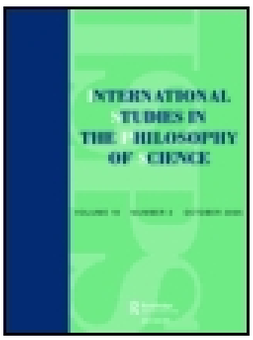

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Jamie Shaw

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Duhem on Good Sense and Theory Pursuit: From Virtue to Social Epistemology

Jamie Shaw

Philosophy, University of Toronto

ABSTRACT

The emerging consensus in the secondary literature on Duhem is that his notion of 'good sense' is a virtue of individual scientists that guides them choosie between empirically equal rival theories (Stump 2007. "Pierre Duhem's Virtue Epistemology." *Studies in History and Philosophy of Science Part A* 38 (1): 149–159; Ivanova 2010. "Pierre Duhem's Good Sense as a Guide to Theory Choice." *Studies in History and Philosophy of Science Part A* 41 (1): 58–64; Fairweather 2011. "The Epistemic Value of Good Sense." *Studies in History and Philosophy of Science Part A* 43 (1): 139–146; Bhakthavatsalam (2017). "Duhemian Good Sense and Agent Reliabilism." *Studies in History and Philosophy of Science Part A* 64: 22–29). In this paper, I argue that good sense is irrelevant for theory choice within Duhem's conception of scientific methodology. Theory choice, for Duhem, is either a pseudo-problem or addressed purely by empirical and formal desiderata depending on how it is understood. I go on to provide a positive interpretation of good sense as a feature of scientific communities that undergo particular forms of education that allow scientists to abandon theory pursuit. I conclude by suggesting that this interpretation entails that virtue epistemological readings of Duhem are insufficient for understanding good sense; we must employ a social epistemological perspective.

KEYWORDS

Duhem; good sense; theory pursuit; theory acceptance; education

1. Preamble

There has been a great amount of ink spilt trying to explicate the origins, characterisation, and methodological implications of Duhem's notion of 'good sense'. Despite the brevity of its discussion, it remains a distinctive feature of his understanding of scientific rationality. Recently, commentators have argued that good sense is a virtue of individual scientists. Good sense, being 'an extra-logical, but not an extra-rational faculty, something like intuition, as opposed to deduction–raison as opposed to raisonnement' (Ariew 1984, fn. 1 317), can be used by scientists to rationally choose between theories when formal and evidentiary criteria have been exhausted. In this paper, I suggest that good sense has been improperly characterised and has a different role in Duhem's thought than commonly supposed. Specifically, I contend that good sense provides criteria for theory *abandonment*, or the determination of when a theory has exhausted its

CONTACT Jamie Shaw jshaw222@uwo.ca Philosophy, University of Toronto, Toronto, ON, Canada

fruitfulness. I go on to show how good sense is best understood from a social epistemological perspective and is grounded in the education of scientists of the history of science. By exploring how Duhem understands good sense in this way, I reconceive the more well-known features of good sense. By doing so, I hope to shed light on Duhem's conception of scientific methodology and provide an interesting position addressing an important problem concerning when a theory should no longer be pursued.

This paper is structured in the following way. First, I review the contemporary literature on Duhem's understanding of good sense and its purported role in theory choice. Following this, I argue that good sense does not emerge in the context of theory choice but, rather, in the context of determining when to cease pursuing a theory. In the final section, I elaborate on my interpretation of good sense and demonstrate how it emerges from Duhem's commitment to the use of history in scientific training.

2. The Received View

While there are a number of subtle differences between the many interpretations of good sense, the emerging consensus posits that good sense provides a solution to the problem of underdetermination by aiding us to choose between empirically equivalent rivals (Stump 2007; Ivanova 2010; Fairweather 2011; Bhakthavatsalam 2017). The shared points of agreement amongst these commentators comprise what I call the 'received view'. Duhem's underdetermination, as the received view describes, arises from the fact that we can never isolate individual hypotheses that should be refuted in light of recalcitrant evidence. As Duhem famously declared:

> The prediction of the phenomenon, whose non-production is to cut-off debate, does not derive from the proposition challenged if taken by itself, but from the proposition at issue joined to that whole group of theories, if the predicted phenomenon is not produced, not only is the proposition questioned at fault, but so is the whole theoretical scaffolding of the physicist. The only thing the experiment teaches us is that among the propositions used to predict the phenomenon and to establish whether it would be produced, there is at least one error; but where this error lies is just what it does not tell us (Duhem 1906/1954, 185).

Because of this account of theory confirmation,[1]

> This holistic character of theory testing led Duhem to argue that we could always save a theory from refutation, that is, to make it fit the empirical evidence, by changing the auxiliary hypotheses … In this way we can produce different theories that will equally well fit the empirical data. This leads to the thesis of the underdetermination of the theory by evidence … because empirical evidence cannot help us when we have to decide between two empirically equivalent rival theories (Ivanova 2010, 59).

Since the history of science is continuous, for Duhem, a theory evolves into distinct theories as a result of ongoing testing and each of those theories is empirically equivalent (see Psillos 2018, section 1.2). Say we have a theory, T_0, which faces a piece of recalcitrant evidence. We could adjust T_0 in different ways, say by modifying hypothesis H_1 or H_2 where modifying H_1 leads to theory T_1 and modifying H_2 leads to theory T_2 such that T_1 is theoretically distinct from T_2. As a result, we have two distinct theories compatible with the same body of empirical evidence.[2] As a solution to this problem, the received view posits that Duhem uses the notion of 'good sense' as a tiebreaker; some cognitive

ability to choose between theories: 'The success condition for good sense is to break the empirical stalemate, and thus to ensure that 'choice worthy theory'' (Fairweather 2011, 142; see also Bhakthavatsalam 2017, 27). While different proponents of the received view disagree what these abilities consist of, they agree on three key points:

(1) Good sense is a virtue of individual scientists
(2) Good sense is normative feature of Duhem's account of methodology.
(3) Good sense provides a solution to the problem of theory choice in cases of underdetermination.[3]

For (1), there is some dispute over what kind of virtue good sense is. Stump, for example, claims that good sense is an intellectual and moral virtue akin to other virtues Duhem praises (e.g. intellectual sobriety, courage, detachment from passions, etc.) (Stump 2007, 152). Ivanova claims that good sense is a virtue specifically honed for weighing complex balances of evidentiary and theoretical concerns (Ivanova 2010, fn. 6 60). Not all scientists are necessarily virtuous, as Duhem was aware that scientists' judgments can be warped by personal idiosyncrasies or party lines. His own dissertation on thermodynamic potential was rejected by panelist Gabriel Lippmann partially due to political differences and frustration that Duhem argued against Lippmann's friend, Marcellin Berthelot, 'cherished' principle of maximum work where every chemical change, without the intervention of external energy, tends towards the production of bodies or systems which evolves the greatest quantity of heat (Ariew 2007). In either case, according to the received view, good sense is a feature of *individuals*.

For (2), good sense is not simply a feature that some scientists happen to have, but something that Duhem wishes to see practiced in science itself (hence *good* sense); 'Duhem *did* see good sense as a part of the scientific method - in fact, an important part of it (Bhakthavatsalam 2017, 27; see also Fairweather 2011, 140–141).[4] As opposed to some of Duhem's successors, such as Polanyi (1958), good sense is delineated in terms of its role(s) in scientific methodology. One specific role to which Duhem allocates good sense, according to the received view, is to choose between underdetermined rival theories.[5] It is this role that I wish to examine.

For (3), the notion of theory choice is often presented in an ambiguous fashion. What does it mean to 'choose' between two theories?[6] At times, some propose that the problem of theory choice is what theory we should *accept*. On this reading, the problem of underdetermination is a problem of which theory we should think is true (or empirically adequate).[7] For instance, Stump writes that

> Holism threatens to make testing impossible, yet Duhem believes that scientific consensus will emerge. While the pure logic of the testing situation leaves theory choice open, good sense does not. Duhem claims that the history of science shows that while there is controversy in science, there is also closure of scientific debates (Stump 2007, 155).

This suggests that good sense closes the debate on what theories we should accept.[8] Similarly, Fairweather claims that, for Duhem, 'If a belief P is the product of a reliable capacity or process [good sense, then] this fact constitutes evidence in favor of P' (Fairweather 2011, 143). As such, 'If the products of good sense reliably turn out to be supported by compelling new evidence, then being the product of good sense will be

evidence for any theory with such a distinguished etiology' (ibid). Good sense allows scientists to look past the logical and evidentiary status of a theory to see its privileged epistemic standing. At other times, theory choice is presented as a problem of which theory to *pursue*; which theories are worthy of further development.[9] For instance, Ivanova writes that '[t]he fact that scientists seem to choose the right theories, the theories *leading to* a more unified and novel predictive theories' (Ivanova 2010, emphasis added, 60). Here, it seems as if good sense allows us to choose which theory is likely to be successful given future pursuit. Because of this ambiguity, it is not clear what the 'problem' of theory choice is. On the acceptance reading, underdetermination provokes the problem of accepting two incompatible descriptions of reality. On the pursuit reading, we are challenged to figure out the grounds for pursuing one theory over another when they are empirical equals.

It is crucial to keep the distinction between pursuit and acceptance separate as they have distinct methodological implications. Laurie Whitt has made this point succinctly:

> Minimally, when scientists decide to pursue a theory they are deciding to work on it … But [this is not] true of theory acceptance. A scientists' decision to accept a theory does not entail a decision to work on it, although the latter decision may also be made. Nor is it the case that a scientist who decides to work on a theory has also thereby decided to accept it … Strong pragmatic commitments follow from [acceptance]: one must at least try to live by the moral code one finds worthy of acceptance. But one's research life need not be lived in accordance with the scientific theory one regards as most worthy of acceptance. The reason is that there may be other promising theories available, theories that deserve to be developed (Whitt 1990, 470–471).

This point has been echoed by Lydia Patton (2012, 237–239) and Hakob Barseghyan (2015, 30–42; see also Barseghyan 2018).[10] Different methodological norms are at play in pursuit and acceptance. A theory can be unacceptable, but pursuitworthy. To be clear, the two are often interrelated. For example, acceptance can dictate the goals of pursuit. Moreover, most (if not all) theories that are accepted are also pursued in the sense that theories are almost always being refined. However, some theories are not acceptable but worthy of further pursuit. These stances are not mutually exclusive, but entail answers to different questions: on what grounds should we accept a theory vs. on what grounds should we pursue a theory? As will be seen, Duhem implicitly separated these epistemic stances since he discusses their logics separately.

3. Duhem on Good Sense and Theory Pursuit

Duhem's notion of good sense plays a much different role than the received view admits. Specifically, I argue against claims (1) and (3) while agreeing with them on (2). My thesis is that Duhem invokes good sense to solve the problem of when to *abandon* a theory. In other words, good sense does not determine which theories we should accept or pursue, but which theories we should *cease* pursuing. Duhem is upfront about this when he introduced the notion of good sense in a section entitled 'Good sense is the judge of hypotheses which ought to be abandoned.' Clarifying what this entails, however, is no easy venture. In this section, I outline my interpretation of Duhem's conception of good sense.

3.1. Good Sense and Theory Abandonment

The view defended here was described in passing by Lakatos (Lakatos 1971, 100).[11] However, neither Lakatos nor anyone else, that I am aware of, has developed this view in detail.[12] Good sense, on this interpretation, is necessary for the cessation of theory pursuit. Specifically, Duhem writes that 'logic does not determine with strict precision the time when an inadequate hypothesis should give way to a more fruitful hypothesis … recognising this moment belongs to good sense' (Duhem 1906/1954, 218). This is because we can always employ 'conventionalist stratagems', in Popper's terms,[13] to alter a theory in light of incoming evidence. We can always shuffle auxiliary hypotheses around in response to recalcitrant evidence and save a theory from being falsified.[14] There is no principle of logic that dictates when a theory has been definitively refuted. As such, Duhem faces an important problem: his account does not allow for the refutation of any theory. This would impinge on many his of other claims, most notably that the history of science is ultimately convergent. Duhem elaborates on this situation:

> When certain consequences of a theory are struck by experimental contradiction, we learn that this theory should be modified but we are not told by the experiment what must be changed … No absolute principle directs this inquiry, which different physicists may conduct in different ways without having the right to accuse one another of illogicality … The first physicist does not have the right to condemn *in advance* the boldness of the second one, nor does the latter have the right to treat the timidity of the first physicist as absurd (emphasis added, 216).

Duhem recognises that the different methods scientists used to modify a theory, whether bold or timid, cannot be condemned 'in advance'. The italicised phrase is crucial to understanding Duhem's claim. Duhem is claiming, here, that our methods of pursuing a theory (i.e. adjusting this hypothesis or that) can only be judged in retrospect. Thus, there is no rational *in situ* way to determine whether we should pursue one line of inquiry over another. This highlights an asymmetry, according to Duhem, between decisions about pursuing a theory versus those that concerning abandonment. On the pursuit reading of theory choice, the received view posits that good sense provides the *conditions* for theory pursuit whereas, on my reading of Duhem, good sense *requires* theory pursuit to begin with. The received view puts the cart before the horse: we can only determine which method of altering a theory was correct *in hindsight*.[15] To know whether T is worthy of *further* pursuit, we must have *already pursued* T to some degree. Good sense requires being attuned to the historical development of a particular theory. While the received view recognises that good sense requires 'training and practice' (Ivanova 2010, 60), if it is allocated to the methodological role of delimiting theory pursuit, then Duhem's view would be self-defeating; it would deprive scientists of the experiences necessary to implement good sense in the first place. Duhem repeats and clarifies this point in *German Science*:

> If, then, he sees one [counterexample], he need not conclude directly and overtly to the falsity of his preconceived idea. He could be faced with some accident of the experiment which need not require the abandonment of his idea. What will determine whether these failures are or are not of such a nature that the supposition in question must be renounced? Good sense. But this judgment will be of just the same type as a judgment in a legal proceeding wherein each of the two parties is faced with evidence some of

> which tends towards conviction and some towards exculpation. Good sense will not return its verdict *until after having weighed the pros and cons with mature consideration* (Duhem 1991, emphasis added, 24).[16]

In the final sentences, we see Duhem recognise that *mature* judgment is needed, one that comes *after* a theory has been pursued to some degree and its pros and cons of the particular theory have been weighed out. Because of these ambiguities during immature stages of theory pursuit, good sense is divided within different members of the scientific community:

> These reasons of good sense do not impose themselves with the same implacable rigor that the prescriptions of logic do. There is something vague and uncertain about them: they do not reveal themselves at the same time with the same degree of clarity to all minds. Hence, the possibility of lengthy quarrels between the adherents of the old system and the partisans of a new doctrine, each camp claiming to have good sense on its side (Duhem 1906/1954, 217).

At some stages of pursuit, good sense is *pluralistic*[17] in the sense that there is disagreement as to whether or not a theory should be abandoned. This is because good sense is *vague enough* to allow room for disagreement about the fecundity of a particular theory. However, Duhem claims that good sense is ultimately convergent:

> this state of indecision does not last forever. The day arrives when good sense comes out so clearly in favor of one of the two sides that the other side gives up the struggle even though pure logic would not forbid its continuation … for Foucault's experiment was *not* the crucial experiment that Arago thought he saw in it, but by resisting wave optics for a longer time Biot would have been lacking in good sense (218).

More generally, good sense becomes 'more clear … as time goes on' (27). Good sense converges in the long run and at *this* stage pursuit should be abandoned. In contrast to Ivanova and Paternotte (2013, 1125) who claim that, for Duhem, 'good sense prescribes to prefer whatever theory one predicts the majority will end up choosing', the consensus is arrived at naturally when good sense becomes clearer amongst the majority of the scientific community. Good sense does not anticipate or direct consensus; it only becomes clearer and then a consensus arrives. This clarified community consensus of good sense amounts to a refutation of the theory.

Moreover, good sense allows scientists to be more fruitful researchers in other dimensions of pursuit.[18] For instance, Duhem writes

> In order to draw consequences out of the preconceived idea that can be compared with facts, which experimental proof will either confirm or condemn, one must deduce. Such deduction is often a quite long and delicate process. It is essential that it be a rigorous process, under pain of making the observational testing depend upon propositions which could not be derived from the hypothesis, and thus of rendering this testing illusory. This reasoning, however, cannot in general be conducted more geometrico, under the form of a series of theorems. The proposition whose consequences one wishes to deduce would not lend itself to this process. The ideas on which it depends are no longer highly abstract but quite simple concepts, like the first objects of the mathematical sciences, or ideas made in a well-known fashion by definition using those concepts. These are ideas richer in content but less precise, less analysed; they issue more immediately from observations. To reason exactly with such ideas, the rules of syllogistic logic are not adequate. They must be assisted by a certain sense of soundness that is one of the forms of good sense (Duhem 1991, my translation, 23).[19]

Once a scientist has good sense, they are more capable of making other forms of ampliative reasoning. These virtues, however, do not determine nor exhaust the methodological import of good sense. Moreover, as will be shown, it is insufficient for even identifying which individuals have good sense. Good sense is not merely a feature of virtuous scientist's minds, but also requires a community consensus that has been reached at a certain stage of theory pursuit.

There are two criteria must be that met for good sense to lead to the abandonment of a theory: it reflects a *consensus* and is *specific enough to determine particular actions*. Good sense is useless unless it can be translated into workable practical imperatives.[20] The former point can be seen by looking at the different stages of theory pursuit. In earlier stages, good sense is indecisive in the sense that it does not lead to an unequivocal attitude amongst the community about whether a theory should be abandoned. If good sense were merely the property of individual scientist's cognitive capacities, then pluralism would pose a problem for Duhem: whose 'good sense' carries methodological weight? However, as we saw, Duhem thinks that theory abandonment comes from outgrowing indecisive stages of good sense when it converges amongst all (or, at least, most) of the members of the scientific community. It is because of this that a virtue epistemology is insufficient for understanding the methodological purpose of good sense: we need to take a social perspective.[21,22]

3.2. Good Sense and Theory Choice, Revisited

To further demonstrate that good sense plays no role in theory choice, as understood within the received view, it is worth looking at Duhem's conceptions of (both readings of) theory choice. The question of what acceptance amounts to, for Duhem, is a massively complicated topic which has occupied the bulk of the secondary literature on Duhem (Vuillemin 1979; Finocchiaro 1992; Dion 2013; Gueguen and Psillos 2017).[23] Older interpretations claim that Duhem was a straightforward instrumentalist where theories are mere instruments that systematise experience (Agassi 1957). Maiocchi (1985) claims that Duhem thought that theories must be combined with theological truths to provide a full understanding of nature. Ben-Menahem (2006) understands Duhem as a kind of conventionalist, Psillos (1999) reads Duhem as a 'minimal realist', and Hacking (1983) calls Duhem an 'anti-realist' and a 'positivist'. Given the dozens of interpretations of Duhem's notion of acceptance, it is impossible to enumerate them all here. What is commonly accepted, however, is that Duhem is a *convergentist*; a point Duhem is emphatic about: 'physical theory is not merely an artificial system, suitable today and useless tomorrow, but … an increasingly natural classification' (Duhem 1906/1954, 240).[24] The history of science, for Duhem, converges towards a unique theory (see Lugg 1990, 409). This theory would be a natural classification. While commentators are divided on what is entailed by this notion, they agree that there is convergence in the long run. This means that underdetermination cannot, for Duhem, pose a threat to theory acceptance; it is simply an obstacle that will be overcome during the course of research.

My interpretation is closely aligned with Kyle Stanford's understanding of Duhemian underdetermination. On Stanford's view,

> Duhem's original worry did not concern the possibility that we might identify empirical equivalents to our best theories that are indistinguishable by any possible evidence at all; it was instead that there might simply be garden-variety alternative hypotheses, not yet even imagined or entertained by us, but nonetheless consistent with or even equally well-confirmed by all of the actual evidence we happen to have in hand … the underdetermined theories are empirically inequivalent and could therefore be differentially confirmed by the accumulation of further evidence (Stanford 2001, emphasis removed, S7).

Underdetermination is an orthogonal issue to theory acceptance. If two or more theories are underdetermined with respect to the evidence, we must pursue them further to see which theory is correct.[25] To further see this point, consider the distinction Stanford makes between 'holist' and 'contrastive' underdetermination. Holist underdetermination concerns what we should do when a theory faces recalcitrant evidence. Contrastive underdetermination concerns the empirical equivalence of two or more rival theories. Contrastive underdetermination is formulated by Duhem thusly:

> But let us admit for a moment that in each of these systems [concerning the nature of light] everything is compelled to be necessary by strict logic, except a single hypothesis; consequently, let us admit that the facts, in condemning one of the two systems, condemn once and for all the single doubtful assumption it contains. Does it follow that we can find in the 'crucial experiment' an irrefutable procedure for transforming one of the two hypotheses before us into a demonstrated truth? Between two contradictory theorems of geometry there is no room for a third judgment; if one is false, the other is necessarily true. Do two hypotheses in physics ever constitute such a strict dilemma? Shall we ever dare to assert that no other hypothesis is imaginable? Light may be a swarm of projectiles, or it may be a vibratory motion whose waves are propagated in a medium; is it forbidden to be anything else at all? (Duhem 1906/1954, 189).

As Stanford notes, contrastive underdetermination concerns 'the ability of the evidence to confirm any given hypothesis *against alternatives*, and the central focus of discussion in this connection … concerns the character of the supposed alternatives' (Stanford 2017). Theory choice, as described by the received view, concerns contrastive underdetermination rather than holist underdetermination. On my view, good sense concerns holist underdetermination but in a peculiar way.[26] It is not arrested by 'future evidence' alone, as Stanford writes, but by the abandonment of a theory as a result of good sense. Good sense does not replace nor anticipate this process of testing; it only comes into play at the latest stages of pursuit to abandon a theory.

One may stop here and suggest that the reading of Duhem's notion of good sense defended in the previous section is just a friendly amendment to the received view. I have argued that good sense allows us to decide when to abandon a theory. This could be read as a means of resolving underdetermination by refuting theories until there is one left. The 'problem' of underdetermination would be slightly different in either case. If we follow the acceptance reading of theory choice, according to the received view, the problem is a synchronic one of choosing which theory is acceptable. Here, the problem of underdetermination is how to stop pursuit to arrest underdetermination from persisting. However, this compromise does not accurately reflect Duhem's position. During pursuit, we may have many theories. To use Duhem's (simplified) example, consider when we are pursuing corpuscular and wave optics simultaneously. For the compromised interpretation to be correct, Duhem must hold that abandoning T_1 (corpuscular theory) is tantamount to accepting T_2 (wave optics).[27] This allows one to

move from abandoning one theory to accepting its rival. However, as Duhem recognises, this would be fallacious since all the pursued theories may be false (see Duhem 1906/1954, 180–186). Discovering that one theory cannot be acceptable does not tell us what theory is acceptable. To appreciate this point more acutely, consider Duhem's stance against crucial experiments:

> Between two contradictory theorems of geometry there is no room for a third judgment; if one is false, the other is necessarily true. Do two hypotheses in physics ever constitute such a strict dilemma? Shall we ever dare to assert that no other hypothesis is imaginable? Light may be a swarm of projectiles, or it may a vibratory motion whose waves are propagated in a medium; is it forbidden to be anything else at all? (Duhem 1906/1954, 190).

The answer to the final rhetorical question is obviously negative, for Duhem; we may not have pursued ('imagined') a theory that could be the best candidate for a natural classification. As such, abandoning $\sim T$ is not equivalent to accepting T; the problem of underdetermination persists. Of course, the refutation of alternatives may be necessary for accepting a unique theory, but it is certainly not sufficient.

But there is a second question concerning pursuit here. Is the abandonment of T tantamount to the pursuitworthiness of its rival, T'? Duhem does not provide any criteria for pursuitworthiness. Rather, he merely provides constraints 'of logic' on pursuit which allows for pursuing any theory that does not violate those constraints. He begins his discussion in an eliminative fashion. First, he considers constraining theory pursuit by metaphysical hypotheses. Since theories do not aim at or require metaphysical presuppositions, according to Duhem, they need not be constrained by them. Second, he considers constraining pursuit by consistency with prior experimental laws. However, in Duhem's analysis of Newton and Ampère, he shows that their theories *contradicted* their predecessors. 'Therefore', Duhem claims, 'we shall not be averse to admitting among the fundamental bases of our physical postulates not furnished by experiment' (219). Eventually, Duhem rests on three constraints:

(1) 'a hypothesis shall not be a self-contradictory proposition, for the physicist does not attend to utter nonsense'
(2) 'the different hypotheses that are to support physics shall not contradict one another'
(3) 'hypotheses shall be chosen in such a manner that from them *taken as a whole* mathematical deduction may draw consequences representing … the *totality* of experimental laws' (220).

(1) is justified by the fact that a self-contradicting proposition does not express anything at all. (2) states that a group of hypotheses ought to cohere with one another. This is justified by simplicity. Physical theory is not a 'mass of disparate and incompatible models' but 'aims to preserve with jealous logical unity … only on this condition will theory tend towards its ideal form' (ibid). (3) is the aim of any physical theory. For Duhem, pursuit is constricted by the aims of physical theories. As Bhakthavatsalam puts it, the 'physicist who pursues logically unified theories rationally justifies the pursuit by identifying a meaning or purpose to the pursuit' (Bhakthavatsalam 2015, 11). Clearly, these aims allow for a great deal of freedom, a point Duhem recognises: 'So long as [the physicist] respects them, the theorist enjoys complete freedom, and he may lay the foundations of

the system he is going to construct in any way he pleases' (ibid). Or, as he later puts it, this 'prescription … is exasperating in the extreme latitude it allows' (221). We can be pluralists in the context of pursuit. Duhem goes on to clarify this point

> In *the course of its development*, a physical theory is free to choose any path it pleases provided that it avoids any logical contradictions; in particular it is free not to take account of experimental facts. This is no longer the case *when the theory has reached its complete development* (206).

Pluralism is allowed *during* pursuit, but once pursuit ends this will not be the case. Theories eventually need to be subjected to good sense, so this eventually will diminish pluralism until we converge on a natural classification. This makes the 'problem' of theory choice on the pursuit reading innocuous since we do not need to choose between theories; we can pursue any theory we please, within the confines of specific logical constraints. Put bluntly, the question of which theory to pursue is a pseudo-problem for Duhem. As a result, good sense does not play any role in theory choice on the pursuit reading since this problem doesn't arise for Duhem in the first place.

However, in several passages, Duhem suggests that good sense aids in making an active choice. We now know that this choice cannot concern the acceptability or pursuitworthiness of a theory. We are now pressed to uncover what kind of choice good sense helps scientists make. Duhem is clearest on this point when he writes that 'logic does not determine with strict precision the time when an inadequate hypothesis *should give way to a more fruitful assumption*' (emphasis added, 218). The same point appears in *German Science*: 'when some disaccord erupts between the corollaries drawn from the suppositions and the results of observation; when in the judgment of good sense this disaccord is intolerable, then the hypothesis in question ought to be abandoned, *to make way for new foundations*' (Duhem 1991, emphasis added, 28). Here, Duhem claims that abandoning a theory entails that a more 'fruitful' theory is deserving of the support previously allocated to its rival. As such, theory abandonment comes with a choice to increase the pursuit of its 'more fruitful' rival. As such, this point does not give us a criterion of pursuitworthiness. What Duhem elucidates is a criterion of *increased* pursuitworthiness. Duhem argues that once we cease pursuing one theory, we will divest our resources onto another theory that seems more promising. Good sense thus facilitates our ability to make a rational choice, but not a choice concerning acceptance or pursuit – but a choice of whether to increase our efforts into developing a particular theory.[28]

4. The Importance of Historical Education

Recall that good sense requires more than virtue: it also requires a community consensus arrived at naturally at the end of pursuing a particular theory. But there is more that can be said to fully understand Duhem's conception of good sense. Specifically, good sense is grounded in pedagogical practices in which scientists are trained in the history of their disciplines. This has the consequence that one may be virtuous and possess good sense but, because they do not have the relevant historical knowledge, cannot come to sound conclusions.

Duhem argues that scientists must undergo a particular kind of education to be endowed with good sense. This does not mean that a scientist must have a PhD in a

particular discipline, since their education may be faulty. For Duhem, the correct education requires schooling scientists in the history of their discipline. This is because a knowledge of the history of a discipline is necessary for understanding what problems a theory is developed to manage and what problems it continues to face. No theory, for Duhem, is the product of pure creativity. Rather, theories are the evolutionary consequences of their historically prior incarnates. In his detailed reconstruction of Newton's discovery of universal gravitation, he argues that it was the result of the development of many of his predecessors ideas. He summarises his findings in *To Save the Phenomena*:

> While Kepler multiplied his attempts at accounting for the motion of the stars by means of the properties of water courses and magnets, while Galileo sought to reconcile the paths of projectiles with the motion of the Earth or derive from this latter motion the explanation of the tides, each of them thought the Copernican hypotheses were founded in the nature of things. But the truth they were gradually introducing into science was that a single dynamics ought to represent, in a single set of mathematical formulae, the motion of the stars, the oscillations of the ocean and the fall of weights. They thought they were updating Aristotle, but they were preparing for Newton (Duhem 1908/1969, 140).

More abstractly, Duhem arrives at the following view:

> However rapid and condensed the evolution of a theory may be, it is always possible to note that a long period of preparation preceded its appearance; between the first sketch and the perfect form to the intermediate stages may escape us to the point that we imagine we are viewing a free and sudden creation, but a preliminary labor has made favorable the ground in which the seed fell; it has made possible the accelerated development, and this labor was followed up in the course of centuries (Duhem 1906/1954, 254).

Duhem thinks that since discovery is an evolutionary notion, a knowledge of the history of science is necessary to 'accelerate' the discovery process. This has pedagogical consequences. We cannot only teach students 'strict logic', since this requires enumerating all possible hypotheses and their logical relations. We must also teach students the 'lacunas and assertions not yet justified, and [the student] ought to see clearly where these lacunas are and what these assertions are; in short, the instruction with which is to be satisfied … should not cause false ideas to germinate in his mind' (258). Because of this, the history of science is crucial in Duhem's pedagogy; these lacunas and open questions are posed by the science that has evolved into its current state.[29] Without historical knowledge, a student will be unlikely to identify the correct problems to address in their research. As Ariew correctly observes '*bon sens* … gets perfected by the practice of history, by our becoming more aware of the failures and successes of previous theories, by thinking about the trajectory of scientific theories, rather than by considering a single theory frozen in time' (Ariew 2007). Education does not *impart* good sense. Rather, good sense becomes informed by learning about the historical trajectories of theories and what future directions they should take. Duhem contrasts this with allowing scientists to use their untampered imagination to develop theories which would only provide them with an innumerable mess of theoretical creations or modifications. Rather,

> Those who have a deeper insight into the history of physical theories know that in order to find the germ of this doctrine of universal gravitation, we must look at the systems of Greek science; they knew the slow metamorphoses of this germ in the course of its millenary evolution, they enumerate the contributions of much century to the work which will receive its viable form from Newton; they do not forget the doubts and gropings through which

> Newton himself passed before producing a finished system, and at no moment in the history of universal attraction do they perceive any phenomenon resembling a sudden creation, nor one instance in which the human mind, free from the impetus of any motive alien to the appeal of past doctrines … would have used all the freedom which logic grants it in forming hypotheses (Duhem 1906/1954, 222).

Given the overwhelming range of possibilities that are not ruled out by pure logic, it is practically necessary to have science students use the history of science as a heuristic in the formulation of their research. Otherwise, they are likely to follow fruitless paths. This is the essence of Duhem's criticism of Maxwell.[30] Duhem writes the following:

> It is not enough for the cosmologist to know very accurately the present doctrines of theoretical physics; he must also be acquainted with past doctrines. In fact, it is not with the present theory that cosmology should be analogous, but with the ideal theory toward which the present theory tends by a continual progress. It is not the philosopher's task, then, to compare present-day physics to his cosmology by congealing science at a precise moment of its evolution, but rather to judge the tendency of theory and to surmise the goal toward which it is directed. Now, nothing can guide him safely in conjecturing the path that physics will take if not the knowledge of the road it has already covered (303).

Maxwell, Duhem claims, deviated from this dictum by 'rashly' inventing new electrodynamics that departed from its empirically successful predecessors from Poisson, Ampère, Weber, and Neumann.[31] He writes:

> At the moment when Maxwell introduced a new magnitude in electrodynamics, the displacement current, at the moment when he marked, as essential hypotheses, the mathematical form of the laws to which this magnitude should be submitted, no properly observed phenomenon required this extension of the theory of currents; that theory was sufficient for representing, if not all phenomena known until then, at least all those whose experimental study had achieved a sufficient degree of clearness. No logical necessity pressed Maxwell to imagine a new electrodynamics (Duhem 1902, 8).

If Maxwell had been more attuned to the historical development of electrodynamics, he would not have broken historical continuity from previous theories. Given that Duhem admits that Maxwell's rashness cannot be condemned using 'pure logic' (Duhem 1893, 366), we can see how it was Maxwell's lack of understanding the trajectory of electrodynamics that led him to needlessly depart from the evolving 'natural order' of previous theories within his domain.

The teaching of the history of science, Duhem thinks, also has a happy side effect of combating dogmatism. Specifically, he claims that understanding the history of science will instill a sense of humility in students so they will continue to work upon the evolution of the currently accepted theories that surround them. He writes,

> Besides, the history of science alone can keep the physicist from the mad ambitions of dogmatism as well as the despair of Pyrrhonian skepticism. By retracing for him the long series of errors and hesitations preceding the discovery of each principle, it puts him on guard against false evidence; by recalling to him the vicissitudes of the cosmological schools and by exhuming doctrines once triumphant from the oblivion in which they lie, it reminds him that the most attractive systems are only provisional representations, and not definitive explanations (Duhem 1906/1954, 270).

Imparting historical knowledge not only helps scientists recognise the trajectory of the theories they are learning about and will be working on, but it also combats a

psychological tendency many people have to see the current incarnation of their favourite theory as 'definitive' rather than a provisional step in an evolution towards natural classification.

Recall that, on my interpretation, good sense provides criteria for abandoning pursuit. As I pointed out, this requires that pursuit *conditions* good sense rather than the other way around. Now we can sharpen this point by saying that it isn't just scientists *immersed* in pursuit (i.e. who happen to practice science during theory pursuit) but scientists with a historical knowledge of the *trajectory* of theory pursuit who have good sense. They must know about the history of testing that a theory has been exposed to and how those tests have been accommodated. Consider, again, Duhem's case of the rejection of corpuscular optics. It had been pursued vigorously for over 200 years, from Descartes' initial formulation in 1637[32] until Foucault's (second) determination of the speed of light in 1862. Despite its initial promise from Newton's prism experiments (once they were replicated), it failed to provide a convincing account of interference patterns, diffraction, or polarisation which had become increasingly prominent given Young's experiments beginning in 1801. It was the increasing pressure of these difficulties that forced physicists, including Biot who was one of the more forceful defenders of the corpuscular theory, to abandon it. Foucault's experiment was 'the last nail in the coffin of the Newtonian particle theory of light' (Cassidy, Holton, and Rutherford 2002, 382). A knowledge of this history, and the increasing inability of the corpuscular theory to accommodate these anomalies in a satisfying way, was necessary for possessing the good sense to abandon the corpuscular theory of light.[33]

Grounding good sense in pedagogical background helps to establish the boundaries of the scientific community as it is necessary for identifying who can possess the relevant kind of good sense. In short, for Duhem, to be a member of the scientific community whose judgment carries any methodological weight, one must have the appropriate pedagogical upbringing.[34] Without grounding good sense in education, we would not know who is within the scientific community and, therefore, has good sense that is worth considering when abandoning a theory. If we simply looked for those who have good sense, the community boundaries would be different and not acceptable for Duhem. An otherwise virtuous scientist, with no knowledge of the history of science, cannot have good sense.

This has implications for how good sense should be evaluated. While different proponents of the received view evaluate good sense in different ways, they agree that it is sufficient to look at individuals or their judgments. Fairweather and Bhakthavatsalam defend 'agent reliabilism' where we look at the character of individual scientists; a scientist has good sense if and only if the *agent* generally makes correct decisions. Ivanova, on the other hand, defends the view that we can look at individual *judgments* and assess their reliability. On my view, neither the individual's character nor the track-record of their judgments is sufficient for identifying good sense. Rather, to identify the methodological import of good sense, we must make three, possibly additional, assessments:

(1) Theory pursuit has been sufficiently advanced such that scientists can make judgments about the trajectory of the theory.
(2) There must be a sufficient degree of consensus regarding when a theory should be abandoned.

(3) The consensus must have emerged from a community grounded in particular pedagogical practices.

As should be clear, this manner of identifying good sense deviates from the received view such that we are not primarily looking at *virtues*, but the *structure of communities* and *stages of pursuit*. To be clear, I am not claiming that Duhem did not have *any* virtue epistemology or an account of what virtues are proper to practicing scientists. What I am claiming is that good sense can be understood as arising from historical pedagogical practices and becomes methodologically relevant when the community converges on a judgment on when a theory should be abandoned.

5. Concluding Remarks

While it is obviously of great importance to discern what views Duhem held, and how he understood good sense, this doesn't exhaust the potential philosophical interest in this topic. Especially since the topic of theory pursuit has been unfortunately marginalised, it is worth noticing and reconstructing the conceptions of theory pursuit that have been defended throughout history. In this paper, I have reconstructed what I take to be the role of good sense in Duhem's conception of theory pursuit. Whether Duhem's view is plausible in its own right depends on future research, but it certainly represents a view that is worthy of further attention.[35] A part of this involves answering questions that do not have clear answers in Duhem's corpus. For example, Duhem does not provide a means for understanding the relationship between the judgments of scientists and community consensuses (List 2005; Pigozzi 2006). How are we to understand how and when a consensus has been reached? Moreover, Duhem's optimism about the natural settling of good sense may be misplaced given recent work on persistent disagreement (Elgin 2010). Can we reasonably expect good sense to converge more often than not? Is there a possibility that streamlining research projects by teaching a particular interpretation of historical trajectories may stifle the creativity of students (Bailin 1990)? Additionally, some, such as Hasok Chang (2012), have argued that some theories (specifically the phlogiston theory) were abandoned prematurely. Did these scientists have good sense or do such case studies present a problem for Duhem's position? Furthermore, some have argued that it is in principle impossible to determine rational limits to pursuit (Feyerabend 1976). Given that good sense evades rational discussion, since it is tacit, how could this argument be addressed? Further engagement with a Duhemian account of theory pursuit may lead to interesting discoveries on these and other fronts suggesting that greater pursuit on this topic is required.

Notes

1. It is disputable whether conformational holism directly leads to underdetermination for Duhem. See Zammito (2004, Chapter 2) and Gueguen (2019) and the citations therein for further discussion.
2. Naess (1972, 48) claims that this does not allow for the invention of "radically new theories" which replace old concepts with incompatible ones because we could only ever have "changes in opinion about which theoretical laws are correct." However, the gradual introduction of new hypotheses could lead to the development of radical theories *eventually* in a

piecemeal fashion. This means we would not have a Gestalt-switch from one incommensurable theory to another, as in Kuhn, but a gradual replacement of hypotheses such that an incommensurable theory eventually descends from its predecessor. See Leite (2012) for an in depth discussion of this issue.

3. At some points, Ivanova claims that good sense plays no role in *justifying* theory choice but only serves as a historical posit to explain these choices. However, she also claims that good sense "can assist practicing scientists when faced with the problem of theory choice" (Ivanova 2010, 63) suggesting that good sense plays a role in theory choice.
4. Ivanova wavers on this point. She writes that "[t]he fact these choices are later supported by empirical evidence shows that good sense leads to the right choices" (Ivanova 2010, 60). In other words, good sense is a reliable indicator of future success and, therefore, "every scientist ought to cultivate his good sense to increase scientific progress and to reach the desired end of science" (ibid). However, she also claims that "Duhem departed on normative theories of rationality because he wanted to account for actual scientific practice and therefore did not want to restrict theory choice to some algorithmic procedure" (64). My guess is that Ivanova equates 'normative' with 'algorithmic.' See Çoko (2015, section 3.3) for further discussion.
5. Bhakthavatsalam (2017) discusses other roles of good sense in Duhem's conception of scientific method as well, especially in theory construction.
6. This ambiguity is present in Kuhn (1982) where he launched theory choice as a topic of inquiry for philosophers of science. The conflation, though, makes sense given Kuhn's understanding of paradigm acceptance which is *both* an evaluation of its current ability to solve puzzles and a *faith* that the paradigm will continue to solve puzzles (that it will be fruitful) (see also Šešelja and Straßer 2013).
7. However, as others have pointed out, the problem of theory choice is a pseudo-problem for instrumentalists since we can 'accept' multiple inconsistent theories as useful tools without contradiction.
8. Though Stump also states that "we need 'good sense' to make a judgment about which path to take" (Stump 2007, 154) which sounds more like pursuit.
9. 'Development' may include all sorts of activities, including testing, theoretical clarification or refinement, extending a theory to new domains, and so forth.
10. In other cases, the term 'acceptance' refers to what I call 'pursuit' and what I call 'acceptance' others have called 'belief' (see Elliott and McKaughan 2014).
11. It is also defended by Martin (1991, 83-84), though he argues that good sense also plays a role in replacing hypotheses that have been rejected which, I contend, is inaccurate (see below). See also Krips (1977).
12. Lakatos criticizes Duhem's good sense for leaving "much to taste and fashion" (Lakatos 1970, 117).
13. "Duhem, in his famous criticism of crucial experiments … succeeds in showing that crucial experiments can never *establish* a theory. He fails to show that they cannot *refute* it" (Popper 1963, fn. 26 150). As will become evident, Popper's interpretation is also incorrect since Duhem had a notion of refutation (though not one Popper would accept).
14. Ariew (2007) denies that Duhem held the 'non-falsifiability' thesis where theories can always be saved from refutation and argues that Duhem only held the weaker claim that recalcitrant experience does not tell us where the error lies. However, he also claims that, for Duhem, the non-falsifiability thesis is an "obvious corollary" and "is a consequence of" conformational holism which contradicts his earlier claim. Other commentators argue that underdetermination only leads to the conclusion that we can hold some proposition come what may in Quine's generalization of Duhem's holism (Giannoni 1967; Wedeking 1969). I agree Duhem's position differs from Quine's since Duhem but only in the sense that the former provides a (non-pragmatic) mechanism for theory abandonment.
15. This point has been made and emphasized before by Martin (1987, 307).
16. Duhem repeats this point a few pages later (Duhem 1991, 28-29).

17. This can be contrasted with Descartes' view, where "Good sense is the best distributed thing in the world … In this it is unlikely that everyone is mistaken, it indicates rather that the power of judging well and of distinguishing the truth from the false—which is what we properly call 'good sense' or 'reason' – is naturally equal in all men, and consequently that the diversity of our opinions does not arise because some of us are more reasonable than others but sole because we direct our thoughts along different paths and do not attend to the same things" (Descartes 1637/1988, 20). Here, good sense is *natural* and, therefore, universal amongst humans, whereas, for Duhem, it is *learned*. See Duhem (1991, 12) for his response to Descartes.
18. This has been discussed before by Bhakthavatsalam (2017).
19. I'd like to thank an anonymous reviewer for bringing this passage to my attention.
20. Scientists may have the same good sense but differ as to what the appropriate practical response is. This is an important qualification, since good sense is inherently vague and not accompanied by detailed practical guidance.
21. Çoko (2015, 81) argues that, for Duhem, good sense is also guided by God or 'divine providence.' I do not have the space to consider this view here, but his is compatible with the view that good sense is something over and above individual scientists. It may be the case that good sense requires a theological dimension to be complete.
22. Some recent literature has not made such a sharp diction between virtue and social epistemology (see Alfano et al. 2020). I will sideline these nuances for now, as they do not concern my primary objective here.
23. This point is disputed within the received view. Ivanova defends the interpretation where good sense does not justify our acceptance of a theory (sometimes), in my vocabulary, whereas Stump and Fairweather argue that good sense pertains to theory acceptance.
24. See Baigrie (1992) for an informative overview of Duhem's ideal of convergence and Ariew and Barker (1992) for a discussion of convergence and continuity in Duhem.
25. For a discussion of this point as it pertains to the value-free ideal, see DiMarco and Khalifa (2019). Of course, there is still the open question of what to accept at a given time. I'm not aware of Duhem tackling this question in depth, so he appears to have bitten the bullet that we cannot uniquely accept a theory during some phases of pursuit. Or, perhaps, the notion of acceptance is out of place in Duhem's framework.
26. On my view, the distinction between contrastive and holist underdetermination is not entirely sharp. Rather, the two should be seen as sides of the same coin. Holist underdetermination *leads to* contrastive underdetermination in the sense that the different responses to recalcitrant evidence led to distinct theories that are compatible with the same body of evidence. Holist underdetermination, at least sometimes, is the first step towards contrastive underdetermination.
27. See Frankel (1976) for a more in-depth historical discussion.
28. Duhem appears to have not considered the idea that decreased pursuit of a theory could be used to increase the pursuit as a newly imagined theory or the possibility that decreased pursuit is not met with shuffling resources elsewhere. After all, perhaps the budget for funding theory pursuit could simply be lowered and shuffled to, say, public housing or eliminated altogether to lower taxes or balance an unbalanced budget.
29. See Stuart (2019) for a related discussion, with a particular emphasis on imagination and Kindi (2005).
30. Part of Duhem's criticism concerns Maxwell's use of models, which is beside the point for the current point.
31. Duhem defends Helmholz's electromagnetism over Boltzmann's precisely because it captures the deductive consequences of Maxwell's equations and is continuous with preceding theories (see Ariew and Barker 1986, 148).
32. The beginning date, of course, depends on which variant of the corpuscular theory we are discussing (e.g., Gassendi's, Descartes', Boyle's, Newton's, etc.).
33. It would be interesting to see how Duhem would appraise the partial revival of the corpuscular theory in Bohr's theory. Indeed, the historical fact that theories often become 'revived' poses an interesting challenge more generally to Duhem's conception of progress.

34. This means that Duhem would be committed to claiming that many scientists nowadays nowadays lack good sense since the pedagogical practices of most disciplines do not include teaching the history of science in a substantive way (see Leite 2002).
35. For a beginning of a critical discussion, see Shaw (2018, 137–144).

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References

Agassi, J. 1957. "Duhem Versus Galileo." *British Journal for the Philosophy of Science* 8: 237–248.
Alfano, M., J. de Ridder, and C. Klein, eds. 2020. *Social Virtue Epistemology*. London: Routledge.
Ariew, R. 1984. "The Duhem Thesis." *The British Journal for the Philosophy of Science* 35: 313–325.
Ariew, R. 2007. "Pierre Duhem." *The Stanford Encyclopedia of Philosophy*. https://stanford.library.sydney.edu.au/entries/duhem/.
Ariew, R., and P. Barker. 1986. "*Duhem on Maxwell: A Case-Study in the Interrelations of History of Science and Philosophy of Science*." *PSA: Proceedings of the Biennial Meeting of the Philosophy of science Association* (Vol. 1986, No. 1, pp. 145–156). Philosophy of Science Association.
Ariew, R., and P. Barker. 1992. "Duhem and Continuity in the History of Science." *Revue Internationale de Philosophie* 46: 323–343.
Baigrie, B. 1992. "A Reappraisal of Duhem's Conception of Scientific Progress." *Revue Internationale de Philosophie* 182 (3): 344–360.
Bailin, S. 1990. "Creativity, Discovery, and Science Education: Kuhn and Feyerabend Revisited." *Interchange* 21: 34–44.
Barseghyan, H. 2015. *The Laws of Scientific Change*. New York: Springer.
Barseghyan, H. 2018. "Redrafting the Ontology of Scientific Change." *Scientonomy: Journal for the Science of Science* 2: 13–38.
Ben-Menahem, Y. 2006. *Conventionalism: From Poincaré to Quine*. Cambridge: Cambridge University Press.
Bhakthavatsalam, S. 2015. "The Rationale Behind Pierre Duhem's Natural Classification." *Studies in History and Philosophy of Science Part A* 51: 11–21.
Bhakthavatsalam, S. 2017. "Duhemian Good Sense and Agent Reliabilism." *Studies in History and Philosophy of Science Part A* 64: 22–29.
Cassidy, D., G. Holton, and F. Rutherford. 2002. *Understanding Physics*. Springer Science & Business Media.
Chang, H. 2012. *Is Water H_2O?: Evidence, Realism and Pluralism*. New York City: Springer.
Çoko, K. 2015. "Epistemology of a Believing Historian: Making Sense of Duhem's Anti-Atomism." *Studies in History and Philosophy of Science Part A* 50: 71–82.
Descartes, R. 1637/1988. "Discourse on the Method." In *Descartes: Selected Philosophical Writings*, edited by J. Cottingham, R. Stoothoff, and D. Murdoch, 20–57. Cambridge: Cambridge University Press.
DiMarco, M., and K. Khalifa. 2019. "Inquiry Tickets: Values, Pursuit, and Underdetermination." *Philosophy of Science* 86: 1016–1028.

Dion, S. 2013. "Pierre Duhem and the Inconsistency Between Instrumentalism and Natural Classification." *Studies in History and Philosophy of Science Part A* 44: 12–19.
Duhem, P. 1893. "L'Ecole Anglaise et les Théories Physiques, A Propos D'un Livre de W. Thompson." *Revue des Questions Scientifiques* 34: 345–378.
Duhem, P. 1902. *Les Théories Electriques de J. Clerk Maxwell: Etude Historique et Critique*. Paris: Herman.
Duhem, P. 1906/1954. *The Aim and Structure of Physical Theory*. Princeton: Princeton University Press.
Duhem, P. 1908/1969. *To Save the Phenomena: An Essay on the Idea of Physical Theory from Plato to Galileo*. Princeton: Princeton University Press.
Duhem, P. 1991. *German Science: Some Reflections on German Science/German Science and German Virtues*. La Salle: Open Court Publishing Company.
Elgin, C. 2010. "Persistent Disagreement." In *Disagreement*, edited by R. Feldman, and T. Warfield, 53–68. New York: Oxford University Press.
Elliott, K., and D. McKaughan. 2014. "Nonepistemic Values and the Multiple Goals of Science." *Philosophy of Science* 81: 1–21.
Fairweather, A. 2011. "The Epistemic Value of Good Sense." *Studies in History and Philosophy of Science Part A* 43: 139–146.
Feyerabend, P. 1976. "On the Critique of Scientific Reason." In *Essays in Memory of Imre Lakatos*, edited by R. Cohen, P. Feyerabend, and M. Wartofsky, 109–143. Dordrecht: Reidel.
Finocchiaro, M. 1992. "To Save the Phenomena: Duhem on Galileo." *Revue Internationale de Philosophie* 182 (3): 291–310.
Frankel, E. 1976. "Corpuscular Optics and the Wave Theory of Light: The Science and Politics of a Revolution in Physics." *Social Studies of Science* 6: 141–184.
Giannoni, C. 1967. "Quine, Grünbaum, and the Duhemian Thesis." *Nous*, 283-297.
Gueguen, M. 2019. "On Separating the Wheat from the Chaff: Surplus Structure and Artifacts in Scientific Theories." (Doctoral Dissertation). University of Western Ontario.
Gueguen, M., and S. Psillos. 2017. "Anti-Scepticism and Epistemic Humility in Pierre Duhem's Philosophy of Science." *Transversal: International Journal for the Historiography of Science* 2: 54–72.
Hacking, I. 1983. *Representing and Intervening: Introductory Topics in the Philosophy of Natural Science*. Cambridge: Cambridge University Press.
Ivanova, M. 2010. "Pierre Duhem's Good Sense as a Guide to Theory Choice." *Studies in History and Philosophy of Science Part A* 41: 58–64.
Ivanova, M., and C. Paternotte. 2013. "Theory Choice, Good Sense and Social Consensus." *Erkenntnis* 78: 1109–1132.
Kindi, V. 2005. "Should Science Teaching Involve the History of Science? An Assessment of Kuhn's View." *Science & Education* 14: 721–731.
Krips, H. 1982. "Epistemological Holism: Duhem or Quine?" *Studies in History and Philosophy of Science* 13 (3): 251–264.
Kuhn, T. 1977. "Objectivity, Value Judgment, and Theory Choice." In *The Essential Tension*, edited by T. S. Kuhn, 320–339. Chicago: University of Chicago Press.
Lakatos, I. 1970. "Falsification and the Methodology of Scientific Research Programmes." In *Criticism and the Growth of Knowledge*, edited by I. Lakatos and A. Musgrave, 91–196. Cambridge: Cambridge University Press.
Lakatos, I. 1971. "History of Science and its Rational Reconstructions." In *PSA 1971*. Vol. VIII, edited by R. Buck and R. Cohen, 91–136. Dordrecht, Reidel: Boston Studies in the Philosophy of Science.
Leite, L. 2002. "History of Science in Science Education: Development and Validation of a Checklist for Analysing the Historical Content of Science Textbooks." *Science & Education* 11: 333–359.
Leite, F. 2012. "*Um Estudo Sobre a Filosofia da História e Sobre a Historiografia da Ciência de Pierre Duhem*." (Doctoral dissertation). Universidade de São Paulo.

List, C. 2005. "Group Knowledge and Group Rationality: A Judgment Aggregation Perspective." *Episteme; Rivista Critica Di Storia Delle Scienze Mediche E Biologiche* 2: 25–38.
Lugg, A. 1990. "Pierre Duhem's Conception of Natural Classification." *Synthese* 83: 409–420.
Maiocchi, R. 1985. *Chimica e Filosofia: Scienza, Epistemologia, Storia e Religione Nell'Opera di Pierre Duhem*. Florence: La Nuevo Italia.
Martin, R. 1987. "Saving Duhem and Galileo: Duhemian Methodology and the Saving of the Phenomena." *History of Science* 25: 301–319.
Martin, R. 1991. *Pierre Duhem: Philosophy and History in the Work of a Believing Physicist*. La Salle: Open Court Publishing.
Naess, A. 1972. *The Pluralist and Possibilist Aspect of the Scientific Enterprise*. Oslo: Universitetsforlaget Press.
Patton, L. 2012. "Experiment and Theory Building." *Synthese* 184: 235–246.
Pigozzi, G. 2006. "Belief Merging and the Discursive Dilemma: An Argument-Based Account to Paradoxes of Judgment Aggregation." *Synthese* 152: 285–298.
Polanyi, M. 1958. *Personal Knowledge: Towards a Post-Critical Philosophy*. Chicago: University of Chicago Press.
Popper, K. 1963. *Conjectures and Refutations: The Growth of Scientific Knowledge*. London: Routledge.
Psillos, S. 1999. *Scientific Realism: How Science Tracks Truth*. London: Routledge.
Psillos, S. 2018. "Realism and Theory Change in Science." *The Stanford Encyclopedia of Philosophy*. https://plato.stanford.edu/entries/realism-theory-change/.
Šešelja, D., and C. Straßer. 2013. "Kuhn and the Question of Pursuit Worthiness." *Topoi* 32: 9–19.
Shaw, J. 2018. "A Pluralism Worth Having: Feyerabend's Well-Ordered Science." (Doctoral Dissertation). the University of Western Ontario.
Stanford, P. 2001. "Refusing the Devil's Bargain: What Kind of Underdetermination Should we Take Seriously?" *Philosophy of Science* 68: S1–S12.
Stanford, P. 2017. "Underdetermination of Scientific Theory." *The Stanford Encyclopedia of Philosophy*. https://plato.stanford.edu/entries/scientific-underdetermination/.
Stuart, M. 2019. "Everyday Scientific Imagination: A Qualitative Study of the Uses, Norms, and Pedagogy of Imagination in Science." *Science & Education* 28: 711–730.
Stump, D. 2007. "Pierre Duhem's Virtue Epistemology." *Studies in History and Philosophy of Science Part A* 38: 149–159.
Vuillemin, J. 1979. "On Duhem's and Quine's Theses." *Grazer Philosophische Studien* 9: 69–96.
Wedeking, G. 1969. "Duhem, Quine and Grünbaum on Falsification." *Philosophy of Science* 36: 375–380.
Whitt, L. A. 1990. "*Theory Pursuit: Between Discovery and Acceptance*." *Proceedings of the Biennial Meeting of the PSA*, pp. 467–483.