

History and Philosophy of Science in Education: Elements of Expert Analysis^{1,2}

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The history and philosophy of science (HPS) plays a special role in education. An elective HPS course on the philosophy of scientific experimentation for young scientists and graduate students of natural science is presented. The course bears a pragmatic character, and its main aims include the development of critical thinking (CT), familiarization with philosophical problems in the relevant areas of knowledge, and the cultivation of a taste for reflective, critical analysis, both individual and group-based, which contributes to deeper understanding of the features of scientific practice in the context of modern complex group cooperation. Students are offered a classical HPS program that included debates on the relationship between empiricism and rationalism, the role of Kant's transcendental philosophy, modern topics associated with the practical success of rationalism in the emergence of modern natural science, and the theory-ladenness of experimentation. Particular attention during the course is paid to the problems of megascience, the inclusion of which is justified by the specifics of the students' engagement with science, technology, engineering, and mathematics (STEM). Emphasis is placed on the structure and typology of the collective subject in the modern educational process as well as in experimental practice. Lessons on the methodology of expert text analysis (META), which are aimed at the development of critical thinking skills and the creation of an interdisciplinary discussion space, are included in the course and relied on the example of the history and philosophy of high energy physics to motivate professional reflection. META classes included in the course prepare graduate students for teamwork in big science, proto-megascience, and megascience. The course offers practical recommendations that could be applied to students' own research and could be useful for practitioners.

Keywords: history and philosophy of science; teaching; high-energy physics; science students; Nature of Science (NOS); critical thinking; methodology of expert text analysis (META)

¹Fermi National Accelerator Laboratory is operated by the Fermi Research Alliance, LLC under Contract No. DE-AC02-07CH11359 with the U.S. Department of Energy, Office of Science, Office of High Energy Physics.

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Introduction

Due to the extreme complexity of contemporary scientific knowledge, contemporary science education is of the utmost importance to lessen the gap between the rapidly developing natural sciences and their teaching methodologies. Of great value for teachers of natural science is discussion of such aspects of modern science as collective experimentation, theory-ladenness, and methodology for learning about the smallest constituents of the physical world, such as elementary particles and nuclei. Educators often need to take a fresh look at the experience of forming a collective self both in practical activities at the level of Big Science, Megascience, Proto-megascience⁴ and in the process of working with texts that accompany science and represent one of its constituent activities. The history and philosophy of science plays an important role in physics education and impacts educators' views as well as students' perception of science courses (Nielsen 1990; Justi 2000; Abd-El-Khalick 2005). This article focuses on the development of physics in the context of teaching the HPS course.

One of the current trends in science education is the reconceptualization of the nature of science (NOS) to move away from the traditional concept of science as the sum of available knowledge and schematic ways of obtaining it, presented to students as ultimate truths. Contemporary teaching methodologies (Erduran & Dagher 2014; Mohan & Kelly 2020) offer perspectives on the NOS that consider the epistemological, social, and political aspects of science as a social institution. It is important that all these aspects are presented in their deep inner relationship, rather than as a collection of disparate plots.

Another contemporary trend in education is the shift of the epistemic subject “from an individual knower to a community of knowers with sociocultural practices derived from a common history of activity” (Kelly 2008) as well as a classroom modeling approach similar that of science laboratories (Nersessian 1999). In the spirit of these suggestions, in the proposed course, we consider the formation and functioning of the critically thinking collective cognitive subject of megascience and apply the META to organize classroom work analogous to that of a science laboratory.

Despite the fact that the use of CT in education (Dewey 1910) has already spread to many stages of the educational process, we agree with the authors (Bailin 2002) who believe that its penetration

⁴ The definitions of Big Science, Proto-megascience, and Megascience are of a particular importance for this course. We define “big science” as the science projects (primarily physics) of big apparatuses, collectives, funding, and duration that came into existence at the end of the 1960s. We define “proto-megascience” and the collective, long-duration science projects (primarily physics) that arose in the early 1970s and were marked by the development of the collective cognitive self—the core of the group of collaborating scientists; such cores were communicatively connected and were making decisions by deliberation. We define “megascience” as developed in the 1990s, based on “big science” projects (in physics, molecular biology, and climatology) that can be characterized by the core of collaboration (communicatively connected similarly to that in “proto-megascience” but with a more complex structure) and the extended peripheric part outside of the communicative core.

in educational methodologies is still insufficient. During their studies as PhD candidates, young natural scientists attend classes through which they prepare for their preliminary doctoral exams. Among these classes, elective courses are sometimes offered that introduce aspects and branches of the HPS. One such elective course, “The Philosophy of Scientific Experimentation,” was developed by the authors. This course is discussed in this paper and includes an introduction to the philosophical problems of scientific experimentation in the natural sciences (primarily physics and biology) and is designed to familiarize students with the history, philosophical problems, and main stages of scientific experiments. The course is aimed at the formation of the students’ skills for the critical analysis of scientific experiments and the activities of an experimentalist, the development of CT⁵, and preparation for preliminary exams in the discipline of the “History and Philosophy of Science.” In developing CT ideas in the framework of our course, we considered positions on the formation of CT, including in the course on HPS (e.g., Bailin, 2002; Davson-Galle, 2004). During the course, students can be invited to join in philosophical reflection regarding scientific research experience in light of historical considerations.

When designing the course, we familiarized ourselves with the curricula of similar courses on the philosophy of scientific experimentation, including those taught by Franklin at the University of Colorado (Franklin 2018) and Perovic at the University of Belgrade (Perovic 2014). In doing so, we enriched our course with historical topics covered by those sources and contemporary references; however, we offered an approach to the material that emphasized the theory-ladenness of contemporary physics and introduced the notion of proto-megascience as the preliminary stage or seed of contemporary megascience. Our view on the communicative space of megascience collaborations acquires a special significance within the META framework. The philosophy of scientific experimentation is a branch of the philosophy of science that seeks to answer questions like the following: How can reliable knowledge be obtained through an experiment? What role does experiment play in science? What is the relationship between experiment and theory? How

⁵ Critical thinking proceeds from the premises that one can think better and good thinking is an independent value of society. The demand for critical thinking arose in the twentieth century when society realized that the radical changes that are constantly taking place in the world require a person to think flexibly, quickly perceive and analyze information, conduct a situational analysis, and make a decision that can radically change their life. That is, in modern conditions the judgment ability became especially in demand. Increasingly, a person or society as a whole was faced with situations for which there are no ready-made decision-making schemes, and it was necessary to think better or be able to analyze, ask questions, put forward hypotheses, discard hypotheses, evaluate one’s own and other people’s statements and arguments, and understand that a true statement is almost always constrained by certain implicit assumptions and theories. The coronavirus pandemic demonstrated this to the fullest extent. A view of those changes is presented in this article, both through the META examples and through examples from the history of science and the practical development of megascience.

is experimental practice organized? What are the similarities and differences between experiments in different sciences?

One of the key features of our course is the absence of claims purporting to be final truths. On the contrary, during our class students were asked to evaluate positions and theories that often contradicted each other; they were encouraged to embrace those positions that most closely matched their own views and professional life experience. The course focused on the role of philosophical reasoning. A significant number of historical examples were given from the fields of physics, engineering, and biology. In some cases, examples were given of experiments in which the participants themselves or the lecturer had personally participated⁶.

To be able to critically analyze the experiments, the students needed to be provided with explanations of philosophical concepts, such as rationalism, empiricism, transcendentalism, positivism, and post-positivism, with which, as it turned out, most of them were not deeply familiar. As will be discussed below, each new chapter of the course began with a brief overview of the previous topic.

We realize that in a course for non-philosophy students, the focus has to be on humanitarian training of the natural scientists and engineers through the introduction of ideas of classical philosophical thought. Another important objective of the course is to encourage young researchers to use philosophy to solve specific problems in the field of their direct professional practice (i.e., physics, biology, and technology).

As a practical task, for instance, the students can be required to independently analyze the article ‘The Collective Author’ by Galison (2003) presented to students by instructors during the lectures along with the ideas of the META (Sorina, 2018). The teacher can task students with highlighting the basic concepts in the article along with questioning, reflecting, and commenting on the text. The course builds on the META and, in turn, draws on ideas of CT. Also, it is especially important for the pragmatic aims of the course that students be asked to identify associations with and analogies between course material and their own professional activities (see the Table).

⁶ The authors constrained themselves mainly to examples from high-energy physics because their own previous research experience is deeply related to physics; nevertheless, we are considering extending our course by using more examples and methodologies from life sciences. However, the biology PhD candidates taking the course grasped its main ideas because of the common methodological issues between physical and biological megascience projects (such as the problem of collectivity and individuality or the problem of division of cognitive labor) and their educational background (the majority of biology PhD candidates received undergraduate training in physics). Introducing elements of physics to life sciences students also encourages them to engage in interdisciplinary and transdisciplinary synthesis, which is a hallmark of the philosophical mindset.

List of basic concepts presented in the text and their most important characteristics	Questioning the text	Reflections and comments	Possible associations and analogies related to the professional practice of the author of the report
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Table. Analytical table of the META

The course presented a novel strategy for teaching HPS to non-philosophers because it was based not only on lectures and reading assignments but also on META lessons. The course syllabus includes the following big topics presented below in more detail: 1) early views on experimentation, 2) theory-ladenness of experimentation, 3) problems of contemporary science and high-energy physics, and 4) the methodology of expert text analysis. Our primary aim in this paper will be to propose a new curricular approach to HPS. It is novel in that it introduces the META and uses megascience as a vehicle for illustrating course content. To our knowledge, it is the first class to do so. Furthermore, when adumbrating the course’s curricular material, we will also report some anecdotal reflections on our experience teaching an iteration of the course to several classes of graduate students during 2018 - 2020.

The course is mainly intended for PhD candidates in natural sciences (and most were physicists). However, the important point is that the life sciences students (at least in our case) received basic undergraduate training in physics (including acquaintance with laboratory work) and comprehended the course material. Many philosophical aspects of megascience—for example, the problem of collective and individual cognition or the problem of division of cognitive labor—are common for high-energy physics and molecular biology, making them equally important for students across the natural sciences.

Presentation of early views on experimentation

To get started, the connections between philosophy, its relevant branches (in this case, the philosophy of science), and scientific experimentation have to be demonstrated for the students. Philosophy can be defined in a multitude of ways, ranging from the reflection on the foundations of culture to the pursuit of science-like knowledge of the most general laws of nature, society, and thought. Given that we were teaching natural science students, we placed an emphasis on the latter definition due to the fact that, despite the differences between philosophy and science, they are united by criticality and integrality. The philosophy of science is, however, a rather distinct field comprised of research largely based on the history of science. Professional natural scientists (and physicists in particular) have made a significant contribution to this field, and its development was initiated in the second half of the nineteenth century.

The philosophy of science is an inquiry into what scientific knowledge is, what its structure and functions are, and according to what laws science develops—that is, a wide range of issues related

to science. Interest in scientific experimentation stems from the fact that it, along with theory, is one of the main instruments for the development of science and the realization of its objectives. In turn, the philosophy of experimentation makes it possible to form a meta-level conceptualization of both perception and the subsequent analysis of specific types of experiments. The course began with a glimpse into the history of the philosophy of science.

While the first scholarship on the philosophy of experimentation appeared only at the beginning of the 20th century, with Duhem (1962) being considered the first philosopher of the modern scientific experiment, experimentation itself as a method of cognition appeared much earlier, owing in particular to the efforts of Bacon at the end of the 16th century and the first third of the 17th century. One of the main questions studied by the philosophy of scientific experimentation, namely, the question of the relationship between theory and experiment, is directly related to the question of what is primary for knowledge, theorizing, and experience. This issue has been the subject of controversy between several lines of philosophical thought, the main representatives of which we discuss below.

In the context of the class, we recommend that both empiricism and rationalism be explained in relation to modern scientific experiments. One of the central metaphors used by Bacon, the most prominent representative of the philosophy of empiricism, in explaining the experimental method was that of the bee and the ant. According to Bacon, the experimenter does not just collect data, like an ant collects food, but instead acts like a bee, which extracts nutrient material from the flowers, disposes of it, and changes it according to its own understanding.

However, as other empiricists did later, Bacon considered the main method of gaining knowledge from experience to be the inductive derivation of hypotheses from experiment. The induction that Bacon proposed was premised on the results of empirical research: for Bacon, as is evident in his criticism of Aristotle, it was important that enumerated objects be empirical ones. At the same time, Bacon was situated within the framework of classical induction, which he had expanded as it acquired new classical features that were included in modern ideas about induction. Bacon explained the features of empirical induction as follows: “What sciences need is a form of induction which takes experience apart and analyses it, and forms necessary conclusions on the basis of appropriate exclusions and rejections (Bacon 2000, p. 17).

At this point, when discussing this material during class, the teacher can ask students to reflect on what it means in modern experiments for there to be “exclusions and rejections,” which are concepts encountered in the experiments with the Large Hadron Collider (LHC) that are necessary for empirical induction. To provoke reflection, an example can be given from atomic physics, namely, Millikan’s measurement of the electron charge in the presentation proposed by Franklin (a modern researcher in the philosophy of experiment) (Franklin 2013). In this case, Millikan relied on some preliminary theoretical or model considerations that enabled him to perform exclusions and rejections (much like Bacon suggested), which testifies to the priority of rational thinking.

Recognizing the role of exclusions and rejections, Bacon insisted on the possibility of an *experimentum (instancia) crucis*, a critical experiment that allows one to choose between two competing hypotheses. As part of the course, the teacher shows that the line of analysis of experimental problems continued in subsequent centuries and was already apparent in the philosophy of science of the 20th century in post-positivism. Lakatos (1970) offered a fundamentally different view of critical experiments, refuting their very possibility; he believed that an experiment could only be considered critical in retrospect. In particular, in experiments conducted in the search for the Higgs boson at the LHC, the theory was formulated *ad hoc* to solve an intra-theoretical problem 50 years in advance of the experiment and, in fact, was actively and successfully used to predict various effects in the framework of the Standard Model long before an experiment took place. Therefore, whether this experiment was critical can be judged only when it becomes clear whether it will bring substantial changes in scientific practice over time. We note that there is a discussion in the contemporary philosophical literature as to whether the Higgs mechanism is *ad hoc* (Friedrich 2014; Schindler 2018) as well as related controversies.

Locke held a special position in the development of empiricism: he believed that a person does not possess innate ideas and principles, since they do not appear, for example, in children or uneducated people; the human soul is initially a white sheet, or a “tabula rasa,” without any signs or ideas. An experiment, from a Lockean standpoint, should not only be a data provider but a provider of ideas as well.

Within the framework of the course, the teacher poses the question as to whether experiments that are not based on theory but that rely on ideas that stem solely from observation are possible in principle. While Locke was convinced that ideas can enter the human mind from external objects and through reflection (the philosophical idea of reflection and its development are precisely Lockean), Hume put forward a famous objection to this view. Hume argued that cognition is predicated on human experience centered on impressions. As an example of his theory of causality, a case study can be examined in the class of the collision of two particles at a collider when the movement of one particle is caused by the movement of the other. According to Hume, we could only directly perceive that the first particle was moving and touched the second, after which the second acquired velocity. However, to move from the impression of the first ball to the idea of the second moving requires a habit or association. Thus, according to Hume, psychological habit or belief is at the heart of the concept of a causal relationship between two phenomena. A causal connection, in contrast to the assumptions of the empiricists, cannot enter the consciousness of the observer from external objects directly. However, we emphasize in the course that few philosophers have taken such an extreme empiricist position.

The importance of this discussion for the methodology of the experiment and its teaching is that it shows the ineffectiveness of the experiment's “own life” (Franklin 2013) in isolation from theory: if, while observing the behavior of particles in the experiment, one can make assumptions about their interactions only from existing experience, then cognition will be limited by psychological habit, while the provisions of the fundamental theory often lead to counterintuitive results.

Empiricism was transformed in response to criticism. In the 20th century, logical positivism (Hempel's theory in particular) emerged as a kind of successor to empiricism. Like the empiricists before them, logical positivists acknowledged the insufficiency of inductivism and admitted the nonexperiential origin of hypotheses and theories.

Another direction of philosophical thought, whose representatives adhered to the opposite view from empiricism on the relationship between the theoretical and the empirical domains, was rationalism, the story of which begins with Descartes. In his view, the innate ideas and deductive abilities embedded within a person provide one with the ability to cognize. We emphasized during the course that, firstly, such a Cartesian view of the ideas of reason lies at the foundation of modern theoretical natural science. In addition, we drew attention to the fact that Descartes was the first thinker to desacralize mathematics. Whereas in the time from Plato to the Middle Ages, numbers and figures were endowed with ontological meaning and construed as divine elements of the universe, for Descartes they became intellectual tools of cognition.

The lectures in the course emphasized that within the framework of the modern approach to the analysis of experimentation, these debates between rationalism and empiricism manifest themselves as follows: theoretical physicists and theoretically-oriented experimenters are searching for new particles at accelerators (e.g., at the LHC) by relying on developed models of phenomena, while empirically-minded experimenters search for new phenomena that are identifiable by virtue of being deviations from previously known patterns. These two strategies of experimentation with modern accelerators are grounded in empiricism and rationalism, and they lead to two approaches in the search for new phenomena: model-based and model-independent searches (the latter referring to the search for violations of the law of the conservation of energy). We note that in the contemporary philosophical literature on scientific experimentation, there is a spirited discussion of exploratory experimentation, i.e., the experimentation that secures its relative autonomy from high theory (Steinle 1997; Franklin 2005; Waters 2007), and the teacher needs to discuss the authors' arguments while keeping in mind the fundamental questions raised by Hume. At this point in the class, it becomes relevant to delve into the arguments of practicing scientists working at the LHC and their views on the theory-ladenness of the measurement process (Beauchemin 2017)⁷.

The next step in analyzing the philosophy of scientific experimentation, as addressed in the course, was associated with the name of Galileo. Although it is sometimes argued that the examples of Galileo's experiments are caricatural (Machamer 2017), we maintain that those examples nevertheless represent invaluable pedagogical models. Rationalistic thinking combined with an instrumental attitude towards mathematics to form the basis of the Galilean revolution in natural science. In particular, by analyzing the law of falling bodies in emptiness, Galileo came to believe

⁷ See also (Galison 1987; Staley 2018; Franklin & Perovic 2021) that introduce the philosophical context of postpositivism and the philosophical problems inherent in experimentation to less-prepared students and specialists in other fields.

that the first law of motion, which should be the simplest (since this is a property of nature), is dictated by reason. Since uniform acceleration—the simplest form of accelerated motion—is postulated by reason, Galileo’s approach is Cartesian and rationalistic. Modern natural science, primarily physics, can be considered to be grounded in the Galilean approach (despite the occasional use of the examples that were suggested to be apocryphal). We also emphasized Galileo’s reductionism. In developing his general scientific method grounded in the mathematization of physics and by observing planets through a telescope, Galileo successfully brought forward the reductionist approach to experimentation—the laws of planetary motion he discovered were reducible to Newtonian mechanics.

This concludes our intellectual tour of the history of early concepts, views on cognition, and their connection with experimentation.

Theory-ladenness in experimentation

Another problem that plays a central role within the course is the theory-ladenness of experimentation.

In the opening lecture of this session, the instructor and the students discuss how even if the phenomenal theory was initially absent in some experiments (e.g., when relic radiation was detected), then the previous background theory or hypothesis (based on the model of the measured phenomenon) must exist. The students were offered an example of a simple experiment in which a pedestrian stumbles on a stone. They were then asked whether the pedestrian’s experience was one of “pure” observation and experience. Through discussion, the students came to see that even walking could be construed as being preceded by a mental model, according to which walking is modeled as movement in free space due to the rearrangement of legs that do not encounter resistance. It is owing to the pre-existing model that the collision of the pedestrian’s leg with a stone is unexpected and surprising, but since a layperson, as a rule, does not reflect on their walking model, this often gives the impression that walking is a non-theory-laden experience. This example allows the listeners to take a fresh look at everyday experience and eliminate some of the misconceptions associated with impressions that can still be attributed to Bacon’s “Idols of the Cave.”

As an example of a process from physics in which the role of theory was not acknowledged, educators can analyze Hacking’s account of an electron gun used to study the scattering of electrons by deuterium to demonstrate parity violation in weak interactions. Electrons for that experiment were prepared by irradiating a gallium arsenide crystal with photons, and since quantum theory only qualitatively explained the appearance of electrons in a crystal, then, according to Hacking, the appearance of these electrons was a non-theoretical process. We explained to the students that at least a model of the gun must have existed because otherwise experimenters would have had no guarantee that the results would be stable. Hacking’s realism

(i.e., electrons are real because we irradiate with them) can be explained in terms of the ability to prepare them in a certain state (i.e. manipulate), which requires instrumental theories (Hacking 1983).

Next, the teacher and the audience should examine other attempts to save empiricism, such as the empirical realism of van Fraassen, who considered the most valuable property of a theory to be its empirical adequacy, that is, the fact that all of its observed properties are found empirically (van Fraassen 2002). We also note that the names of Feigl and Kant, for different reasons, can be associated with empirical realism.

During discussion of these topics, the teacher shows that, first, such a version of empiricism still requires a preceding theory for empirical verification of its conclusions, and second, empiricism does not treat other characteristics of a theory to be as important as the theory's predictive ability, which often turns out to be as important or more important than its descriptive ability.

We also examined Franklin's arguments about avoiding what he calls a "vicious circle" in the theory-ladenness of measurement. In his account of the vicious circle, Franklin suggests that if one measures the temperature of bodies with a mercury thermometer, which functions due to the thermal expansion of bodies, but at the same time one calibrates one's measurement with a thermometer that operates according to a different principle, e.g., a constant pressure gas thermometer, then one can avoid the theory-ladenness of an account of thermal expansion. In the lecture, we discussed how such a methodological approach is practically important for the experiment, but it introduces another instrumental theory—one that relates pressure to temperature, which is based on the theoretical concept of temperature—that cannot be completely eliminated from the conditions of the experiment. However, as Franklin correctly points out, the presence of theories in an experiment is not itself problematic; moreover, theories enable one to establish a measurement error.

In the context of the class, the students should then be invited to give an example of an experiment in which phenomenal theories would be absent. In our experience of proposing this task, the students found it difficult to give such an example and thus came to agree with the arguments of the post-positivists.

Problems of big science and high-energy physics

The philosophical and methodological problems of big science, and of high-energy physics in particular, are among the central topics of the course. Based on the above antithesis of rationalism and empiricism, it seems important in the course to show that, historically, questions arose not only about what the source of knowledge is, but also about what the subject of cognition (the self) is. This is a relevant topic for megascience due to the fact that a modern scientific experiment, primarily in high energy physics, is a complex sociocultural phenomenon, since it entails the organized and self-organizing interaction of hundreds and thousands of specialists. Scientific

collaboration, which initially referred to a group of participants in a certain scientific project, has become increasingly more complex since the end of the first third of the 20th century.

It is important to captivate students and show them that the history and philosophy of science is not only history as such, but that it is a modern intellectual activity whose relation to history is similar to the relationship between theory and experiment in science: the history of science constitutes an empirical basis for illustrating philosophical ideas. The course offers a comparative analysis of classical problems in the history of philosophical thought and modern problems of megascience. In modern megascience, the problem of self can be viewed in such a way that one has to distinguish between the collective experimentalist as a whole, which is at its core an empirical collective self, collaboration as a group that shares a common intention but which is not necessarily included in the cognition process, and the author of the statements and publications of the megascience experiment that arises as a construct of the core of the collective experimentalist. The difference between the author of the knowledge statements of the collaboration (the community of intention) and the cognitive self is essential to properly assign credit for research work. The history of the development of big science and megascience makes it possible to apply Latour's actor-network theory and the concept of trading zones to represent the collective experimentalist as a network of actors.

In the context of the class, the educator can facilitate a discussion of the concept of big science (Weinberg 1961), and then define its types as megascience (Hoddeson 2008) and proto-megascience (Pronskikh 2016). We draw attention to the fact that along with the increases in cost, the complexity of theories and equipment, duration, data volumes, and the size of teams in science, as megascience emerged, structural changes also occurred related to the division of communities of theorists, experimenters, and instrumentalists (Galison 1987) and the degeneration of experiments into long chains tied to specific equipment and technologies, which lose epistemic criteria for the ending of the experiment (Hoddeson 2008). Thus, one of the distinguishing features of megascience is the instrument-centric nature of experiments.

The characteristic traits of the social organization of megascience and HEP were presented to students via the work of Galison (1987), Traweek (1988), and Knorr-Cetina (1990). In particular, attention was drawn to the division of labor (theorists, experimenters, and instrumentalists) and anthropological analogies in the description of social groups (separation, different professional languages, limited and formalized communication between groups, hierarchy in groups, limited mobility between groups, and rituals of avoidance).

The students' attention should be drawn to the differences between the languages of theorists and experimenters (first discussed in Galison (1987): a theorist, as a rule, will be able to understand the language of the experimenter and the instrumentalist, but not vice versa. In this regard, during the class, the lecturers emphasized the practical importance of theoretical education and the philosophical outlook for young scientists. These tools allow them to navigate the social intricacies of scientific organizations and engage in the most epistemically meaningful kinds of

activity. In addition, the lectures also emphasized the importance of theoretical and mathematical education in the early stages of one's career, which was a priority in Galilean natural science as well.

In addition to these issues, in our curriculum the educator discussed⁸ with students the objectivity of criteria for scientific discovery (Franklin 2013). Discovery standards are usually based on statistical criteria, which are the result of communal agreements. The same statistical significance of the results that allowed authors of papers in the 1960s to announce the discovery of particles was subsequently perceived as only “evidence” and then published as just a “search for” particles. In other words, the interpretation of statistics becomes historical and sociological, which emphasizes the importance for the students to study the history of the development of their disciplines and the philosophical and humanitarian foundations of this formation.

Here, we drew some analogies between physics in megascience and biology. In physics, a scientific fact can be deemed a material construct (Pickering 1985), which arises from the agreement of three parts: (1) a material installation, (2) a testable theory of the phenomenon, and (3) a theory that addresses instruments, data analysis, and background. During experiments, cycles of mutual resistance and adaptation occur between the three parts. Likewise, in biology (Latour 2005), it is not interpretations that are constructed, but the very events or artifacts themselves. The laboratory acts as a place where things (i.e., objects and processes) get the opportunity to show their obstinate dispositions. A fact in biology, according to Latour, is a laboratory construct, as is the quark (Pickering 1984). Methodological choices in biology (Knorr-Cetina 1990) are often similar to those in megascience and dictated by random circumstances, such as access to resources or the availability of personnel, but similarly, the availability of a working instrument, appropriate personnel, and resources determines the continuation of a megascience experiment (Hoddeson 2008). Thus, the modern historiography of science provides a rich empirical basis for illustrating philosophical ideas.

Briefly, for the sake of furthering class discussion, we recommend that the teacher next explains the foundations of Kant's idealism (Kant 1997), which to some extent reconciled rationalism and empiricism in the sense that transcendental categories and empirical experience are synthesized to form knowledge; Kant's idealism does not deny the epistemic value of experience, but it does require that certain perceptual categories precede any experience, and this is consistent with the theory-ladenness of experimental research. As an illustration of the relevance of Kant's ideas for a modern large experiment, we discussed the work of Galison in “The Collective Author” and explain the concept of a collective self. Together with the students, the teacher arrived at the conclusion that the formation of a collective entity is a key task in creating a successful megascience project. The listeners should be asked to identify the cognizing self in the case of

⁸ We frequently use “discussed” while describing lessons because (especially according to the META methodology), our lessons include discussions between the teacher and students and between student groups (the core group of “experts” and the periphery)—similar in form to the classic Socratic dialogue.

scientific collaboration for homework, and they are also asked to fill out an analytical table for the final lesson (see Table). We discussed how Kant's transcendental philosophy provides an important conceptual tool for the interpretation of cognitive processes in modern natural science and demonstrated how contemporary philosophical studies (including those by Foucault (Foucault 1984) and Deleuze (Deleuze 1994)) developed this understanding.

Expert text analysis methodology (META)

CT involves the skill of reflection on one's own cognitive activity; development of analytical skills; ability to work with concepts, judgments, inferences, inquiries; ability to evaluate the same skills in others; and ability to identify and analyze various types of errors. The META develops all of these skills and shows how they work in teams. Teamwork is especially important in the development of modern big science.

CT proceeds from the premises that one can think better and good thinking is an independent value of society. The demand for CT arose in the twentieth century when society realized that the radical changes that are constantly taking place in the world require a person to think flexibly, quickly perceive and analyze information, conduct a situational analysis, and make a decision that can radically change their life. That is, in modern conditions the judgment ability became especially in demand. Increasingly, a person or society as a whole was faced with situations for which there are no ready-made decision-making schemes, and it was necessary to think better or be able to analyze, ask questions, put forward hypotheses, discard hypotheses, evaluate one's own and other people's statements and arguments, and understand that a true statement is almost always constrained by certain implicit assumptions and theories. The coronavirus pandemic demonstrated this to the fullest extent. A view of those changes is presented in this article, both through the META examples and through examples from the history of science and the practical development of megascience.

During the course, the participants were invited to analyze the classical texts of the philosophy and methodology of science as well as contemporary classics such as the work of Galison in "The Collective Author."

The proposed methodology for expert analysis of a text (META) (Sorina 2018) included two stages: (1) study and analysis of the text and (2) discussion of the text in expert groups. The results of the text analysis at the first stage (which is performed by the students individually) are compiled in a table (see Table). Amongst the students, the table facilitated deeper insight into the work, which provoked further reflection along the following line of development: from basic concepts to questions to reflections to associations.

After drawing up tables for the text analysis, a group of students chose two to four participants from among its members to become “experts” (the main expert is the teacher who delegated part of their powers to the expert group while maintaining their leadership in the discussions). An “expert” was chosen based on a student’s desire and preparation for that role. In preparing for the META lesson, the student “experts” should carefully study the text, formulate questions, and discuss them amongst themselves and with the teacher, deciding in what sequence and how they will ask questions to the rest of the group, and how they would comment on those questions. During the joint session, the experts should ask the group members questions, comment on the answers, and if an incorrect answer is given, ask the other participants until the group finds an answer that seems sufficient to the expert group. Within the framework of this methodology, the main study group was divided into subgroups: the “experts,” the rest of the group, and the main expert (teacher). Through the META, the seminar is transformed into a practically significant and interactive lesson with elements of gamification.

In the discussion, the normative requirement should be implemented according to which all errors are to be considered errors of the collective actor represented by the group as a whole. In this case, the correction of a wrong answer contributed to the growth of a collective self (including “selves” such as the group as a whole and the expert subgroup separately) and, of course, the individualized self, which persists along with the collective self. In our view, the logic of the work of such a group in relation to the growth of collective subjectivity is analogous to experimental collaboration in megascience, including its core (experts) and periphery. Moreover, students’ preparation for laboratory work in megascience essentially boils down to their preparation for the collective cognitive activity, which is effectively modeled with the META approach to classroom. The work of such a group was concluded through a reflexive analysis during which the “experts” evaluate the work of the group, and the group assesses the work of the experts. In other words, both individual and group reflexivity are invoked (see, for example, West 1997). The criterion for the success of the lesson can be the instances of insight of some participants, who from the authors’ experience, often remarked that before the lesson they were unclear on the text, but in the course of the group work were able to answer many of their questions and independently reach a lot of conclusions.

The authors of the article surveyed students from various specializations, including physicists and engineers (who were the main participants in this course in the philosophy of scientific experiment) and cultural management and strategic consulting specialists who worked using the META platform. Approximately one hundred students were surveyed, including those who attended the course distantly because of the pandemic. Students were asked to respond to an open-ended question about how they assess the possibilities of working on the META platform, both offline and online. The survey showed that students were interested in cooperative teamwork and highlighted the effectiveness of META. The survey participants believed that the META teamwork (even online) accomplishes the following: (a) fills gaps in communication, (b) helps find “out-of-the-box” solutions to the problems discussed, (c) forms additional responsibility to one another

due to the results of collective cognition (so typical for megascience), (d) teaches negotiation and active listening, (e) prevents the loss of effective communication skills, and (f) creates additional motivation to find solutions to the problems under study.

This course on the philosophy of experimentation is innovative; there is little academic literature available on the topic. Hence, the burden of explaining the material falls on the teacher and should be alleviated by our article.

Conclusion

We have described the main ideas of an elective course in the philosophy of scientific experimentation for young scientists and graduate students of non-philosophical specializations (primarily natural sciences). The course is aimed at shaping students in obtaining the knowledge necessary for successful practical work, a career in a modern scientific laboratory, and preparation for passing doctoral exams in HPS. The course has practical aims focused on the actualization of the experience of scientific research and the formation of CT.

It is suggested that for the students, the major difficulty is connecting philosophical ideas and concrete practice. The proposed course made it possible to help establish this connection. A large part of the lectures in the course are devoted to big science, megascience, and their distinctive features. The course concluded with classes on the META, which contributed to students' assimilation of and reflection on the course material. Overall, because of its reliance on META, the course presents a novel strategy for teaching HPS to non-philosophers.

The logic of the course's presentation, in accordance with contemporary educational trends, reflects a reconceptualized view of the NOS as a historical unity of epistemological and sociopolitical processes. The historical, epistemological, and sociopolitical aspects of megascience unraveled in our course are presented to the classroom in an integrated way as different projections of a single historically unfolding institutional-cognitive process.

Under the contemporary conditions of the twenty-first century, the narratives about the problems of reasoning and the features of thinking and intellectual activity have begun to change. The methodology proposed within this article, the META, not only develops the ideas of CT but also demonstrates how CT works in an HPS course. The article supports the idea that CT should be a central aspect of science education and exemplifies how this can be done by modeling the classwork on the example of collaborative discussions in a megascience scientific laboratory.

Acknowledgements

The authors would like to thank the Editor, two anonymous reviewers, and Prof. P. Michas for their careful reading of the manuscript and valuable suggestions.

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