DOI: 10.1017/psa.2026.10263

This is a manuscript accepted for publication in *Philosophy of Science*.

This version may be subject to change during the production process.

Peirce, Abduction, and Inverse Problems in the Geosciences

Alisa Bokulich

Department of Philosophy, Boston University, Email: abokulic@bu.edu

Abstract

Charles Peirce's most well-known contribution to logic and scientific methodology is his account of *abduction*. However, what exactly Peirce meant by abduction is subject to perennial dispute. My aim in this paper is two-fold: First, I interpret Peirce's abduction through the lens of his research in geophysics and argue this supports interpreting it as a kind of inverse modeling. Second, I show that the methods Peirce outlined for managing the underdetermination of abductive inferences are the same as those deployed by geoscientists to manage the nonuniqueness of geophysical inversions. I conclude by emphasizing the value of reintegrating Peirce-the-Philosopher with Peirce-the-Geoscientist.

Acknowledgement

This paper is dedicated to the memory of George E. Smith (1938-2024)—a wonderful scholar, mentor, and friend whom we lost too soon. It was George's lecture on using seismology to probe the interior of the Earth that helped open up the new subfield of philosophy of seismology and that first inspired me to write this paper.

Funding Statement

None to declare

Declarations

None to declare

https://doi.org/10.1017/psa.2026.10263 Published online by Cambridge University Press

1. Introduction

One of Charles Sanders Peirce's most well-known contributions to logic and the philosophy of scientific methodology is his account of *abduction* (also called *retroduction*) as a third mode of inference alongside induction and deduction. However, what exactly Peirce meant by abduction has been a subject of perennial dispute. Interpretations of abductive inference have ranged from it being the trivially false fallacy of affirming the consequent, to the nontrivially problematic inference to the best explanation (IBE), to a claim about pursuitworthiness, and much else in between. What has been largely missing from these analyses of abduction, however, is a consideration of how Peirce's work as a practicing geoscientist motivated and informed his understanding of abduction.

My aim in this paper is two-fold: First, I offer an interpretation of Peirce's abduction through the lens of Peirce's research in geophysics, specifically his work on gravimetry (measures of variations in Earth's surface gravity) and more broadly the then newly emerging field of seismology, which Peirce's student, Harry Fielding Reid, helped establish. Gravimetric and seismological data are the two primary resources for gaining access to the unobservable interior of the Earth. However, this "inversion" process from surface data to inferences about the unobservable substructure of the Earth is typically nonunique, i.e., underdetermined. Indeed, it was precisely in this area of geophysics—and during Peirce's lifetime—that so-called *inverse problems* were first recognized and the preliminary mathematical methods for performing inversions were first developed. I argue that this historical scientific context in which Peirce was deeply immersed lends further support to interpreting his abductive reasoning as a kind of inverse modeling, broadly construed.

Despite progress in the now robust mathematical field of inverse modeling, managing the non-uniqueness of geophysical inversion remains a challenge for fields like seismology. My second aim in this paper is to show how the methods that Peirce outlined for dealing with the underdetermination inherent in abduction remain helpful strategies for dealing with the nonuniqueness of geophysical inversions today. Let us begin with the puzzle of Peirce's abduction.

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2. The Puzzle of Peirce's Abduction

Both the label Peirce ascribes to his distinctive mode of inference and his understanding of its relationship to deduction and induction changed subtlety throughout his career. The concept of abduction (though not yet the name) seems to have first appeared in Peirce's Harvard lectures of 1865 (Peirce, W1.180); [1] it was initially named "hypothesis" (Peirce 1866, W1.428), but this label was later rejected as confusing (Peirce 1883, pp. 141). By 1896, Peirce introduces two new names for this inference—*abduction* and *retroduction*—which he uses interchangeably throughout the remainder of his career.

Peirce distinguishes abduction from induction by noting that one is the "reverse" of the other, with abduction being the inference that begins with the data or 'facts': "Abduction makes its start from the facts, without, at the outset, having any particular theory in view. . . . Abduction seeks a theory. Induction seeks for facts." (Peirce 1901, EP2, p. 106). He continues, "abduction 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" (Peirce 1901, EP 2, p. 107). Peirce later comes to see Abduction, Deduction, and Induction not as three separate methods, but as three stages of an integrated scientific methodology, which first moves from facts to hypothesis (abduction), then from hypothesis to experimental consequences (deduction), and finally, the experimental testing of those predictions (induction) (Peirce 1901, EP2, pp. 95-97; Potschka 2018, p. 22).

Peirce increasingly uses the term *retroduction*, explaining "I call it retroduction because it starts at consequents and recedes to a conjectural antecedent" (Peirce 1908, MS905). He argues "Retroductive reasoning is the only one of the three which produces any new idea" (1906, MS[R]753.3). Peirce's retroduction seems to have been inspired by William Whewell's inference associated with *colligation*, and indeed he cites Whewell both in his earliest discussions of abduction (e.g., 1865b) and in his later accounts of retroduction (1898). Both Peirce and Whewell describe the method of inference as often being a part of an iterative process of "happy guesses" from an expert mind (Whewell 1847, p. 41; Peirce [undated] in Eisele 1985, p. 901). Peirce analogizes the scientist trying to retroductively infer an underlying causal or explanatory hypothesis from the data as someone playing the party

[1] 'W' refers to the multivolume *Writings of Charles S. Peirce: A Chronological Edition*, followed by the volume number (1) and the page number (180); Ed. Max Fisch, Bloomington: Indiana University Press, 1982.

https://doi.org/10.1017/psa.2026.10263 Published online by Cambridge University Press

game of 20-Questions: although there are an infinite number of guesses one could make and never hit upon the answer, clever questioning can often narrow in on the answer in less than twenty tries (Peirce 1901, EP2, p. 109). [2] With this condensed overview of Peirce's writings on this topic, let us now turn to a brief survey of the widely varying interpretations of Peirce's abduction.

3. Interpretations of Peirce's Abduction

In the well over a century and a half since Peirce introduced this notion, no philosophical consensus has yet to emerge about what exactly Peirce meant by abduction nor whether there is in fact such a third form of inference, distinct from induction and deduction. In her excellent review, Anya Plutynski organizes the various debates around Peirce's abduction into four problems. She writes,

> "Peirce left a legacy of puzzles about abduction. . . . Debates in the literature have often circled around one or more of four central interpretative challenges, which I will call the *formalization indeterminacy problem* [should abduction be formalized?}, the *boundary problem* [Is abduction distinct from induction (& deduction)?], the *justification problem* [Is abduction a reliable form of inference?], and the *descriptive problem* [Does abduction describe scientific practice, and if so which features of scientific practice?]." (Plutynski 2011, p. 229)[3]

Plutynski offers no resolution to these four problems, but does note that Peirce is in part to blame.

One of the simplest, and perhaps most uncharitable, interpretations of Peirce's abduction sees it as just the inductive *fallacy of affirming the consequent* (e.g., Schvaneveld 2012). More popular, is to identify abduction with *inference to the best explanation* (IBE). This interpretation has been defended by Peter Lipton (2000) and Cheryl Misak (2006), who writes "the very idea of abduction, what is today known as 'inference to the best explanation,' is due to Peirce" (Misak 2006, p. 16).[4] More recently, Daniel McKaughan

[2] There is much more to be said about the close relationship between Peirce's abduction and Whewell's "discoverer's induction", but a full discussion is regrettably outside the scope of this paper.
[3] As I will discuss more below, my own focus will be on this fourth "descriptive" problem (Does abduction describe an actual feature of scientific practice?), answering 'yes', and the degree of success of that scientific practice will be taken as providing a partial answer to the third "justification "problem.
[4] For an argument against the identification of abduction with IBE see McAuliffe 2015.

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(2008) has divided interpretations of abduction into those, like the IBE interpretation, that see abduction as a mode of reasoning that *justifies* beliefs about the probable truth of hypotheses versus those that see abduction as a method for *generating* explanatory hypotheses, arguing both are wrong. He instead defends what he calls the *Pursuitworthiness Interpretation*, though he notes "Peirce does not use the term 'pursuit' in this connection" (p. 452).[5]

Ilkka Niiniluoto, in his book *Truth-Seeking by Abduction*, takes a conciliatory approach, arguing "one may question whether the sharp dichotomy between discovery and justification is useful at all, as abduction clearly is related to both of them" (Niiniluoto 2018, p. 14). He continues, "For these reasons, in this book we shall give a broad survey of different aspects of Peirce's great idea of abductive inference—including its various roles in truth seeking, discovery, pursuit, strategic reasoning, confirmation, and inference to the best explanation" (p. 18). Niinuluoto relates abduction to a wide spectrum of methods, ranging from the method of analysis and synthesis to Bayesian confirmation. Of particular relevance to my project here, is Niiniluoto's inclusion of inverse problems as an example of Peircean abduction: he writes, "the new growing branch of applied mathematics called inverse problems deals successfully with various kinds of abductive inference within a variety of scientific disciplines" (Niiniluoto 2018, p. 51; see also Niiniluoto 2011). Although this identification of abduction with inverse modeling might seem prima facie surprising, I will argue that it can find further support by situating Peirce's philosophical work on abduction within the historical scientific context of his work as a practicing geoscientist performing pendulum gravity measurements—something that Niinuluoto's work on Peirce and inverse modeling does not discuss. Moreover, Niinuluoto's focus on the special case of a *unique* inverse solution, as illustrated by Johann Radon's theorem discussed in Chapter 4 of his book, misses what is most valuable about recognizing abduction as a kind of inverse modeling, namely Peirce's novel strategies for managing the *nonuniqueness*, or underdetermination, that is far more typical in geophysical inversion.

[5] For a discussion of Peirce's account of pursuitworthiness, as expounded in his "Economy of Research", see Bokulich and Brewer (under review).

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4. Peirce the Geoscientist: Gravimetry, Seismology, and Geophysical Inversion

A surprising omission from the large volume of work that has been written about Peirce's abduction is a consideration of how his research as a scientist might have informed his philosophical account. Although Peirce is remembered as a philosopher, his primary job for over thirty years, from the time he graduated Harvard in 1859 until his retirement in 1891, was working as a geoscientist at the U.S. Coast and Geodetic Survey (hereafter "the Survey"). The Survey was the first government-funded scientific organization in the U.S. In addition to mapping the coast lines of the U.S., the Survey was in charge of conducting research on a wide variety of geosciences, including especially those we would today put under the umbrella of *geophysics*, which includes geodesy (study of shape of the Earth), gravimetry (measuring variation in Earth's surface gravity), geomagnetism (Earth's magnetic field lines), astronomical studies of longitude, oceanography, meteorology, and a field that was just beginning to emerge in Peirce's lifetime: seismology.

Peirce's scientific area of expertise at the Survey was gravimetry, which involved using pendulums to measure minute differences in Earth's surface gravity at different locations. Peirce was promoted to Assistant of the Survey (the second highest position) in 1867 and put in charge of pendulum gravity measurements in 1872. To improve the precision and accuracy of these measurements, Peirce designed his own pendulums, made contributions to metrology[6] (such as by determining a more accurate conversion between the meter and the yard), and developed a list of corrections for various confounding factors and sources of error in the sensitive gravity measurements (e.g., Lentzen and Multhauf 1965, Lenzen 1972, Crease 2009).

Peirce's pendulum gravity measurements were initially conducted in the service of geodesy to determine the degree of polar flattening of the Earth, which was also being measured by triangulation networks, and which, as Richard Howarth (2007) recounts, initially gave quite different values for polar flattening.[7] Peirce and his junior colleague, John Hayford (who began as a "computer" at Survey, eventually succeeded Peirce as Assistant at the Survey) were instrumental in effecting a convergence to a consensus value for Earth's polar flattening.

[6] Metrology (not to be confused with meteorology) is the science of measurement.
[7] For a philosophical discussion of the resolution of this challenge see Ohnesorge 2021 and 2022.

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Over the course of Peirce's career in geodesy, the task of a precise determination of polar flattening began to recede in importance. At a conference on pendulum gravity measurements in 1882 Major John Herschel (son of the more famous natural philosopher by same name) raised questions about the continued utility of high-precision gravity measurements (Herschel 1883, p. 504-505). In a decisive reply, Peirce delivered his lecture "Six Reasons for the Prosecution of Pendulum Experiments," which prophetically laid out a program for future gravity research that continues to this day (e.g., Marson 2012). Of particular relevance is Peirce's third suggested use for gravity measurements: "Geologists affirm that from the values of gravity at different points useful inferences can be drawn in regard to the geological constitution of the underlying strata" (Peirce 1883, p. 507). This project would be undertaken in earnest by Hayford who mapped the gravity anomalies (differences between theoretically computed and observed values of gravity) geographically, drawing lines of equal anomaly on a map of the U.S. (Hayford and Bowie 1912a,b). This idea of Peirce's, which was systematically carried out by Hayford, was the source of inspiration for the geologist Grove Karl Gilbert:

> "The positive and negative anomalies are not indiscriminately mingled, as should be expected if the anomalies had the character of accidental errors, but fall into groups. . . . The anomaly map is in some way an expression of subterranean structure, for it tells of the distribution of mass. As the subterranean structure is a product of the earth's history, the distribution of anomalies has a historical significance. To determine the nature of this significance is a problem in interpretation." (Gilbert 1913, p.32)

As I will detail more below, this problem in interpretation was precisely the sort of inference Peirce was trying to capture with his account of abduction.

The scientific problem that Peirce, Hayford, and Gilbert were grappling with is the focus of a field of applied mathematics known today as *inverse theory*. Although inverse theory is now known to be applicable to a wide range of scientific problems, it got its start in geophysics, and more specifically in the use of both gravity data and seismic data to infer facts about the interior of the Earth. Introductory textbooks on inverse theory typically introduce the topic with this example of using gravity data to infer the substructure of the Earth (e.g., Parker 1977; Tarantola 2005). In his book *Inverse Problem Theory* Albert Tarantola writes,

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> "consider measurements of the gravity field around a planet: given the distribution of mass inside the planet, we can uniquely predict the values of the gravity field around the planet (forward problem), but there are different distributions of mass that give *exactly* the same gravity field in the space outside the planet. Therefore the inverse problem—of inferring the mass distribution from observations of the gravity field—has multiple solutions (in fact, an infinite number)." (Tarantola 2005, p. *xi*)

While the *forward problem* begins with a causal structure or model and then calculates what data it should produce, *inverse problems* begin with a set of observational data and then try to reason back to the causal structure that produced that data. As Tarantola explains, while the forward problem has a unique solution, the inverse problem is almost always nonunique, leading to a problem of underdetermination.[8]

The origin of the field of mathematics that tries to solve inverse problems traces back to the work of the mathematician Gustav Herglotz (1907) and the geophysicist Emil Wiechert (Wiechert and Geiger 1910).[9] With a small group of international scientists, Wiechert helped found the International Seismological Association in 1904. Among that small group was a former student of C.S. Peirce's: Harry Fielding Reid.

Reid obtained his bachelor's degree from Johns Hopkins University in 1880 and PhD in geophysics in 1885, overlapping with Peirce's brief tenure as a professor at Johns Hopkins (1879-1884). Reid was one of just three students in Peirce's year-long Elementary Logic class 1880-1881, where Peirce lectured on deduction, induction, and abduction (Pietarinen and Chevalier 2014). In 1903 Reid recounts attending the Second International Seismological Conference at Strassburg and learning about Wiechert's newly invented inverted pendulum seismometer to record earthquakes (Reid 1903). At this conference it was decided to establish the first International Seismological Association (ISA), and Reid was selected to be the representative from the U.S. Reid identifies two uses for seismology: first, he emphasizes how systematic recording of seismic data on the surface of the Earth can be used to infer information about the hidden interior and substructure of the Earth; second, once these structures are better known, their causal role in the production of earthquakes can be better understood (Reid 1904, p.4). In this first case, Reid is arguing that seismic data can be used in

[8] For philosophical discussions of the underdetermination that arises in inverse modeling, especially in the context of the geosciences, see Miyake 2010, Belot 2015, Bokulich and Oreskes 2017.
[9] For more details on this history of seismology and origin of inverse theory see Schweitzer 2015 and Miyake 2023.

https://doi.org/10.1017/psa.2026.10263 Published online by Cambridge University Press

the same way that Peirce, Hayford, and Gilbert had used gravimetric data. This too requires solving a nonunique inverse problem, just as with gravimetric data. In the second case, Reid hoped the seismic data could use be used to identify the underlying causal mechanisms responsible for earthquakes. In both these projects Fielding would make important advances, first in using seismic data to discover fault lines in Earth's crust, and second, in proposing as the underlying mechanism of earthquakes what he called the elastic rebound theory, which is still viewed as largely correct today.

The key event that sparked both Reid's elastic rebound theory and Wiechert's inverse theory was the catastrophic 1906 San Francisco earthquake. Both Reid and Gilbert were selected as part of the commission to go investigate the quake, and they produced a thousand-page report of the California Earthquake Commission, which was funded by the Carnegie Institution, whose benefactor Andrew Carnegie had identified the geosciences as a top research priority. Just four years before the San Francisco earthquake commission, Peirce had also applied to the Carnegie Institution to write his magnum opus on logic, which would have provided a detailed clarification and elaboration of his abductive reasoning. He writes, "My paper of April 1867 on this subject divides arguments in to Deductions, Inductions, Abductions... I consider this to be the key of logic" (Peirce 1902 in Eisele 1976, p. 22). Peirce argues that this detailed study of logic is needed for the science of his day to progress:

> "It is my belief that science is approaching a critical point in which the influence of a truly scientific logic will be exceptionally desirable. Science, as the outlook seems to me, is coming to something not unlike the age of puberty. . . . The influence of the conceptions of methodeutic[10] will at that moment be decisive." (Peirce 1902 in Eisele 1976, pp. 34-35)

Unfortunately, his Carnegie application was not successful and his comprehensive account of logic and abduction would never be written. Nonetheless, this brief review of the historical scientific context that Peirce was deeply immersed in, lends strong support to interpreting his abductive reasoning as being inspired by, and in part concerned with, geophysical inverse modeling. Indeed, the problems that Peirce and his scientific colleagues

[10] Peirce explains what he means by *methodeutic*, as follows: "one branch of logic is methodeutic, which should investigate the general principles upon which scientific studies should be carried on" (Peirce1905, Adirondack Summer School Lectures, MS [R] 1334, 29).

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were working on are the very same problems that geophysicists continue to grapple with today:

> "In geophysics, we are concerned with a wide variety of inverse problems. Examples include imaging the Earth's interior and determination of earthquake source parameters using observed seismic waves; the determination of the Earth's density structure from gravity measurements" (Käufl et al. 2016, p. 1710)

Peirce not only recognized the challenge of the nonuniqueness inherent in inverse modeling and abduction, but also offered several suggestion for how this underdetermination might be overcome. The strategies Peirce outlined for managing nonuniqueness are in fact many of the same general strategies used in geophysical inversion today.[11]

5. Peircean Strategies for Managing Underdetermination in Geophysical Inversion

As we saw, Peirce was on the leading edge of a small international community of geoscientists who were grappling with the problem of geophysical inversion in order to learn about the interior structure of the Earth. His application to the Carnegie Institution in 1902 suggests he saw his work on abduction as being critically important for the future progress of the geosciences. Throughout his career, Peirce identified the geosciences as being a paradigmatic example of an abductive science: "Of the natural sciences, we have, first, the classificatory sciences, which are purely inductive zoölogy, mineralogy, and chemistry. Then we have the sciences of theory . . . astronomy, pure physics, etc. Then we have the sciences of hypothesis [abduction]—geology" (Peirce 1878, EP1, p. 199).

The key features of abduction, recall, are, first, that "Abduction makes its start from the facts" (EP2, p. 106) and, second, that, of the "two kinds of scientific reasoning, Induction and Hypothesis. . . . Hypothesis alone affords us any knowledge of causes. . . . [It is employed in] Geology" (Peirce 1866, WP1, p. 428). In other words, abduction is an inference from data back to the underlying causes of data. Third, those underlying causes are typically "not capable of direct observation" (Peirce 1878, EP1, p. 198). Finally, in addition to being an inference that begins with the data ("facts") and reasons back to the unobservable underlying

[11] My focus here is on the broad, scientific methodological strategies common to Peirce and current geoscientists working on geophysical inversion, not the more narrowly construed sophisticated mathematical techniques associated with inverse theory as a field of applied mathematics today. The nonuniqueness of inversions limits the effectiveness of these mathematical techniques, requiring that scientists then supplement their investigations with these broader Peircean strategies, as we will see below.

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causes, the fourth feature is that abductive inferences are typically radically underdetermined (i.e., nonunique):

> "Think of what trillions of trillions of hypotheses might be made of which one only is true; and yet after . . . a dozen guesses . . . [the scientist] hits pretty nearly on the correct hypothesis. By chance he would not have been likely to do so in the whole time that has elapsed since the earth was solidified" (Peirce 1903, CP5. 172)

How is it that Peirce thinks the scientist can go from trillions of trillions to one after just a dozen or so guesses? Although Peirce sometimes attributes it to a special "light of nature" (e.g., CP5.604), elsewhere in his work he makes several suggestions about the principles and strategies that should guide the choice of causal hypothesis when reasoning abductively.

The first strategy strikes right to the heart of Peirce's philosophy. Peirce titles his final Harvard lecture *Pragmatism as the Logic of Abduction*, where he writes,

> If you carefully consider the question of pragmatism you will see that it is nothing else than the question of the logic of abduction. . . . For the maxim of pragmatism is that a conception can have no logical effect or import differing from that of a second conception except so far as . . . it might conceivably modify our practical conduct differently from that second conception. (Peirce 1903, EP2, p.234).

The pragmatic maxim, thus, can be used to reduce the underdetermination inherent in abduction, or inverse modeling, by grouping together as equivalent those hypotheses or models that make no practical difference to our inferences or actions. This strategy is closely related to a second, broader strategy that I refer to as the *adequacy for purpose approach* (e.g., Parker 2020; Bokulich and Parker 2021), which Peirce articulates as follows: "The principles upon which abduction ought to be conducted ought to be determined exclusively by considerations of what purpose it subserves and how it may best subserve that purpose" (Peirce 1901, CP7.220, fn18, p. 139; see also EP2, p.85).[12] How these two strategies of pragmatism and adequacy for purpose can aid in geophysical inversion has been clearly articulated in a recent scientific article on geophysical inversion in hydrogeology:

[12] For current discussions of the adequacy for purpose approach, which were developed independently of Peirce in the context of modeling and data respectively, see Parker (2020) and Bokulich and Parker (2021).

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> "The inversion of data and the creation of subsurface models that 'match' the data is rarely an end goal. Practical field applications start with a purpose or decision question: . . . Such a question of purpose leads to a number of follow up questions. What subsurface structures impact this decision the most? (Linde et al. 2015, p.95)

As Linde et al. note, often one doesn't need to know every detail of the substructure of Earth, and so can focus instead on just those features of the underlying structure that most impact your purpose. By focusing on the classes of hypotheses or models that would differentially affect your inferences or actions, the underdetermination can be greatly reduced.

The next pair of strategies that Peirce identifies for managing the underdetermination of abduction is to find ways to eliminate some of the rival classes of purpose-relevant hypotheses. Peirce appeals to two sources: Expert judgement and additional experiments. On the first, Peirce writes, "If you ask an investigator why he does not try this or that wild theory, he will say, 'It does not seem reasonable.'" (Peirce 1903, EP2, p. 128; CP5.174). Next Peirce says the scientist should look to those hypotheses that with additional experimental testing or data can be quickly refuted. Geophysicists today emphasize a similar strategy: "[M]easured hydrogeological or geophysical data can be complemented by ancillary information on the heterogeneity of subsurface formations that is obtained from borehole data, analog outcrops or databases of previously studied sites. Expert knowledge is also important" (Linde et al. 2015, p.87). Of course, one is typically not at liberty to conduct endless experiments or gather infinite amounts of additional data—a limitation that brings us to Peirce's third strategy.

Peirce's third strategy for dealing with the underdetermination inherent in abductive reasoning is to make use of his pioneering work on the *economy of research,* which helps scientists strategize about *which kinds of data* are most important to gather to narrow down the possibility space. As a government employee working for the U.S. Coast & Geodetic Survey who had to justify every penny and hour he spent, Peirce was continually made aware of the need for an economy of research. Peirce published a whole essay on the economy of research, which appeared as an appendix to the 1876 *Report of the Superintendent of the United States Coast Survey*. The scientific context that inspired this work was Peirce's pendulum gravity research and a question of the optimal number of times the reversible pendulum should be swung with its heavy side up and heavy side down in order to reduce

https://doi.org/10.1017/psa.2026.10263 Published online by Cambridge University Press

uncertainty.[13] In their review of geophysical inverse modeling strategies, Linde et al. express similar concerns about the economy of research and how scientists can manage the uncertainties more effectively. They write, "computing limitations are often an issue. . . . [and] it is often unclear to what extent small imperfections in our increasingly complex statistical and physical models affect predictions and uncertainty estimates. . . .We emphasize that the goal . . . in hydrogeophysical inverse modeling is . . . to enable more informed conclusions and decisions under uncertainty" (Linde et al. 2015, pp.97-98). It is unfortunate that Peirce never had the opportunity to further develop his strategies for managing the underdetermination inherent in abductive reasoning, but it is striking how much the strategies deployed by geophysical inverse modeling today has developed along largely Peircean lines.

In this paper I have argued that a key to solving the puzzle of Peirce's theory of abduction requires situating it within the context of Peirce's long career as a practicing geoscientist, performing gravity measurement for the U.S. Coast and Geodetic Survey. As we saw, one of the biggest challenges facing gravity research and the newly emerging field of seismology in Peirce's day was how to infer the substructure of the Earth on the basis of data collected at the surface, and more troublingly the nonuniqueness these inversions posed. Finally, I showed how the strategies Peirce outlined for managing the underdetermination of abductive inferences have come to be the same general methodological strategies that geoscientists deploy today in managing the nonuniqueness of geophysical inversions. This provides further evidence that our understanding of Peirce-the-philosopher and his account of abduction can be deepened by reintegrating it with a better understanding of Peirce-the-geoscientist.

[13] A full discussion of Peirce's economy of research is outside the scope of this paper, but see Bokulich and Brewer (under review) for more discussion.

https://doi.org/10.1017/psa.2026.10263 Published online by Cambridge University Press

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