Physicists' Views on Scientific Realism

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Abstract

Do physicists believe that general relativity is *true*, and that electrons and phonons *exist*, and if so, in what sense? To what extent does the spectrum of positions among physicists correspond to philosophical positions like scientific realism, instrumentalism, or perspectivism? Does agreement with these positions correlate with demographic factors, and are realist physicists more likely to support research projects purely aimed at increasing knowledge? We conducted a questionnaire study to scrutinize the philosophical stances of physicists. We received responses from 384 physicists and 151 philosophers. Our main findings are 1) On average, physicists tend toward scientific realism, and slightly more so than philosophers of science. 2) Physicists can be clustered into five groups. Three show variants of scientific realism, one is instrumentalist, and one seems undecided or incoherent. 3) Agreement with realism weakly correlates with approval of building a bigger particle collider. 4) Agreement with realism weakly correlates with the seniority of physicists. 5) We did not find correlations with other factors, such as whether physicists focus on theoretical or experimental research and whether they engage with applied or basic research.

1. Introduction

Does physics get at the fundamental truths about the universe? Should we believe that all the strange things that physics tells us about – black holes, quasiparticles, vacuum fluctuations – really exist? Or is physics maybe not about anything quite so "deep," but mostly about technological progress and observable processes? These questions have occupied philosophers of science for a long time, in many a heated debate. In the past decades, various philosophical positions have been developed and defended. At the center stands the position of *scientific realism*, the view that we should have high epistemic trust in physics. This typically entails the belief that our most successful theories are (approximately) true, and things like atoms and electrons exist. Proponents of *instrumentalism* doubt this. In addition to the classical positions, some positions suggest we should only have epistemic trust in parts of science (selective realism), frame scientific research as always being conducted from within a perspective (perspectivalism), or stress the irreducible plurality of approaches and theories in science (pluralism).

These debates have taken place within philosophy, largely separated from discussions among scientists themselves. Our goal is to remedy this by surveying physicists's beliefs on various issues in the scientific realism debate. With the recent practice turn in philosophy of science, more attention has been paid not only to the daily practices of scientists, but also to what scientists believe. Our project is in line with recent endeavors to include scientists' opinions in philosophy of science through questionnaires (e.g., Steel et al, 2017 on scientists' attitudes on science and values, Robinson et al, 2019 on philosophical attitudes of scientists regarding realism, replication, values, and other topics, and Schindler, 2022 on theoretical virtues). More particularly, we are following in the footsteps of Beebe and Dellsén (2020), who compared the extent to which scientists of various fields and scholars in history and philosophy of science (HPS) and Science and Technology Studies (STS) agree with scientific realism. One of their main findings is that natural scientists agree more strongly with scientific realist views than social scientists and HPS/STS researchers. We believe (as do they) that complementary studies can yield further insights, in particular by focusing on specific scientific fields. The main goal of our study is to obtain a more fine-grained picture of *physicists'* attitudes towards scientific realism. We chose the field of physics because the scientific realism debate is largely dominated by examples from physics, such as the existence of unobservable physical entities like atoms and electrons and the truth of theories like general relativity. This is not surprising. While physics is widely seen as the most fundamental, successful, and exact science, its objects are also largely unobservable, accessed only through many layers of theoretical and mathematical constructions and instruments.

One might wonder why philosophers of science should pay attention to what physicists believe – after all, physicists might be experts in their science, but that does not make them experts in *philosophy* of science.[1] Nevertheless, we believe it is judicious to integrate scientists' opinions and attitudes in debates in philosophy of science, for several reasons. For one, some philosophers of science make claims about what physicists or scientists believe, often in support of their own claims (e.g. Hacking, 1983, 262; Fine, 1984, 261; Jones, 1988, 171; Åberg, 1991, 43; Stanford, 2006, 51; Bird, 2022, 48). The assumption here is that physicists' beliefs on certain matters can lend some credibility to a philosophical view. For example, if physicists routinely use incompatible models without ever wondering which one is "the true one", this might support a form of epistemic pluralism (Egg, 2019, 126). Conversely, if a philosophical position conflicts with the majority view among physicists, this position may require additional justification and, ideally, a psychological explanation of physicists' incorrect beliefs on the matter (Rowbottom dedicates an entire chapter to such an explanation in Rowbottom, 2019a). All of this is not to say that physicists have the last word on philosophical matters related to

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[1] We thank an anonymous reviewer for raising this point.

their science, but their views should at least be *acknowledged* when defending a philosophical view, even (or especially) when such views are criticized. Furthermore, in the same way that observing the practice of science can yield insights for philosophy of science (e.g. on the role of tacit knowledge and skills in scientific inquiry), describing the beliefs and attitudes of practicing scientists may inspire the development or refinement of philosophical positions (e.g. on the compatibility or incompatibility between different sets of instrumentalist and realist ideas).

Our survey draws a map of physicists' beliefs regarding various issues in the scientific realism debate, with several goals in mind. The first one is to find out to what extent physicists agree with scientific realism. This involves calculating an overall "realism score" for physicists, as well as looking at the level of agreement and disagreement for particular statements. The second goal is to examine what lies behind the concept of the "average physicist". Is the totality of physicists a homogeneous group or, on the contrary, a heterogeneous group behind which we can find different sub-groups? If so, do these sub-groups correspond to distinct and maybe even opposing philosophical positions? We used cluster analysis to answer these questions, and hypothesized that clusters might not align with positions straightforwardly expressed in philosophy of science. If so, such results could yield potentially interesting input for philosophical research. Further, we added demographic questions to look for correlations of realist views and demographic factors (experimental or theoretical physics, basic or applied physics, field of research, and time in the field). Should we expect experimental physicists to have stronger beliefs in the existence of unobservable entities that they manipulate in the lab, as Hacking suggests (1983, 262)? Are physicists working in applied fields more inclined to be instrumentalists than their peers? We hypothesized that such factors might be correlated with someone's attitude towards scientific realism. Finally, we asked participants whether we should build a particle collider bigger than the LHC. We hypothesized that realist physicists might be more inclined to agree with this. If so, this could point to practical implications of realist or instrumentalist stances with respect to funding decisions.

Among our results are the following: on average, physicists tend towards scientific realism, and more so than philosophers of science. This aligns with Beebe and Dellsén's study, which showed that physicists are more realists than HPS/STS scholars (78% of which were primarily philosophers of science). The cluster analysis reveals five clusters within the group of physicists. We propose to interpret them as standard scientific realism, moderate scientific realism, pluralist-perspectival realism, perspectival instrumentalism, and one cluster that is hard to interpret and appears undecided or inconsistent. Furthermore, we report a weak correlation between physicists' agreement with scientific realism and their agreement with the claim that a bigger particle collider should be built. We also found a weak correlation between career stage and agreement with realism. We did not find any correlation between agreement with realism and other external factors (theoretical or experimental physics, basic or applied physics, and field of research).

2 Methods

Our study's aims, procedures and methods were pre-registered in a time-stamped registry prior to the research being conducted (link upon request).

2.1 Questionnaire

We devised an online questionnaire that we invited physicists and philosophers of science to fill out. Participants were asked to rate 30 statements by moving a slider on a continuous scale between 0 ("This sounds completely wrong to me") and 100 ("This strikes me as exactly right"). The intermediate points were not anchored.The statements were presented in a non-random order and are shown in Table 1. Answers were editable.

During the development of the questionnaire, we conducted informal interviews with physicist colleagues to discuss different versions of the statements, to ensure the statements were as understandable as possible to a non-philosophical audience. Preliminary versions of the questionnaire were piloted among a small group of physicists, and their feedback was used to further revise the questionnaire. An initial version of the questionnaire was also reviewed and tested by colleagues in philosophy of science, this time with the added goal of testing the alignment of the respondents' realism score with their self-reported philosophical position.

In formulating questionnaire statements, we sought to avoid technical philosophical vocabulary. For example, we used the term "imperceptible" instead of "unobservable" because the term "observation" is used differently in physics and philosophy of science. We anticipated that, despite our efforts, many physicists would find our statements unclear. Accordingly, our guidelines read: "The goal of this survey is to test your reaction towards philosophical statements about physics. Many of the statements may seem unclear. For example, terms like 'truth' and 'reality' can be understood in many ways. Please answer according to your immediate inclination." To reduce ambiguity in the interpretation of our questionnaire, we not only used general statements, but added statements about specific theories and entities of physics, like general relativity and electrons. In the following, we will present the philosophical positions covered by the statements found in the questionnaire.

2.1.1 Philosophical Statements

The debate on scientific realism covers a wide variety of positions (for an overview, see Saatsi, 2018), and scientific realism itself is notoriously difficult to define (Chakravartty, 2011, Rowbottom, 2019b). Our questionnaire was intended to cover the most prevalent positions in contemporary discussions. The full list of philosophical statements can be found in Table 1.

We take *standard scientific realism* to involve four basic elements (following, for example, Psillos, 1999 and Niiniluoto, 2020). The first and most important one is the high *epistemic trust* in successful science, covered by the general statement "Our most successful physics shows us what the world is really like" (S1), and a weaker version of this claim, based on CERN's description of its mission,[2] that reads "Physics uncovers what the universe is made of and how it works" (S2). We also included statements about the truth of theories (S8) and the discovery and existence of imperceptible entities (S6, S4). Since we cannot know *which* theories and entities participants had in mind for these general statements, we added specific statements about general relativity (S21), the Big Bang (S20), and electrons (S13, S14, S15, S17, S18). Standard scientific realism also includes a commitment to *metaphysical realism* about the entities that are believed to exist: atoms, electrons, etc. are mind-independent objects with mind-independent properties, where "mind-independent" is understood both in the sense of causal and individuative mind-independence (Page, 2006). To avoid philosophical vocabulary, we tested agreement with metaphysical realism indirectly, by proposing the statement that intelligent beings in a distant galaxy would discover the same entities as our best physics (S11). Agreement with this statement suggests that such objects are parts of "nature's joints," instead of being the products of particular ways of interacting with and representing the world. We also included the statement that "Electrons exist 'out there', independently from our theories" (S14) to test agreement with metaphysical realism more directly. The third element of standard scientific realism is of a *semantic* nature: the construal of truth in terms of correspondence between language and world, and reference relations between the terms of our theories and entities in the world. Again, we tested for this indirectly, focusing on the example of general relativity (GR). We not only provided the statement that GR is true (S21) but included additional claims: that GR "teaches us about the nature of spacetime" (S22) and that "GR is not the revelation of an underlying order of nature" but "a tool that helps us make predictions and construct GPS" (S23). We hypothesized that participants agreeing with both S21 and S22 held a correspondence theory of truth, while participants agreeing with both S21 and S23 held a

2 https://home.cern/about/who-we-are/our-mission

pragmatist or empiricist notion of truth (conceived in terms of empirical adequacy or fruitfulness). The fourth element of standard scientific realism is the view that the primary goal of science is the discovery of true theories (S10).

The multiplicity of statements allowed our participants to indicate agreement with some or all tenets of scientific realism. Of particular interest to us are two kinds of selective realism. The first is a version of (epistemic) *structural realism*, which places high epistemic trust in our theories and their structural features, by contrast with what they tell us about the nature of unobservable entities (Ladyman, 1998, Votsis, 2018). We proposed the statement that "a physical theory cannot tell us what the universe is really made of, but the mathematical structure of our best theories represents the structure of the world" (S27). The second is *entity realism* which, by contrast, places higher epistemic trust in the existence of unobservable entities. Typically, entity realism is focused on entities that we think of as "things," and that can be manipulated in laboratories: electrons, atoms, cells, and so on (Hacking, 1983, Cartwright, 1983). Since we wondered whether physicists' entity realism would also include entities that are less "thing-like," we added a statement about phonons (S19), a type of quasiparticle.

The position opposed to scientific realism of any flavor is *instrumentalism* (as defended by Poincaré, Duhem or Mach, or today by Kyle P. Stanford [2006] and Darrell Rowbottom [2019a]). Instrumentalists believe that physics is a highly successful and useful instrument which nevertheless does not give us insights into the fundamental nature of reality (S3). Accordingly, theories are not literally true stories about the underlying reality behind the surface phenomena, but useful instruments for the classification, prediction, and manipulation of phenomena (S9). Instrumentalism tends to involve the belief that the unobservable entities postulated by such theories are only useful *fictions* (S5) or *constructions* (S7). They usually endorse a version of the "Pessimistic Meta-Induction" as a motivation for their instrumentalism (S12). If instrumentalists hold a correspondence theory of truth, they believe that scientific theories describing unobservable phenomena are not true, but at most empirically adequate. They do not believe that the terms defining unobservable entities refer to actual entities in the world. Instead, they might at most hold that such entities "exist" or are "real" in an internal sense, i.e., as an internal claim made within a theory or model that does not purport to describe the mind-independent world (S16).[3]

Aside from scientific realism and instrumentalism, we added statements to test positions that do not clearly map onto the realist-instrumentalist spectrum. One of them is *pluralism*, in its epistemic or methodological version. According to epistemic pluralism, different models or theories can provide different and even incompatible descriptions of a target system and nevertheless be of equal epistemic value (S25) (Massimi, 2018, 168). We added a statement about the truth of Newtonian mechanics (S24) to indirectly test a propensity towards epistemic pluralism. Methodological pluralism is the view that having mutually conflicting theories of the same phenomena is valuable for physics (S28).[4] While epistemic pluralism is incompatible with epistemic monism, the view that there is only one true description or theory of "the way the world is," methodological pluralism is perfectly compatible with it. Indeed, one might take methodological pluralism to be the best way to reach that one true description. Related to

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[3] We chose not to include constructive empiricism in our list of philosophical positions, even if it is generally considered to be the other influential form of antirealism in the literature. This position was tested in Beebe and Dellsén's questionnaire, who found that the two statements did not cluster with other realist or antirealist statements (Beebe and Dellsén 2020, 354), suggesting that van Fraassen's position "may not connect in substantial ways with the broad set of issues involved in other discussions of scientific realism" (359).

4 For example, Hasok Chang's "active pluralism," which consists in "keep[ing] multiple systems of knowledge alive," and "facilitat[ing] productive interactions between them through integration, co-optation and competition" (Chang 2012, xx).

pluralism is *perspectivism*, which takes different scientific theories to provide different perspectives on the world or certain phenomena. We proposed two statements: one is a simplified reformulation of Michela Massimi's view according to which scientific knowledge is both historically and culturally situated (S29) (Massimi, 2018, 164). The other is Peter Lipton (2007)'s reformulation of Ronald Giere's view that "scientific models are idealized structures that represent the world from particular and limited points of view" (S30).

An additional statement was included in the questionnaire, not to test a philosophical inclination at all, but rather a potential consequence of it: the opinion that "we should build a particle collider that is bigger than the LHC" (S26). While there are many issues that could influence someone's opinion on the matter (Are the costs acceptable? Is it likely that new particles will be found with it?), we hypothesized that a physicist's agreement with scientific realism will make them more likely to approve of such a project. This is because the main goal would be to gain knowledge about the "building blocks" of the universe and test the truth of fundamental theories (the realist's main interest), and not technological advances (the instrumentalist's main interest).

In summary, 22 questions were taken to test participants' inclinations towards scientific realism or instrumentalism. In Table 1, statements testing inclinations towards scientific realism are indicated in blue, statements testing inclinations towards instrumentalism are indicated in brown. Exceptions are S19, S20, S24, S26, S27, S28, S29 and S30, indicated in grey, most of which are compatible with both scientific realism and instrumentalism. While we expect scientific realists to believe in the existence of electrons, we do not think they necessarily believe in the existence of phonons (S19) and the Big Bang (S20).

	General statements	Philosophical position
S1	Our most successful physics shows us what the world is really like**.**	Sc. realism (strong)
S2	Physics uncovers what the universe is made of and how it works.	Sc. realism (moderate)
S3	Our most successful physics is useful in many ways, but physics does not reveal the true nature of the world.	Instrumentalism
S4	The imperceptible objects that are part of our most successful physics probably exist. *(with "*imperceptible*" we mean objects that cannot be perceived with our unaided senses, e.g. electrons, black holes, ...)*	Entity realism
S5	The imperceptible objects postulated by physics are only useful *fictions*.	Fictionalism, instrumentalism
S6	Physicists *discover* imperceptible objects	Sc. realism
S7	Communities of physicists *construct* imperceptible objects.	Constructivism, instrumentalism
S8	Our best physical theories are true or approximately true.	Sc. realism
S9	Physical theories do not reveal hidden aspects of nature. Instead, they are instruments for the classification, manipulation and prediction of phenomena.	Instrumentalism
S10	The most important goal of physics is giving us true theories.	Realism about goal
S11	If there was a highly advanced civilization in another galaxy, their scientists would discover the existence and properties of many of the imperceptible objects of our current physics.	Sc. realism, metaphysical realism
S12	I expect the best current theories in physics to be largely refuted in the next centuries – in the same way that successful theories were largely refuted in the past.	Scientific antirealism, PMI
	Specific statements	
S13	Electrons exist.	Entity realism
S14	Electrons, with all their properties, exist "out there," independently from our theories.	Entity realism, metaphysical realism
S15	Our theories are getting closer to the real nature of the electron.	Entity realism, metaphysical realism
S16	Electrons are postulated as real within our models; it does not make sense to ask whether they exist "outside" or independently of the theory/model.	Internal realism
S17	There is something in the world that behaves like (what we would define as) an electron.	Entity realism, internal realism
S18	Electrons are (at least) as real as toe-nails and volcanoes.[5]	Entity realism
S19	Phonons exist.	Entity realism

[5] The formulation is taken from Hacking 1983, 21.

S20	There really was a Big Bang.	Sc. realism, speculative physics
S21	General relativity is a true theory	Sc. realism
S22	General relativity teaches us about the nature of spacetime	Sc. Realism
S23	General relativity is not the revelation of an underlying order of nature. It is a tool that helps us make predictions and construct GPS, for example.	Instrumentalism
S24	Newtonian mechanics is a true theory	Sc. realism, pluralism
S25	If a phenomenon can be explained both by a classical model and by a quantum model, neither of the models is closer to the truth than the other.	Epistemic pluralism or antirealism
S26	We should build a particle collider that is bigger than the LHC.	-
	Additional views	
S27	A physical theory cannot tell us what the universe is really made of, but the mathematical structure of our best theories represents the structure of the world.	Structural realism
S28	Having mutually conflicting theories about the same phenomena is valuable for physics.	Methodological pluralism
S29	Our scientific knowledge is the product of the prevailing cultural traditions and historical periods in which they were formulated	Cultural/historical perspectivism
S30	Scientific theories and models are idealized structures that represent the world from particular and limited points of view.	Perspectivism

Table 1: List of statements and their philosophical interpretation. Statements marked as blue are considered realist, statements marked as brown are considered antirealist or instrumentalist, grey statements were considered neutral and not taken into account in the calculation of the realism score.

2.1.2 Demographics Questions

After presenting these statements, we asked participants to indicate whether they are a "physicist," "philosopher of science" or "neither (specify)." Self-identified physicists were asked:

1) whether their work tends to be theoretical or experimental
2) whether their work is rather basic or applied research
3) how many years they have been doing research in physics from the start of their PhD (options in years: 0, 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 10-15, 15-20, 20-25, 25+)
4) what their field of research in physics is

We hypothesized that these factors might influence someone's agreement with scientific realism. However, we had no specific hypotheses concerning which demographic factors would make agreement with realism more or less likely.

Self-identified philosophers were asked about their position in the debate on scientific realism. We offered the options: Scientific realism, Instrumentalism, Constructive empiricism, Entity realism, Structural realism, Perspectivism, Pluralism, Social constructionism, Relativism, Logical empiricism, and Other (option to specify). They could agree with multiple options.

Participants who identified as neither physicists nor philosophers of science were not asked any further question and their answers were not included in this study.

2.2 Data collection and preparation

We used the platform Qualtrics to set up the online questionnaire and collect data. To obtain data from physicists, we collected email addresses from publications in *Physical Review Letters*, *Applied Physics Letters*, and *European Physical Journal Applied Physics* (2645 addresses in total), and sent them email invitations. In addition, we contacted colleagues who work in physics and asked them to share the survey link with their peers. To collect philosophers' data, we sent out email invitations to two mailing lists: Philos-L and HPS Cambridge. We started sending out invitations in July 2021 and ended collecting data in November 2021. In total, we got 1,028 responses. We automatically removed participants that did not complete the questionnaire (N=385) or who identified as neither physicists nor philosophers of science (N=106). Further, we visually inspected the data and found participants who produced answers with a corrupted data format or obviously invalid answers, for example setting the slider on 50 for all statements (N=2). After removing all these cases, we found that the fastest participant required 2 minutes and 58 seconds for completion. The answers in this dataset appeared consistent; hence we decided not to exclude any subjects due to the overly quick completion of the questionnaire. The median time for completion was 8 minutes and 20 seconds.

2.3 Data Analysis

Technical details on all analyses are reported in the supplementary. Analyses were performed with MATLAB 2021a and all scripts are available in the online materials. Out of 30 questions, only 22 were designed to test participants' position along different dimensions of the realism/instrumentalism spectrum. Only these were used to determine a participant's agreement with scientific realism. To simplify the data interpretation, all 22 questions were aligned in the same direction, ranging from an extreme instrumentalist position (Score = 0) to an extreme realist position (Score = 100). This required the inversion of eight items (S3, S5, S7, S9, S12, S16, S23, S25).

We analyzed physicists' answers by principal component analysis (PCA), an unsupervised learning method that is popular in the analysis of psychological data (Velicer & Jackson, 1990; Jolliffe & Cadima, 2016), to describe the questionnaire's structure and dimensionality. In the present study, we hypothesized that PCA would be able to explain the physicists' philosophical positions in the questionnaire by only a few variables. These variables could be interpreted as fundamental continua that define a physicist's philosophical position. In a control analysis, we also applied the closely related exploratory factor analysis for the same purpose.

Next, we analyzed physicists' answers by a k-means clustering algorithm to create a typology of physicists regarding their philosophical position. K-means is an unsupervised learning algorithm that clusters data in an n-dimensional data space given a pre-defined number of clusters. In simple words, the algorithm tries to describe the data set by assigning physicists to a group based on the similarity in their answers in the questionnaire. A good cluster solution finds a typology for which differences between physicists within a cluster are as low as possible, but high between the clusters. The mean score of each answer within a cluster can be used to describe the typical position of all physicists within a cluster. Second, we sorted philosophers into the physicists' clusters. We assessed the similarity of each philosopher with each of the physicists' clusters and assigned the philosopher to the closest cluster. We then used the self-assigned philosophical stances to evaluate the physicists' philosophical stances.

Finally, we performed group comparisons between all clusters for the demographic variables and opinion on building a bigger particle collider. Further, we aimed to assess how demographic variables relate to an overall degree of scientific realism. As a proxy for a participant's degree of inclination towards scientific realism (their "realism score"), we used the mean score of the 22 questions that aimed to assess scientific realism or instrumentalism. Before that, we aligned all questions in the same conceptual direction, i.e. that higher values indicated inclination towards scientific realism.

2.4 Data Availability

The full question catalogue, all the study's anonymized data, detailed results, and all analysis scripts are publicly available on Mendeley Data at the following web address: https://data.mendeley.com/datasets/w2pfxfj9gb/1.

3 Results

3.1 Sample Composition and Descriptive Data

After automatic and manual data cleaning, 535 valid and complete records remained. They consisted of 384 physicists and 151 philosophers. We report the mean values of physicists' answers for each question in Table 2 and boxplots with the median and quartiles of each answer in Figure 1. Among the physicists, 171 focused on experimental research, 212 on theoretical physics. 305 judged their work to be basic research and 78 as applied research. 123 physicists were within the first 5 years after the start of their PhD, 86 within 5-10 years, 68 within 10-15 years, 37 within 15-20 years, 13 within 20-25 years, and 55 over 25 years.[6] On average, the 151 philosophers agreed with 1.99 philosophical positions. The most commonly reported position was 'Scientific Realism' which was reported 62 times. A detailed report can be found in figure 2. Physicists' agreements with the 30 philosophical statements were heterogeneously distributed. While the answers for some questions were evenly distributed, others were highly skewed towards high scores that represented more realist positions.

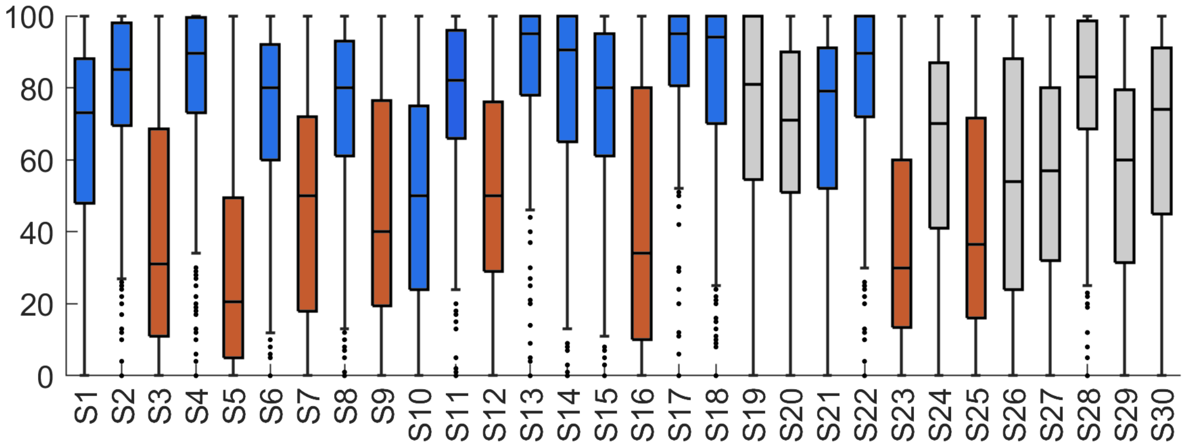

Figure 1: Boxplots showing the median and quartiles of answers in the group of physicists. Dots indicate outliers. The colors indicate whether a statement was in favor of scientific realism (blue), instrumentalism (brown) or an additional position (grey).

[6] Note that discrepancies between the sum across all categories and the total number of physicists were due to very few participants that skipped the corresponding questions.

3.2 Principal Component Analysis and Factor Analysis

Principal components analysis (PCA) and Factor Analysis were unable to identify a low-dimensional structure of possible latent variables underlying the questionnaire. Any low-dimensional description of the physicists' positions, e.g. by 2 or 3 latent main variables, was insufficient to account for a meaningfully large proportion of the overall variance in the data. Given the complexity of this analysis and its little value, we report details only in the supplementary. This failure to identify an interpretable and more simple structure behind the physicists' answers suggests that the physicists' positions might be highly complex and heterogeneous (see discussion in 4.5). An additional PCA on the philosophers' answers to the 22 questions came to similar conclusions, albeit a low-dimensional set of components was able to explain more variance than for the physicists.

3.3 K-means Cluster Analysis

The gap statistic suggested five clusters to describe the physicists' data. The resulting clusters consisted of between 61 and 101 physicists each (see Table 2).

	Cluster 1	**Cluster 2**	**Cluster 3**	**Cluster 4**	**Cluster 5**	**Mean**
# Participants	**61**	**101**	**79**	**78**	**65**	**384**
S1 REAL	30.3	**84.6**	**82.3**	58.6	52.8	64.8
S2 REAL	54.5	**92.8**	**89.6**	**79**	69.7	79.3
S3 INST	67.5	**18.9**	**29.6**	32.8	66.1	39.6
S4 ER	54.6	**92.6**	**89.5**	**77**	**78**	80.3
S5 FICT	66.1	**9.2**	**24.1**	**26.8**	37.9	29.7
S6 REAL	43.2	**86**	**85.5**	66.1	65.5	71.6
S7 CONST	64.5	**24**	55.2	40.7	61	46.5
S8 REAL	46.8	**88.7**	**88.2**	63.6	**71.7**	74
S9 INST	**71.2**	**18**	46.7	35.9	**78.5**	46.3
S10 REAL	**25.2**	65.9	61.4	36.9	49.2	49.8
S11 MR	57.3	**92.8**	**86.6**	68.1	69.1	76.9
S12 INST, PMI	66.9	38.4	52.2	49.8	58	51.4

S13 ER	55.7	**96.4**	**95**	**86**	**83.2**	85.3
S14 ER, MR	43.3	**95.3**	**89.4**	**76**	**72**	78
S15 ER, MR	43.8	**87**	**89.5**	**72**	65.5	74
S16 IR	61	**22.2**	43.8	45.6	61.6	44.2
S17 ER, IR	**76.7**	**92**	**92.4**	**81.9**	**88.9**	87
S18 ER	48.9	**94.4**	**93.2**	**76.5**	**77.5**	80.4
S19 ER, PLUR	42.7	**82.8**	**84.8**	**73**	**73.1**	73.2
S20 REAL	48.3	**81**	**76.2**	64.4	68	69.2
S21 REAL	37.6	**83.6**	**87.2**	59.2	**74.1**	70.5
S22 REAL	61	**90.5**	**93.4**	**82.4**	**74.7**	82
S23 INST	62.7	**17.8**	**25.2**	32.7	64.8	37.4
S24 REAL, PLUR	34.2	**71.3**	**79.3**	47.3	**73.1**	62.5
S25 PLUR	54.2	**22.2**	60.6	34.7	57.2	43.7
S26 (LHC)	(45.5)	(64.5)	(53.6)	(53.9)	(52.8)	55.1
S27 STRUC	58.8	39.4	61.9	58.8	64.5	55.3
S28 PLUR	**83.1**	**74.8**	**79.7**	**79.7**	**81.6**	79.2
S29 PERSP	66.5	41.5	56.4	50.4	**73.6**	55.8
S30 PERSP	**81.6**	46.8	**77.5**	56	**81.4**	66.4

Table 2: Result of cluster analysis. The numbers indicate the mean values of agreement for each cluster. The color code highlights strong agreement (bold green), moderate agreement (green), moderate disagreement (red) and strong disagreement (bold red). A score between 40 and 60 was considered neutral and was not highlighted. In the first column, we abbreviate the tested philosophical position in the following way: scientific realism (REAL), entity realism (ER), metaphysical realism (MR), internal realism (IR), instrumentalism (INST), fictionalism (FICT), constructivism (CONST), perspectivism (PERSP), pluralism (PLUR), and structural realism (STRUC), pessimistic meta-induction (PMI).

We first interpreted the clusters using our judgment regarding the philosophical positions assigned to each statement (cf. section 2.1.1) and evaluated the different clusters' level of agreement or disagreement with respect to these positions. Based on this method, we identified the positions with which physicists in each cluster were in strong agreement (>70), moderate agreement (60-70), neutral or undecided (40-60), moderate disagreement (30-40), and strong disagreement (<30). Based on this first method, the philosophical positions represented in each cluster are the following: cluster 1 is predominantly instrumentalist and perspectivist, cluster 2 is strongly realist, cluster 3 is realist, pluralist, and perspectivist, cluster 4 is moderately realist with a stronger agreement with entity realism, and cluster 5 shows agreement with nearly all views. Given the surprising result regarding cluster 5, we also visually inspected the data to check whether this was an averaging effect. We found that, contrary to what the averages suggest, the majority of participants in cluster 5 do disagree (moderately or strongly) with several statements, while those who do agree with all statements (usually at the exception of S5) are the exception.

For the second method of cluster interpretation, we coordinated the self-ascribed positions of philosophers with the different clusters of physicists (see Figure 2). The number of philosophers assigned to each cluster ranged from 5 to 30. Their self-assigned philosophical stances are reported in figure 2. Of the 151 participating philosophers, 44 were associated with cluster 1, 41 with cluster 2, 8 with cluster 3, 42 with cluster 4, and 16 with cluster 5. Note that philosophers could agree with more than one position.[7] Philosophers assigned to cluster 1 generally endorsed antirealist positions (instrumentalism, social constructivism, relativism), while philosophers assigned to clusters 2 and 4 endorsed realist positions (scientific realism, entity realism, structural realism). The results for these clusters are in line with the preliminary analysis based on our own assignments of philosophical positions, presented above. It is noteworthy that very few philosophers were sorted into clusters 3 and 5. We provide a more detailed discussion of the clusters' philosophical positions in section 4.1.

[7] We would like to note that a few combinations of views were surprising. In particular, four philosopher participants combined scientific realism with instrumentalism, two combined it with social constructionism, and two with constructive empiricism.

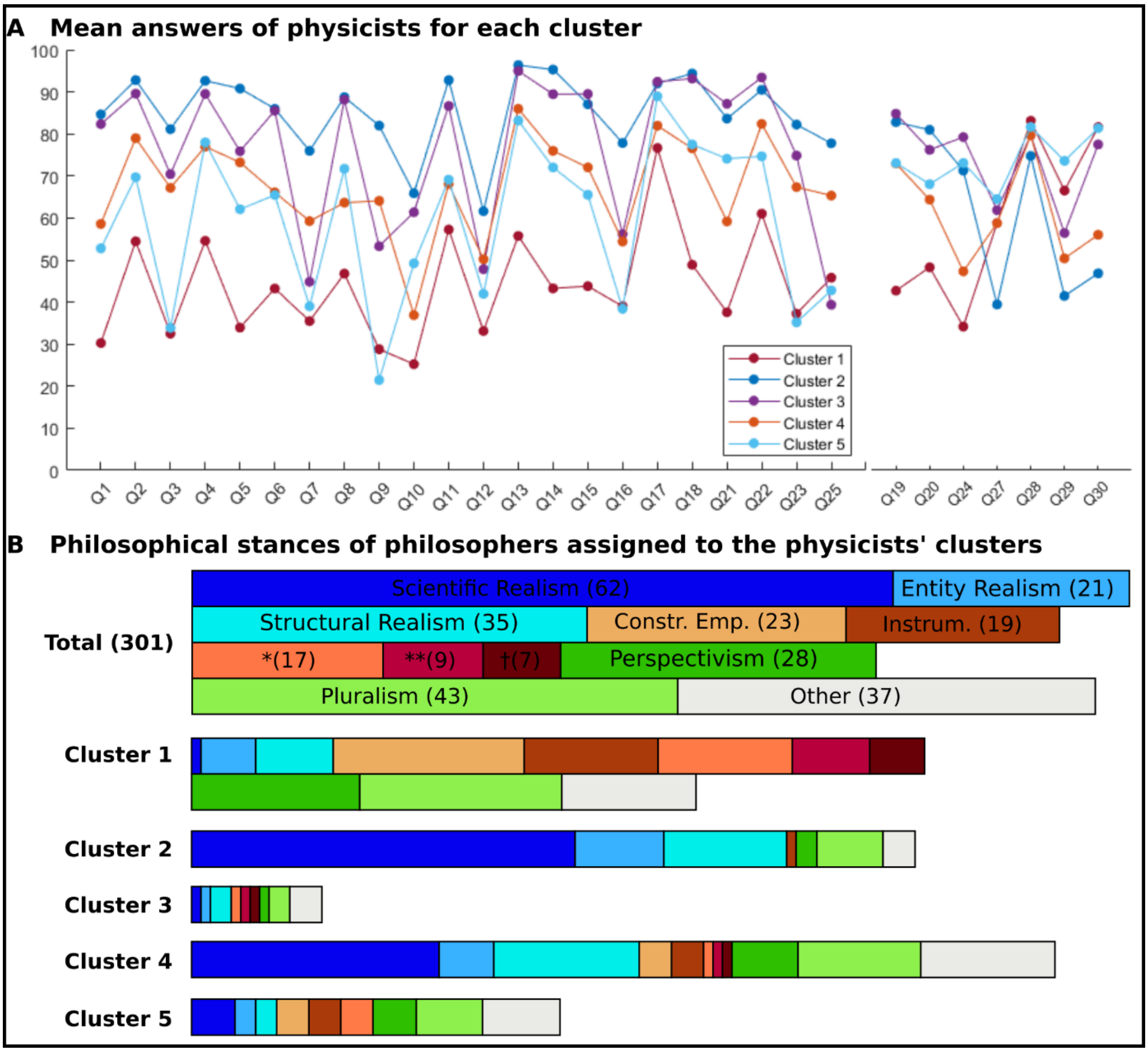

*Figure 2: Physicists' clusters. A) Mean answers of physicists across clusters for the 22 realism/instrumentalism questions and the 7 additional questions. The values for the instrumentalist statements are inverted, so that high numbers indicate agreement with realism for the first 22 statements. The lines only serve to guide the eye. B) Self-ascribed philosophers' positions, as matched to the physicists' clusters. Note that philosophers were able to self-assign multiple philosophical stances. *Social constructionism **Relativism †Logical empiricism. Variations of blue are used for realist positions, variations of brown colors for instrumentalist positions, and green for neutral positions.*

3.4 Additional Analyses

We hypothesized that physicists agreeing with scientific realism might be more in favor of building a particle collider bigger than the LHC (see section 2.1.1). With the statistical comparisons across clusters, the test across all groups became significant for the physicist's opinion on building a new particle collider (S26; H(4) = 12.71, $p < .05$). However, corrected posthoc tests did not find the answers to S26 to differ between specific clusters (all $p > 0.07$). Given the significant first test, we continued to follow our hypothesis and specifically looked at the correlation between the inclination towards scientific realism (measured as described in section 2.3) and the answers on S26. We found a weak correlation between both ($r = .171$; $p < 0.001$), implying that, as we had hypothesized, realist physicists were slightly more in favor of building a new particle collider.

To investigate the relationship between the time spent in physics and agreement with realism, we tested whether the time spent in physics would differ across the clusters. We found that the time since the start of the PhD studies differed significantly across clusters($H(4) = 20.04$, $p < 0.001$), and posthoc comparisons revealed that physicists in cluster 1 were significantly less senior than in cluster 2 (corrected $p = .006$) and 3 (corrected $p = .013$), and, likewise, physicists in cluster 5 were significantly less senior than in cluster 2 (corrected $p = .027$) and cluster 3 (corrected $p = .029$; see Figure 3). In addition, we found a weak correlation between the realism score and seniority ($\varrho=0.26$; $p<.001$), which suggests that physicists are more realist with increasing experience.

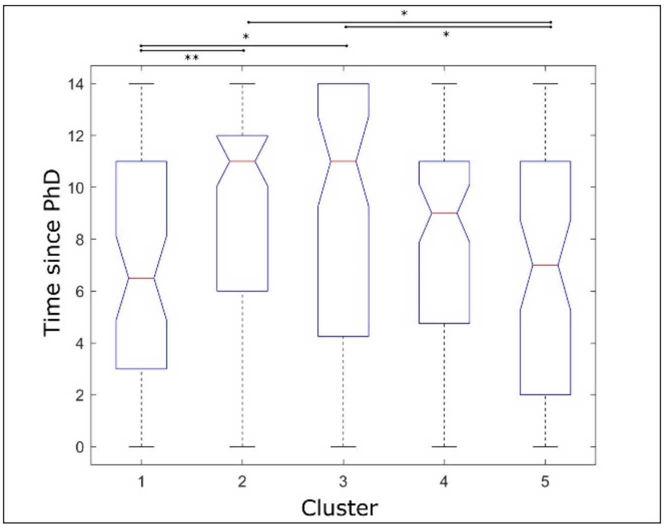

*Figure 3: Time spent in physics from the start of the PhD across clusters. Values 0-10 on the vertical axis denote the years spent in physics. The value 11 corresponds to 10-15 years, 12 to 15-20 years, 13 to 20-25, and 14 to 25+ years. Asterisks indicate significant differences in corrected posthoc tests. * p < 0.05; ** p < 0.01.*

Regarding other demographic factors, we neither found differences between clusters regarding the proportion of theoretical vs. experimental physicists ($\chi^2(4, N = 382) = 3.87$, p = .43), nor between physicists in basic vs. applied research ($\chi^2(4, N = 382) = 2.83$, p = .59). We additionally explored if the inclination towards scientific realism was associated with the demographic variables using permutation-based two-sample t-tests. We found no difference in the inclination towards scientific realism between theoretical physicists and experimental physicists (p = 0.97) nor between physicists working in applied research and basic research (p = 0.50). Neither did we find differences between the different subfields of physics, i.e. 'Nuclear and particle physics," "Atomic, molecular and optical physics," "Condensed matter physics," 'Astrophysics," "Applied physics" and "Other" (H(5) = 4.32, p = .50).

Finally, we compared the realism score between physicists and philosophers. A permutation t-test found that philosophers were less realist than physicists ($p < 0.01$; mean[physicists] = 68.9; mean[philosophers] = 64.5). This aligns with the result of Beebe and Dellsén's study (2020, 355-356), which found that physicists are more realist than HPS scholars (78% of which were primarily philosophers of science). However, the difference we found does not appear to be as pronounced as in their study.[8] This could be explained by the presence of STS scholars and historians of science in their sample, who might have a stronger inclination towards antirealism and instrumentalism than philosophers of science.

[8] According to their study, the "Standard Scientific Realism Score" of physicists is 5.6 out of 7, while that of HPS and STS scholars is 4.6 out of 7 (Beebe and Dellsén, 348, Figure 5).

4 Discussion

4.1. Interpretation of Clusters: Landscape of Physicists' Philosophical Positions

Our cluster analysis provides us with an interesting view of the landscape of physicists' philosophical positions, which we further discuss below. However, it should be noted that our interpretation of the different clusters is based on the following assumptions: first, the respondents in each cluster understood the statements in roughly the same way; secondly, the mean values for each statement within each cluster were taken to indicate the representative position for the whole cluster, regardless of the individual variations between the members of the cluster. Further, cluster analysis is a descriptive method that allows one to intuitively grasp data patterns, but it is not an inferential method that allows us to draw unambiguous conclusions about the subject-matter. For example, the number of clusters k could have been estimated differently, and more or less fine-grained classifications by physicists could also shed light on the matter.

Cluster 1: The Perspectival Instrumentalists

This cluster is the most antirealist cluster overall. Participants disagree with the realist statement according to which "our most successful physics shows us what the world is really like (S1 = 30.3), and instead strongly agree with the instrumentalist statement that "physical theories do not reveal hidden aspects of nature; instead, they are instruments…" (S9 = 71.2). They also strongly disagree with the statements that physics aims at giving us true theories (S10 = 25.2), and do not believe that General relativity or Newtonian Mechanics are true theories (S21 = 37.6, S24 = 34.2). They are neutral concerning the statement that electrons exist (S13 = 55.7). They agree with the claims that unperceivable objects are useful fictions (S5 = 66.1) and that scientists "construct" (S7 = 64.5), rather than "discover" (S6 = 43.3) unperceivable objects. However, they are still very confident that there is "something in the world that behaves like (what we would define as) an electron" (S17 = 76.7), which shows that even the most antirealist physicists do not believe that electrons are pure inventions. They strongly agree with perspectivism (S30 = 81.6), and moderately agree with its social version (S29 = 66.5). They have the highest level of agreement among the different clusters with methodological pluralism (S28 = 83.1), although other clusters also largely agree with that version of pluralism (between 74.8 and 81.6). Unsurpringly, the large majority of philosophers assigned to this cluster endorsed antirealist positions, among which Constructive empiricism (17), Instrumentalism (12), Social constructivism (12), but also Pluralism (18) and Perspectivism (15).

Cluster 2: The Standard Scientific Realists

This cluster was strongly realist in the standard sense defined in section 2.1.1 and did not yield any surprising results or combination of views. Participants in this cluster strongly agree with the general realist statements (S1 = 84.6, S2 = 92.8) and with the claim that the best physical theories are true or approximately true (S8 = 88.7). They believe that aliens in a distant galaxy would discover the same unperceivable objects and properties of our current physics (S11 = 92.8) and that electrons and their properties exist "out there" (S14 = 95.3). They moderately agree with the statement that the most important goal of physics is to give us true theories (S10 = 65.9). It is worth noting that they are quite confident in the truth of Newtonian mechanics (S24 = 71.3). We will return to physicists' attitude towards Newtonian mechanics in section 4.3. Unsurprisingly, philosophers assigned to this cluster predominantly endorsed Scientific realism (34), with a few also endorsing Structural realism (11) and Entity realism (8).

Cluster 3: The Pluralist-Perspectival Realists

For most statements, cluster 3 exhibits only slightly lower realist scores than cluster 2. However, it would be a mistake to conclude that cluster 3 is simply a more moderate realist version of cluster 2. Indeed, interesting differences emerge when looking at the statements regarding which cluster 3 is *much less* realist than cluster 2. They strongly agree with the statement regarding the truth of Newtonian mechanics (S24 = 79.0, which is also the highest score of all clusters). This indicates a tendency towards pluralism, which is confirmed by their moderate agreement with the claim that an experiment explained by a classical and a quantum model is equally close to the truth (S25 = 60.6, the highest level of agreement among all clusters). This marks an important point of contrast with cluster 2, which strongly disagrees with the same statement. This pluralism is also in line with cluster 3's strong agreement with a perspectivist view of theories and models (S30 = 77.5, by contrast with cluster 2's neutral response), and their more neutral attitude towards the instrumentalist view of theories (S9 = 46.7, by contrast with cluster 2's strong disagreement). With regard to unobservable entities, cluster 3 exhibits an interesting combination of strong agreement with realism about unobservable entities (S13 = 95, S17 = 92.4, S19 = 84.8), including a form of metaphysical realism (S11 = 86.6, S14 = 89.4, S15 = 89.5), with a neutral attitude towards constructivism (S7 = 55.2) and internal realism (S16 = 43.8), by contrast with cluster 2, which strongly disagrees with both. A possible interpretation of this combination lies in the participants' pluralist and perspectivist tendencies: different theories and models are ways of getting at some subject-matter from several points of view. Their position might therefore be close to Michela Massimi's perspectival realism, which combines perspectivism about scientific knowledge with a robust form of realism about the target of representation (Massimi, 2018, 2022). Nevertheless, only 4 philosophers were assigned to this cluster (compared to 38 with cluster 4, 27 with cluster 1, and 20 with cluster 2). This could mean two things. Perhaps the position that emerges from this cluster constitutes a unique combination of views that does not exist in the current scientific realism debate. While most perspectivists defend some form of realism, they are often opposed to metaphysical realism (Giere, 2006, 4-5; Massimi, 2022, 67, 227). These physicists might share many of the perspectivist's insights regarding scientific knowledge while maintaining a form of metaphysical realism about entities. Whether this view is coherent and deserves to be part of the philosophical landscape is something for philosophers to appraise. An alternative interpretation is that these physicists actually endorse a metaphysically "innocent" interpretation of the statements, in line with Massimi's perspectival realism about *modally robust phenomena*. In this case, the view endorsed by these physicists does exist in philosophy of science. The low number of philosophers assigned to this cluster might only point to the divergence in interpretation of the relevant statements by philosophers of science. The ones who agree with Massimi's form of perspectival realism may have indicated lower levels of agreement to these statements and thus been assigned to different clusters.

Cluster 4: The Moderate Realists

This cluster is moderately realist, and maybe the most moderate cluster *tout court.* Participants in this cluster moderately agree with the realist statements that clusters 2 and 3 strongly agree with (e.g. S1 = 58.6, S6 = 66.1, S8 = 63.6), and moderately disagrees with constructivist or instrumentalist statements (e.g. S3 = 32.8, S7 = 40.7, S23 = 32.7). A point worth noting is that, while they are confidently realist about unobservable entities (S5 = 73.2, S13 = 85.6, S14 = 75.9, S15 = 72, S17 = 81.9, S19 = 76.5), they are less confident about the truth of scientific theories (S8 = 63.6, S21 = 59.2, S24 = 47.3). Also, they do not believe that giving us true theories is the most important goal of physics (S10 = 36.9). And while clusters 2 and 3 show clear confidence in the truth of Newtonian mechanics, participants in cluster 4 remain neutral (S24 = 47.3). However, they do believe that General relativity teaches us about the nature of spacetime (S22 = 82.3). Overall, we interpret this cluster as moderately realist, with a tendency towards entity realism. The dominant position of philosophers assigned to this cluster is

Scientific realism (22). Surprisingly, a relatively high number of philosophers indicated structural realism among their preferred positions (13), while few indicated entity realism (5). This seems to indicate a lack of coherence on the philosophers' side.

Cluster 5: The Undecided Ones?

This group enigmatically combines different and sometimes opposing philosophical positions, as participants in this cluster agree with nearly all positions. Similarly to cluster 1, this cluster indicates strong agreement with instrumentalism (S9 = 78.5, S23 = 64.8) and perspectivism (S29 = 73.6, S30 = 81.4). However, they also believe in the truth of theories in general (S8 = 71.7), the truth of general relativity (S21 = 74) and Newtonian mechanics (S24 = 73). While they moderately agree with the instrumentalist interpretation of GR (S23 = 64.5), they also believe that GR teaches us about the nature of spacetime (S22 = 74.7). They are strongly realist about entities and electrons (S4 = 78, S13 = 83, S14 = 72, S17 = 89, S18 = 77.5). In fact, the only statement they moderately disagree with is the claim that imperceptible objects are only useful fictions (S5 = 37.9). However, as noted in section 3.3, this general agreement with all philosophical positions is partly due to an averaging effect. This explains some inconsistencies in the average responses. For example, the average participant agrees with the metaphysical realist statement that electrons exist "out there," independently of our theories (S14 = 72), *and* with the internal realist statement that it does not make sense to ask whether electrons exist outside or independently of theories (S16 = 65.5). When devising the survey, we assumed that both statements contradicted each other. When looking at individual responses, we found that 23 out of 65 participants in cluster 5 agreed with both statements. This is not insignificant, but not the majority either. Similarly, the average participant in cluster 5 agrees with both the statements that physicists discover (S6 = 65.5) and construct (S7 = 60.1) imperceptible objects. While those statements do not necessarily contradict each other, none of the other clusters agreed with both. When looking at individual responses, we found that 30 participants out of

65 agreed with both statements. Unsurprisingly, very few (7) philosophers were assigned to this cluster.

Regarding participants in the cluster that did express general agreement with most statements, one possible interpretation is that these physicists do not *have* a view on scientific realism. They perceive very different statements as plausible and are not decided between them. Another interpretation is that the philosophical framework we use to analyze their attitudes somehow does not match their views. A third possible interpretation is that these physicists hold incoherent views on the topic of scientific realism.

This cluster analysis shows that physicists do not have a unified view on the question of scientific realism and its different dimensions. This, in itself, is an important consideration to keep in mind for philosophers of science who wish to integrate physicists' beliefs and attitudes into their philosophical views. While scientific realism appears to be the most prevalent attitude among physicists, philosophers of science cannot draw generic conclusions as to what physicists believe (such as "most physicists are realists", Åberg, 1911, 43; or on the contrary, "physical scientists turned their backs on realism", Fine, 1984, 261) without taking into account the diversity of opinions among physicists.

4.2. Points of Consensus and Division Among Physicists

Looking at the totality of answers, it is interesting to identify the few statements for which there *is* a clear consensus among physicists, based on the distribution of answers for individual statements (cf. Figure 1). Most of these are the "weak" realist statements: S2 ("Physics uncovers what the universe is made of and how it works"), S4 ("The imperceptible objects that are part of our most successful physics probably exist"), S13 ("Electrons exist"), S17 ("There is something in the world that behaves like (what we would define as) an electron"), S18 ("Electrons are (at least) as real as toe-nails and volcanoes"), S22 ("General relativity teaches us about the nature of spacetime"). These statements combine the highest level of agreement with a narrow distribution. In our view, this somewhat constrains the way some philosophical positions in philosophy of science should be defended. While this does not mean that such statements should be universally accepted by philosophers of science just because physicists believe them, a heavy argumentative burden does fall on philosophical views that reject any of these statements. In particular, they need to explain why the vast majority of physicists are wrong about these matters. This kind of explanation is given by Rowbottom (2019a), who provides psychological explanations for the widespread inclination towards scientific realism among philosophers and physicists alike. Nevertheless, a better strategy for those who wish to reject standard forms of scientific realism may be to accept a "surface level" reading of these statements, while offering alternative interpretations of what they mean. For example, Massimi's perspectival realism can accommodate these statements while specifying that physics does not describe the "hidden goings on" of nature but rather "modally robust phenomena" (2022, 15). Similarly, Rowbottom can accept "talk of electrons" while explaining that such talk should not be taken "literally" (2019a, 33).[9] This strategy is further vindicated by the fact that physicists' consensus regarding the claim that "Electrons exist" breaks down once different formulations of this ontological commitment are provided. This indicates that the locus of philosophical contribution concerns the way existence claims should be interpreted (semantic/referential realism, internal realism, phenomena or things-in-themselves, natural kinds).

Conversely, there are statements on which physicists appear to be divided or undecided, i.e., where there is no clear consensus towards agreement or disagreement and a large distribution of answers. Most of these statements tend towards instrumentalism or constructivism: S3 ("Our most successful physics is useful in many ways, but physics does not

[9] Nevertheless, Rowbottom's version of instrumentalism will have difficulties accommodating the claim that "Electrons are (at least) as real as toe-nails and volcanoes".

reveal the true nature of the world"), S7 ("Communities of physicists *construct* imperceptible objects"), S9 ("Physical theories do not reveal hidden aspects of nature. Instead, they are instruments for the classification, manipulation and prediction of phenomena"), S16 ("Electrons are postulated as real within our models; it does not make sense to ask whether they exist 'outside' or independently of the theory/model"), S25 ("If a phenomenon can be explained both by a classical model and by a quantum model, neither of the models is closer to the truth than the other"). Other statements concern physicists' epistemic trust towards current theories (S12 "I expect the best current theories in physics to be largely refuted in the next centuries – in the same way that successful theories were largely refuted in the past") and the goal of physics (S10 "The most important goal of physics is giving us true theories"). The lack of consensus on these statements can be explained by different factors. Some statements might be too ambiguous or unclear. The average physicist might struggle to understand what is meant by entities being "constructed", or entities existing "outside" a model or theory, thereby preventing them from definitely agreeing or disagreeing with such claims. For other statements, the lack of consensus may indicate a real divison of opinions among physicists, for example, regarding the goal of science or the epistemic trust we should have in our current best theories. Either way, these statements highlight areas where philosophy of science can contribute the most. For example, talk of "construction" of entities might be unclear, but not so absurd as to elicitate a wholesale rejection of the claim by physicists. It falls upon philosophers to clarify the different senses in which entities may or may not be constructed. Regarding the divisive questions, the role of philosophy of science is also pivotal in advancing arguments or counterarguments that may not be readily available to physicists (e.g. drawing on the history of science, assessing the validity of the inference to the best explanation, etc.).

4.3 Comparison between Physicists and Philosophers of Science

As noted in section 3.4, our study found that physicists are slightly more realist than philosophers of science. In itself, this result does not say anything about the credibility of scientific realism. On the one hand, we may want to trust physicists' opinions on their own science and the epistemic trust we should have towards it. On the other hand, many of the relevant arguments in the debate are philosophical in nature and/or draw from the history of science (inference to the best explanation, pessimistic meta-induction, unconceived alternatives, semantic arguments). This suggests that physicists may not be the best juges on these questions. This is not to say that physicists' opinions should not constrain the philosophical debate at all (see 4.2).

Aside from the difference in degrees of realism, an interesting point of divergence between physicists and philosophers lies in their pluralist attitudes towards entities and theories. The average physicist moderately agrees with the claim that Newtonian mechanics is true (S24 = 62.4), by contrast with the average philosopher of science who is mostly neutral (S24 = 44.0) (see Table 3 for all results). This is the largest difference we found between physicists and philosophers. The average physicist is also close to neutral with respect to the pluralist statement that quantum and classical models are equally close to the truth (S25 = 43.7 points) whereas the average philosopher moderately disagrees (S25 = 36.3). One possible explanation of this result is that physicists take "Newtonian mechanics" to refer to the mathematical formulation of the theory, while philosophers include the ontological commitments of the theory (e.g. absolute space and time, Newtonian forces), which are seen as incompatible with those of general relativity. Physicists might also take Newtonian mechanics to be an approximation of general relativity.

	Mean Value of Agreement (from 0 to 100)	
	Physicists	**Philosophers of science**
S1 REAL	64.8	58.8
S2 REAL	79.3	68
S3 INST	39.6	43.8
S4 ER	80.3	72.7
S5 FICT	29.7	32.3
S6 REAL	71.6	68.3
S7 CONST	46.5	40.6
S8 REAL	74	68.5
S9 INST	46.3	41.8
S10 REAL	49.8	53
S11 MR	76.9	62.7
S12 INST, PMI	51.4	62.2
S13 ER	85.3	80.7
S14 ER, MR	78	68.6
S15 ER, MR	74	67.2
S16 IR	44.2	39.5
S17 ER, IR	87	81.7
S18 ER	80.4	69
S19 ER, PLUR	73.2	61.8
S20 REAL	69.2	63.8
S21 REAL	70.5	63
S22 REAL	82	71.3
S23 INST	37.4	37.8
S24 REAL, PLUR	62.5	44
S25 PLUR	43.7	36.3
S27 STRUC	55.3	41.4
S28 PLUR	79.2	74.7
S29 PERSP	55.8	58.8
S30 PERSP	66.4	67.3
# Participants	**384**	**151**

Table 3: Answers from physicists and philosophers of science. The numbers indicate the mean values of agreement for each group (from 0 to 100). See Table 2 for the list of abbreviations.

4.4 Demographic Factors

We did not find any significant correlation between the realism scores of the experimental and theoretical physicists, between applied and basic physics, or between fields within physics. We think this is an interesting result in itself. For example, one could have expected a more instrumentalist attitude towards theories from physicists working in applied physics than in basic physics, or a stronger entity realism from experimental physicists manipulating entities in the laboratory (see Table 4). The latter might lead to a reconsideration of Hacking's (1983) arguments for entity realism based on the experimental manipulation of entities.

	Mean Value of Agreement (from 0 to 100)	
	Experimental physicists	**Theoretical physicists**
S13 ER	85.8	85
S14 ER, MR	79.6	76.8
S15 ER, MR	76.3	72.3
S16 IR	45.1	43.4
S17 ER, IR	87.3	86.5
S18 ER	81.5	79.7
S19 ER, PLUR	73.6	72.7
# Participants	**171**	**212**

Table 4: Comparison between experimental and theoretical physicists for statements related to entity realism. The numbers indicate the mean values of agreement for each group. See Table 2 for the list of abbreviations. See the supplementary for the full table.

However, we did find a correlation between having a realist position with the time spent in the field, and we also found a difference in time spent in the field between clusters. The realist clusters 2 and 3 contain more senior researchers than the instrumentalist cluster 1 and the "undecided" cluster 5. Various interpretations are possible. One is that this is a learning effect: the longer people stay in physics, the more closely they move towards scientific realism – maybe because the knowledge they gain about physics makes realism more compelling to them, or because they grow more accustomed to the view. It could also be the case that people more inclined towards scientific realism are more strongly motivated to stay in academia. Another explanation is a cohort effect, i.e., that more experienced physicists were trained in a period in which realist positions were more popular.

4.5 The Complexity of an Individual's Position on Scientific Realism

Principal component analysis (PCA) and factor analysis are commonly used to describe high-dimensional data with only a few variables, and, for example in psychology, these few variables are often interpreted to be latent variables that underlie the data. In the current study, both methods failed to deliver a set of few variables that satisfyingly describe the data, which means that the philosophical position of a physicist cannot be broken down into a few fundamental variables. The first explanation for this finding is that our questionnaire assessed overly complex, high-dimensional latent variables. Alternatively, this finding might be rooted in an incoherence in answers, which is also illustrated by the 5th cluster with enigmatically contradictory answers. According to this interpretation, a potential low-dimensional set of latent variables describing a physicist's stance on realism cannot be identified because, if they exist, they are not coherently linked to answers to explicit statements. Another indication for this interpretation is that the first PCA factor in philosophers explained much more variance than in physicists. Philosophers should be more familiar with philosophical positions on realism, and, possibly, they rated the statements in coherence with an elaborated philosophical stance. Therefore, the primary continuum underlying this stance might be better suited to describe the rating in philosophers.

4.6 Practical Consequence of Agreement With Realism

Many fields of physics are directly relevant to making changes in our daily lives, like research on new kinds of sensors or on medical technology. In these cases, it is clear why an instrumentalist would find it worthwhile to continue such scientific projects. But some research projects are motivated in a way that directly aim at gaining deep insights about the fundamental nature of reality. This is the case of the research conducted with the LHC: the goal is to study the "fundamental building blocks" of reality.[10] More specifically, the goal is to test and refine the Standard Model of particle physics, by confirming the existence of inferred particles (e.g. the Higgs Boson) and discovering new particles. The Future Circular Collider (FCC) at CERN would "extend the research currently being conducted at the LHC".[11] This kind of research appears to be more closely aligned with the standard realist view that the goal of science is to gain insights into the fundamental nature of reality or to increase the verisimilitude of theories, and less with the instrumentalist view that the goal of science is "to provide the fully developed human with as perfect a means of orienting himself as possible" (Mach, 1959) or to "[furnish] us with more predictive power and understanding concerning observable things" (Rowbottom, 2019a, 2). We hypothesized that, for this reason, an instrumentalist would be less likely to endorse the construction an even bigger (and more expensive) collider than the LHC. We found a weak correlation between participants' agreement with scientific realism and their agreement with S26 "We should build a particle collider that is bigger than the LHC." Of course, many other factors influence physicists' judgment regarding the desirability a research project that costs billions of dollars, including the allocation of research funds to other projects of more immediate practical concern (such as climate science). However, this positive result does suggest that, among the many potential factors involved, one's overall stance regarding realism plays a role. This itself suggests that one's position in the scientific realism debate can have practical implications regarding the kind of research projects deemed worthy of pursuit.

[10] https://indico.cern.ch/event/421552/sessions/170229/attachments/884218/1242859/LHC.pdf

[11] https://home.cern/science/accelerators/future-circular-collider

5. Conclusions

The main findings of our survey are: 1) On average, physicists tend towards scientific realism, and slightly more so than philosophers of science. 2) Cluster analysis identified five different sub-groups of physicists. We interpret the first four positions as perspectival instrumentalism, standard scientific realism, pluralist-perspectival realism, and moderate scientific realism. Physicists in the fifth cluster might be undecided, incoherent, or support a view that is not represented by standard philosophical frameworks. 3) Agreement with realism weakly correlates with the opinion that a bigger particle collider should be built. This suggests that a physicist's philosophical stance on this topic might influence research strategies and funding decisions. 4) Agreement with realism weakly correlates with the time a physicist has spent in the field, where more senior researchers tend more towards realism. 5) We did not find a correlation with other factors (theoretical vs. experimental research; applied vs. basic research; and field of research). The data we obtained from our survey is rich and could form the basis of additional statistical analyses on the responses given by physicists and philosophers of science.

There are several ways in which our results could influence or contribute to the scientific realism debate: first, we have identified points of consensus among physicists that constrain which philosophical positions are *prima facie* acceptable; and conversely, points of division among physicists which identify areas where philosophers of science can contribute the most. For example, while almost all physicists believe that electrons exist, they do not agree in what sense that claim should be understood. Secondly, we have shown that, apart from these few points of consensus, physicists' overall views on scientific realism are too complex and varied for generic references to physicists' stance towards realism to be made in the literature. We also believe that qualitative analyses are needed in order to complement our quantitative results. For example, interviews with physicists that hold representative positions in the landscape of physicists' philosophical views could lead to a better understanding of their positions and the ways in which they either fit or differ from the traditional frameworks used in philosophy of science. Further qualitative studies could also be conducted to examine how philosophical stances towards realism or antirealism influence the practice of science. For example, what are the practical differences, if any, between a physicist's ontological commitment to electrons described in terms of metaphysical realism or in terms of internal realism? Such questions suggest a fruitful avenue of research at the intersection of the scientific realism debate, philosophy of science in practice, and empirical philosophy.

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References

Åberg, Claes. (1991). "Realism and Relativism in Modern Physics". *Synthese*, Vol. 89, No. 1: 41-61.

Beebe, James R., and Finnur Dellsén. (2020). "Scientific Realism in the Wild: An Empirical Study of Seven Sciences and History and Philosophy of Science." *Philosophy of Science* 87, no. 2: 336–64. https://doi.org/10.1086/707552.

Bird, A. (2022). *Knowing Science*. 1st ed. Oxford: Oxford University Press. https://doi.org/10.1093/oso/9780199606658.001.0001.

Cartwright, N. (1983). *How the Laws of Physics Lie*. Oxford: Oxford University Press. https://doi.org/10.1093/0198247044.001.0001.

Chakravartty, A. (2011). Scientific realism. In E. N. Zalta (Ed.), *Stanford encyclopedia of* *philosophy*.

Egg, M. (2018). “Entity Realism.” In *The Routledge Handbook of Scientific Realism*, edited by Juha Saatsi, 1st ed., 120–32. Routledge Handbooks in Philosophy. New York: Routledge. https://doi.org/10.4324/9780203712498-14.

Fine, A. I. (1984). “The Natural Ontological Attitude.” In Scientific Realism, edited by J. Leplin, 261–77. University of California Press.

Giere, R. N. (2010). Scientific Perspectivism. Chicago, IL: University of Chicago Press. https://press.uchicago.edu/ucp/books/book/chicago/S/bo4094708.html.

Hacking, I. (1983). *Representing and Intervening: Introductory Topics in the Philosophy of Natural Science*. Cambridge: Cambridge University Press. https://doi.org/10.1017/CBO9780511814563.

Jolliffe, I. T., and Jorge C. (2016). “Principal Component Analysis: A Review and Recent Developments.” *Philosophical Transactions of the Royal Society A: Mathematical, Physical and Engineering Sciences* 374, no. 2065 (April 13): 20150202. https://doi.org/10.1098/rsta.2015.0202.

Jones, R. (1988). “Scientific Realism in Real Science.” *PSA: Proceedings of the Biennial Meeting of the Philosophy of Science Association* 1988 : 167–78.

Kaiser, H. F. (1960). “The Application of Electronic Computers to Factor Analysis.” *Educational and Psychological Measurement* 20: 141–51. https://doi.org/10.1177/001316446002000116.

Ladyman, J. (1998). “What Is Structural Realism?” *Studies in History and Philosophy of Science Part A* 29, no. 3: 409–24. https://doi.org/10.1016/s0039-3681(98)80129-5.

Lipton, P. (2007). “The World of Science.” *Science* 316, no. 5826: 834–834. https://doi.org/10.1126/science.1141366.

Massimi, M. (2018). “Perspectivism.” In *The Routledge Handbook of Scientific Realism*, edited by Juha Saatsi, 1st ed., 164–75. Routledge Handbooks in Philosophy. New York: Routledge.

https://doi.org/10.4324/9780203712498-14.

Massimi, M. (2022). *Perspectival Realism*. Oxford, New York: Oxford University Press.

Niiniluoto, I. (2020). “Interdisciplinarity from the Perspective of Critical Scientific Realism.” In *New Approaches to Scientific Realism*, edited by Wenceslao J. Gonzalez, 231–50. Berlin: De Gruyter. https://doi.org/10.1515/9783110664737-011.

Page, S. (2006). “Mind-Independence Disambiguated: Separating the Meat from the Straw in the Realism/Anti-Realism Debate.” *Ratio* 19, no. 3 (September): 321–35. https://doi.org/10.1111/j.1467-9329.2006.00330.x.

Psillos, S. (1999). *Scientific Realism: How Science Tracks Truth*. Philosophical Issues in Science. London ; New York: Routledge. https://doi.org/10.4324/9780203979648.

Robinson, B., C. Gonnerman, & M. O’Rourke. (2019). “Experimental Philosophy of Science and Philosophical Differences across the Sciences.” *Philosophy of Science* 86, no. 3 (July): 551–76. https://doi.org/10.1086/703553.

Rowbottom, D. P. (2019a). *The Instrument of Science: Scientific Anti-Realism Revitalised*. New York: Taylor & Francis, 2019.

Rowbottom, D. P. (2019b). “Scientific Realism: What It Is, the Contemporary Debate, and New Directions.” *Synthese* 196, no. 2 (February 1): 451–84. https://doi.org/10.1007/s11229-017-1484-y.

Saatsi, Juha, ed. (2018). *The Routledge Handbook of Scientific Realism*. Routledge Handbooks in Philosophy. New York: Routledge/Taylor & Francis Group. https://doi.org/10.4324/9780203712498.

Schindler, S. (2022). “Theoretical Virtues: Do Scientists Think What Philosophers Think They Ought to Think?” *Philosophy of Science* 89, no. 3 (July): 542–64. https://doi.org/10.1017/psa.2021.40.

Stanford, P. Kyle. *Exceeding Our Grasp: Science, History, and the Problem of Unconceived*

Alternatives. New York: Oxford University Press, 2006. https://doi.org/10.1093/0195174089.001.0001.

Steel, D., Gonnerman, C., & O'Rourke, M. (2017). "Scientists' Attitudes on Science and Values: Case Studies and Survey Methods in Philosophy of Science." *Studies in History and Philosophy of Science* 63: 22–30. https://doi.org/10.1016/j.shpsa.2017.04.002.

Velicer, W. F., & Jackson, D. N. (1990). "Component Analysis versus Common Factor Analysis: Some Issues in Selecting an Appropriate Procedure." *Multivariate Behavioral Research* 25, no. 1: 1–28. https://doi.org/10.1207/s15327906mbr2501_1.

Votsis, I. (2018). "Structural Realism and Its Variants." In *The Routledge Handbook of Scientific Realism*, edited by Juha Saatsi. Routledge Handbooks in Philosophy. New York: Routledge/Taylor & Francis Group. https://doi.org/10.4324/9780203712498-10.