Scientific Representation and Science Learning

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Abstract

In this article I examine three examples of philosophical theories of scientific representation with the aim of assessing which of these is a good candidate for a philosophical theory of scientific representation in science learning. The three candidate theories are Giere’s intentional approach, Suárez’s inferential approach and Lynch and Woolgar’s sociological approach. In order to assess which theory is more promising, I will compare the three candidate theories to two aspects of scientific representation in science learning that emerge from empirical research on science learning. I label these aspects as the intentional and normative character of scientific representation in science learning. As I argue, whereas the other competing accounts of scientific representation can only capture one of the two aspects highlighted in this article, the inferential conception has the capacity to capture them both in a coherent way. Thus, I conclude that the inferential conception seems to be a fruitful philosophical theory of scientific representation in science learning.

Keywords: science learning, scientific representation, inferential conception, disciplinary norms

Introduction

In this article, I discuss the concept of scientific representation in science learning. The main aims are to examine three examples of philosophical theories of scientific representation in mature science and to try to assess which of these seems to be a good candidate for a theory of scientific representation in science learning.

In order to achieve my main aim, I will compare the three candidate theories to two aspects of scientific representation in science learning that emerge from empirical studies of science learning as crucial aspects of science learning. I label these aspects as the intentional and normative character of scientific representation in science learning. The first refers to the idea that the agent’s intention determines the direction of representation, that is, the idea that the vehicle of representation points at a real phenomenon. The second aspect refers to the idea that representation relation is in part determined...
by disciplinary norms, that is, rules about what counts as a correct representation within a scientific community. The theory that is able to account for both aspects will be considered a good candidate for a theory of scientific representation in science learning.

The three theories of scientific representation I take into account are: (1) the intentional account (Giere, 1988, 2004, 2006); (2) the inferential account (Suárez, 2004); (3) the science technology and society account (Lynch & Woolgar, 1990).

As I argue, whereas the other competing accounts of scientific representation can only capture one of the two aspects highlighted in this article, the inferential conception has the capacity to capture them both in a coherent way. Thus, I conclude that the inferential conception seems to be a fruitful philosophical theory of scientific representation in science learning and a promising starting point for a philosophy of science learning project more generally.

I begin in the next section with an introduction to the philosophical discussion about scientific representation. This introduction will serve to clarify the different positions in the debate. The third section is devoted to the analysis of research on science learning and to the identification of the three aspects of scientific representation in science learning.

The article concludes in the fourth section with a summary of this article’s claims.

Three Theories of Scientific Representation

I begin this section by trying to reconstruct the philosophical problem of scientific representation. This will provide a framework for the three approaches I discuss in this article. I then go on and present the three chosen approaches: Giere’s intentional approach; Lynch and Woolgar’s approach; Suarez’s inferential approach. The choice of the first two approaches is motivated by the fact that they lie at two opposite theoretical poles: the former is strongly focused on the cognitive dimension of representations, whereas the latter is strongly focused on the social one. Furthermore, I have added Suárez’s approach because, as I argue later, it can provide a common ground for both paradigms.

The philosophical discussion has focused on putting forward necessary and sufficient conditions for scientific representation. In this respect, it is useful for us to introduce the distinction between informational and functional theories of scientific representation. On the one hand, there are those who claim that representation is best understood as a relationship between what is represented (or the target of representation) and what is used to represent the target (the vehicle of representation). These approaches are labeled as informational. This relationship is supposedly dyadic and objective, that is, it holds between the vehicle and the target independently from the user of the representation. For instance, a model of a bridge is a representation of a bridge if and only if it has the relevant properties of its target, independent of whether the user of the model knows about it or not. The term informational refers to the claim that theories of scientific representation should account for how the vehicle of representation conveys information about the target. Examples of these approaches are discussed by van Fraassen (1994) and by Bueno and French (2011).

On the other hand, some researchers have criticized the dyadic and objective view of representation as unsatisfactory. These critics have remarked how the different informational
approaches are neither able to identify sufficient nor necessary conditions for scientific representation (Suárez, 2003). On the contrary, some researchers have suggested that a theory of representation should focus on what kind of work is done by the vehicle of representation in relation to its target. These approaches are labeled as functional. Many of these approaches have stressed the models’ ability to allow surrogative reasoning. For instance, the possibility of manipulating a model bridge makes it possible for us to draw conclusions that can afterwards be applied, ceteris paribus, to the full-scale bridge. Examples of these approaches are found in Suárez (2004), Contessa (2007), and Weisberg (2007).

Giere’s Approach
Giere has discussed the concept of scientific representation in a number of places (1988, 2004, 2006, 2010). His position is usually summarized in one main claim:

(Q) S uses X to represent W for purpose P (Giere, 2004, p. 743)

In which:

- S denotes an agent: agents can be individual scientists or groups of scientists.
- X is a vehicle: vehicles are models intended as abstract objects. (Giere, 2004, p. 743)
- W is a target: this is an aspect of the real world. An aspect is a part of a phenomenon that is under the scientist’s investigation.
- P is a purpose: that is, a goal of the representational activity. According to Giere, the content of this relatum consists of the user’s intentions. This means that, according to Giere, the purpose of a representing activity must be analyzed in terms of the agent’s beliefs and desires. (Giere, 2004, p. 743)

This view about representation ascribes great importance to the user of scientific representation, since the necessary condition for something to represent a phenomenon is that there is a user intending to do so. However, Q only states what the necessary relata are of the representation relation. It does not describe the nature of the representation relation. For this reason, on top of Q, Giere adds similarity as a condition for successful representation (Giere, 1988, p. 81). To formulate a statement concerning the relationship between a model and a phenomenon is to put forward a similarity claim. For this reason, Giere’s approach to scientific representation has typically been classified among the informational approaches. Even though Giere claims that scientific representation is not a dyadic relation, he still claims that representational claims are similarity claims between a target and a model. I discuss later the objectivity of these claims.

Similarity alone can lead to vacuously true representation claims, since ‘Anything is similar to anything else in countless respects, but not anything represents anything else’ (Giere, 2004, p. 743). Therefore, every similarity claim must come together with a specified degree and scope (Giere, 1988, p. 81). The latter refers to the fact that objects are similar in some respects and never tout court. Twins can be similar in how they look like, whereas football teams can be similar in their playing style. The former refers to the fact that, whatever the scope of similarity, a perfect match is rare in science. The trajectory of planets can be modeled with Newton mechanics if we accept a certain margin of error and with general relativity if we accept another margin of error. However, we do not expect either model to give us the exact trajectory of planets.
The scope and degree of similarity in Giere’s theory are agent-dependent. The scope is equivalent to the part of reality that the agent intends to represent. Thus, modeling the trajectory and the velocity of planets in the solar system excludes such aspects like the color or age of planets from the target of representation. Once the target is fixed, the scope of similarity claims is fixed as well. The choice of what part of a phenomenon to represent does not, however, suffice to fix the degree of similarity. This degree is determined by the user’s intended representational purpose, that is, the purpose of the representation. Reconsider, for instance, the example of the trajectory of the planets in the solar system. Two different models will satisfy two different degrees of similarity. We might say that there is a user-independent criterion for choosing the correct degree of similarity, and thus choosing the best representation, between the two options. For instance, we might simply say that the theory with the smallest margin of error is always the best and that a correct representation is the one with the smallest margin of error in the market.

However, this might not be a viable option. If we exclude the possibility of a perfect match between a model and a target, and if we assume a situation with a large number of different models all tending to have the closest-to-perfect match, then the choice between two models might be difficult. Therefore, other criteria might determine the choice of a model, such as computational complexity. The tradeoff between the closeness to a perfect match and manageability depends on the purpose of representation. Depending on what we want to achieve with our model, we might relax the margin of error. Thus, general relativity might be an unnecessarily complicated choice for modeling the trajectory and acceleration of a pen falling from my desk. Newton mechanics will do for that specific purpose. It turns out that the degree of similarity is also user-dependent.

Before closing this section, we should mention the issue of the objectivity of similarity claims. As Giere puts it: ‘Claims about features of the world remain as objective as they ever were’ (Giere, 2004, p. 748). Giere argues that we should not conclude that his similarity approach implies a form of relativism concerning the truth of similarity claims. Similarity degrees are user-dependent but, under the assumption of a certain similarity degree, users do not determine the correctness of similarity claims. Therefore, scientific claims are still either objectively true or false.

Suárez’s Approach

Among the functional approaches there is one that has gained certain popularity. This approach, sometimes labeled inferential, has been defended by Suárez (2004), Swoyer (1991), Contessa (2007), and Rodríguez and Bonilla (2009). In this paper, I focus on Suárez’s version of this approach. According to the inferentialist, the representation relation between a target \( B \) and a vehicle \( A \) is best understood in the following way:

\[
\text{(INF)} \quad A \text{ represents } B \text{ only if (a) the representational force of } A \text{ points towards } B, \\
\quad \text{and (b) } A \text{ allows competent and informed agents to draw specific inferences regarding } B. \quad (\text{Suárez, 2004, p. 773})
\]

Suárez’s approach is functional. In order to obtain the representation relation between a target and a vehicle, the latter must allow the agent to draw inferences about the former. If we only designate a vehicle to represent a target, and no inference about the target is made possible, then we cannot talk about scientific representation taking place.
The terms \( A \) and \( B \) in INF are intuitively clear: they are the vehicle and target of representation. The directionality and force of representation instead require some explanation. The concept of force is exhausted by (b): the capacity of allowing competent and informed agents to draw relevant inferences. Instead, the direction of representation, which is formulated in terms of \( A \) pointing toward \( B \), refers to the logical structure of the representation relation. Representation is arguably non-symmetric, that is, if \( A \) represents \( B \), then, generally, \( B \) does not represent \( A \).²

Oddly, Suárez does not seem to provide a definition for the terms informed and competent agent. I will return to the latter later in the article. As for the former, with the lack of better specification, we can assume that the informed agent has access to enough information about the target and the vehicle to use the vehicle as a model of the target. We should neither assume complete access to information nor access to only correct information about the target. This is necessary to allow the agent to misrepresent the target.

Before moving forward in our discussion, there is an aspect of INF that requires a short detour. Apparently, Q partially overlaps with INF. However, INF is supposed to work as an alternative to informational theories of scientific representation such as Q. Therefore, a short clarification of this point is needed to have a clearer picture of INF.

This asymmetry has its origin in yet another distinction, that is, between successful scientific representation and scientific representation simpliciter.³ As I mentioned earlier, Suárez has criticized the criteria for successful representation, such as similarity, arguing that they are neither sufficient nor necessary for scientific representation simpliciter (Suárez, 2003).⁴ However, many defenders of the similarity approach concerning successful representation seem to endorse a functionalist view similar to Suárez’s as defining the necessary conditions for scientific representation simpliciter. As we have seen in the previous section, Q agrees with INF in that the polyadic character of representation is a necessary condition for scientific representation simpliciter. In this regard, we can say that the two theories overlap. Giere’s contention against Suárez is that further criteria are needed to account for successful scientific representation, and, pace Suárez, this criterion is generally that of similarity. Hence, as we have seen in the previous section, representation claims are similarity claims. In the economy of Suárez’s critique of similarity, the real disagreement involves the possibility of introducing necessary (and/or sufficient) conditions for successful representation on top of the necessary conditions for scientific representation simpliciter.

This provides us with a picture of INF as a broad and minimalist approach to scientific representation, one that only puts forward necessary conditions. This is done, as discussed by Suárez, to account for misrepresentation. According to Suárez, any satisfying definition of scientific representation must be able to account for the distinction between misrepresentation, that is, vehicles that are used to represent a target but fail in doing that, and vehicles that do not represent it at all.

Lynch and Woolgar on Scientific Representation
The first two approaches aimed at providing a conceptual analysis of scientific representation. As we have seen in the previous sections, they tried to provide the necessary and/or sufficient conditions for scientific representation. This implies a normative aspect. These approaches do not try to cover all possible concrete examples of scientific
representation. Nor do they try to incorporate all kinds of contextual factors that are
involved in the practice of representation, even though both approaches are practice-
oriented. They aim at defining how scientific representation should work.

The third approach I examine assumes a different methodological point of view. Instead
of analyzing the concept of scientific representation, it considers it as a natural phenom-
\[\text{enon. Therefore, instead of providing the necessary and sufficient conditions for what}
\text{scientific representation should be like, it seeks to provide an empirical analysis of how}
\text{the practice of representation actually looks like.}

This approach is the one discussed by Lynch and Woolgar (1990). This book is framed
within the family of approaches that are usually labeled as sociology of scientific knowledge,
science and technology studies, or science, technology and society (STS). As these labels
suggest, the main focus of this approach is the sociological investigation of science as a
human practice.

I am going to use the acronym STS to label Lynch and Woolgar approach to scientific
representation, but only by means of synecdoche. This means that when I abbreviate this
approach with STS, I do not imply that Lynch and Woolgar’s approach reflects a general
attitude among STS scholars.

Actually, we cannot really talk about a general theory of scientific representation, since
the two STS scholars do not provide explicit conditions for representation. The aim of
Lynch and Woolgar’s (1990) book is to analyze scientific representation as a particular
species of scientific practice. Therefore, the chapters in the book are more focused on
the analysis of local and restricted cases of representational practices. However, in the
introduction chapter, which is authored by Lynch and Woolgar themselves, we can find
some important hints of a more general approach to scientific representation that are rel-
levant for our discussion.

The claims about scientific representation that are relevant for our discussion are con-
tained in two quotations. As Lynch and Woolgar stated:

\begin{quote}
Representation can represent other representations in complex socio-technical
\text{networks: the sense conveyed by a picture may derive as much from spatio-tem-
\text{poral order of other representations as from its resemblance or symbolization of}
\text{some external object. (Lynch & Woolgar, 1990, p. 5)}
\end{quote}

Further, in the same chapter, the authors stated:

\begin{quote}
Serial organizations are progressive […] Close examination between one rep-
\text{resentation and another reveals transferences of graphic and other materials}
\text{across a series of disjointed surfaces. (Lynch & Woolgar, 1990, p. 8)}
\end{quote}

In these two citations, Lynch and Woolgar pointed out an interesting aspect of scientific
representation that other approaches seem to underestimate, that is, the fact that scientific
representations are often related to other representations.

In order to relate this claim to the general discussion of this article, it is necessary to
point out that, since representation is considered a phenomenon and not a concept, the
focus here shifts from abstract to concrete representations, that is, symbolic, graphic,
textual, and all other sorts of material vehicles of representation. From this point of
view, and looking at representation as a species of scientific practice, we can say that
representations are, more often than not, related to other representations. Hence, whereas Giere and Suárez looked at the relation between a vehicle and a target, Lynch and Woolgar considered the relation between different vehicles.

This shift implies necessarily that the nature of the relation is different. Giere claimed that similarity claims are the basic constituents of the representation relation, whereas Suárez argues that the crucial facts about the representation relation lie in the possibility of allowing surrogate reasoning. These kinds of considerations must be abandoned as soon as we shift our perspective from the relation with the target to the relation with other concrete representations.

How are different concrete representations then related to one another? According to Lynch and Woolgar (1990), representing practices consist of series of translations from representation to representation. A chemist might inspect the peaks of a graph generated by a gas chromatographer. These peaks are then translated into further graphic representations, such as a chart showing different measurements. Finally, these new representations are translated into a final representation: a research paper.

In order to obtain a more consistent conception of scientific representation, we have to take a step further in the reconstruction of STS. Since we are looking at these translations as practices, then all these translations must be regulated by specific rules of practice. We call these rules disciplinary norms of representation. These norms regulate the praxis within a community of scientists as to what counts as a scientifically correct or acceptable representing practice within the community. Different concrete representations are related to one another by means of these norms. This means that the way scientists proceed from one concrete representation to another depends on what is accepted among the members of a disciplinary community. The fact that these norms are norms of representation separates them from other kinds of scientific norms, such as epistemic norms, regulating the inferences that underlie these representations.

Norms of representation are established as the result of negotiations between the different agents involved in a community of scientists. Furthermore, as for all kinds of social norms, these norms imply some payoffs for the individuals who abide by them. These payoffs have been analyzed in detail by Latour and Woolgar (1979, chapter 5) in what they called the cycle of credit. According to Latour and Woolgar (1979), norms of scientific practice are the consequence of individual scientists’ activity. What individual scientists do is to try to maximize their credibility. In order to obtain credibility, they must succeed in publishing papers. The papers require data, which in turn require equipment. This latter requires money, which is accessible for researchers that have some credibility. Therefore, abiding by a disciplinary norm provide scientists with the credibility that is needed to convert data into papers. Papers enhance credibility, which ensures grants, which, in turn, finance new papers. Furthermore, as Latour and Woolgar (1979) point out, scientists do not seek to accumulate credibility for the sake of credibility itself: ‘The objective of market activity is to speed up the credibility cycle as a whole’ (Latour & Woolgar, 1979, p. 207).

Therefore, representation is, from the perspective of STS, the process of translating material representation to material representation; these translations are done according to disciplinary norms of representation; these norms are the consequence of the scientists investing in credibility and thereby establishing a cycle of credit.
Representation in Science Learning

In this section, I summarize and analyze a number of empirical results on science learning. The next section focuses on research on the cognitive dimension of science learning. The section following focuses on the social dimension of science learning.

The following discussion requires a methodological clarification. What I attempt to do is analyze empirical results to argue that a certain aspect of science learning is crucial for scientific representation in science learning. This means that I attempt to draw philosophical conclusions from empirical observations.

Now the problem is that philosophical conclusions are supposed to capture the essence of a concept, in a way that is independent of the concrete contingencies of individual events. A philosophical theory of scientific representation in science learning should therefore have a regulative and normative character. This is why I analyze the results, which are about learning as an observable phenomenon, in terms of scientific representation, which instead is considered here as a philosophical concept. In other words, I attempt to abstract from the contextual factors aspects that might characterize a particular result.

However, abstracting from the particular results might not be sufficient. Therefore, I have attempted, as much as possible, to select results that indicate trends in educational research, which might indicate that the observed aspects are crucial for science learning, according to what empirical research tells us about science learning. Since empirical results are defeasible, this further move solves the problem only to a certain extent. Therefore, a part of these reflections must be interpreted conditionally. This means that my conclusions are valid only to the extent to which the empirical result actually point out a constitutive feature of science learning.

Cognitive Approaches to Science Learning

In this section, I examine the cognitive approach in educational research. By cognitive approach, I mean the family of approaches in educational research that have as a minimal common denominator the assumption that learning is in the mind of the learner.

The theoretical framework that is often connected to the cognitive approach to science learning is constructivism. In this article, I intend constructivism to be in accordance with Sjøberg’s (2010) discussion of the issue in the International Encyclopedia of Education. Accordingly, constructivism is defined here as the hypothesis that (a) knowledge is constructed by the learner, rather than received, and that (b) knowledge is ‘represented in the brain as conceptual structures and it is possible to model and describe these in some detail’ (Sjøberg, 2010, p. 486).

In terms of scientific representation, constructivist research investigates how the mental life of learners affects and determines the relation between the target of representation (intended here as a phenomenon in the real world) and its vehicle (the learner’s concrete, linguistic or graphic way of representing the target). Furthermore, whereas scientists use as the basis for their representation the results of their observations together with the already established models and theories, learners at times have to continue without observational bases. Of course, this is a matter of different educational systems and different educational levels. However, we can safely say that not all representations in science education are
based on observation. For the cases in which observation is missing, learners use other models as a substitute for observation.

**INTENTIONALITY**

A number of empirical studies have stressed the intentional character of learning. In this section, I focus on one particular study that gives us a clear example of this aspect and discuss its consequences for scientific representation.

In a study with university undergraduates, Halldén (1999) examined students’ understanding of probability. The task presented to the students was the same as that explained in Kahneman and Tversky’s (1982) well-known study of statistical intuitions. The students were presented with the following description:

Linda is 31 years old, single, outspoken, and very bright. She majored in philosophy. As a student, she was deeply concerned with issues of discrimination and social justice, and also participated in anti-nuclear demonstrations. (Kahneman & Tversky, 1982, p. 496)

Thereafter, the students were asked to assess which statement was more probable between (1) Linda is a bank-teller, and (2) Linda is a bank-teller who is active in the feminist movement. Kahneman and Tversky (1982) observed that the majority of students chose alternative (2). This answer is wrong from the point of view of probability. In fact, according to the conjunction rule (a basic rule of probability), the conjunction of two propositions must be less or equally probable than its disjunct propositions. They concluded that the respondents’ answers were wrong because they used a heuristic of representativeness, that is, a set of decision rules that leads students to choose the alternative that implies the essential characteristic of the phenomenon.

This result is quite relevant for scientific learning. In fact, the classic paradigm of learning often labeled as conceptual change (Posner, Strike, Hewson, & Gertzog, 1982) would interpret scientific learning as the linear shift from the heuristic of representativeness to statistical thinking. Learning happens when bad heuristics are substituted with good ones.

In his later study, Halldén (1999) replicated Kahneman and Tversky’s (1982) setting with a small modification: examined students were given the possibility to motivate their answer after the test. The aim of this setting was to investigate the relationship between the representativeness heuristic and statistical thinking in a deeper way. After being informed about the correct answer, the students were asked to comment on their initial answer. The analysis of the answers indicated that:

The outcome of the exercise supports the view that students tend to perceive problem-solving tasks in the context of everyday life and consequently apply the kind of problem-solving strategies that they use in every-day life […] This means that many of the students chose not to use the methods of probability theory to solve the problem, preferring instead a kind of causal reasoning or good reason assay analysis, not because they did not understand or were unable to apply probability theory but because they did not find it meaningful to do so in this particular case. (Halldén, 1999, p. 59, emphasis added)
The terms ‘causal reasoning’ and ‘good reason assay’ refer in the citation earlier to the heuristic of representativeness. Halldén’s (1999) findings provide us with a further dimension that departs from the standard account of conceptual change and which is grounded on a crucial observation: when asked to comment on their initial answer, a number of students demonstrated awareness of the conjunction rule.

This result indicates a crucial distinction between Kahneman and Tversky’s (1982) study and Hallden’s (1999) study. In the former, we have two distinct situations: on the one hand, we have errors of application, these errors happen when individuals have acquired a scientific concept but apply it in a defective way. On the other hand, we have errors of comprehension: these errors occur when the students have not acquired the correct concept and therefore apply an incorrect decision heuristic. This is indicated both by Kahneman and Tversky’s (1982) study and by the classic scheme for conceptual change: learning implies a shift from wrong to right (Posner et al., 1982).

However, since the students who chose answer (2) were aware of the conjunction rule, the dichotomy between errors of application and errors of comprehension is no longer sufficient to explain what is going on here. Some students applied an alternative heuristic even if they had acquired the correct concept. We have three distinct situations:

(a) Student X thinks the presented task is a statistical problem. She uses statistics to solve the problem and answers (2). The reason for this answer is that the student is either still not very competent in the conjunction rule or simply got it wrong. This is a case of an error of application.

(b) Student Y is not sufficiently competent in statistics. She interprets the task as an R-problem. The R-framework is a model of social behavior that implies the representativeness heuristic. The student answers (2). In the R-framework, (2) is the correct answer, so the student just applies the R-framework. This is a case of an error of comprehension.

(c) Student Z is quite competent in statistics, but she also thinks the presented task is an R-problem. The student answers (2). The student thinks that (2) is the correct answer for the situation (but could have chosen answer (1) in another situation).

The third case shows how the dichotomy between errors of comprehension and application is insufficient in those cases in which learners have multiple and inconsistent conceptions of the same phenomenon. The difference between (b) and (c) does not concern the judgment about the students’ answers. This means that we might interpret (2) as a wrong answer in both cases. On the contrary, the difference is relevant for science learning since (c) implies that the standard model of conceptual change is too simplistic. A satisfying theory of science learning must be able to account for both what constitutes a misconception and what generates it. The standard view can only account for the former, but not for the latter.

What does the difference between (b) and (c) tell us about scientific representation? First, the task implies scientific representation since the students are required to develop a probabilistic model of a sociological phenomenon. Given the available information about Linda, what job would she (or any other individual with those characteristics) have?

The R-framework in (b) and (c) is a model, that is, a vehicle of representation. Now, if we ignore the intentional aspect of (c), that is, the fact that the choice of the R-framework is
one of two possible modeling strategies, then (b) collapses into (c). If we do not consider the R-framework as the *chosen* vehicle for the representation of the targeted phenomenon, then the student’s answer becomes a matter of necessity, given the accepted framework. However, any satisfying theory of representation in science learning must necessarily be able to account for the learners’ choices and strategies. There is a crucial *learning* difference between *using* an alternative heuristic and *choosing* an alternative heuristic. Since the agent is aware of the difference between the two heuristics, as some of the students in Halldén’s (1999) study seem to be, then this difference is grounded on the learner’s intention and not in a linear change of conceptual framework. Hence, a satisfactory theory of scientific representation in science learning should be able to account for the intentionality of learners’ representations.

Let us then see how our three theories fare in relation to this aspect of science learning. Giere’s Q is the account that fits the intentional aspect of science learning in the most straightforward way. The formulation of Q implies that the intentions of the user determine the representation relation between a vehicle and a target. Therefore, Giere’s account provides, by default, a suitable account of the intentionality of science learning. As Giere stated:

>[R]epresentation with models cannot just be a matter of similarity between a model and the thing modeled. There are two major reasons why this is so. First, we need to know which similarities matter. That there will always be some similarities is vacuously true. Second, as Suárez (2003) has emphasized, similarity is a symmetrical relation while representation is asymmetrical. If we add the intentions of an agent or agents, both of these problems disappear. [... ] Agents specify which similarities are intended, and for what purpose. This conception eliminates the problem of multiple similarities and introduces the necessary asymmetry. (Giere, 2010, p. 274)

Giere’s (2010) qualification of the intentionality claim gives us some important insights into Halldén’s (1999) study. The way in which the students represented the phenomenon described in the task could not be assessed in terms of the similarity between the students’ representation and the target phenomenon. This would have collapsed (a), (b), and (c) into one another since all we would have left would be the target and the vehicle of representation, that is, Linda’s problem and the answer (2), which in this case are equivalent for (a), (b), and (c).

Suárez’s INF does not make use of intentional terminology in its formulation. Actually, in a later paper (Suárez, 2010), he rejects the view that the direction of representation is essentially intentional. Suárez opposes the intentional view to what he calls the *indented use* view. This view implies that the direction of representation is fixed in the context of ‘some established collective practice’ (Suárez, 2010, p. 99).

However, even though the direction of representation is not essentially intentional, INF is nonetheless able to account for the intentionality of science learning, although not in the same straightforward and specific way as Q. The main virtue of INF in this case is the reference to the user of representation. Even if the direction of representation is collectively negotiated, this does not exclude that individual users intentionally represent a target by means of some vehicle. When we consider individual agents and their representations,
what constitutes the direction of representation is the fact that the agent intentionally takes the vehicle to represent the target, not the opposite. The fact that the agent intends \( A \) to represent \( B \) is equivalent to saying that the representational force of \( A \) points toward \( B \).

Let us imagine a competent and informed agent \( S \), who belongs to some epistemic community \( C \), and a vehicle \( A \) that have some representational force, that is, it allows \( S \) to draw specific inferences about a target \( B \). Can we now imagine how the representational force of \( A \) could be directed toward \( B \), without this implying that \( S \) intends \( A \) to represent \( B \)? Even if all the other members of \( C \) take \( A \) to represent \( B \), it would imply that \( S \) could use \( A \) to draw relevant inferences about \( B \), without taking \( A \) to represent \( B \). However, using \( A \) to draw relevant inferences about \( B \) implies, by the definition of the term ‘using’, intending \( A \) with \( B \). Hence, the direction of representation sufficiently exhausts the intentionality of representation as a special case of the intended use view, which is to say that INF can account for the intentionality of science learning.

Finally, our third competing theory, STS, does not fare equally well as INF and Q in this respect. Lynch and Woolgar’s (1990) approach conflicts with the intentional character of scientific representation in one fundamental way. In order for a theory of disciplinary norms to account for intentional action, norms must be defined in terms of the beliefs of the individuals involved in them. This is the case of one of the main contemporary approaches to social norms, that is, Cristina Bicchieri’s The Grammar of Society (2005). Simply put, according to Bicchieri (2005), social norms are the result of equilibria in the normative beliefs of the individuals in a group. Norms arise as the result of people’s preferences and expectations.

However, this is not the approach to social norms that informs the conception of disciplinary norms of STS. The approach to norms that is more pertinent to Lynch and Woolgar’s (1990) analysis of representation is, arguably, the practice theory of norms.

The difference between the preference approach and the practice approach to social norms has been discussed in a clear way by Risjord (2014, pp. 167–171). As Risjord (2014) noted, according to practice theory, social norms are patterns of group behavior rather than patterns of beliefs. Norms emerge as the result of the interaction between agents in a community. This means that while a norm might not be explicitly formulated in language, and not intentionally accepted by the members of a community, it still might be implicitly enacted as a result of these members’ behavior.

Latour was clear about this point in his analysis of the cycle of credit:

> It is important to stress [the credibility model’s] complete independence of any argument concerning motivation. [O]ur credibility model can accommodate a variety of types of motivations. It is not necessary, therefore, to doubt the motivations expressed in informants’ accounts. Scientists are thus free to report interest in solving difficult problems, in getting tenure, in wanting to alleviate the miseries of humanity, in manipulating scientific instruments, or even in the pursuit of true knowledge. Differences in the expression of motivation are matters of psychological make-up, ideological climate, group pressure, fashion, and so on. (Latour & Woolgar, 1979, p. 207)

The analysis of disciplinary norms can diverge sensibly from that of the intentions of the individual members of a scientific community. As a result, Lynch and Woolgar’s (1990)
approach to representations make it overdetermined by individual intentions. This means that the STS approach to scientific representation implies that we can identify what kinds of disciplinary norms of representation regulate the relationship between different material representations, but these norms can diverge from individual preferences and expectation motivating the individual representational strategies. Hence, STS cannot account for the intentional character of learners’ representations.

Besides, the analysis of intentionality in science learning provides us with an interesting insight about the relation between STS and INF. As discussed in the preceding paragraphs, INF can incorporate the importance of the social dimension of scientific representation in a way that does not conflict with the learners’ intentions. INF is a moderate position between Giere’s cognitive view and the sociological perspective of STS. Nor, as I discuss in more detail in the next section, does INF imply that an individual’s intentional states exhaust a disciplinary norm that is accepted among a group. This is the sense of Suárez’s claim that the direction of representation is not essentially intentional.

The Social Dimension of Science Learning

In this section, I summarize and analyze two examples of research on the social dimension of science learning. Within this perspective, the vehicle of representation intended as concrete and observable representation, such as a drawing, a text, a mathematical equation, or even just a verbal utterance. The target of representation is a phenomenon in the real world. Let us then look at what empirical research on the social and linguistic dimension of learning can tell us about scientific representation.

NORMATIVITY

In a study by Roth and Tobin (1997), a physics lesson for a group of prospective elementary teachers was analyzed in terms of the graphic and material resources used to explain a physical phenomenon: a ball rolling down an inclined plane.

In this study, the researchers observed that the physical explanation of this phenomenon involved the ability to place a series of different material inscriptions in succession, consisting of the following series of inscriptions:

(a) A verbal description of the phenomenon
(b) A numeric table indicating time
(c) A numeric table indicating position
(d) A numeric table indicating velocity
(e) A numeric table indicating acceleration
(f) A first equation defining velocity in terms of position and time
(g) A first graph of a function associating time and position
(h) A second equation defining acceleration in terms of velocity and time
(i) A second graph of a function associating velocity and time
(j) A third graph associating acceleration and time

This result is relevant due to the observation that learning entailed both the ability to draw relevant inferences and the ability to manage the different systems of signs in a way that is adequate for a particular discipline. For instance, students’ learning consisted in equal measure of being able to calculate velocity as a function of space and time, and
to draw the velocity graph from the list of numbers contained in the numeric tables for time and velocity. The first ability depends on mathematical inference making, whereas the second depends on the ability to interpret and use the signs appearing in an equation or in a graph in a suitable way.

As Roth and Tobin conclude:

> The equivalence of two inscriptions such as a data table and a corresponding graph cannot be deduced but has its origin in the social practice of treating them in an equivalent way. There are ontological gaps that are bridged by the practices shared within a scientific community. The equivalence of a series of velocity–time data and a plot on a Cartesian graph is a matter of convention and a matter of identity or truth. That some people (scientists or students) are able to treat series of inscriptions as equivalent is due to their familiarity with collective practices of translation real-world phenomena into cascades of inscription. (Roth & Tobin, 1997, p. 1086)

Roth and Tobin’s (1997) results tell us that there is a socially normative aspect to physics learning that involves acquiring familiarity with the relevant symbolic systems. A second example of this is discussed by Roth (1996) in another article. In this paper, a group of 46 high school physics students were observed in a one-year period during which they were struggling with a computer simulation of Newtonian motion phenomena. Instead of observing what kind of norms were present in a particular instructional setting, Roth tried to observe the kind of negotiations that are involved in disciplinary norms. A process involving four stages could be observed:

(a) **Introduction of a language game.** In this phase, the students set the stage for a common linguistic standard by introducing a set of main terms (in this case force, velocity, and time). At this stage, the individual interpretations of these terms by the students are highly flexible. The same student could ascribe different meaning to force. The point is to create linguistic contact with the other students involved in the learning situation.

(b) **Curtailment.** The interpretive flexibility of the first stage is progressively constrained by the interaction of the students with the simulation and with the teacher. Expressions and phrases are introduced in the group parlance.

(c) **Emergence of Newtonian discourse.** As Roth explains: ‘The data clearly indicate that students did not instantly change from inappropriate to appropriate science talk. Rather, the Newtonian science talk emerged slowly and tentatively from the “muddle” of their earlier talk’ (Roth, 1996, p. 183).

(d) **Converge toward Newtonian discourse.** Collaboration among students continually makes the group parlance more consistent.

As the researcher stresses, independently and parallel from the development (or lack thereof) of some mental conception of motion, the students evolved a shared Newtonian discursive practice. Roth concludes that:

> [S]tudents’ learning could be described in terms of evolutionary changes of their descriptive language about a Newtonian micro world and as the co-emergence
of new ways of “seeing” and talking. […] The present setting allowed students to move from their own, everyday ways of talking to ways shared in specific scientific communities. These ways of talking emerged from the interactions within small groups. This development of shared ways of talking thus led to distributed rather than individual achievements. (Roth, 1996, p. 186)

This example gives us some important insights on the idea of scientific representation in science learning. Roth’s (1996) four-phased model indicates how scientific parlance is negotiated along the learning process. This indicates the presence of two parallel processes, determined by different factors. Apart from individual learning, which is determined by inferential matters concerning the relationship between the model (the computer simulation) and the target (the trajectory of a moving body), we have the development of a Newtonian discourse, which instead is a matter of negotiation among the members of a group.

These two examples together indicate how disciplinary norms (such as norms of scientific parlance) can influence what counts as genre-correct representation in a given instructional setting. These social norms are necessary aspects of the practice of learning to model phenomena in a discipline-appropriate way. Therefore, any attempt to identify the necessary conditions for scientific representation in science learning should be able to account for these aspects.

Assuming the correctness of this claim, what explanation of scientific representation is able to account for the role of disciplinary norms in science learning? Of course, STS would quite straightforwardly capture the importance of this aspect. Recall that STS analyzed scientific representation as the process of translating material representation to material representation, according to disciplinary norms of representation, with the aim of obtaining credibility to reinvest in the cycle of credit. As these results indicate, there is an important character of socialization in a scientific practice that is a necessary condition for learning since modeling requires the use of a system of signs. Learning to follow the discipline-appropriate norms is a basic and usual requirement of institutionalized science education. STS provides an account of this socialization by arguing that the translations from one inscription to another are regulated by disciplinary norms of representations, and that those norms are the consequence of the interaction between learners generating a market of credibility.6

The agreement between this research strand and STS is, of course, not a matter of coincidence. Many empirical researchers that investigate the social nature of learning employ methods of analysis that are embedded in broader theoretical frameworks close to STS.7

Arguably, not only STS, but INF as well is capable of accounting for the socially normative aspect of representation in science learning. This is implied by the term ‘competent’ in condition (b) of INF.

Since, as I mentioned, Suárez does not seem to discuss the meaning of competence in INF, I will try, in what follows, to qualify the claim that competence is a normative term in the relevant sense of ‘normative.’ First, we can plausibly exclude that competent agents are those who have enough grounds for drawing inferences since that is exhausted by the term ‘informed’ in the same condition. We might instead understand the competent agent as
one that, provided the sufficient information, is able to draw ‘specific’ inferences about the target. This might however be too strong for Suárez’s account, if by specific we mean correct. INF is a minimalist and deflationary account that is meant to capture both representation and misrepresentation. If the competent agent is the one that draws the right inferences from the available information, then INF can only catch successful representation. For instance, the results from Halldén’s (1999) study will not fit anymore as an example of scientific representation. Competent must mean something less reliable than this, but that nonetheless can account for how models help us in actually learning about the targets of our representations.

Maybe the competent agent is one who correctly discriminates the ‘specific’ disciplinary norm for the situation. For instance, there could be more than one suitable (that is, capable of allowing inference) representation strategy in a given setting, so that the choice of which one to choose depends on the disciplinary norm that is relevant for that setting. The competent agent will act according to which disciplinary norm is appropriate for the situation. This implies that these disciplinary norms can account for something about competent representational performance, but they do not completely determine correct representational performance. I suggest that the candidate for this should not be a norm of rationality (intended as what makes an inference correct), but a social disciplinary norm, which is a coordinated group behavior that is capable of grounding normative beliefs in the members of a group.

We have seen that Suarez himself hinted that this is his own view. As he pointed out:

On this view [the intended-use view] representation is an activity carried out by a community engaged in a collective social practice—and the underlying norms of the practice determine representational sources and targets. (Ladyman, Bueno, Suárez, & van Fraassen, 2011, p. 432)

If, as it seems to be the case, this interpretation of ‘competent agent’ is correct, then this normative dimension can account for different normative aspects emerging from research on science learning. The kinds of shared linguistic structures, such as discursive practices, described in the studies I discussed in this section are all good examples of this kind of social interactions. Scientific representation is governed, as all other kinds of representation, by discipline-specific linguistic praxes. INF seems therefore to provide a moderate yet satisfying account of the role of disciplinary norms for scientific representation in science learning.

The third and last account in our list, Giere’s Q, seems instead to fail in providing an account of the role of disciplinary norms for scientific representation in science learning. Apparently, this account ascribes intentionality a too-important role in scientific representation, allowing the individual modeler the capacity to set the standard for competent representational performance on solely intentional grounds. In this way, Giere’s account misses the difference between intentional and intended use conception of representation discussed by Suárez.

As I discussed earlier, we cannot consider competent representing performance on the sole basis of the inference drawn by an individual. Competence implies conformity with a disciplinary norm, and we can, in certain cases, fail to identify the relevant disciplinary norm if we (as I believe Giere would argue) consider the individual’s beliefs about what counts as
correct representation as sufficient indicators of the relevant disciplinary norm. In certain learning situations, learners’ individual beliefs on what is to represent competently might deviate from the norm that results from the interaction of different learners. Hence, in the same way as the STS account seemed to be unable to account for the intentional character of learners’ representation, Giere’s account seem to fail (at least in certain cases) in capturing its normative character.

**Scientific Representation and Science Learning**

In this section, I integrate the conclusions drawn on the previous sections. Generally speaking, INF seems to be a promising account of scientific representation in science learning, at least if compared with the competing accounts that I took in consideration in this article.

The conclusion I have drawn earlier can be summarized in the following way: I identified two aspects that, from the analysis of empirical research on science learning, seem to be crucial aspects of scientific representation in science learning. These are summarized in Table 1 as intentionality and normativity.

Different accounts of scientific representation can account for different aspects of learners’ representation. Giere’s Q can sufficiently account for intentionality, but seems to be unable to account for how representing in science education happens in accordance to one or more disciplinary norms.

Lynch and Woolgar’s STS could provide a strong account for the normative character of scientific representation in science learning. However, this account turned out to be too narrow since it can only account for disciplinary norms, remaining tacit concerning the individual beliefs related to the representing activity. This implies that norms can emerge from all possible types of beliefs. Now, since both intentional and normative aspects proved to be equally necessary, STS cannot be a good candidate for a theory of scientific representation in science learning.

However, only INF could capture both the intentional and normative aspects of learning, and this is due to the broadness of this account discussed earlier. Not only does it succeed where the others do not, but it is also able to incorporate the advantages of both Q and STS. The concept of competent users accounts for the fact representing practices are localized in a social context, without the need to reduce disciplinary norms to individual beliefs. The concept of the direction of representation accounts for individual learners’ choices, allowing the latter to interpret the normative aspects of the representing practice in the way she deems as more appropriate. This way can be wrong, as we saw in the discussion of Halldén’s (1999) results, but this does not mean that scientific representation is not taking place.

| Table 1: A summary of the claims |
|-------------------------------|
| 
| Intentionality | Normativity |
|----------------|-------------|
| INF            | ✓           | ✓           |
| Q              | ✓           | ×           |
| STS            | ×           | ✓           |
As a result, INF seems to be the most promising of the three examined accounts: it is able to account for both aspects of representation that seem to be crucial for science learning, and it is not affected by the difficulties that affect the two other competitors. The resulting theory of scientific representation in science learning is a broad one: one that is able to account for the role of different contextual factors.

Before concluding, it should be noted that the dispute between individual and social accounts of learning is one that has a long history in educational science. Still, the constructivist and socio-cultural paradigms nearly exhaust the current landscape of research on science learning, and these two paradigms are still considered by many to be theoretically and methodologically incommensurable. INF seems, therefore, to provide a solid ground for a theory of science learning that might succeed where others have failed: to account for the relation between the cognitive and social aspects of science learning. This might generate some suspicion that it is a too-good-to-be-true account.

The main virtue of Suárez’s approach consists in its capacity to avoid inconsistency. This virtue can explain how this account is able to reconcile two apparently incommensurable aspects of learning. As we saw earlier, STS could not account for the intentionality of representation, since the norms that ground translations can diverge from the individual’s representational intentions. Therefore, a normative account of scientific representation seems to be unable to account for the user’s representational choices. Then, we saw that Giere’s intentional conception of representation could not account for how disciplinary norms emerge from the interaction between learners. If INF implies a conception of disciplinary norms that is consistent with individual intentions, how can it account for the discrepancy between disciplinary norms and individual beliefs that emerged from the empirical results earlier? There seems to be a contradiction in INF.

The way in which INF avoids this inconsistency seems to rest in the separation between its two necessary conditions. Throughout this article we have considered two kinds of normative aspects: one is the socially negotiated direction of representation discussed by Suárez, and the other is concretized in the disciplinary norms of representation regulating the systems of signs used within a community to represent different phenomena. The first regards the relationship between target and vehicle, is collectively negotiated, but must be consistent with individual intentions, since individual representation is intentional. This normative aspect constitutes the intended use conception of the direction of representation and is the content of the first condition of INF.

The second normative aspect regards the relationship between different representations and emerges from social interaction, which allows for discrepancies between group behavior and individual motives. This normative aspect determines a competent agent in the second condition of INF. As argued earlier the competent user is capable of representing according to the appropriate disciplinary norm, but this agreement may or may not be the result of the individual’s intention. This means that the competent user might abide by a disciplinary norm as the result of the awareness that she ought to do so, but this is not necessary. In this way, there is no internal contradiction in INF.
Conclusion

In this article, I have argued that Suarez’s inferential approach to scientific representation is a promising candidate for an account of scientific representation in science learning. First, it is capable of accounting for a number of crucial aspects of learners’ representation, by providing an account in which these aspects cohere into a single framework. Second, the inferential approach has proven to be a better account than a number of competing approaches to scientific representation since it is not affected by the difficulties that affect its competitors.

Notes

1. This distinction has been introduced and discussed by Chakravartty (2010), who, however, concludes that the two terms are not opposed to one another but rather complementary. This article assumes instead that the contention between informational and functional theories of scientific representation is genuine. See Chakravartty’s (2010) paper for a more detailed discussion.
2. The reason for arguing for non-symmetry instead of asymmetry is that the former is a weaker and less plausible claim than the latter. The former means that not all representation relations are symmetric, whereas the latter means that no representation relation is symmetric. Arguing for non-symmetry leaves the possibility of symmetric representations relations open (for instance, mathematical representation relations might be symmetric).
3. This term was introduced by Contessa (2007).
4. Furthermore, since successful representation is a subset of representation simpliciter, similarity cannot a fortiori work as a condition for successful representation.
5. I choose here to differentiate between the R-framework and the heuristic of representation. The first implies the second, but the two are not the same thing. Heuristics are sets of rules for making inferences. Therefore, in the context of theories of representation, they look more like Giere’s principles (1988, p. 76). These are ‘general templates for the construction of more specific models’ (Giere, 2006, p. 60). Heuristics would fit this definition, since they are the principle from which more specific models. However, some heuristics might be quite specific, making them look like particular models. Therefore, I refrain from claiming that heuristics are, generally speaking, different from models. The heuristic of representativeness is, in the context of Hall-dén’s (1999) study, more a principle than a model.
6. In the same way as the scientists’ cycle of credit, the negotiation of a scientific parlance among learners must imply some payoff. As Latour and Woolgar noted, the credibility market is not a simple matter of exchange of currency between the market’s agents. The main objective is the growth of circulation of information (Latour & Woolgar, 1979, p. 207). It would be interesting to investigate the counterpart of this payoff in the case of science learning. We could not reduce all payoff to the fact that learners seek to get grades, since this would exclude a great deal of investors involved in the same cycle of credit, such as teachers, school principals, local school administrators, policy-makers and so on. All these agents are interested in investing their credibility in the market of science learning. I am thankful to Jesús Zamora Bonilla for bringing this aspect to my attention.
7. For instance, Roth (1998) cites Latour (1987) in his sociocultural critique of constructivism (Roth, 1998, p. 1019).
8. Evidence for this claim is that the Second International Handbook of Science Education (Fraser, McRobbie, & Tobin, 2012) takes these two approaches as exhausting the research field on science learning.
9. Some instances of sociocultural criticisms of constructivism (conceived as individual-based research) can be found in (Leach & Scott, 2003; Roth, 1998; Schoultz, Säljö, & Wyndhamn, 2001).
References

Bicchieri, C. (2005). The grammar of society: The nature and dynamics of social norms. Cambridge: Cambridge University Press.

Bueno, O., & French, S. (2011). How theories represent. *The British Journal for the Philosophy of Science*, 62(4), 857–894.

Chakravarty, A. (2010). Informational versus functional theories of scientific representation. *Synthese*, 172(2), 197–213.

Contessa, G. (2007). Scientific representation, interpretation, and surrogative reasoning. *Philosophy of Science*, 74(1), 48–68.

Fraassen, B. C. van. (1994). Interpretation of science: Science as interpretation. In J. Hilgevoord (ed.), *Physics and our View of the World* (pp. 169–187). Cambridge: Cambridge University Press.

Fraser, B. J., McRobbie, C. J., & Tobin, K. G. (Eds.) (2012). *Second international handbook of science education*. Dordrecht: Springer.

Giere, R. N. (1988). *Explaining science: A cognitive approach*. Chicago, IL: University of Chicago Press.

Giere, R. N. (2004). How models are used to represent reality. *Philosophy of Science*, 71(5), 742–752.

Giere, R. N. (2006). *Scientific perspectivism*. Chicago, IL: University of Chicago Press.

Giere, R. N. (2010). An agent-based conception of models and scientific representation. *Synthese*, 172(2), 269–281.

Halldén, O. (1999). Conceptual change and contextualization. In W. Schnozt, S. Vosniadou, & M. Carretero (Eds.), *New perspectives on conceptual change* (pp. 53–65). Oxford: Pergamon, Elsevier Science.

Kahneman, D., & Tversky, A. (1982). On the study of statistical intuitions. *Cognition*, 11(2), 123–141.

Ladyman, J., Bueno, O., Suárez, M., & Fraassen, B. C. van. (2011). Scientific representation: A long journey from pragmatics to pragmatics. *Metascience*, 20(3), 417–442.

Latour, B. (1987). *Science in action: How to follow scientists and engineers through society*. Cambridge, MA: Harvard University Press.

Latour, B., & Woolgar, S. (1979). *Laboratory life: The construction of scientific racts*. Princeton, NJ: Princeton University Press.

Leach, J., & Scott, P. (2003). Individual and sociocultural views of learning in science education. *Science & Education*, 12(1), 91–113.

Lynch, M., & Woolgar, S. (1990). *Representation in scientific practice*. Cambridge, MA: MIT Press.

Posner, G. J., Strike, K. A., Hewson, P. W., & Gertzog, W. A. (1982). Accommodation of a scientific conception: Toward a theory of conceptual change. *Science Education*, 66(2), 211–227.

Risjord, M. (2014). *Philosophy of social science: A contemporary introduction*. New York, NY: Routledge.

Rodriguez, X. de D., & Bonilla, J. Z. (2009). Credibility, idealisation, and model building: An inferential approach. *Erkenntnis* (1975–), 70(1), 101–118.

Roth, W. (1998). Learning process studies: Examples from physics. *International Journal of Science Education*, 20(9), 1019–1024.

Roth, W. (1996). The co-evolution of situated language and physics knowing. *Journal of Science Education and Technology*, 5(3), 171–191.

Roth, W. M., & Tobin, K. (1997). Cascades of inscriptions and the re-presentation of nature. *International Journal of Science Education*, 19(9), 1075–1091.

Schoultz, J., Säljö, R., & Wyndhamn, J. (2001). Heavenly talk: Discourse, artifacts, and children’s understanding of elementary astronomy. *Human Development*, 44(2–3), 103–118.

Sjoberg, S. (2010). Constructivism and learning. In P. Peterson, E. Baker, & B. McGaw (Eds.), *International Encyclopedia of Education* (3rd ed., pp. 485–490). Oxford: Elsevier.

Suárez, M. (2003). Scientific representation: Against similarity and isomorphism. *International Studies in the Philosophy of Science*, 17(3), 225–244.
Suárez, M. (2004). An inferential conception of scientific representation. *Philosophy of Science, 71*(5), 767–779.
Suárez, M. (2010). Scientific representation. *Philosophy Compass, 5*(1), 91–101.
Swoyer, C. (1991). Structural representation and surrogative reasoning. *Synthese, 87*(3), 449–508.
Weisberg, M. (2007). Who is a modeler? *The British Journal for the Philosophy of Science, 58*(2), 207–233.

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