fourth and fifth section. I will also try to clarify consequences of my criticism for general taxonomy of experimentation; specifically, upper Galison's taxonomy. Before that, I will briefly introduce several recent studies in history of scientific experimental practice.

Historical work itself, prerequisite for development and critique of experimental philosophy, is not always clearly separable from philosophical work. Therefore it is desirable to keep certain reserve to these experimentation case studies. However, they are invaluable for finding interrelationship patterns of instrumentation, experimental questions, theories, and other elements present in an acceptable taxonomy of experimentation. Presentation of historical studies will focus on methods used to obtain experimental results. Examples have been chosen to illustrate diversity in this respect, and specifically, of course, to support the philosophical solutions discussed in this paper. All of them will be instances where theory testing, traditionally regarded as the only form of experimentation, is not playing a major role.

2. Historical cases of experimentation

2.1 Cosmic rays

Karl Jansky located in the 1930s the source of interference in transatlantic radio communications coming from the center of our galaxy. Working in the same laboratory in 1965, radio-astronomers Arno Penzias and Robert Wilson adapted the radio telescope, originally created to detect radio waves deflected from the Echo balloon satellites[1], in order to study this phenomenon. According to the former astronomical beliefs, they expected to find energy sources in the Milky Way and other galaxies. Trying to measure these energy sources and other points in the sky, they received values "around 3.5°K more than *expected*" (italics added), with excess temperature isotropic, unpolarized, and independent of seasonal (July 1964 to April 1965) and daily variations (Penzias & Wilson, 1965, 419-20). The obtained result of radiation uniformly distributed in space was not expected due to any previous astronomical theory, and the lack of ways to interpret it caused some hesitation in Penzias and Wilson to publish results; they did so only after thorough check of used instrumentation and acquired results.

This accidental discovery of cosmic microwave background radiation coincided with theoretical work of Dicke, Peebles & Wilkinson, which as a consequence of the Big Bang predicted explosion residues in the form of temperature uniformly distributed throughout the Universe (Penzias &Wilson, 1965, 420). This subsequent interpretation made the cosmic radiation, from previously an unusual experimental result, an important confirmation of today accepted cosmological theory of the Universe creation.

2.2 Galvanism

At the end of the 18th century, after Galvani discovered animal electricity, numerous researchers conducted experiments regarding this phenomenon (see Trumpler, 1997). The first reaction was to check his result; whoever did it tried to get a positive result (ibid, S76 – 7). What is

1 The first passive communications satellites launched by NASA in 1960. and '64. These first spacecrafts were metalized balloons, primarily used as passive reflectors of microwave signals.

particularly interesting is that each of these verification experiments was different[2]. However, nearly everyone was unconvinced in Galvani's theoretical explanation – that spasms in the frog muscles are caused by animal electricity. In the absence of theoretical guidance, many researchers have started to systematically vary those elements they suspected are the key ones (from the metal used for muscle stimulation, to the sexual maturity of dissected frogs). Published results contain descriptions of more than a thousand different experiments.

According to Trumpler's classification, they can be divided into four groups (ibid, S77 – 80). Experiments in the first group seek to simplify the phenomenon by eliminating redundant or finding necessary experimental procedures and elements; strategy especially important for accidental discoveries, such as Galvani's. The second group includes attempts to optimize the effect – in this case, finding experimental conditions that amplify muscle contractions, which served as the test of the phenomenon. In that aim, variations were, for example, carried out in terms of age or gender of frogs. The third group Trumpler calls "exploration": it contains experimental setting variations without some guiding principle in mind.[3] Finally, the fourth group are experimental setting adjustments, either for some practical application or testing related phenomena. Critical to note is that these groups are not clearly bounded and that a variant of the same experiment often falls into several groups, especially in the first three (which are usually the focus of philosophy of experimentation)[4]. In the end, no theory or even an empirical generalization didn't came out as a result of this research – it was not even determined whether electricity is included into the phenomenon. All that was obtained in this relentless experimental work is abundance of individual cases descriptions.

2.3 Electromagnetic induction

Rapid development of electromagnetism in 1831. faced the question whether magnetism affects electricity. Michael Faraday, probably

2 Although the main cause of this is that most researchers have not been properly introduced to Galvani's experimental procedure, it wouldn't be correct to say that this makes the case unrepresentative. In fact, checking results (mainly due to practical reasons) is usually performed only when there is at least a newer (more precise) instrument available.

3 Perhaps the more appropriate name for this group of experimental variations would be "systematic varying".

4 The fourth group is an interesting insight into intertwining of scientific (experimental) practice, but this is a goal that exceeds the current paper.

stimulated by recent improvements in electromagnets, designed an experiment with two separate coils wound on the iron ring. Connecting the first coil to the battery, fugacious current was induced in the second coil. This result was not sufficient to claim effects of magnetism on electricity. Due to complexity of the original experimental setting, Faraday designed second experiment[5] which didn't involve coil connected to the power source: it consisted only of one magnet and one coil connected to a galvanometer. After many variations of this simplified experiment, it became clear that the relative motion of the magnet and the wire is the essential factor. Further variations of this movement produced a large number of specific, concrete experimental variations, indescribable in a general way. To this end, Faraday attempted to formulate an empirical regularity by searching for the reference system in which to express the relative motion of the wire and the magnet (Steinle, 2002, 417): he tried with the magnetic poles, the direction of the wire, the magnet's axis direction, the compass directions, Ampere's hypothetical circular currents within the magnet, and "magnetic curves" – patterns formed by iron filings around the magnet (Faraday, 1932a, § 114, f.). Only in the last case he was able to formulate regularity consistent with the experimental results gained: the current is induced in the wire as long as it intersects the magnetic lines (Faraday, 1932a, §114 and 1932b, §260).This regularity not only successfully explained all experimental results, but also allowed Faraday to deduce other induction effects. It introduced the concept of magnetic curves into scientific thinking. This concept, later renamed "lines of force", will become fundamental of electrodynamic field theory.

2.4 The DNA microarray

Paul Spellman and collaborators conducted in 1998. a series of experiments aiming to understand the regulation of gene expression during the cell cycle (see Franklin 2005, 891). The most important difference compared to the previous experiments in this area was instrumentation used: a microarray enables measuring the relative expression of *all* cellular messenger RNA. While previous instruments could measure the presence and quantity of one mRNA per measuring in an experiment that lasts longer than a day, a microarray can measure 25 000 equally

5 What is counted as a different experiment, and what as a variation, is a matter of degree and convenience. Here, contrary to the previous section, by "experiment" is meant a series of variations within one experimental setting (for e.g. variation in the material of the core and the wires, geometry of the setting, battery type, etc.).

informative measurement at once (more than one scientist, with previous technique, could measure in the entire life) (Franklin 2005, 892). During experiments with microarrays, researchers have collected a total of 400 000 individual measurements of the mRNA levels, and with Fourier's analysis was determined that around 800 genes exhibits a variation in the mRNA level during the cell cycle – a dramatic increase compared to approximately 100 genes that were previously known to have this property. The experiment wasn't investigating a particular hypothesis or set of mechanisms, but the goal was to observe the regulation of genes during the cell cycle and to create a "catalog" of genes whose transcript levels vary (Spellman et al, 1998.[6] according to Franklin, 2005, 892-3). Scientists themselves have barely begun to deal with the incredible amount of data resulting from this experiment. They are posted on internet site, and some laboratories are fully dedicated to analyzing the data collected only in this experiment.

3. Exploratory experimentation

Taxonomy of experimentation presented in the introduction creates indefinite logical space, not clear exactly for how many types of experimentation. Moreover, it is not clear whether there are clearly distinguishable types, or just different, more or less overlapping forms of experimentation.[7] However, if we limit ourselves to the first element of the upper taxonomy – the aim of experimental research – certain classes can be distinguished.

First, traditionally is considered that there are experiments designed in order to test certain theories. Much, of course, depends on what exactly counts as theory, but closer analysis will not be possible here. Characteristic example is famous Arthur Eddington's measuring of starlight deviation by the Sun's gravitational field, during the solar eclipse in 1919, in order to test the theory of general relativity. In theory-driven experimentation scientists have well-formed theory on mind, from the design and conduction of the experiment, to its assessment. These experiments are characteristically constructed with particular expectations of different possible outcomes, and instrumentation is usually made in such a manner to allow detection of only those alternatives.

6 Comprehensive Identification of Cell Cycle-Regulated Genes of the Yeast *Saccharomyces cerevisiae* by Microarray Hybridization", *Molecular Biology of the Cell* 9, 3273–3297.

7 Perhaps in the form of diachronic, partly related traditions (see Galison, 1988, 526-7)

Friedrich Steinle emphasizes an alternative to theory-driven experimentation which he calls "exploratory experimentation". It is experimentation "driven by the elementary desire to obtain empirical regularities and to find out proper concepts and classifications by means of which those regularities can be formulated" (Steinle, 1997, S70). The most significant feature of this experimental work is systematic variation of the experimental parameters. It is guided by unspecific guidelines, methodological in character, and results in a variety of broadly dispersed experiments (Steinle, 2002, 422). Among the most important methodological guiding principles there are:

- varying a large number of different parameters;
- determining necessary (essential) and modifying parameters;
- seeking stable empirical rules;
- finding appropriate (linguistic)representations for formulation of these rules;
- constructing "simple", "elementary", or "pure" cases, where rules are presented in particular clarity (Steinle, 1997, S70) .

Philosophically the most interesting feature of exploratory experimentation (EE) is its epistemic significance. Its cognitive goal is to find empirical rules and systems of these rules; which each subsequent theory in that field will have to explain or incorporate. Experimental discovery (discussed in (2.1)) that each part of the universe has a temperature about 3.5°K higher than expected is an example of this relationship. Difference between experiment and observation here is not relevant because in this context they both have the same epistemic goal – empirical regularity.[8] Background cosmic radiation is not description of finite number of sources, but generalization that pertains to indefinitely many individual cases. Discovery that cosmos uniformly radiates has an immense scientific value, regardless of the encompassing theory.

In many cases regularity formulation requires revision of existing concepts and categories, or the formation of new ones. Stable and general formulation of the experimental results is not always possible within existing classificatory and conceptual schemes. A typical case, partially the basis of Steinle's philosophy of experimentation (1995, 1997, 2002), is Faraday's discovery presented in section (2.3). The focus of Faraday's

8 More on observation in sciences with "historical" elements (astronomy, evolutionary biology...) as a form of "natural-history experimentation" will be in the last section.

experimental procedure used for capturing empirical regularity was hampered by insufficiency and inadequacy of the conceptual means – known alternatives for fixing the coordinate system could not enable formulation of the regularity. Stable regularities are obtained only by acknowledging that these categories are inappropriate and by formation of "magnetic curve" concept. This term isn't discovered independently and then applied to experimental results; it is formed during the complex process in which experimentation and conceptualization were closely intertwined (Faraday, 1832, §114; Steinle, 1997, S71, and more generally in 2002, 421).[9]

The case of electromagnetic induction is in a sense ideal. In many other cases the epistemic goal of EE – finding empirical regularities – is not reached. An example is the case of galvanism presented in section (2.2). Despite exhaustive experimental work, desired result of phenomenological regularity or correlation is not achieved. On the other hand, this case is a paradigmatic example of methodology-driven research. Extensive variation of the experimental parameters, searching for the essential elements and conditions, and optimization of experiment (construction of "simple" or "pure" cases) – are precisely the features of EE emphasized by Steinle.

Two important points are evident in this example. First, not every EE results in phenomenological regularity and Steinle is aware of this (1997, S72). Its defining characteristic is holding specific cognitive objective, not necessarily its fulfillment. Otherwise, success and failure in this respect are not always easy to distinguish, because the aimed scope of empirical regularity is a pragmatic question and a matter of explorer's choice (Steinle, 2002, 420). In addition, we must not lose sight of the note from the beginning of this section – that this whole classification of experimentation types is assorted only with respect to the first element of Galison's taxonomy of experimentation – the aim of the experimental research. The experiments that, according to the epistemic aim, will be classified as EE may consist of significantly different experimental procedures.

Second point is that Steinle's views on EE result from the analysis of specific historical cases of experimentation. They are based on the analysis of Dufay, Ampere, Faraday, and Goethe's work. Empirical foundation of

9 According to Steinle, "One reason for the great complexity of such formation processes is that concepts and classification schemes cannot be "tested", but rather have to prove their appropriateness in some way" (1997, S71).

his approach is characteristic of the so-called "New experimentalism" (shift in the philosophy of science inspired by Hacking's work) and, in particular, for the upper Galison's taxonomy. This position is reached by a process similar to one Steinle attributes to cases of EE. Certain incompleteness (or openness) of Steinle's philosophy of EE, and Galison's classification of experiments are both just the products of this empirical (i.e. inductive) approach.

4. Theoretical foundations of establishing a classification of EE

Kevin Elliott tried, based on Steinle's and others works about EE, to develop *systematic* characterization of EE and classification of its subtypes (Elliott, 2007). Development of principled set of categories or dimensions for organizing EE, Elliott bases on what he considers the most fundamental, uncontroversial features of EE. First, all the authors which point out EE as a form of experimental practice are reacting against the previous philosophical literature that considered entire experimental work as a means of theory-testing. Hence, from this negative perspective, "the most fundamental characteristic of EE seems to be that it ... does not serve the aim of testing theories or hypotheses" (Elliott, 2007, 10).[10] From this negative trait results a positive feature of EE: "*Because* EE does not involve testing specific predictions of a particular theory, there is a "looseness" in its structure that allows for, and encourages, variation in the experimental data collected." (ibid, italics added). The first, negative trait of EE implies also its third main characteristic – the role that theory plays in guiding EE.

Based on these three fundamental features of EE, Elliott develops EE classification scheme by suggesting three dimensions in which EE types vary (2007, 10):

(I) The positive aim of the experimental activity;

(II) The role that theory plays in the experimental activity;

(III) The methods or strategies used for varying parameters.

10 This is strictly speaking a mistake because Steinle, discoverer, so to speak, of EE says exactly the opposite: "Although exploratory experimentation is not theory-driven, it is not the counterpart of theory-driven experimentation. There may be various types of experimentation not driven by theory. Exploratory experimentation is but one of them, namely that one which has the goal of finding empirical rules and systems of those rules." (1997,S71)

These dimensions are framework for organizing forms of EE, developed by principle, and needs to be filled with characteristic examples of experimentation (Elliott, 2007, 9-10).

The problem with Elliott's EE systematization is that it is based on the negation of an inappropriate, pre-hackingian understanding of experimental practice. First, deduction of the scientific practice forms from principles seems, to say the least, very strange: if we want to know what activities scientists are involved in, it is best to analyze actual cases. In addition, "fundamental feature" not-serving-to-theory-testing is not what drives, enables or guides any experimentation. It is only its negative quality – EE also doesn't serve to technological innovation, but so what? Taking this as "the most fundamental characteristic" looks like a categorical error. Secondly, deriving proposed dimensions from cited fundamental characteristics is far-stretched. This is particularly the case with the first dimension – from that that theory testing is not the aim of EE, it does not follow that the experimental activity has a positive goal (I).

These remarks, however, are not crucial because the most important thing about Elliott's classification is whether it provides an adequate framework for classification of EE subtypes. To test this, we will closely examine proposed dimensions in which experimentation vary. We will check them using the known cases of experimentation, and by comparing them with Steinle's theoretical framework and Galison's taxonomy. I will claim that this systematization is not an improvement over Steinle's approach in a sense that it fails to clarify and organize EE in the intended manner. Nevertheless, some of its elements can be adjusted to contribute understanding experimental practice in general.

4.1 The positive aim of the experimental activity

Before the first dimension is examined closer, at first glance you see that its name is identical to the first element of Galison's taxonomy. Elliott's addition is in sketching some characteristic types of experimental aims (2007, 19):

(a) Identifying regularities and developing new concepts;

(b) Isolating or manipulating particular entities or phenomena;

(c) Developing experimental techniques, instrumentation or simulations;

(d) Resolving anomalies.

(a) is explicitly taken from Steinle. (b) is focused on entities. It sounds like completely different thing than regularities or concepts (a), but how we are going to experimentally grasp these entities? Entities are known only through regularities. Consequently, (b) and (a) are interdependent. It is no wonder that Steinle (1997), who stressed out (a), and Burian (1997), who stressed (b), were both accredited for discovering EE to the philosophy of science.

(c) is considered by Steinle as EE condition or initial part – e.g. Ampere's development of "astatic needle", instrument for terrestrial magnetism isolation, which eventually led to the electric circuit discovery (2002, 413-4). In addition, it is unclear why (c) in general should be counted as EE, and not as some separate type of experimentation.[11] Finally, distinguishing (d) as an exploratory aim is very problematic, because it does not look like an elementary goal. Rather, it is a very complex process that involves, perhaps, theory-testing, experimental study of anomalous phenomena, and theory modification. More importantly, (d) is significantly intertwined with theory and theory-testing, hence the fact that involves EE at some point doesn't make it an EE subtype.

Therefore, except in the first two points, it is doubtful that (I) is presenting "exploratory" aims. Hence, and especially because of (a) and (b)'s interdependence, presented aims are not diverse enough to constitute some sort of "dimension". It is necessary to have more "characteristic exploratory aims"; otherwise we are on the same place where Steinle and Burian have led us to. It wouldn't make any difference if we, on the other hand, try to look on (I) as presenting aims of experimentation in general, instead specifically of EE. Developing instrumentation (c) would still need additional arguments to be accounted as an aim of experimentation, and not as its preparatory work, and (d) would be inappropriate because of its intertwining with theoretical work. If this is so, then this whole "dimension" comes down to Steinle and Burian's ideas, and does not constitute any improvement over the first element (1) of Galison's taxonomy.

11 Elliott says himself that "a number of authors are starting to emphasize that EE of the sort that creates instrumentation, simulations, and effective experimental protocols [(c)] is necessary in order to make EE of the sorts described by Steinle and Burian [(a) and (b)] possible" (2007, 11), but he doesn't explain why this type of preliminary experimenting (c) should nevertheless be assorted into EE, and not as a separate kind of experimentation. Also, as mentioned earlier, one should consider Steinle's suggestion that creation of instrumentation is part of the experimental process, not an authentic experimental aim, and therefore would not fall under (I) at all.

4.2 The role that theory plays in experimental activities

As for the role that theory plays in the experimental activities (II), Elliott (2007, 19) differentiates types when the theory is:

(e) Playing a minimal role relative to other forms of experimentation;

(f) Providing background information;

(g) Serving as a starting point or contrast;

(h) Being constituted by exploratory projects or strategies.

Varying types of EE in this dimension does not seem problematic at first glance, since it is possible to distinguish experiments more or less guided by theory. Steinle's example of electromagnetic induction presented in (2.3) contains minimum theoretical participation (e). Greater theory guidance – expressed in more extensive theoretical background knowledge (f) – is present in Franklin's example from (2.4). However, (e) is a negative role – it only says that theory is (almost) absent. Background knowledge (f) can vary in different experiments, but it is not certain whether there is any, if at all clear, criterion for distinguishing degree of its presence. (g) is another point too sophisticated with respect to the proposed criterions. Elliott (g) associates with (d) because "[t]heory seems especially likely to play this role when EE has the aim of resolving anomalies." (2007, 13) This further complicates the situation because we have seen (d) is not an elementary goal and "determining how [...] a particular theory has gone wrong or how it applies in a somewhat new context [purpose of (g)]" (ibid.) also looks as a *complex* theory-role, and hence not a proper subtype of EE. In addition, it should be examined whether the theory *not* serving as a starting point or contrast (g) is today possible at all, because, in Hacking's words, it seems that only the mind powered by the theoretical models can begin to solve the mysteries of modern science (1983, 154). If this is really inevitably, than (g) wouldn't be a theory-role peculiar to EE, but a necessary condition of modern experimentation in general.

Exploratory strategies that structure research (h) according to Elliott "play something like the traditional role of "theory" in a particular domain"(2007, 13). These "research patterns" fundamentally restructure scientific disciplines and areas of knowledge. This is originally Galison's idea of experimental tradition's on which the stability of science rests (1988, 526-7), and it is an essential insight into the history of science.

However, this is a leap from individual experiments to the entire class, and it belongs to the meta-level compared to the one which is analyzed in the other points. I do not see how this feature of experimental tradition can be classified as the role that theory plays in experimental practice (II) – namely, the fact that theory is constituted by research strategies (h) still leaves room for her to take some role from (e-g) and so far we can't say that (h) belongs to this dimension.

Therefore, even if we exclude (h), we are left with the problem of differentiating (e-g) and the issue of complexity and of general presence of (g). Even without (g), (e) and (f) are not discernible clearly enough, in order to this dimension makes a difference in the form of *discernable* types of EE – and without them the mere observation that the degree of background knowledge may vary (on which (e) and (f) reduce) does not bring anything not already included in the second element of Galison's taxonomy (2).[12]

4.3 Methods or strategies for varying parameters

Finally, the third dimension of EE "diversity" – methods or strategies for varying experimental parameters (III) – leaves a significantly different impression than the first two. It contains the following forms (Elliott, 2007, 19):

- (i) Working as an individual investigator to vary elements of an experimental setup;
- (j) Using multiple experimental techniques to characterize a phenomenon;
- (k) Using "high-throughput" instrumentation to collect large quantities of data;
- (l) Working as a community to design a range of experiments that vary key parameters;
- (m) Developing models and simulations that can vary parameters.

(i) is non-controversial, although quite uninformative case. Conducting experiment at community level (l) is typical for many experiments today – some research has become so complex that it is actually impossible for a single researcher to carry them out. This division of scientific labor is

12 Over and above, for (e) and (f) to be EE subtypes, besides proposing criterion for identifying the degree of background knowledge, it is necessary to explain how its higher or lower presence changes the character that EE has.

an interesting epistemological phenomenon, and cognitive situation in which individual researchers are, and the system of their relations is undoubtedly something that demands special philosophical attention. Does it form a separate EE type or the relationship of community to the world remains the same (as of an individual) is another matter, and the answer is not provided by Elliott. Namely, the change in the epistemic position of an individual scientist (who is in (l) only a part, not a whole) does not imply that there has been a change in the character of the research – that an aim of research, theory-role or a method or strategy for varying parameters are changed. It is possible that (l) is the same as (i), only on a grand scale and with certain epistemic blindness of the individual researchers; and so far not a special kind of strategy for varying parameters (III). It is possible there is nothing methodologically new in it. After all, every scientist in the world, as part of the scientific community, relies on the work of other scholars and it is not even certain that the aforementioned epistemological situation is specific particularly to (l), and not to modern science in general.[13]

Using multiple experimental techniques and instruments (j) was pointed out by Burian in (1997). He argues that this EE type is especially important for molecular biology because of contingent historical processes by which biological regulatory systems were developed. This is associated with Brandon's idea that biological sciences require more descriptive work than fields such as physics, because of a large number of contingent parameters (Brandon, 1994, 69). This kind of experimental work, which extensively includes contingent and/or historical elements, it is not necessary to understand as EE. Following Steinle's suggestion (1997, S69) Maureen O'Malley suggests to understand it as a separate form of experimentation (in addition to EE and theory-testing[14]) (2007, 14). This type she calls "natural history/experimentation" (NHE). It includes various activities of discovery, classification, comparison and testing of special features, and generally deals with phenomena that are less controllable (O'Malley, 2007, 14). It is characteristic of the sciences, such as astronomy and molecular biology, dealing with phenomena unique (or unrepeatable) in the world. Considering historical studies conducted in the last three decades, as far as I know, and especially according to Burian's (which is Elliott's basis for (j)), Franklin's and O'Malley's works on molecular biology, it seems the use

13 For more about this epistemological phenomenon of intertwined knowledge and methodology as characteristic of modern science in general see (Hardwig, 1991).

14 Further, theory-driven experimentation (TDE).

of many techniques (j) usually goes within the experimentation that could rather be classified as NHE than EE.

Finally remains the use of "high-throughput" instrumentation (k), and the development of models and simulations (m). (k) as an EE type is extensively discussed in (Franklin, 2005), from where example presented in section (2.4) is taken. As the main reason why it represent a separate type, Franklin emphasizes the question of research *efficiency*, which is manifested in massive amounts of data, unachievable through conventional instrumentation (2005, 897). However, this method for varying parameters threats to expand, as Franklin foresees, to include other forms of experimentation (including TDE) (ibid.), and thus ceases to be an EE subtype.

A similar point could be noticed for (m).[15] The development and use of models and simulations (m) is possible to use as for EE, as in order to test certain theories. Consequently, my suggestion would be to understand (k) and (m) as methods for varying parameters regardless of the type of experimentation, and to set them as dimensions by which *all* experimentation may vary, not just EE. They should then be incorporated into Galison's taxonomy, as a revision of its third element – the experimental equipment. This way we would get a general account of experimentation, since mentioned types are characteristic for several forms of experimentation, including EE.

To summarize, it is an open question whether (l) represents a particular method for variation of parameters, or not. (i) is completely uninformative and the only significance derives from the contrast with (problematic) (l). Classifying (j) as an EE type is misidentification; on contrary, relevant studies show that (j) usually appears as a form of NHE. Finally, (k) and (m) are not methods specific to EE and it would be better to understand them as methods or strategies of experimentation in general.

5. Conclusion

It is not at all clear that it is possible to develop taxonomy of experimentation from particular principles as Elliott claims. There is no systematic

15 And also for the above-discussed (L) (if it turns out it is a type of (III)). Namely, working as a community – which is the essence of (L) – occurs in TDE cases also. A characteristic example would be the search for the Higgs boson at CERN. Here, however, caution is needed, because, as O'Malley points out, scientists sometimes present other forms of experimentation as TDE, in order to facilitate obtaining funds for research (2007, 16).

connection between subtypes, and it is insufficient for one principled system to produce only already known types. Moreover, these types are problematic even if we understand them as empirical generalizations, that is, classification of EE derived from known cases. We have seen that, when the problematic forms are precluded, the aims of experimental activity (I) and the role of theory in it (II) as they are characterized in Elliott's systematization are reduced respectively to (1) and (2) of Galison's taxonomy and Steinle's analysis of EE. And Elliott's third dimension does not succeed in its aim of distinguishing between different types of EE, although it highlights important elements for understanding experimentation in general.

Here I have particularly in mind the use of high-throughput instrumentation (k), and developing models and simulations (m), as forms of experimental methods or strategies characteristic to all types of experimentation. If we would place this Elliott's (reduced) dimension instead of "experimental equipment" (3) as the third element in Galison's taxonomy, we would improve it in the following way: (3) does not points out specifically in what way the object-apparatus-detector system (experimental equipment system) can vary (cf. Hacking 1988, 509), and Elliott's (k) and (m)[16] do just that. (k) and (m), as can be seen in Elliott (2007, 14-5), are essentially *the choice of* (certain) *instrumentation*, and therefore they are a natural development of the Galison's category "experimental equipment" (3). These two specific types of "methods, strategies or instruments" enable variation of the experimental equipment at an open series, analogously to variation of other elements (or dimensions) of this taxonomy.[17]

My opinion is that Elliott's systematization of EE, when elements (specifically or at all) not belonging to EE are removed, does not contribute *directly* to further understanding of EE. All these remaining elements are already pointed out by Steinle and Burian, with the exception of Franklin's example from (2.4). If you look closely at this case of experimenting, we see its characteristic trait – high-throughput instrumentation, does not deviate from the EE aim – search for empirical regularities and classificatory schemes. As Franklin points out, Spellman & associates had aimed "to observe the regulation of genes during the cell

16 (k) is due to Trumpler (2005), and (m) due Morgan (2003).
17 Moreover (3), thus understood, would be independent of the other dimensions, i.e. (1) and (2); unlike Elliott's dimensions where aims of experimentation (I) in some cases can be used to condition the used methodology (III) (2007, 10-11).

cycle and to create a 'catalog' of genes whose transcript levels vary" (see above, 2.4). By identifying that "around 800 genes exhibits a variation in the mRNA level" they precisely achieved the epistemic goal Steinle is emphasizing, although by significantly different form of instrumentation. Characteristic of Steinle's approach to EE is that it leaves space for the development of new experimental methods, techniques and instruments. Because of this incorporated openness it fits perfectly in taxonomy like Galison's, because its forms are free to vary by the dimensions of experimental equipment / methods or strategies for varying parameters (3) and the state of knowledge prior to experiment (2).

It seems to me that Elliott's analysis provided a clearer understanding of experimentation in general, although in a negative way: developing Galison's taxonomy by Elliott's proposals we have clarified the outer boundaries and extracted features non-specific to EE. Talk about dimensions (or more precisely sets, as there is no continuity of the forms) by which experimentation varies, when applied to experimentation in general, rather than EE, enables taxonomy which naturally accommodates *openness* of experimental science to new methods. It provides understanding of experimentation forms without restriction to certain methodologies and theory-roles. Following Hacking's idea that the growth of knowledge is too "motley" – it is not to expect that it is currently reducible, or that will stick in the future to one methodological framework (1983, 152). Perhaps we should focus only on aims and not differentiate types of EE according to other dimensions – methods or theory roles. Keeping the name "EE" for the search for empirical regularities will enable exactly this hackingian methodological openness of experimental science.

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Istraživačko eksperimentisanje i taksonomija eksperimentisanja

Apstrakt

Preobražaj filozofije nauke tokom poslednje tri decenije dobrim delom zasniva se na uvidu filozofa u eksperimentalnu stranu nauke. Centralne stvari u ovom polju, kao što su klasifikacija osnovnih elemenata i vrsta eksperimentisanja, još uvek su u povoju. Predmet rada biće jedna ova vrsta, Stajnleovo „istraživačko eksperimentisanje" (IE), i njeno mesto u taksonomiji eksperimentisanja. Nakon predstavljanja niza istorijskih slučajeva eksperimentisanja, analiziraću Eliotovu sistematizaciju podvrsta IE. Tvrdiću da ona ne predstavlja razvoj Stajnleovih shvatanja, ali da se može iskoristiti za unapređenje opšte taksonomije eksperimentisanja. Posebna pažnja biće obraćena na isprepletanost razvoja taksnomije eksperimentisanja i razumevanja oblika eksperimentisanja koja nemaju za cilj testiranje teorije – specifično IE.

Ključne reči: istraživačko eksperimentisanje, taksonomija, Fridrif Stajnle, Novi eksperimentalizam, metodologija.