A Peircean pathway from surprising facts to new beliefs

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Abstract
The concept of abduction was extensively analysed by the pragmatist philosopher Charles Sanders Peirce (1839–1914) more than a century ago. Modern philosophers typically treat abduction as being the same as “inference to the best explanation”, and often even attribute this position to Peirce. But this was not his position. For him, abduction involved inference to any possible explanation. He was particularly concerned with how people respond to experiences they were not expecting by acquiring new beliefs which would make such experiences expected. We spell out the eight cognitive steps from unexpected experience to new belief that are implicit in Peirce’s work on abduction and, using a particular historical example, we show how promising this theory of belief acquisition is. We identify two lacunae in this theory which will need to be filled in if we are to have a complete theory of how unexpected experiences (“surprising facts”) give rise to new beliefs.
1. Introduction

Charles S. Peirce coined the term “abduction”. His views about the nature of abduction changed quite substantially over the course of his intellectual life. In his early work (up until about the beginning of the 20th Century; see, for example, Peirce, 1866, 1878, 1883), Peirce distinguished abduction – considered as an argument form, which he was then calling “hypothesis” – from deduction and also from induction.

He began from the simple deductively valid argument form:

- **Rule.** All Bs are C
- **Case.** a is B

Therefore

- **Result.** a is C

On Peirce’s account, an argument of this form constitutes an *explanation* of the Result by the Rule and the Case.

The argument form that Peirce called “hypothesis” and, later, “abduction” involved a reorganisation of the premises and conclusion of the deductively valid form, as follows:

- **Result.** a is C
- **Rule.** All Bs are C

Therefore

- **Case.** a is B

In Peirce’s example (1866, W 1:425), we find (the Result) that light exhibits what he called “phenomena of polarisation” and we know (the Rule) that ether waves exhibit such phenomena. From this, we might infer that light is a case of ether waves.

- **Result.** Light exhibits phenomena of polarisation
- **Rule.** All ether waves exhibit phenomena of polarisation

Therefore

- **Case.** Light is ether waves.

This argument is not, of course, deductively valid. Rather, it is *ampliative*: the conclusion goes beyond the premises. The Case is “brought forward” (W 1:425) as a possible *explanation* of the Result, given the Rule.

Induction, which is also ampliative, involved a different reorganisation of the premises and conclusion of the deductively valid argument form, with the Rule (rather than the Case) becoming the conclusion:

- **Case.** a is B
- **Result.** a is C

Therefore

- **Rule.** All Bs are C

In Peirce’s example (ibid.), we consider some cloven-hoofed animals – say, cattle, swine, sheep and deer (the Cases; a, b, c and d are B) – and find (the Result) that they are herbivorous (a, b, c and d are C). From this, we might infer the generalisation (the Rule) that all cloven-hoofed animals are herbivorous (All Bs are C).
In short, in Peirce’s early work, abduction (hypothesis) was a specific pattern of inference—distinct from, but closely related to—both deduction and induction, and hypotheses that were brought forward as possible explanations of a Result had a specific logical form (the Case), as required by that pattern of inference.¹

In his later work, however, from about the beginning of the 20th Century onwards, Peirce promulgated a different concept of abduction, as has been pointed out by Burks (1946), Cooke (2006) Atkin (2010), and especially by Fann (1970). His later concept of abduction was no longer constrained by the conception of abduction, deduction and induction as closely related patterns of inference, with abduction leading to a hypothesis with a specific logical form. On the contrary, now “any kind of hypothesis can be adopted on [the basis of abduction], provided it plays an explanatory role” (Psillos, 2011, p. 132).

Furthermore, Peirce considered abduction, deduction, and induction, not simply as patterns of formal inference, but as three stages of the scientific method. We concur with Fann (1970, p. 10) that Peirce’s “second position certainly represents Peirce’s mature judgment on the matter [of abduction]”. So it is Peirce’s later conception of abduction with which we will work in this paper.

In the first detailed presentation of his later account of abduction, Peirce (1901a, ‘On the logic of drawing history from ancient documents, especially from testimonies’) began from the notions of surprise, expectation, and explanation. When something appears as surprising, there must have been a prior expectation and the scientific impulse is “to strive to reconcile the new to the old” (1901a, EP 2:88; CP 7.188). Thus, Peirce said: “Each branch of science begins with a new phenomenon which violates a sort of negative subconscious expectation” (ibid.). A fact that is surprising—that is, contrary to expectation—demands an explanation; that is: “such a proposition as would lead to the prediction of the observed facts, either as necessary consequences or at least as very probable under the circumstances” (1901a, EP 2:94–95; CP 7.202). Given this background, abduction is the step of “adopting a hypothesis as being suggested by the facts” (EP 2:95; CP 7.202).

In ‘Hume on miracles’ (1901b), Peirce wrote:

A hypothesis ought, at first, to be entertained interrogatively. Thereupon, it ought to be tested by experiment so far as practicable. There are two distinct processes, both of which may be performed rightly or wrongly. (CP 6.524)

The first of these two processes is the abductive inference, as a result of which a hypothesis is considered as a possible explanation of a surprising fact or, as we might say, entertained as a research question (that is, “interrogatively”).

Peirce described the second process as:

The operation of testing a hypothesis by experiment, which consists in remarking that, if it is true, observations made under certain conditions ought to have certain results,

¹ In his early work, Peirce adopted a framework of syllogistic logic, within which arguments were to be classified. See, for example, Peirce (1867), ‘On the natural classification of arguments’ (especially W 2:43–46 on induction and hypothesis). For a review, see Burch (2018) (especially Section 3, ‘Deduction, induction, and abduction’).
and then causing those conditions to be fulfilled, and noting the results, and, if they are favorable, extending a certain confidence to the hypothesis. (1901b, CP 6.526)

This process of testing (and confirmation, by degrees) is what Peirce, in his later work, called *induction*. It is certainly very different from the simple inference of a generalisation (the Rule) from a finding (the Result) for particular Cases, to which Peirce applied the term in his early work. To the extent that it is the early use that is closer to the dictionary meaning (*induction* The inference of a general law from particular instances, *OED*), Peirce’s later use of the term “induction” is potentially misleading or confusing. The contrast between abductive inference and experimental testing (whatever the latter is called) is, however, clear.

Peirce conceived abduction and induction (that is, experimental testing) as the first stage and the concluding stage of scientific reasoning:

> The method of either is the very reverse of the other’s. Abduction makes its start from the facts, without, at the outset, having any particular theory in view, though it is motived by the feeling that a theory is needed to explain the surprising facts. Induction makes its start from a hypothesis which seems to recommend itself, without at the outset having any particular facts in view, though it feels the need of facts to support the theory. Abduction seeks a theory. Induction seeks for facts. In abduction the consideration of the facts suggests the hypothesis. In induction the study of the hypothesis suggests the experiments which bring to light the very facts to which the hypothesis had pointed. (1901a, ‘On the logic of drawing history from ancient documents’, EP 2:106; CP 7.218)

It is commonly considered² that the canonical formulation of Peirce’s later conception of abduction was provided in the seventh of his Harvard Lectures on Pragmatism in 1903:

> It must be remembered that abduction, although it is very little hampered by logical rules, nevertheless is logical inference, asserting its conclusion only problematically or conjecturally it is true, but nevertheless having a perfectly definite logical form.

Long before I first classed abduction as an inference it was recognized by logicians that the operation of adopting an explanatory hypothesis,—which is just what abduction is,—was subject to certain conditions. Namely, the hypothesis cannot be admitted, even as a hypothesis, unless it be supposed that it would account for the facts or some of them. The form of inference therefore is this:

> The surprising fact, C, is observed;
> But if A were true, C would be a matter of course.
> Hence, there is reason to suspect that A is true.

> Thus, A cannot be abductively inferred, or if you prefer the expression, cannot be abductively conjectured, until its entire contents is already present in the premiss, “If

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A were true, C would be a matter of course.” (1903a, Harvard Lecture 7, EP 2:231; CP 5.188–9)

In what follows, we will often refer to this text and, especially, to Peirce’s *canonical rendering* of the logical form of abductive inference (in the three indented lines, beginning “The surprising fact, ...”).

2. Abduction and belief acquisition

People acquire new beliefs in a variety of ways. One of the most important of these is that one acquires new beliefs as a response to experiencing events that one did not expect. What role does abduction as conceived of by Peirce play in this route to belief acquisition? We will now sketch an account of the Peircean pathway from the noticing of a surprising (unexpected, unpredicted) fact to the final adoption of a belief which makes that fact no longer surprising.

We propose, following Peirce, that this pathway involves eight steps, grouped into three stages: Abduction (Steps 1 – 4), Deduction (Step 5), and Testing and Confirmation (Steps 6 – 8). (Peirce refers to this third stage as “induction”.) These eight steps are:

**Abduction**
1. Observation of a surprising fact
2. Generation of an explanatory hypothesis
3. Assessment of whether the hypothesis is worthy of further examination
4. Abductive inference that the hypothesis can justifiably be considered a candidate for being the true explanation of the surprising fact and should be tested: that is, the hypothesis is to be adopted and further evaluated as a candidate-for-belief

**Deduction**
5. Deductive inference of predictions from the candidate-for-belief

**Testing and confirmation (Induction in Peirce’s terminology)**
6. Experimental testing of such predictions
7. Assessment, and some degree of confirmation or refutation, of the candidate-for-belief in the light of the results of the experiments
8. Acceptance of the candidate-for-belief as a scientific result and/or adoption of the candidate-for-belief as a belief

We will offer an illustrative example to show how we think this Peircean framework operates. Our example is drawn from Dudley (1724, pp. 198–9; see also, Zirkle, 1932; Visser, 1986, p. 25) and concerns the cultivation of corn by Native Americans.

In the 17th Century and earlier, corn was a crucial feature of the lives of Native Americans. At some point in that period – it is not known exactly where or when – those who cultivated corn observed the following Surprising Fact. When corn whose cobs had one kernel colour (say, yellow) was grown in one row and corn whose cobs had another kernel colour (say, red) was grown in an adjacent row, corn plants began to appear in each row...
whose cobs had a surprising property: there were some cobs with some yellow and some red kernels.\(^3\)

We envisage the following train of events and, for each step, we begin with Peirce’s account.

### 2.1 Observation of a surprising fact

Peirce said:

> [A]ll knowledge begins by the discovery that there has been an erroneous expectation of which we had before hardly been conscious. (1901a, ‘On the logic of drawing history from ancient documents’, EP 2:88; CP 7.188).

Every inquiry whatsoever takes its rise in the observation … of some surprising phenomenon, some experience which either disappoints an expectation, or breaks in upon some habit of expectation. (1908, ‘A neglected argument for the reality of God’, EP 2:440–441; CP 6.469)

Consider Peirce’s canonical rendering of the logical form of abductive inference, described above. The first step along the Peircean pathway furnishes the first line (“The surprising fact, \(C\), is observed”) – the first premise of the abductive inference to the conclusion “there is reason to suspect that \(A\) is true”.

**In our example**, the surprising fact of the occurrence of mixed-colour cobs was observed. Why was this fact surprising? Because the corn-cultivators had previously learned that, although there were different colours of corn (yellow, red, purple, white) all the plants grown from seeds of a single type, and all the cobs on a single plant, and all the kernels on a single cob, always had the same colour (say, all yellow or all red); and so that was what they were expecting.

If we take \(C\) (in Peirce’s canonical rendering of the logical form of abductive inference) to be the surprising fact that mixed-colour cobs occurred, then we have the first of the four steps that comprise abduction:

> The surprising fact of the occurrence of mixed-colour cobs is observed.

### 2.2 Generation of an explanatory hypothesis

A surprising fact calls for an explanation – “an explanation is needed when facts contrary to what we should expect emerge” (1901a, ‘On the logic of drawing history from ancient documents’, EP 2:94; CP 7.202) – and the observation of a surprising fact leads to a process that Peirce described as follows:

> The inquiry begins with pondering these [surprising] phenomena in all their aspects, in the search of some point of view whence the wonder shall be resolved. At length a

\(^3\)The first American description of this surprising phenomenon was provided in a letter that Cotton Mather of Massachusetts sent to James Petiver FRS in 1716. The letter was not published but has been reproduced by Conway Zirkle (1935, pp. 104–6). Zirkle says: “That the different color varieties of corn would contaminate each other was known to the Indians [Native Americans], who learned to plant their ceremonial corn at a distance from their ordinary crop” (1969, p. 29).

What is needed is a hypothesis or conjecture that would explain the surprising fact or phenomenon; that is, a proposition which:
- if it had been known to be true before the [surprising] phenomenon presented itself, would have rendered that phenomenon predictable, if not with certainty, at least as something very likely to occur. It thus renders that phenomenon rational, – that is, makes it a logical consequence, necessary or probable. (1901a, EP 2:89; CP 7.192)

We will assume that it is this explanatory relationship between a hypothesis and a surprising fact that Peirce intended to capture with his terminology “if A [the hypothesis] were true, C [the surprising fact] would be a matter of course” (1903a, EP 2:231; CP 5.189; emphasis added). It is important to note that this explanatory relationship is not that of being the best or the true explanation of the surprising fact, but simply that of being a possible explanation – one possible explanation among others.

Consider again Peirce’s canonical rendering of the logical form of abductive inference (ibid.). In the second step along the Peircean pathway, a hypothesis A – with the property that, if it were true, the surprising fact C would be a matter of course – comes to mind. Thus, the second step furnishes the second line (“But if A were true, C would be a matter of course”) – the second premise of the abductive inference, to add to the first.

In our example, what was needed was a hypothesis (a proposition) or a theory (a set of propositions) with the property that, if it were true, mixed-colour cobs would be a matter of course; and if it were believed to be true, mixed-colour cobs would be expected.

Suppose someone hypothesised the following three propositions:
- H1: When corn plants are grown in adjacent rows, their roots will intermingle underground.
- H2: When roots from two corn plants intermingle, new plants will grow from these intermingled roots.
- H3: Each of these new plants will display characteristics from both of the plants from which its roots came in such a way that, if one of these plants were yellow-kernelled and the other were red-kernelled, the new plant would have cobs with some yellow kernels and some red kernels.

If this theory (comprising the three hypotheses H1, H2 and H3) were true, mixed-colour cobs would be a matter of course; so the theory is a possible explanation of the surprising fact. It seems that the Native Americans did indeed generate and then accept this specific intermingling roots theory (Dudley, 1724, p. 199).

If we take A (in Peirce’s canonical rendering) to be the intermingling roots theory, then we now have the first and second premises for an abductive inference:
- The surprising fact of the occurrence of mixed-colour cobs is observed;
- But if the intermingling roots theory were true, the occurrence of mixed-colour cobs would be a matter of course.
2.3 Assessment of whether the hypothesis is worthy of further examination

The property of an explanatory hypothesis, that if it were true the surprising fact would be a matter of course, is critical. In his canonical rendering, Peirce proceeded from the two premises directly to the step of abductive inference, namely, “Hence, there is reason to suspect that A is true”. Elsewhere, however, Peirce offered additional desiderata.\(^4\) These made it clear that satisfaction of the critical criterion (formulated in the second premise) was not by itself sufficient for a hypothesis H to merit being considered a candidate for being the true explanation of the surprising fact SF (see e.g. 1901a, ‘On the logic of drawing history from ancient documents’; 1901b, ‘Hume on miracles’; 1903b, Lowell Lecture 8).

Amongst these desiderata was, first, that the hypothesis “must be capable of being subjected to experimental testing” (1901a, EP 2:107; CP 7.220). Just as necessary, Peirce said, was “the consideration of economy” (ibid.), which – in scientific research, as elsewhere – argues for efficient deployment of limited resources of time, energy and money.\(^5\) Thus, for example, Peirce suggested:

> [I]f there be any hypothesis which we happen to be well provided with means for testing, or which, for any reason, promises not to detain us long, unless it be true, that hypothesis ought to be taken up early for examination. (1901b, CP 6.533).

A hypothesis must be testable and reasonably economical and, as Kapitan observes, “Peirce packed a great deal into his notion of economy” (2000, p. 6; see also p. 10). Alongside the desideratum of efficient use of resources there are the explanatory virtues of strength and breadth, simplicity and naturalness, and so on. Peirce used the term “plausible” to indicate:

> a theory that has not yet been subjected to any test, although more or less surprising phenomena have occurred which it would explain if it were true, [and which] is in itself of such a character as to recommend it for further examination. (1910a, ‘Notes on the doctrine of chances’, CP 2.662; emphasis added).

If a hypothesis generated at Step 2 does not sufficiently satisfy the critical criterion and the additional desiderata of testability and economy, then a different hypothesis is needed. So the system must now generate some new hypothesis which might adequately satisfy those requirements. If, on the other hand, a hypothesis does adequately satisfy the critical criterion and the additional desiderata, that hypothesis is passed on to the next step along the pathway – the step of abductive inference (Section 2.4). Thus, the third step furnishes a third premise for the abductive inference:

> The hypothesis A is testable and reasonably economical.

(For simplicity of expression, we use the term “economical” here to include both efficient deployment of resources and explanatory virtues.)

\(^4\) Note that these desiderata cannot be used to aid in the generation of a hypothesis, because they can only be applied after a hypothesis has been generated.

\(^5\) In his 1903 Harvard Lectures on Pragmatism, Peirce had almost nothing to say about the place of economic considerations in the scientific method – and nothing at all about economic considerations and abduction. But in the same year, he described “the question of Economy” as “what really is in all cases the leading consideration in Abduction” (1903b, Lowell Lecture 8, CP 5.600).
For Peirce, the critical criterion and the additional desiderata “guide us in abduction, or the process of choosing a hypothesis” (1901a, EP 2:106; CP 7.220). Here “choosing a hypothesis” does not mean “generating a hypothesis”; it means deciding that an already-generated hypothesis deserves further examination. We shall use McKaughan’s (2008) term “pursuit-worthy” to express “recommendations about which available hypotheses are to be tested” (2008, p. 458).

In our example, it is plausible (in the ordinary sense of that term) that the intermingling roots theory is pursuit-worthy. It meets the critical criterion: if it were true, mixed-colour cobs would be a matter of course. The theory is testable in principle and might be efficiently tested by experiment or – perhaps better – by observation. The theory has reasonable explanatory strength and breadth; and it comes fairly naturally to human minds, and is not gratuitously complex.

2.4 Abductive inference that the hypothesis can justifiably be considered a candidate for being the true explanation of the surprising fact and should be tested: that is, the hypothesis is to be adopted and further evaluated as a candidate-for-belief.

The next step along the Peircean pathway is the step that specifically involves abductive inference. We shall consider this initially as the inference from the two premises in the first two lines of Peirce’s canonical rendering to the conclusion in the third line of that rendering.

Peirce gave several descriptions of the step of abductive inference, such as the following:

This step of adopting a hypothesis as being suggested by the facts, is what I call abduction. I reckon it as a form of inference, however problematical the hypothesis may be held. (1901a, ‘On the logic of drawing history from ancient documents’, EP 2:95; CP 7.202)

On account of this Explanation, the inquirer is led to regard his conjecture, or hypothesis, with favor. (1908, ‘A neglected argument for the reality of God’, EP 2:441; CP 6.469)

It is of the utmost importance that we should interpret the conclusion of the abductive inference – “there is reason to suspect that A [the hypothesis] is true” – in a way that is consistent with Peirce’s own recognition that the explanatoriness of a hypothesis does not, by itself, make the hypothesis probably true. The ultimate aim is to adopt as a belief, a hypothesis “which [i] is likely in itself and [ii] renders the facts likely” (1901a, EP 2:95; CP 7.202), but the second premise of the abductive inference does not ensure that the first of these two requirements is met. Thus the conclusion of the abductive inference cannot be that the hypothesis A is true, nor even that it is probably true.

Peirce said: “A hypothesis ought, at first [that is, before it is tested], to be entertained interrogatively” (1901b, ‘Hume on miracles’, CP 6.524; emphasis added). In the sixth of his 1903 Harvard Lectures on Pragmatism, he said: “Abduction is the process of forming an explanatory hypothesis. ... Abduction merely suggests that something may be. ... it
merely offers suggestions” (1903a, Harvard Lecture 6, EP 2.216–7; CP 5.171). So in what way does the fact that, if the hypothesis A were true, the surprising fact C would be a matter of course, give us reason to suspect that A is true?

Noting Peirce’s use of the terms “conjecture”, “entertain interrogatively”, and “suggest”, we propose to interpret the conclusion of the abductive inference along the following lines.

The hypothesis A can justifiably be considered a candidate or suspect for being the true explanation of the surprising fact C.

This interpretation of the conclusion seems to make tolerable sense of what Peirce said immediately after his canonical rendering of the logical form of abductive inference: Thus, A cannot be abductively inferred, or if you prefer the expression, cannot be abductively conjectured, until its entire contents is already present in the premiss, “If A were true, C would be a matter of course.” (1903a, EP 2:231; CP 5.188–9)

If we are to conjecture A abductively (that is, if we are to consider hypothesis A as a candidate for being the true explanation of the surprising fact C) then it needs to be the case that A is at least a possible explanation of C. Showing that A is a possible explanation of C would involve unpacking the contents of the hypothesis A (the empirical consequences that follow from that hypothesis, on Peirce’s account) to show that those consequences encompass the hitherto surprising fact C.

To take account of Peirce’s additional desiderata, the abductive inference made at Step 4 depends upon three (rather than just the initial two) premises:

The surprising fact, C, is observed
(this premise is provided by Step 1);
But if [the hypothesis] A were true, C would be a matter of course
(this premise is provided by Step 2); and
The hypothesis A is testable and reasonably economical
(this premise is provided by Step 3).

The conclusion drawn at Step 4 would then be:
The hypothesis A can justifiably be considered a pursuit-worthy candidate for being the true explanation of the surprising fact C.6

In our example, we envisage that the Native Americans of the time could have proceeded by abductive inference from the three premises:
The surprising fact of the occurrence of mixed-colour cobs is observed;
But if the intermingling roots theory were true, the occurrence of mixed-colour cobs would be a matter of course; and
The intermingling roots theory is testable and reasonably economical.

6 Kapitan (1990) considers a formulation of abductive inference in which there is a third premise about the hypothesis being “economical” and the conclusion is that the hypothesis is “plausible” in the sense of “worthy of further examination” (1990, p. 501).
to the conclusion:

The intermingling roots theory can justifiably be considered a *pursuit-worthy* candidate for being the true explanation of the surprising occurrence of mixed-colour cobs.

We do not know whether the native corn-cultivators subjected the intermingling roots theory to any testing, nor whether they considered any other candidate explanations of the occurrence of mixed-colour cobs. It appears that they may have terminated their belief-formation processes at this point, and simply adopted the intermingling roots theory as a belief, rather than engaging in anything to do with testing this theory (i.e. they did not proceed beyond Step 4 to Step 5).\(^7\)

Believing, without testing, the first and only hypothesis to have been generated might seem to go far beyond what abduction licenses. But Peirce himself acknowledged that the initial acceptance of a particular hypothesis as a candidate explanation of a surprising phenomenon might range, in different cases, “from a mere expression of it in the interrogative mood, as a question meriting attention and reply ... to uncontrollable inclination to believe” (1908, ‘A neglected argument for the reality of God’, EP 2:441; CP 6.469; emphasis added).

### 2.4.1 The four steps of abduction: Frankfurt’s paradox

At this point, after the first four steps, we pause our progress along the Peircean pathway in order to consider a general issue about abduction.

In an influential commentary, Frankfurt (1958) raised a number of problems for Peirce’s account of abduction. First, he pointed out:

the seeming paradox that Peirce holds both that hypotheses are the products of a wonderful imaginative faculty in man and that they are products of a certain sort of logical inference. (1958, p. 594).

Second, Frankfurt observed that the hypothesis \(A\) already occurred in the antecedent of the second premise of the abductive inference:

If [the hypothesis] \(A\) were true, \(C\) would be a matter of course.

Consequently:

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[T]he \text{ idea that hypotheses originate as the conclusions of abductions, or that new ideas result from abductive inferences, cannot be accepted. (ibid., p. 595)}
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This point is reinforced if the abductive inference includes a third premise in which the hypothesis is again mentioned:

The hypothesis \(A\) is testable and reasonably economical.

Our distinction between generation of the explanatory hypothesis (Step 2) and the abductive inference proper (Step 4) is intended to leave room for the idea that “the

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\(^7\) Zirkle (1969) informs us that the early German botanist Tabernaemontanus (who wrote a book in 1588) held that mixed-colour cobs “came about through a special act of the Deity, who did it merely to impress the inquisitive botanists” (1969, p. 29). By comparison, the Native Americans were positively enlightened despite their neglect of theory-testing.
creativity belongs to an earlier phase of abductive thinking [that is, earlier than the abductive inference proper]” (Kapitan, 1990, p. 503).

2.4.2 The four steps of abduction: Inference to the best explanation
A second general issue about abduction is how it is related to inference to the best explanation (IBE). The conception of abduction as involving IBE is dominant in contemporary philosophy. For example:

- It appears that much of what the mind does best is ‘abduction’, or ‘inference to the best explanation’. (Fodor, 2000, p. 97)
- Abductive arguments (arguments to the best explanation) ... (Bermúdez, 2001, p. 550)
- ‘abduction’ or inference to the best explanation (Campbell, 2003, p. 142)
- The type of inference exhibited here is called *abduction* or, somewhat more commonly nowadays, *Inference to the Best Explanation*. (Douven, 2017, Section 1).

But this IBE conception of abduction is significantly different from Peirce’s notion, even though it is often (wrongly) attributed to Peirce (for discussion, see McAuliffe, 2015). Abduction (in Peirce’s use of the term) is “the First Stage of Inquiry” (1908, EP 2:441; CP 6.469), encompassing the first four steps along the Peircean pathway, as against *deduction* (the second stage) and *testing and confirmation* (the third stage, which Peirce called “*induction*”). This first stage of the scientific method clearly cannot be *equated* with IBE.

It is true that Step 3 (Assessment of whether the hypothesis is worthy of further examination) takes account of explanatory virtues (such as explanatory strength and breadth) and that explanatory virtues are relevant to which explanation is best. But strategic selection of a hypothesis as pursuit-worthy cannot take account of subsequent steps – the experimental testing of predictions that can be deduced from the hypothesis (1901b, CP 6.525).

There is no guarantee that even the most pursuit-worthy candidate explanation will be the true (and thus the best) explanation of the surprising fact. Indeed, Peirce encourages the opposite expectation, advising us to assume that the first hypothesis that we test will be refuted (1901a, EP 2:107; CP 7.220). If the predictions from some particular hypothesis are “verified ... again and again” (1901c, ‘Laws of nature’, EP 2:74), we may well infer that it is the true explanation of the surprising fact. But this inference to the best explanation does not belong in the *first stage of inquiry*, but in the third stage. In short, inference to the best explanation is not what Peirce meant by “abduction”.

2.5 Deductive inference of predictions from the candidate-for-belief
We now continue along the Peircean pathway from surprising facts to new beliefs. After Step 4 has indicated that a hypothesis is to be considered a pursuit-worthy candidate-for-belief, “the first thing that will be done ... will be to trace out its necessary and probable

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8 Explanatory virtues would be contributions to a candidate explanation’s ‘loveliness’, in Lipton’s (2004) terminology. The *loveliest* candidate explanation is the one that would “provide the most understanding”, whereas the *likeliest* candidate explanation is the one “best supported by the evidence” (Lipton, 2004, p. 57; emphasis added).
experiential consequences”⁹ (1901a, EP 2:95; CP 7.203). Peirce referred to this fifth step along his pathway as deduction.

As Peirce said:

The hypothesis must be tested. This testing, to be logically valid, must honestly start ... with examination of the hypothesis, and a muster of all sorts of conditional experiential consequences which would follow from its truth. (1908, ‘A neglected argument for the reality of God’, EP 2:441; CP 6.470)

Similarly:

[W]hat is usually the best way [following abduction], he may turn to the consideration of the hypothesis, study it thoroughly and deduce miscellaneous observable consequences, and then return to the phenomena to find how nearly these consequences agree with the actual facts. (1910b, Letter to Paul Carus, CP 8.232)

In our example, it does not seem that the Native American corn-cultivators sought to deduce any predictions from their subterranean-based intermingling roots theory of mixed-colour cobs. But that is not because their theory could not yield any predictions. Consider the following two predictions from their theory in relation to a scenario in which yellow-kernelled corn is grown on row A and red-kernelled corn on row B:

**Prediction 1** If row A and row B are on opposite sides of a canal or river, mixed-colour cobs will not occur, because root-intermingling will not be possible.

**Prediction 2** If row A and row B are separated by a high wooden fence, mixed-colour cobs will still occur, because root-intermingling will still be possible.

These consequences, deduced from the intermingling roots theory, are, in effect, predictions about the results of possible experiments (or possible observations).

### 2.6 Experimental testing of such predictions

Along the eight-step Peircean pathway, the next step after deduction of predictions is testing of these predictions. Peirce said:

The operation of testing a hypothesis by experiment ... consists in remarking that, if it is true, observations made under certain conditions ought to have certain results, and then causing those conditions to be fulfilled, and noting the results. (1901b, ‘Hume on Miracles’, CP 6.526)

Similarly:

[H]aving reflected that if that theory be true, then under certain conditions certain phenomena ought to appear (the stranger and less antecedently credible the better), [the reasoner] proceeds to experiment, that is, to realize those conditions and watch for the predicted phenomena. (1902a, ‘Reasoning’, CP 2.775)

In short, once predictions have been deduced from the hypothesis, the sixth step is “to test the hypothesis by making the experiments and comparing those predictions with the actual results of experiment” (1901a, ‘On the logic of drawing history from ancient

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⁹ Note a distinctive feature here of Peirce’s approach: hypothesis evaluation does not consist of comparing rival hypothesis as in e.g. Bayesian assessment of the likelihood ratio between competing hypotheses. Hypotheses are evaluated singly, not comparatively.
documents’, EP 2:96–7; CP 7.206). As Peirce notes, this is “not to be done while lolling in an easy chair, since it consists in actually going to work and making the experiments” (1903c, ‘Sundry logical conceptions’, EP 2:288).

**In our example**, the two predictions could be tested by planting corn of different colours on opposite sides of a canal or river, and by planting on opposite sides of a wooden fence. Alternatively, one could rely on experiments of Nature: looking for plots of corn that were already being grown in these two situations. Judge Paul Dudley of Massachusetts reported observations of exactly these kinds, in 1724. First, he reported that mixing of kernel colours had taken place over distances of several metres and, in one case, where there was “a broad ditch of water” between the rows (Dudley, 1724, p. 199). Second, he reported that no mixing of kernel colours had taken place when “a high board fence” separated fields of corn of different colours (ibid.).

### 2.7 Assessment, and some degree of confirmation or refutation, of the candidate-for-belief in the light of the results of the experiments

Peirce said:

The experiment is made. If the prediction from the hypothesis fails, its failure may be so utter as to be conclusive; or, maybe, nothing more than an alteration of the defective theory need be undertaken. If … the prediction be verified, and if the same thing happen again and again …, one begins to doff one’s cap to the rising star that nature herself seems to favor. (1901c, ‘Laws of nature’, EP 2:74)

**In our example**, Dudley’s observations were inconsistent with the predictions deduced from the intermingling roots theory. Dudley, himself, noted that the roots of corn plants extended only up to 1.5 metres, whereas the communication of colours took place over several metres (sometimes even up to twenty or twenty-five metres) and across a canal. From this, he concluded that the intermingling roots theory “must certainly be a mistake” (1724, p. 199). Dudley also proposed that the communication between plants that resulted in the mixing and interchange of colours was air-based, not earth-based; and he offered the observation that a high fence prevented any mixing or alteration of colour as evidence supporting that hypothesis.

Thus, as Peirce said would often be the case, the first explanatory hypothesis was refuted:

That which is to be done with the hypothesis is to trace out its consequences by deduction, to compare them with results of experiment …, and to discard the hypothesis, and try another, as soon as the first has been refuted, as it presumably will be. How long it will be before we light upon the hypothesis which shall resist all tests we cannot tell; but we hope we shall do so, at last. (1901a, ‘On the logic of drawing history from ancient documents’, EP 2:107; CP 7.220; emphasis added)

The intermingling roots theory had to be discarded and it was time to try another. A return to the beginning of the Peircean pathway, and the generation of a new explanatory hypothesis, was called for.

By “and try another” in the quotation immediately above, Peirce had in mind that if a hypothesis were refuted at Step 7, then a new explanatory hypothesis would have to be
generated – that is, there would have to be a return from Step 7 to Step 2. Peirce also allowed that “we cannot tell” how many iterations of refute–discard–try another there will be before we come to a hypothesis that will “resist all tests” – there might be several such iterations. Peirce envisaged that the operation of the Peircean pathway could include recursion or looping – not only from Step 7 back to Step 2 but also, as McAuliffe (2015) notes, from Step 3 back to Step 2:

The most charitable way to interpret Peirce is to view abduction as a process with multiple steps. A hypothesis is first formed with the criteria for good abduction in mind [Step 2]. Then, the hypothesis is evaluated [Step 3] to see if it is testable, economical to test ... etc. If not, then the process repeats. (2015, p. 304)

After the intermingling roots theory had been refuted, a new and better hypothesis would have two crucial properties. First, like the intermingling roots theory, it would have the property that, if it were true, the occurrence of mixed-colour cobs would be a matter of course. Second, unlike the intermingling roots theory, it would have to be consistent with Dudley’s two observations.

2.8 Acceptance of the candidate-for-belief as a scientific result and/or adoption of the candidate-for-belief as a belief

Peirce said:

[A] single experiment may absolutely refute the most valuable of hypotheses. ... When, however, we find that prediction after prediction, notwithstanding a preference for putting the most unlikely ones to the test, is verified by experiment, ... we begin to accord to the hypothesis a standing among scientific results. (1901a, ‘On the logic of drawing history from ancient documents’, EP 2:97; CP 7.206)

In our example, Dudley’s observations were sufficient to refute the intermingling roots theory and his proposal that mixing of kernel colours depended on air-based communication between plants provided at least the outline of an alternative theory. Just a few years after Dudley’s paper was published, James Logan of Pennsylvania began a letter to Peter Collinson FRS: “As the notion of a male seed, or the farina fœcundas in vegetables is now very common ...” (Logan, 1735, p. 192). This indicated that Logan was familiar with the theory of sexual reproduction in plants (e.g. Camerarius, 1694) and with the ideas that the stamen is the male organ of the plant and that pollen is the “male seed”.

In the case of corn, the stamens form on the tassels at the top of the plant and pollen is carried in the air (by the wind rather than by insects) to the silky fibres on ears of the same plant or other plants (depending on the direction and strength of the wind). The pollination of a silky fibre results in a kernel being produced and, because each kernel is the result of a separate union, different kernels on the same cob may be the products of pollen from different corn plants. Thus, the theory of sexual reproduction in plants and, specifically, the role played by wind-borne pollen from the tassels of corn plants, provided an explanation of the occurrence of mixed-colour cobs. It also explained Dudley’s two
observations – communication of colours is obstructed by a high fence but not by a canal.\footnote{It would seem that Dudley, himself, was at least somewhat familiar with this theory. He wrote, for example: “I am therefore humbly of opinion, that the stamina [stamens] or principles of this wonderful copulation, or mixing of colours, are carried thro’ the air by the wind” (1724, p. 199).}

Logan deduced from this theory various predictions about what would happen if one cut off the tassels of corn plants, or removed a proportion of the silky fibres, or enclosed ears with their silky fibres in muslin bags. He then carried out the required experiments in his garden and the results were as predicted. Logan’s experiments contributed to an extended process of scientific enquiry, which has led to the theory of sexual reproduction in plants – and specifically in corn – being accorded some standing among scientific results.

2.9 How mandatory is this entire pathway, according to Peirce?

In Peirce’s writing about the stages of the scientific method, his pathway ended, not in some individual’s adoption of a belief, but in a hypothesis being accorded some standing or in scientists doffing their caps to a theory (1901a, EP 2:97, CP 7.206; 1901c, ‘Laws of nature’, EP 2:74). Peirce said that “the word ‘belief’ is out of place in the vocabulary of science” (1901a, EP 2:85; CP 7.185), but he did not consider that what he said about abduction was irrelevant to the everyday adoption of beliefs. Rather, he acknowledged that what “scientifically” had the status of an explanatory hypothesis might be so well supported by experimental testing that “practically” it was “perfectly certain” – and worthy of belief rather than doubt. For example: “It would surely be downright insanity to entertain a doubt about Napoleon’s existence” (1898, ‘The first rule of logic’, EP 2:54; CP 5.589).

Importantly, Peirce also suggested that a subject might be strongly inclined to adopt a putatively explanatory hypothesis as a belief, even without any deduction of predictions from the hypothesis and experimental testing of those predictions. Thus, Peirce wrote:

\begin{quote}
On account of this Explanation, the inquirer is led to regard his conjecture, or hypothesis, with favor. As I phrase it, he provisionally holds it to be “Plausible”; this acceptance ranges in different cases – and reasonably so – from a mere expression of it in the interrogative mood, as a question meriting attention and reply, up through all appraisals of Plausibility, to uncontrollable inclination to believe. (1908, EP 2:441; CP 6.469; emphasis added)
\end{quote}

and

\begin{quote}
By Plausible, I mean that a theory that has not yet been subjected to any test, although more or less surprising phenomena have occurred which it would explain if it were true, is in itself of such a character as to recommend it for further examination or, if it be highly plausible, justify us in seriously inclining toward belief in it, as long as the phenomena be inexplicable otherwise. (1910a, CP 2.662; emphasis added)
\end{quote}

We take the term “uncontrollable” (in the first passage) as implying, in Peirce’s thinking, that not all of the steps along the Peircean pathway are actually taken. If the hypothesis has been adopted as a belief at Step 8 then (we assume) it has previously reached Step 4
of being considered a pursuit-worthy candidate for being the true explanation of the surprising fact. So Steps 1 to 4 (the abduction stage) have been executed. But Steps 5 to 7, involving what Peirce referred to as “deduction” and “induction”, have been skipped.

The subject has proceeded directly from Step 4:

The hypothesis is to be considered a pursuit-worthy candidate-for-belief.

...to Step 8:

Adoption of the candidate-for-belief as a belief.

What could trigger such short-cutting? Peirce said that this could occur “as long as the phenomena be inexplicable otherwise” (CP 2.662). But that is naturally read as requiring that all the possible alternative explanatory hypotheses have been considered and found wanting – which is unworkable.

We suggest instead that, after the hypothesis is generated at Step 2, the properties that are assigned to it at Step 3 may make it so attractive – pursuit-worthy to such a high degree – that an uncontrollable inclination to believe is generated. In the context of the Peircean pathway from surprising facts to new beliefs, “uncontrollable inclination to believe” means:

Now go directly from Step 4 to Step 8.

That does seem to be consistent with what Peirce wrote in the second passage. The hypothesis is “in itself of such a character as to … justify us in seriously inclining toward belief in it” (our emphasis): here Peirce is proposing that it is an intrinsic rather than a comparative property of the hypothesis that leads to its immediate acceptance.

3. Two gaps to be filled in an account of belief acquisition

If we are to explain how people acquire new beliefs as a response to experiencing events that they did not expect then developing an account of the Peircean pathway from surprising facts to new beliefs is surely a very promising approach. There would be two gaps, however, remaining to be filled.

3.1 The problem of hypothesis generation

At Step 2 along the Peircean pathway, the following question naturally arises:

By what cognitive process or mechanism can people derive, from an empirical observation of a surprising fact SF, some hypothesis H about the world which has the specific property that if H were true SF would be expected?

In our example, when a Native American first observed the unexpected occurrence of mixed-colour cobs (e.g. cobs with some yellow and some red kernels), by what cognitive process did this experience give rise to the intermingling roots theory?

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11 In his discussion of pursuit-worthiness, McKaughan (2008) says that “abductive reasoning makes practically grounded comparative recommendations about which available hypotheses are to be tested (2008, p. 458; emphasis added). But what we envisage here is not a comparative assessment of the pursuit-worthiness of several hypotheses. Rather, it is a single hypothesis being generated and being found, by the subject, to be pursuit-worthy to a very high degree. As we explain below (Sections 3.2 and 3.3), our proposal is that hypotheses can be considered one at a time, in order of their generation.
Peirce said: “In abduction the consideration of [the surprising fact] suggests the hypothesis” (1901a, ‘On the logic of drawing history from ancient documents’, EP 2:106; CP 7.218; emphasis added). The word “suggests” suggests a psychological process leading from consideration of the surprising fact SF to hypothesis H’s arising or coming to mind. Indeed, Peirce was specifically concerned with such psychological processes (both as they operate in scientific thinking and also as they operate in everyday belief formation). For example, he referred to “the whole series of mental performances between the notice of the wonderful phenomenon [SF] and the acceptance of the hypothesis [H]” (1908, EP 2:441; CP 6.469). Furthermore, Peirce wrote about psychological processes and, particularly, about associative processes (e.g. 1892, ‘The law of mind’; 1893, ‘Association’); and he conducted psychological experiments (1885; c. 1907).

Peirce did not, however, provide a fully satisfactory account of the processes that are involved in generating a hypothesis. From the perspective of our explanatory aims, this is an important gap in Peirce’s account of abduction. But the gap is unsurprising given Peirce’s primary aim (and, of course, given the fact that Peirce was writing more than a century ago).

Peirce distinguished between logic, on the one hand, and psychology, history and sociology, on the other (see Fann, 1970, p. 36). If Peirce’s primary aim was to explore the “purely logical doctrine of how discovery must take place” (1902b, ‘Partial synopsis of a proposed work in logic’, CP 2.107; emphasis added), then it is no shortcoming – relative to that aim – that he did not provide a fully satisfactory empirical account of the psychological processes that are actually involved in generating a hypothesis. But there remains a gap to be filled.12

3.2 The problem of multiple hypotheses

Peirce said that, after the surprising fact was observed, a conjecture, hypothesis or theory – in the singular – arose. But he also explicitly considered how hypothesis testing should proceed when multiple hypotheses (e.g. two or thirty-two hypotheses)13 were to be considered. Thus, Peirce clearly allowed for the possibility that Step 2 (hypothesis generation) might furnish multiple hypotheses for multiple abductive inferences:

The surprising fact, C, is observed;
But if A1 were true, C would be a matter of course.
Also if A2 were true, C would be a matter of course.
Also if A3 were true, C would be a matter of course.
...

Peirce indeed acknowledged that there were innumerable hypotheses – or, at least, unmanageably many – possessing the property that if the hypothesis were true, the surprising fact would be a matter of course:

12 We note the general point that drawing on empirical research may help us to answer ‘How possible?’ questions that are raised by philosophical arguments.

13 See the following two examples: “[i]f two hypotheses present themselves, ...” (1903b, Lowell Lecture 8, CP 5.598; emphasis added) and “Let us suppose that there are thirty-two different possible ways of explaining a set of phenomena. ...” (1901b, ‘Hume on miracles’, CP 6.529; emphasis added).
The possible explanations of our facts may be strictly innumerable. (1901a, EP 2:107; CP 7.219)

The true hypothesis is only one out of innumerable possible false ones. (1901a, EP 2:107; CP 7.220)

The possible theories, if not strictly innumerable, at any rate exceed a trillion — or the third power of a million. (1903b, CP 5.591)

Is Step 2 along Peirce’s pathway to be understood, then, as generation of innumerable explanatory hypotheses? Is the conclusion of the abductive inference at Step 4 that innumerable hypotheses are be considered pursuit-worthy candidates-for-belief? Or do only a few hypotheses remain at Step 4, after Step 3’s assessment of whether each of innumerable hypotheses is worthy of further examination? Surely generation, or assessment, or adoption and further evaluation of innumerable hypotheses – or even just trillions – is not realistic as an account of any aspect of human cognition.

This is the problem of multiple (innumerable) hypotheses and it seems to reveal a second gap in Peirce’s account of abduction. If there are innumerable explanatory hypotheses, how is it possible to generate, assess, adopt, and evaluate just a single hypothesis (at a time). In our example, how was it just this one candidate explanation of the occurrence of mixed-colour cobs – the intermingling roots theory – that the Native Americans arrived at?

Peirce discussed the existence of innumerable hypotheses all possessing the property that, if the hypothesis were true, the surprising fact would be a matter of course. But he connected it to a somewhat different problem. Peirce’s question was not how it is possible to generate (and assess, and so on) a single hypothesis, but rather how it is possible to generate the correct hypothesis, given that “the chances are too overwhelmingly against the single true theory … ever having come into any man’s head (1903b, CP 5.591). Thus:

A physicist comes across some new phenomenon in his laboratory. … Think of what trillions of trillions of hypotheses might be made of which one only is true; and yet after two or three or at the very most a dozen guesses, the physicist hits pretty nearly on the correct hypothesis. (1903a, Harvard Lecture 6, EP 2:217; CP 5.172)

Peirce also offered some remarks toward a solution to this problem:

[Ab]duction is, after all, nothing but guessing. We are therefore bound to hope that, although the possible explanations of our facts may be strictly innumerable, yet our mind will be able in some finite number of guesses, to guess the sole true explanation of them. (1901a, ‘On the logic of drawing history from ancient documents’, EP 2:107; CP 7.219)

According to Peirce, this was not just a hope:

[I]t is a primary hypothesis underlying all abduction that the human mind is akin to the truth in the sense that in a finite number of guesses it will light upon the correct hypothesis. (EP 2:108; CP 7.220)

And, he said, the “primary hypothesis” was empirically supported:
Inductive experience supports that hypothesis in a remarkable measure. For if there were no tendency of that kind ... then we never could have made any progress in science at all. (ibid.)

Peirce expressed this empirical fact about abduction in several ways:
- the human mind is akin to the truth” (1901a, EP 2:108; CP 7.220);
- a natural light, or light of nature, or instinctive insight, or genius, tending to make [people] guess [laws of nature] aright, or nearly aright (1903b, Lowell Lecture 8, CP 5.604);
- man’s mind ... naturally thinks somewhat after nature’s pattern” (c. 1907, ‘Guessing’, CP 7.39).

This empirical fact, however it is expressed, calls for explanation – presumably, in terms of a substantive account of the processes involved in hypothesis generation.

As we have noted, Peirce provided no such account. Furthermore, none of his appeals to “guessing” or “instinct” or “insight” or “genius” provides a fully satisfactory solution to his problem of multiple hypotheses – still less to ours. Our hope is that a substantive account of hypothesis generation – drawing on hints that Peirce, himself, provided – will offer a solution to our problem of multiple hypotheses and to Peirce’s.

3.3 Filling in the gaps
The abductive process by which an explanatory hypothesis is generated in response to observation of a surprising fact has been seen by some authors as utterly mysterious:
- It is ... a mystery, not just a problem, how mental processes could be simultaneously feasible and abductive and mechanical. (Fodor, 2000, p. 99)

But this is because these authors have considered that such hypothesis generation must require an exhaustive search of everything one knows, to locate information relevant to the surprising fact. That seems completely infeasible.

In the account of the Peircean pathway that we are currently developing, we offer a feasible alternative. Hypothesis generation is an associative process that directly activates relevant information in memory, an idea that was indeed hinted at by Peirce himself:
- Upon finding himself confronted with a phenomenon unlike what he would have expected under the circumstances, he [the reasoner] looks over its features and notices some remarkable character or relation among them, which he at once recognizes as being characteristic of some conception with which his mind is already stored, so that a theory is suggested which would explain ... that which is surprising in the phenomena. (1902a, ‘Reasoning’, CP 2.776; first emphasis added)

If, as we suggest, explanatory hypotheses are generated by an associative process, then the time taken to generate a hypothesis will vary with the strength of the associations between the surprising fact and the relevant stored knowledge. In that case, hypotheses will be generated asynchronously, allowing them to be considered one at a time in order of their generation. We propose this solution to our problem of multiple hypotheses in the account of the Peircean pathway that we are currently developing. Furthermore, the
way in which the strength of associative connections is adjusted in response to experienced co-occurrences promises an unmysterious reading of Peirce’s remark:

There can, I think, be no reasonable doubt that man’s mind, having been developed under the influence of the laws of nature, for that reason naturally thinks somewhat after nature’s pattern. This vague explanation is but a surmise; but there is no room to believe that it was merely by luck that Galileo and other masters of science reached the true theories after so few wrong guesses as they did. (c. 1907, CP 1.39; emphasis added)

4. Conclusion

For Peirce, abduction did not involve inference to the best explanation of a surprising fact C, but inference to a possible explanation. Here, a possible explanation is a hypothesis (candidate-for-belief) which, if true, would make the surprising fact C no longer surprising but instead expected. Peirce also proposed additional features that would make a possible explanation worthy of further examination. Peirce was thus offering an important account of one of the ways in which people acquire new beliefs.

In this paper, we have set out an account of an eight-step Peircean pathway from observation of a surprising fact to adoption of a new belief. We have also identified two significant gaps in the account. If these gaps can be filled in a reasonable way, we will have a satisfactory account of how new beliefs are acquired via Peircean abduction. We are currently developing an account which, we believe, does make good these two lacunae, and is compatible with hints in some of Peirce’s writings.
References to works by Charles Sanders Peirce
References are given to the following collections of works by Peirce:

References are given in the form (CP [volume].[paragraph])

References are given in the form (W [volume]:[page])

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(1866) *The Logic of Science; or, Induction and Hypothesis – Lowell Lectures of 1866*, Lecture 5 (W 1:423–440).
(1892) The law of mind (CP 6.102–163).
(1893) Association (CP 7.388–467)
(1901b) Hume on miracles, Section 1, ‘The nature of hypotheses’, and Section 2, ‘The testing of hypotheses’ (CP 6.522–536).
(1902a) Reasoning (CP 2.773–778).
(1902b) Partial synopsis of a proposed work in logic (CP 2.79–118)
(1903b) Some Topics of Logic bearing on Questions now Vexed – Lowell Lectures of 1903, Lecture 8, ‘How to theorize’ (CP 5.590–604).
(c. 1907) Guessing (CP 7.36–48).
(1910a) Notes on the doctrine of chances (CP 2.661–668).
(1910b) Letter to Paul Carus (CP 8.214–238).
References to works by other authors


