

Scientific Realism Versus Antirealism in Science Education

Abstract

Scientific realists believe both what a scientific theory says about observables and unobservables. In contrast, scientific antirealists believe what a scientific theory says about observables, but not about unobservables. I argue that scientific realism is a more useful doctrine than scientific antirealism in science classrooms. If science teachers are antirealists, they are caught in Moore's paradox when they help their students grasp the content of a scientific theory, and when they explain a phenomenon in terms of a scientific theory. Teachers ask questions to their students to check whether they have grasped the content of a scientific theory. If the students are antirealists, they are also caught in Moore's paradox when they respond positively to their teachers' questions, and when they explain a phenomenon in terms of a scientific theory. Finally, neither teachers nor students can understand phenomena in terms of scientific theories, if they are antirealists.

Keywords

Moore's Paradox, Science Education, Scientific Antirealism, Scientific Realism

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1. Introduction

One of the debates in philosophy of science surrounds the question of whether we should believe that successful scientific theories, such as the special theory of relativity, evolutionary theory, and the kinetic theory of heat, are true. Scientific realists ('realists' hereafter) and antirealists take opposing positions concerning the epistemic status of successful scientific theories. The debate between them remains active in the philosophy of science literature. This paper connects the literature with science education, attempting to determine which is a more useful doctrine, realism or antirealism, for the purpose of science education.

This paper is structured as follows. In Section 2, I make explicit what realism and antirealism assert, using the kinetic theory of heat as an example. In Section 3, I introduce eminent antirealist scientists and philosophers of science. In Section 4, I present the four most salient arguments for accepting antirealism and rejecting realism, drawing on the philosophy of science literature. In Section 5, I display pedagogical disadvantages of antirealism over realism. In the end it will become clear that realism is a more useful doctrine than antirealism for the purpose of science education, and hence science teachers and students should be realists.

2. Realism vs. Antirealism

Following Hilary Putnam (1975) and Stathis Psillos (1999), I define realism as the view that successful theories, such as evolutionary theory, the special theory of relativity, and the kinetic theory of heat, are (approximately) true. (I drop the qualifier 'approximately'

henceforward.) To say that a theory is successful means that it “has led to confirmed predictions and has been of broad explanatory scope” (Laudan, 1981: 23). Thus, realists do not believe that *any* scientific theories are true. They believe that only the theories which have high explanatory and predictive powers are true. To believe that a theory is true is to believe both what it says about observables and unobservables. Unobservables, which are also called theoretical entities, are such entities as electrons, molecules, neutrinos, and genes. We cannot observe theoretical entities with our naked eyes, but theories postulate their existence in order to explain and predict phenomena. In contrast, observables are such entities as trees, computers, and stones. We can observe them with our naked eyes.

Antirealism is defined in this paper as the position that what successful theories say about observables is believable, but what they say about unobservables is not. Thus, antirealists do not believe that successful theories are true. Nor do they believe that unobservables postulated by a theory are real. They do not believe, for example, that electrons, molecules, neutrinos, and genes are real. They, however, believe that trees, computers, and stones are real. In that sense, they are less skeptical about the world than Cartesian skeptics. Cartesian skeptics do not even believe that observables are real on the grounds that it might be evil demon, not the physical universe, that causes perceptions, experiences, and sensations in our mind. Antirealists reject Cartesian skepticism, contending that macroscopic objects exist.

The kinetic theory of heat claims that molecules are in constant motion, obeying Newton’s laws of mechanics, that the mass of an object is the sum of the mass of the constituent molecules, and that the temperature is the mean kinetic energy of the molecules. Molecules are unobservables in that they cannot be observed with our naked eyes, but the kinetic theory of heat postulates their existence to explain various heat phenomena. For example, a fireplace is hot, and ice is cold. According to the kinetic theory of heat, the fireplace is hot because its constituent molecules move fast. The ice is cold because its constituent molecules move slowly. When a hot object and a cold object touch each other, they assume the average temperature because the fast-moving molecules collide with the slow-moving molecules. The result of the collision is that the speed of the fast-moving molecules decreases, and the speed of the slow-moving molecules increases.

Realists and antirealists take different epistemic attitudes toward the kinetic theory of heat. Realists believe, for example, that molecules are in constant motion, obeying Newton’s laws of mechanics, and that the heat phenomena are real. In contrast, antirealists do not believe that molecules are in constant motion, although they believe that the heat phenomena are real. Thus, the scope of antirealist beliefs is restricted to observables whereas that of the realist beliefs encompasses both observables and unobservables. In the following section, I introduce several celebrated antirealists in the history and philosophy of science.

3. Antirealists

When Nicolaus Copernicus (1473-1543) put forward the heliocentric system, many thinkers resisted his hypothesis that the earth moves around the sun. They admitted, however, that the Copernican theory accurately predicted the positions of planets. So Andreas Osiander (1498-1552), one of those thinkers, treated “the circle representing the earth’s orbit as a mathematical fiction, useful for computations alone” (Kuhn, 1957: 187). As far as Osiander was concerned, the heliocentric system was merely a useful instrument for computing the positions of planets, and the earth is at rest at the center of the universe. The traditional name for his position is instrumentalism. Instrumentalism is the view that a theory is an instrument for making predictions, and it does not purport to represent unobservables. Thus, an

instrumentalist does not believe what a theory says about unobservables, although he believes what it says about observables.

Pierre Duhem (1861-1916), a French physicist, mathematician, historian, and philosopher of science, claimed that a physical theory is an instrument for organizing our thoughts about observables. Specifically, he said that a physical theory “is a system of mathematical propositions, deduced from a small number of principles, which aim to represent as simply, as completely, and as exactly as possible a set of experimental laws” (Duhem, 1914/1982: 19). Note that on Duhem’s account, a physical theory aims to represent experimental laws. Given that an experimental law is couched in observational terms, Duhem’s contention implies that a physical theory does not purport to depict unobservables.

In the similar vein, Niels Bohr (1885-1962), one of the founders of quantum mechanics, claimed that “[t]he task of science is both to extend the range of our experience and reduce it to order” (Bohr, 1934: 1). On Bohr’s account, it is not the task of science to describe unobservables. Its task is rather to expand data and organize them into a coherent and compact system. Note that he defines his position in terms of the task of science, not in terms of his commitment to what a theory says. We can see, however, that his position does not allow for beliefs about unobservables. He refused to accept the theoretical claims of science, and was determined to accept only the observational claims of science.

Percy Bridgman (1882-1961), a Nobel laureate physicist, developed a position called operationism or operationalism. According to operationalism, “we mean by any concept nothing more than a set of operations” (Bridgman, 1927: 5). This proposal can be illustrated by Edwin Hung’s following example:

x has an excess of hydrogen ions =_{df} If a litmus paper is placed in x, then x will turn red. (Hung, 1997: 227)

Note that the definiendum contains the theoretical term ‘hydrogen ions’ referring to unobservables, whereas the definiens contains only observational terms. Thus, on Bridgman’s proposal, a theoretical sentence can be translated into an observational sentence, and hence a theory can be purged of theoretical terms. A theory free of theoretical terms makes claims only about observables. Believing such a theory does not go beyond observables. Thus, the scope of an operationalist’s beliefs is restricted to observables.

Kyle Stanford (1970-Present), a recent leading antirealist philosopher of science, claims that “we might use our theories for prediction, intervention, and other pragmatic purposes without believing the theoretical descriptions they offer of the natural world” (Stanford, 2006: 197). Thus, we are justified in believing, for example, that a cold object and a hot object will assume the average temperature if they are in contact with each other. But we are not justified in believing that the fast-moving molecules collide with the slow-moving molecules.

The positions of the preceding scientists and philosophers of science are slightly different from each other. For example, Osiander would say that a theory is neither true nor false, but that it is a useful or a useless, depending on whether it accurately predicts observable events or not. In contrast, Bridgman would say that a theory, a collection of observational claims, is true or false, depending on whether it corresponds to observables or not. Such subtle differences among the aforementioned antirealist thinkers, however, do not matter for the purpose of this paper. What is important in this paper is that none of them believes that successful theories are true, and hence all of them deserve the appellation

‘antirealists.’ More importantly, they are all subject to the criticism I raise in this paper. Before unfolding the criticism, however, I motivate antirealism in the following section.

4. Motivation for Antirealism

Antirealism is not an irrational doctrine. As we have seen in the previous section, renowned scientists and philosophers of science endorse it. They embrace it for various reasons. I cannot go over all those reasons in this paper due to lack of space. In this section, I introduce only the four most salient arguments for antirealism.

First, what a theory says about unobservables is so repugnant in the light of our preexisting metaphysical beliefs that we reject it. Osiander, for example, was a Lutheran priest firmly believing that the earth is at rest at the center of the universe. Because of this preexisting metaphysical belief, he could not accept the Copernican hypothesis that the sun is at the center of the universe, and that the earth moves around the sun. For another example, what quantum mechanics claims about unobservables is so bizarre that Bohr refused to believe it. It claims that a microscopic object has incompatible properties simultaneously and indeterminately, but it comes to have one of them definitely when we measure them. For example, an electron has the property of spin-up with 50% probability and the property of spin-down with 50% probability at the same time. When we measure the properties, however, the electron assumes one of those properties with 100% probability. We cannot even visualize the microscopic states of affairs described by quantum mechanics. It just sounds counterintuitive that an object has incompatible properties indeterminately when we do not observe it, but it comes to have one of them definitely when we observe it. So it is tempting to reject what quantum mechanics says about unobservables.

Second, realists believe that a theory is confirmed and disconfirmed when its prediction turns out to be true and false, respectively, i.e., a positive experimental outcome and a negative experimental outcome increases and decreases, respectively, the probability of a theory. Duhem (1914/1982) and Quine (1951) retort, however, that it is not a single theory but a group of theories that meets the tribunal of experience. A theory under a test needs to be conjoined with auxiliary assumptions in order to issue observational consequences which can be compared with observables. When an observational consequence does not agree with an observable event, it is not necessarily the theory under the test that should be thrown out. The consistency of the system of the beliefs can be maintained, if a revision is made elsewhere in the system. Logic does not tell us which revision we ought to pursue. So we cannot say that the probability of a theory increases and decreases, respectively, when it passes and fails an empirical test. Observational data cannot pinpoint which member of the group is true and which member of the group is false.

The third argument relates to the problem of underdetermination which occurs when a theory competes with another theory. The rival theories make similar claims about observables but different claims about unobservables. Henri Poincaré (1902/1952: 65-66) provides a useful example. A geometrical theory claims that the world is a finite sphere, that the space is Euclidean, that light travels on circular paths, and that an object expands as it moves toward the center of the sphere and shrinks as it moves toward the circumference of the sphere. A rival theory claims that the world is infinite, that the space is Lobachevskian, that light travels in straight lines, and that an object neither expands nor shrinks when it moves around. As far as the inhabitants of the world are concerned, the two competing geometrical theories are empirically equivalent. The observational data cannot determine which of them is true, i.e., the rival theories are underdetermined by observational data. In such circumstances, we might reject what the rival theories say about unobservables but

accept what they say about observables.

The fourth argument, perhaps the strongest one, is the pessimistic induction according to which since past theories turned out to be false, present theories will also turn out to be false. Past theories are such theories as the Ptolemaic theory, the phlogiston theory of combustion, the caloric theory of heat, and the ether theory of light. These theories were in fashion in the past. We no longer believe that they are true. Present theories are such theories as the Copernican theory, the oxygen theory of combustion, the kinetic theory of heat, and the special theory of relativity. These theories are in fashion in the present. If the pessimistic induction is correct, we ought to resist the realist belief that successful present theories are true. The pessimistic induction of one form or another is advocated by scientists and philosophers of science, such as Henri Poincaré (1905/1952: 160), Ernst Mach (1911: 17), Larry Laudan (1977: 126), Hilary Putnam (1978: 25), Kyle Stanford (2006: 20), and Brad Wray (2013).

5. Pedagogical Disadvantages

5.1. Grasping

Teachers have many goals in science classrooms. Realists would say that one of teachers' goals is to help students form beliefs about both observables and unobservables as depicted by a theory. In contrast, antirealists would say that it is teachers' goal to help students form beliefs about observables, but not about unobservables. They would, however, agree that teachers have the goal to help students grasp the content of a theory. In this section I expose problems that arise when antirealist teachers attempt to help their students grasp the content of a theory, and when antirealist students attempt to answer their teachers' questions that are asked to check whether students have comprehended the theory.

In order to help students comprehend a theory, teachers should explicate what it says about unobservables and what it says about how unobservables relate to observables. Teachers have to say, for example, the following sentences in order to teach the kinetic theory of heat to their students:

- (M) A material object is made up of molecules. The molecules are in constant motion, obeying Newton's laws of mechanics. The faster the molecules are, the hotter the object is.

Note that (M) consists of claims about unobservables and how unobservables relate to observables. Teachers should utter the sentences like the ones in (M) so that students can understand what the kinetic theory of heat says about the world. It does not matter whether teachers' goal is to help their students form beliefs about molecules and heat phenomena, or it is merely to help their students form beliefs about heat phenomena. Without uttering sentences like the ones in (M), teachers cannot do the job of helping their students comprehend the kinetic theory of heat.

A problem is that antirealist teachers do not believe that the kinetic theory of heat is true. So they cannot say the sentences like the ones in (M). They cannot say, for example, that a material object is made up of molecules, the reason being that they do not believe that unobservables, including molecules, are real. Their assertion of the sentence 'A material object is made up of molecules' conflicts with their antirealist commitment. In other words, there is a gap between what they should say as teachers and what they believe as antirealists.

Imagine that antirealist teachers say, "A material object is made up of molecules" in order to help their students comprehend the kinetic theory of heat, and then add, "But I don't

believe a material object is made up of molecules” in order to express their antirealist position. It is, however, odd to say, “A material object is made up of molecules, but I don’t believe a material object is made up of molecules.” To assert such a sentence involves what Ludwig Wittgenstein (1953: 190) calls Moore’s paradox. Moore’s paradox occurs when we assert a sentence of the form: p , but I do not believe that p . George Moore (1944) first discovered that it is absurd to say, “It’s raining, but I don’t believe it’s raining.” There are several attempts in philosophy language to explain why it is absurd to assert a Moorean sentence (Lee, 2001; Green and Williams, 2007; Chan, 2010; Green and Williams, 2011; Williams, 2013). It requires, however, going off at a tangent to explore these different accounts of Moore’s paradox. What is important for the purpose of this paper is the fact that antirealist teachers run into Moore’s paradox.

Unlike antirealist teachers, realist teachers do not encounter Moore’s paradox. Realist teachers believe that the kinetic theory of heat is true, so they are happy to assert the sentences like the ones in (M). They believe, for example, that a material object is made up of molecules. Accordingly, they are happy to say to their students, “A material object is made up of molecules.” Unlike antirealist teachers’ speech acts, realist teachers’ speech acts accord with what they believe.

Let me turn now to students’ side. Suppose that students are exposed to their teachers’ sentences like the ones in (M). As a result, they know what the kinetic theory of heat says about the world. Now, teachers ask students some questions to see whether their explication was effective, i.e., whether students have grasped what the kinetic theory of heat says about the world. For example, teachers ask, “What is the connection between the behavior of the molecules and the temperature of a material object?” What should students do?

The answer to this question depends on whether students are realists or antirealists. Realist students can answer, “The faster the molecules move, the hotter the object is.” They do not have a problem giving such an answer because they believe that the kinetic theory of heat is true. Their speech acts agree with what they believe. In contrast, antirealist students cannot say the sentence ‘The faster the molecules move, the hotter the object is’ because they do not believe that theoretical entities, including molecules, are real. If they say the sentence despite their antirealist commitment, their speech acts deviate from what they believe.

Imagine that antirealist students say, “The faster the molecules move, the hotter the object is,” in order to answer their teachers’ question, and then add, “But I don’t believe the faster the molecules move, the hotter the object is” in order to express their antirealist commitment. It is, however, absurd to say, “The faster the molecules move, the hotter the object is, but I don’t believe the faster the molecules move, the hotter the object is.” Moore’s paradox has arisen.

5.2. Explaining

Let me turn to a problem that arises when antirealist teachers and antirealist students attempt to explain phenomena in terms of theories. Antirealists do not believe that theories are true. (To be cited) argues that Moore’s paradox arises when antirealists use theories to explain phenomena. Explaining phenomena in terms of theories requires the belief that the theories are true. Unless you believe that they are true, you cannot use them to explain phenomena. His contention on the doxastic requirement of scientific explanation has an interesting implication on science education. I explore the implication in this section.

To learn a theory involves acquiring the ability to explain phenomena on its terms. If students cannot explain heat phenomena in terms of the kinetic theory of heat, we cannot say that they have understood what the kinetic theory of heat says about the world. In order to

help students acquire such ability, teachers may have to explain a heat phenomenon in terms of the kinetic theory of heat, present a new heat phenomenon, and then ask students to explain the new phenomenon in terms of the kinetic theory of heat. Antirealist teachers, however, cannot go through this process because they do not believe that the kinetic theory of heat is true. Consider that a hot object and a cold object assume the average temperature when they are in contact with each other. Antirealist teachers cannot explain this heat phenomenon in terms of the kinetic theory of heat because they do not believe that molecules are real. Specifically, they cannot say, “The hot object and the cold object assume the average temperature because the fast-moving molecules collide with the slow-moving molecules.”

Imagine that antirealist teachers say to their students, “The hot object and the cold object assume the average temperature because the fast-moving molecules collide with the slow-moving molecules” in order to explain the heat phenomenon in terms of the kinetic theory of heat, and then add, “But I don’t believe the hot object and the cold object assume the average temperature because the fast-moving molecules collide with the slow-moving molecules” in order to express their antirealist commitment. It is absurd to assert these two sentences consecutively. Antirealist teachers are caught in Moore’s paradox. The conjunction of the two sentences has the form: p , but I do not believe that p . Students would only be puzzled, wondering whether they should accept or reject their teachers’ explanation.

Unlike antirealist teachers, realist teachers do not have a problem explaining the heat phenomenon in terms of the kinetic theory of heat. They believe that the fast-moving molecules collide with the slow-moving molecules. Consequently, they are happy to say to their students, “The hot object and the cold object assume the average temperature because the fast-moving molecules collide with the slow-moving molecules.” Since their speech acts are in line with what they believe, they can avoid Moore’s paradox.

Let me turn now to students’ side. Suppose that teachers present a new phenomenon and ask their students to apply the kinetic theory of heat to it. For example, teachers rub two pieces of cold metal at high speed. As a result, the two pieces become hot. They ask their students to use the kinetic theory of heat and explain why they became hot. As teachers, they want to check whether their students acquired the ability to apply the kinetic theory of heat to this new phenomenon. How would students respond to their teachers’ request?

Students would respond differently, depending on whether they are realists or antirealists. Realist students believe that the molecules increased their speed. So they are happy to say, “The two pieces of cold metal became hot because the molecules increased their speed.” In contrast, antirealist students cannot say so because they do not believe that unobservables, including molecules, are real. Moore’s paradox occurs, if they say, “The two pieces of cold metal became hot because the molecules increased their speed,” in order to comply with their teachers’ request, and then add, “But I don’t believe the two pieces of cold metal became hot because the molecules increased their speed” in order to express their antirealist commitment. Their consecutive utterance of these two sentences will only puzzle their teachers.

5.3. Understanding

Let me turn now to a problem that arises when antirealist students and antirealist teachers attempt to understand phenomena in terms of theories. Recall that antirealists do not believe that theories are true. (To be cited) argued that we come to understand phenomena only when we form new beliefs about them, and that if we want to understand phenomena in terms of theories, we ought to believe that the theories are true. His contention on the doxastic

requirement of scientific understanding of phenomena has an interesting implication on science education. I explore the implication in this section.

Suppose that two pieces of cold metal are rubbed at high speed in a classroom. Before coming to the classroom, students did not know why two pieces of cold metal become hot when rubbed at high speed. They are just exposed to their teachers' explanation that the two pieces of cold metal became hot because the constituent molecules increased their speed. They now understand why the heat phenomenon occurred. The teachers' explanation gave rise to their understanding of the phenomenon. Given that the explanation is nothing but the sentence 'The two pieces of cold metal became hot because the molecules increased their speed,' we can say that students came to understand the phenomenon as a result of forming the new belief that the molecules increased their speed. Without this new belief, the understanding of the phenomenon would not have arisen in their minds, i.e., it would still be a mystery to them why the two pieces of cold metal become hot.

Antirealist students do not believe that theoretical entities, including molecules, are real. So the new belief that the molecules increased their speed is not available to them. Accordingly, they still do not understand why the two pieces of cold metal became hot, despite their teachers' explanation that the two pieces of cold metal became hot because the molecules increased their speed. The teachers failed to enlighten antirealist students on the phenomenon from a theoretical point of view. In general, teachers are bound to feel frustrated, if they aim to help antirealist students understand why a phenomenon occurs from a theoretical point of view.

We might grant for the sake of argument that antirealists can understand phenomena in terms of theories without believing that they are true. A problem is that Moore's paradox arises when antirealists express their alleged understanding of phenomena. Consider the following dialogue between teachers and students:

Teachers: The two pieces of cold metal became hot because the molecules increase their speed.

Students: I now understand why they became hot, but I don't believe the molecules increased their speed.

Teachers would be perplexed by the students' remark. The students are indirectly caught in Moore's paradox. When they say, "I now understand why they became hot," they are indirectly saying that the molecules increased their speed. Thus, to say, "I now understand why they became hot, but I don't believe the molecules increased their speed" amounts to saying "The molecules increased their speed, but I don't believe the molecules increased their speed."

Unlike antirealist students, realist students do not have a problem understanding the heat phenomenon in terms of the kinetic theory of heat. They believe what a theory says about unobservables, so they accept their teachers' explanation that the two pieces of cold metal became hot because the molecules increased their speed. They form the new belief that the molecules increased their speed. As a result, they now understand why two pieces of cold metal became hot. Their teachers succeeded in enlightening them on the phenomenon from a theoretical point of view.

Like antirealist students, antirealist teachers do not believe that the molecules increased their speed. So they do not understand why the two pieces of cold metal became hot. Despite the lack of the understanding of the phenomenon, however, they should, as teachers, explain the phenomenon to their students, i.e., they should say to their students, "The two pieces of

cold metal became hot because the molecules increased their speed.” In a nutshell, they should do their job of explaining the phenomenon to their students despite the fact that they themselves do not understand why it occurred. It appears that they have no choice but to talk as if they understood the phenomenon.

6. Conclusion

Scientists and philosophers of science advocate antirealism for various reasons. I argued that if science teachers accept antirealism, they are caught in Moore’s paradox when they help their students grasp the content of a theory, and when they explain a phenomenon in terms of a theory. Teachers ask questions to their students to check whether they have grasped the content of a theory. If students accept antirealism, they are also caught in Moore’s paradox when they respond positively to their teachers’ questions, and when they explain a new phenomenon in terms of a theory. In addition, neither teachers nor students can understand phenomena in terms of scientific theories, if they are antirealists. All these pedagogical problems evaporate, if teachers and students accept realism and reject antirealism.

One caveat is in order. I am not claiming that antirealist teachers cannot teach a theory to their students whatsoever, or that they cannot explain phenomena in terms of a theory whatsoever. I admit that they can do those things. My contention is that when they do those things, what they say diverges from what they believe or they are caught in Moore’s paradox. In order to diffuse my objection against antirealism, antirealists need to show how antirealist teachers can help students comprehend theories, and how they can explain phenomena in terms of theories, without saying more than what they believe or without being caught in Moore’s paradox. More importantly, antirealists owe us an account of how we can understand phenomena in terms of theories without believing that the theories are true. They need to tell us exactly how those three activities are possible, using a specific example like the kinetic theory of heat. I must emphasize that realists do not have such a burden because they believe that theories are true.

Finally, should we accept realism and reject antirealism because realism is advantageous and antirealism is disadvantageous for the pedagogical purpose? It is not simple to answer this question. On the one hand, antirealists have sophisticated arguments in favor of antirealism as we have seen in Section 3. On the other hand, they are all huge topics in philosophy of science, and this paper is not the right place to assess them. Suffice it to say here that (to be cited) raised other objections to antirealism, and that (to be cited) defended realism from the pessimistic induction and from the problem of underdetermination. In any event, this paper is intended to raise an additional objection to antirealism.

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