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Understanding Natural Science Based on Abductive Inference: Continental Drift

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Abstract This study aims to understand scientific inference for the evolutionary procedure of Continental Drift based on abductive inference, which is important for creative inference and scientific discovery during problem solving. We present the following two research problems: (1) we suggest a scientific inference procedure as well as various strategies and a criterion for choosing hypotheses over other competing or previous hypotheses; aspects of this procedure include puzzling observation, abduction, retroduction, updating, deduction, induction, and recycle; and (2) we analyze the "theory of continental drift" discovery, called the Earth science revolution, using our multistage inference procedure. Wegener's Continental Drift hypothesis had an impact comparable to the revolution caused by Darwin's theory of evolution in biology. Finally, the suggested inquiry inference model can provide us with a more consistent view of science and promote a deeper understanding of scientific concepts.

Keywords Abductive inference · Wegener's continental drift hypothesis · History of science

1 Introduction

Charles S. Peirce argued that in addition to deduction and induction, there is a third mode of inference called "hypothesis" or "abduction." He characterized abduction as reasoning "from effect to cause" and "the operation of adopting an explanatory hypothesis" (Niiniluoto 1999). Abduction differs from deduction, which moves from the rule and individual case to the result. It also differs from induction, which goes from the individual case and results to the rule. Peirce's 1866 model of reasoning by "hypothesis" from result and rule to case (2.623) is familiar:

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[PA1] All beans from this bag are white. (Rule)
These beans are white. (Result)
Therefore, these beans are from this bag. (Case) (CP 2.623)

In 1878, he formulated probabilistic versions of the Barbara syllogism **[PA1]** and its inversions by replacing the universal rule, "All the beans from this bag are white", with a statistical generalization, "Most of the beans in this bag are white" (2.627). In this situation, we might characterize the hypothesis as an inference to an inference to an effect to its probabilistic or statistical cause.

In Peirce's **1903** lectures on pragmatism, he tentatively presented a different pattern to which abductions should conform (CP 5.145). In this form **[PA2]** of inference, C is a statement or set of statements describing a set of facts, and A is another statement or set of statements that supposedly explain these facts. This general abduction scheme is presented as follows (cf. Hanson 1958, p. 86).

[PA2] 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. (CP 5.145).

The premises of **[PA2]** accurately portray the scientific process, as research typically begins with a problem (a puzzling or surprising phenomenon) and aims to generate a solution in terms of an explanatory hypothesis (Kapitan 1997, p. 480). Abduction can thus be understood as a mode of inference in which explanations are sought to describe (anomalous or surprising) phenomena. The first premise of abduction is "result(C)," the second is "rule(A→C)," and the third, as the conclusion, is "case(A)."

The syllogistic form of abduction shows that abduction is an ampliative inference (Psillos 2000; Magnani 2001; Walton 2004). Deduction is called the truth preserving inference because the conclusion is necessarily true if the premises are true and the reasoning process is valid. By contrast, the abductive conclusion goes far into the range of information whose truth cannot be warranted by the premises.

Students are not taught how to reason well but are instead taught to maintain their logical virtue (i.e., to avoid logical fallacies and learn what is and is not admissible and valid). Schools have focused on the *definitory* rules of logic and largely neglected *strategic* rules. Definitory rules describe valid rules in a particular system of logic. As an analogy, "the definitory rules of chess describe what each player is allowed to do (how chessmen may be moved, etc.). However, if one knows only the definitory rules of chess, one cannot say that one plays chess well. Excellence in chess requires that the player master the *strategic* rules of the game" (Paavola 2005).

Abduction is more frequently used in everyday "common-sense" reasoning and expert-level problem solving than is generally recognized. Thus, "abduction is the *process* of forming an explanatory hypothesis (5.172) that must cover all the *operations* by which theories and conceptions are engendered (5.590), including not only the *invention* of hypotheses but also their *selection for further consideration"* (Kapitan 1997, p. 475).

Peirce stated the following:

(a) Every inquiry whatsoever takes its rise in the observation, … of some surmising phenomenon, ….(CP, 6.469)
(b) "The inquiry begins with pondering these phenomena in all their aspects, in the search of some point of view whence the wonder shall be resolved. At length a conjecture arises that furnishes a possible Explanation, by which I means a syllogism exhibiting the surprising fact as necessarily consequent upon the circumstance of its occurrence together with the

truth of the credible conjecture, as Premises" (CP, 6.469). According to Paavola (2005), abductive reasoning strategies can guide the process and the way in which premises are searched for. According to this approach, abductive inference starts from small details and characteristics, and the goal is to find a hypothesis that would explain these details 'as a matter of course (PA2, Second Premises)' (CP 5.189). Clues and minute details give hints and suggestions for hypotheses (CP 2.755).

(c) 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" (CP, 6.469).

We thus propose that premise one (a) in [PA] is "surprising observations", premise two (b) in [PA] is "conjecture and invention of hypotheses", and conclusion (c) in [PA] is " selection of hypotheses."

How can abduction be a form of inference distinct from deduction and induction (as the unfettered play of amusement or a response to a *surprising fact*) and a form of recursive analysis that includes deduction and induction? Referring to the concept of abduction as amusement and to that of recursive analysis as retroduction can eliminate much confusion surrounding abduction, as the classical HD method includes distinction between the pre- and post-trial hypothesis evaluation.

"Whewell required the use of a hypothetical theory to "explain phenomena which we have observed" and "foretell phenomena which have not yet been observed," indicating that they are "of a kind different from those which were contemplated in the formulation of our hypothesis" (Whewell 1847, pp. 62–65). And "Imre Lakatos undertook to specify conditions under which old evidence does provide support for hypothesis H. Old evidence provides support only within the context of competition between hypotheses" (Losee 2001, p. 227).

Though many argumentations (Park 2005), according to Rescher (1978, p. 8), Peirce saw qualitative induction as an evolutionary process of variation and selection. Two component processes are involved here:

1. Hypothesis production, or *abduction*: the purely conjectural proliferation of many alternative explanatory hypotheses that are relatively plausible.
2. Hypothesis testing, or *retroduction:* eliminating hypotheses based on observational data.

The result of the overall process is that science proceeds by repeatedly eliminating rival hypotheses in favor of one preferred candidate. Each stage of the *abduction-retroduction cycle* reduces a cluster of conjectural hypotheses to an accepted theory.

Abduction is a first phase of inquiry in which ideas are generated. Differing from the evidential viewpoint, the methodological viewpoint emphasizes that abduction is one phase in the inquiry process; hypotheses and ideas are generated using abduction and should be tested with deduction and induction (Chiasson 2005). In his theory of reasoning, Peirce abandoned the idea of a syllogistic classification of reasoning. He instead identified three reasoning forms, i.e., abduction, deduction and induction, and three stages of scientific inquiry, i.e., hypothesis generation, predictions, and evaluation (Flash and Kakas 2000, p. 7). In Peirce's categorization, abduction can generate propositional examples that can be used in induction in predictive way by deduction, and induction can generate generalized rules that can be used in abduction as facts (background knowledge). Abduction thus generates examples for induction. The essential step in categorical inductive generalization is extending the universal quantifier's scope from the sample to the population.

Peirce interpreted abduction as the inferential creative process of generating a new hypothesis. There are two main epistemological meanings of the word abduction (Magnani 1988): (1) abduction that only generates plausible hypotheses (selective or creative) and (2) abduction considered as inference to the best explanation (IBE), which also evaluates hypotheses.

All we can expect from "selective" abduction is that it tends to produce hypotheses with some chance of being the best explanation upon further examination. Selective abduction always produces hypotheses that give at least a partial explanation of the data and have "a small amount of initial plausibility". In the syllogistic view concerning abduction as an inference to the best explanation, as Peirce advocated, one might require that the final chosen explanation be "the most plausible explanation." In the latter sense, Magnani's epistemological model describes the classical meaning of selective abduction as an inference to the best solution using the complete abduction-deduction-induction cycle (Magnani 1999, pp. 220–222). If new information emerges during this first cycle, hypotheses not previously considered can be suggested and a new cycle occurs.

One of Magnaini's central distinction is (2) abduction considered as the inference to the best explanation (IBE), which also evaluates hypotheses (Magnani 2001, p. 19). IBE formulations by Harman have concentrated more on evaluating and justifying suggested hypotheses rather than emphasizing hypotheses' generative aspects. Lipton's IBE interpretation has brought it closer to the generative interpretation. We thus claim that this IBE is considered retroduction because it is a weak evaluation, and the practical evaluations of suggested and selected hypotheses are hypothetico-deduction (deduction-induction).

According to McLaughlin (1982), the Bayesian methodology advanced by Salmon's justification (1967, p. 118) considered the prior probability used when discussing the plausibility of hypothesis discovery. These plausibility/analogy, simplicity, and coherence discussions must include not only the justification of hypotheses but also their discovery. Explanatory criteria are needed because rejecting a hypothesis requires demonstrating that a competing hypothesis provides a better explanation. In some cases, e.g., when choosing scientific hypotheses or theories, where the role of "explanation" is dominant, conclusions are reached according to rational criteria like consilience or simplicity (Magnani 2001, p. 27).

As a final remark on *consilience*, the maximally consilient hypothesis or theory is one that explains every fact. This would be achieved by having sufficient flexibility in the set of auxiliary hypotheses to ensure that any phenomenon could fall under the theory. *Simplicity* handles the problem of the conceptual complexity level of hypotheses with equal consilience. Ockham's razor strongly influences the evaluation: simplicity can also be highly relevant when discriminating between competing explanatory hypotheses (Magnani 2001, p. 26).

According to Thagard (1988, p. 54), "abduction" is becoming an increasingly popular term in artificial intelligence, but its meaning is being stretched to cover various hypothesis evaluations and formations. This meaning is beyond what Peirce intended. We here concentrate on mechanisms for generating hypotheses. Four kinds of abduction have been implemented in PI: simple, existential, rule forming, and analogical. Simple abduction produces hypotheses about individual objects, e.g., rock musicians. Existential abduction postulates the existence of previously unknown objects, e.g., new planets (see the discovery of Pluto). Rule-forming abduction produces rules that explain other rules and is thus important for generating theories that explain laws. Analogical abduction uses past hypothesis formation cases to generate hypotheses similar to existing ones.

1.1 Simple Abduction

A young man, Michal, is dressed outrageously is to be explained.
If x is a rock musician, then x can dress outrageously.
Hence Michal is a rock musician.

1.2 Existential Abduction

Neptune had slight departures from its predicted orbit, astonishingly.
If x planet is near y planet,
x is perturbed, and there must be y planet that causes it.
Therefore, perturbing Neptune, there can be y certain planet nearby.

1.3 Rule-Forming Abduction

Neptune had slight departures from his predicted orbit, astonishingly.
Assume that all celestial objects are under gravitational law.
If x planet is near y planet,
x is perturbed, and there must be y planet that causes it.
Therefore, perturbing Neptune, there can be y certain planet nearby, so Gravitational Law is formulated to explain this perturbation.

Based on our prior store of declared knowledge in other domains, we use *analogical abduction* to invent a hypothesis (a tentative explanation) for a puzzling or surprising phenomenon based on existing knowledge in other domains:

For example,
…. an atomic nucleus is observed by Rutherford.
if.…planets(p2) orbit the Sun(p1) in heliocentric theory(T1), *and*…atomic nucleus(p4) in atomic theory(T2) are like Sun(p2) in the heliocentric theory(T1),
then.…perhaps electrons(p3) will orbit an atomic nucleus(p4).
Therefore (Hence), there is reason to suspect that Rutherford's atomic theory is true

Heuristically generating empirical data plays an especially large role in all earth sciences because, in contrast to physics and chemistry, earth science entails many contingent facts, both qualitative and quantitative, that must be addressed and rationally organized. It is also necessary for both research and applied earth science to derive statements from these empirical facts that can be used, at least on a preliminary basis, as if they were laws, which happens even before any scientifically satisfying explanations for the phenomena are available. Each such regularity poses a question that can only be answered at the theoretical level: the question of how the inductively found regularity can be explained using universal laws and theoretical interconnections. Explorers must rearrange or reconstruct the given data to answer their specific problem or inquiry (Engelhardt and Zimmermann 1982).

Using classical logic, the system increases its stock of truths as knowledge is added and inferences are made. There is no mechanism for discarding information or revising beliefs. This aspect of classical logic is termed "monotonic." In non-monotonic systems, inferences can be made using available data, but these inferences can be rejected and new ones made when new data become available (Fischler and Firschein 1987, p. 96). "Non-monotonic reasoning as a form of reasoning contrasts standard deductive reasoning" (Brewka et al. 1997, p. 1).

If new information suggests hypotheses not previously considered, a new cycle starts. The cyclic nature of the epistemological model stresses its non-monotonic character. New information can significantly decrease the likelihood of a previous hypothesis, even to zero (Peng and Reggia 1990, p. 125). Non-monotonic inference is thus time-dependent logic (Trigg 1991, p. 5). Its conclusions must be flexibly revised or retracted when new information contradicts a previously proposed conclusion. It makes conclusions based on typicality in the absence of information about its atypicality (Fischler and Firschein 1987, p. 96).[1]

Above all, the gap between the appearance of a statue observable through the senses and the underlying mechanism from which it emerges seems unbridgeable. What mode of inference or logic can link the sensory perceptions of the statue to this underlying mechanism? The required mental acrobatics necessitate a creative leap, clearly indicating that induction and deduction are of no use. In the literature on the various inference modes, the only reasoning that involves a creative leap is "abduction" (Wuisman 2005). Analogical abduction, or rule-forming abduction, is necessary for the creative leap (Oh 2010). In the scientific process, it is necessary to update or recreate existing hypotheses for more plausible hypotheses based on newly available information (Peng and Reggia 1990, p. 6). These changes may be conducted after retroduction as preliminary tests, after an induction to corroborate a hypothesis, or as rejected tests.

1.4 Research Goals

This study aims to explore the use of abductive strategies throughout the history of science and develop a program of scientific inference processes based on abductive inference. To accomplish this objective, we present the following two research problems: (1) understanding the scientific inference process and (2) understanding the "theory of continental drift" discovery, known as the Earth science revolution, using our suggested inference procedure. Wegener's continental drift hypothesis is comparable to the revolution caused by Darwin's theory of evolution in biology. The paper then discusses recent prior work (Šešelija and Weber 2012) and compares it to my work based on abduction. Not surprisingly, historians and philosophers of science have sought to use this episode as a case study to test theories of scientific change (Frankel 1985; Le Grand 1988; Stewart 1990).

2 Scientific Inference Based on Abductive Inference Strategies Involving the Deduction-Induction Cycle

We suggest a scientific inference procedure that enhanced Magnani's (2001, 2009) and Oh's research (2012) as well as various strategies and the criterion for choosing hypotheses, puzzling observation, abduction, retroduction, updating, deduction, induction, and recycle, as in Fig. 1.

2.1 Generating Creative Hypotheses

Stage (1), "Anomalous or surprising observation": An exploratory stage occurs in which a puzzling or surprising observation is made and a causal question is raised. To invent possible hypotheses, it is necessary to reconstruct data by arranging and selecting evidence in accordance with the reasoner's inquired concerns (Engelhardt and Zimmermann 1982, p. 211). *Data Abstraction*: An *abstraction or reconstruction* process can be used to organize available data into a small set of necessary and important entities to explain puzzling, surprising, and unfamiliar evidence using the observational theory-dependence. *Stage (2)*, "Invention

[1] Gabbay and Woods (2005 p. 120) later applied it to *non-monotonic* reasoning as instrumental value. Thagard (2010) recently argued that a term such as "gabuction" could be used be used to cover the generalized notion of abduction.

of hypotheses”, occurs when multiple hypotheses are generated by simple abduction and analogical *abduction* strategies.

Stage (3), “Selection of a hypothesis”, covers all phenomena that are present. The preliminary test stage occurs in which tests are developed to select or eliminate hypotheses by *retroductive strategies*. This is a weak test for a hypothesis, as the least a hypothesis should do is explain the puzzling observation that led to its generation based on we already know (Lawson 2010).

In the *If/then/Therefore* form of the previous retroductive argument, we get the following:

> *If* …H (main hypothesis), *and* …A (auxiliary hypotheses), *then* …(expected results). *But(yes)* …(already observed results).” *Therefore(Hence)*. . H and A (eliminated or selected).”

Simplicity handles the problem of the conceptual complexity level of hypotheses with equal consilience: “the degree of coherence of a hypothesis with what it explains and with its cohypotheses is inversely to the numbers of cohypotheses. For example, H1 is preferred to H2 and H3 because it accomplishes the explanation with no cohypotheses” (Thagard 1992, p. 77).

Stage (4), *Updating existing hypothesis*: Updating and selecting hypotheses involves updating or recreating existing hypotheses based on newly available information (Peng and Reggia 1990, p. 6) to develop more plausible hypotheses. This stage may be independent of newly available information (e.g., data, theories). According to Peng and Reggia (1990, p. 6), based on many studies, human diagnostic reasoning often involves “ hypothesis generation” (forming candidate explanations), “hypothesis updating” (updating existing hypotheses or generating new ones based on newly available information), and “hypothesis testing” (disambiguating existing hypotheses). It describes the different roles that such basic inference types play in developing various kinds of medical reasoning (e.g., diagnosis, therapy planning, monitoring), but it can also be extended and regarded as an illustration of changes in scientific theories (Magnani 1999, p. 19).

2.2 Hypothesis Testing: Corroborating Selective Hypotheses: Deduction-Induction Phase

The *Deduction-Induction Phase* handles the hypothesis evaluation process.

Stage (5), *Deduction*, is connected to prediction. After establishing a hypothesis about a phenomenon, certain predictions derived at a time t1 can be revised at t2.

Stage (6), *Induction*, (not used here to mean an amplitude process for generalizing knowledge) corroborates those hypotheses whose expected consequences are consistent with the observed data and refutes those that fail this test. Induction is the final testing of an abduced hypothesis; by completing the epistemological model cycle, it produces the best explanation. If new information suggests hypotheses that have not been previously considered, a new cycle starts (Magnani 2001, pp. 73–74). It is non- monotonous in the next recycle stage for our research.

> *If* …H (main hypothesis), *and* …A (auxiliary hypotheses), *then* …(expected results). And *(But)*…. (observed results).” *Therefore(Hence)*. .H and A (supported or unsupported)…”

2.3 Recycling

2.3.1 Updating Existing Hypotheses: Deduction-Induction Recycle

Stage (7): Updating existing hypotheses: Deduction-Induction Recycle

Abduction based on updating a new data-deduction-induction recycle

After comparing the prediction with the obtained results, the experimenter may find that the hypothesis has been confirmed, some modification is indicated, or the hypothesis must be abandoned.

In the first case, the *(Route A): an updating existing hypothesis-deduction-induction* cycle is needed for a case with no modification to theory T or a set of auxiliary hypotheses A to explain both the more predictable phenomena with more plausibility and the conservative dynamic consilience.

In the second or third case, *(Route B): based on updating data, generating new hypotheses*, a change in T or A is used to explain a phenomenon that the theory in its original form cannot explain. It successfully explains new kinds of facts, which is known as radical dynamic consilience; a revision or retreat in T is used to explain new data with non-monotonous inference using a new abduction-deduction-induction cycle. A *poor match* cannot "disprove" or falsify a hypothesis in any ultimate sense. It also cannot be said to falsify a hypothesis with certainty because the failure to achieve a good match may be *the fault of the test condition(s) (a revision)* rather than the fault of the hypothesis (Salmon 1995). The procedure must be recycled until a hypothesis is generated that is supported when tested on one or more occasions. In the present example, the initial conclusion was that the hypothesis test was faulty. However, repeated attempts and a closer inspection of the test condition(s) led to rejecting the main hypothesis *(retreat)*, which allowed generating, testing, and supporting an*alternative hypothesis*.

Magnani consider them as follow:

> If during this first cycle new information emerges, hypotheses not previously considered can be suggested and a new cycle takes place. In this case the nonmonotonic character of abductive reasoning is clear and arises from the logical unsoundness of the inference rule: it draws defeasible conclusions from incomplete information. It is important to allow the guessing of explanations for a situation, to discount and abandon old hypotheses, to enable the tentative adoption of new ones, when new information about the situation makes them no longer the best (Magnani 2009, pp. 16–17)

3 Forming a Hypothesis for Continental Drift and Plate Tectonics

In this study, scientific inferences contain three components: generating creative hypotheses, hypothesis evaluation, and cycling. These processes are now explored to understand the continental drift theory formation as a revolution in Earth Science, similar to evolution by natural selection in biology or gravity for understanding the orbits of planets.

This research thus gives a paragraph summarizing the history of continental drift and plate tectonics before fitting this history into an abductive inference scheme.

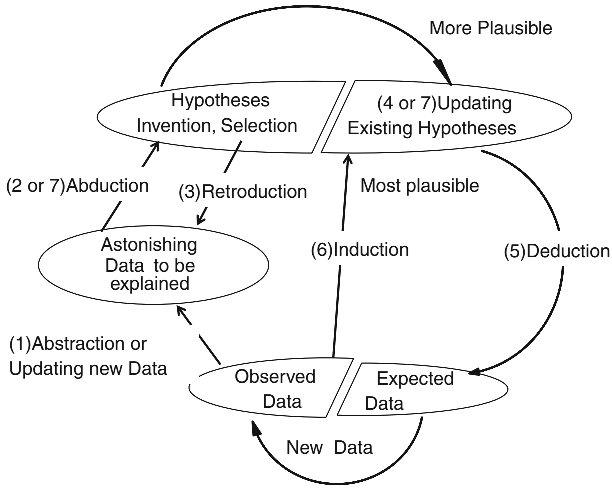

Fig. 1 The scientific inference process based on abductive inferences (from Oh 2012, p. 231)

3.1 Historical Overview of the Evolution of the Continental Drift Hypothesis

3.1.1 The Contractionism Hypothesis Crisis

By the later part of the 19th century, most geologists believed that massive episodes were caused by the relatively sudden crumpling of the crust, needed to relieve the pressure built up as the interior of the earth cooled and reduced in volume. Any part of the earth's surface might be pushed down to form an ocean bed or pushed up to form continents and mountains, depending on the precise location of the weakness that gave way to the pressure caused by contraction. By the early 20th century, the cooling-earth model had come under fire, as the theory of radioactive heating suggested that the internal temperature could be maintained over thousands of millions of years. In his physics of the Earth's Crust in 1991, the British geophysicist Osmond Fisher collected evidence suggesting that the continental rocks were composed of lighter material than those from the deep ocean bed (Bowler and Morus 2005, pp. 239–240). The contraction mechanism of mountain building was dead, and it seemed obvious to Wegener that horizontal continent movements would provide an alternative explanation. At a now notorious meeting of the American Association of Petroleum Geologists in 1926, the drift theory was openly rejected. The old idea of the sunken land bridge was still used to explain the fossil evidence (Oreskes 1999, p. 64). This study thus considers only the contractionism hypothesis as a traditional rival theory for the Continental Drift hypothesis.

3.1.2 A Puzzling Fit

As Leonardo da Vinci noticed on early charts, continents in some regions looked as if they would fit together like jigsaw puzzle pieces if the intervening ocean were removed. In 1620, Francis Bacon also wrote of "certain correspondences" between shorelines on either side of the South Atlantic. In 1885, Eduard Suess, a respected Australian scientist, suggested that the southern Hemisphere's continents might once have been a single large landmass. He based his beliefs in part on the similarities of fossils found on these continents, especially fossils of the fern *Glossopteris*. Although so accurate a fit almost certainly could not have occurred by chance, no one had yet proposed a mechanism that could separate whole continents into moving pieces (Garrison 2002, p. 66). Wegener could explain certain correspondences between shorelines on either side of the South Atlantic if he assumes arbitrary assumptions. His rival, contractionism, judged that he could not explain the correspondences using a jigsaw fit.

3.1.3 The Continental Drift Hypothesis by Alfred Wegener

Alfred Wegener, a German meteorologist, is generally credited with developing the *continental drift* hypothesis in 1915. Wegener proposed that all landmasses were originally united in a single supercontinent that he called *Pangaea*, from the Greek meaning "all land." According to Wegener, *Pangaea* had broken into pieces approximately 200 million years ago. Since then, the pieces had moved to their present positions and were still moving (Wicander and Monroe 2006, p. 29).

Wegener's evidence included the apparent shoreline fit of continents across the North and South Atlantic and new information on offshore contours obtained by contemporary oceanographic expeditions. He pointed to Suess's *Glossopteris* and other fossils, areas of erosion apparently caused by the same glacier in tropical areas now widely separated (e.g., South Africa, India, and Australia), and the appearance of rock sequences and mountain ranges of the same age on continents now widely separated. Unlike anyone before him, Wegner also proposed a mechanism to account for the hypothetical drift. The spinning Earth with its centrifugal effect, coupled with the tidal drags on the continents from the combined effects of sun and moon, would account for the drifting continents (Garrison 2002, p. 66). They were unable to propose an alternative power source that could move the massive granitic continents.

Wegener did not live long enough to solve the geophysical problem. In December 1927, Holmes read a paper to the Edinburgh Geologist Society, where he revealed his drift colors. It was an extraordinary presentation and anticipated much of what was to come. Not only did he accept that "drift" had occurred, but he also suggested its elusive mechanism. Holmes' work with radioactive elements had made him aware of the possibility that they could be a source of heat (Fortey 2004, p. 140). Even so, no one had paid any attention, and Holmes's suggestions did nothing to boost the fortunes of Wegener's theory.

3.1.4 Continental Drift Revived due to Paleomagnetism and Polar Wandering

Interest in continental drift revived during the 1950s as a result of new evidence from paleomagnetic studies. Paleomagnetism is the remanetism in ancient rocks recoding the direction of Earth's magnetic poles at the time of the rock's formation. The apparent location of the north magnetic pole on continents is shown for different periods on each continent's polar wandering path (Wicander and Monroe 2006, p. 35).

3.1.5 Seafloor Spreading Updating Continental Drift, Testing Seafloor Spreading with new data, and Magnetic Reversals

The early debate about continental drift and the data on apparent polar wandering had centered on evidence drawn from the *continental crust*. If the continental crust moves, should the oceanic crust not also move? In 1962, Harry Hess of Princeton University hypothesized that the seafloor generation mechanism could be explained if the seafloor moved sideways, away from the oceanic ridges. His hypothesis came to be called the *seafloor spreading* hypothesis and was soon proved correct. Paleomagnetism again provided the proof. Three geophysicists, Fredrick Vine, Drummond Matthew, and Lawrence Morley, proposed a powerful test for the Hess theory (Skinner and Porter 2000, p. 461).

3.1.6 Plate Tectonic Theory Updating Seafloor Spreading

These main points answered the main objection to Wegener's ideas, e.g., that movement must occur with minimal resistance from friction. Plate tectonics says that as the lithosphere moves, the crust is rafted along as a passenger. Continents move, but they do so only as portions of larger plates, not as discrete entities. If, as the theory of seafloor spreading required, new oceanic crust is created along mid-ocean ridges, either the Earth must be expanding and ocean basins growing or an equal amount of old crust must be being destroyed. The Benioff zones provided the answer to the puzzle. The only places where intense deformation occurs are at any edges along which plates impinge on each other. Such plate margins are active zones; plate interiors are stable regions (Skinner and Porter 2000, pp. 461–463).

3.2 Generating and Selecting Creative Hypotheses: Abductive Inference

"**Puzzling Observation**"

- **Strategies**: Data abstraction or reconstruction based on new data

We first considered the "fit" of the coasts on the continent, and we then considered the affinity among fossils from different continents, all based on data reconstruction. We claim that abstract strategies may be covered using all scientific inference process as follows:

> Wegener was not the first to notice that the apparent "fit" between the coastlines of Africa and South America makes it look as though the Atlantic Ocean had been created by the continents being pulled apart. However, Wegener was the first to build this insight into a whole theory that sought to explain a wide range of geological phenomena in terms of continental drift hypothesis (Bowler and Morus 2005, p. 238).

What is presented through these phenomena? (State issue): The coasts of Africa and South America seem to be a perfect fit (Fig. 2).

"**Invention of Hypotheses**"

- Unexplained and Astonishing phenomenon: expressing causal questions

What do you say this phenomenon of fitting together resembles? (Make an analogy) ⋆ The torn pieces of a newspaper with matching edges.

- **Strategies: Simple Abduction or Analogical Abduction**

Philosophers use the term abduction to refer to the process of creative hypothesis generation (Hanson 1958). Abduction involves sensing ways in which the current situation is somehow similar (analogous) to other known situations and using this similarity as a source for hypotheses in the present situation (Lawson 2010) (Fig. 3).

"Wegener himself had described the logic behind many observations: 'It is just as if we were to refit the torn pieces of a newspaper by matching their edges **(at first)** and then whether the lines of print run smoothly across **(next).** If they do, there is nothing left but to conclude that the pieces were in fact joined this way.'" (Fortey 2004, p. 138).

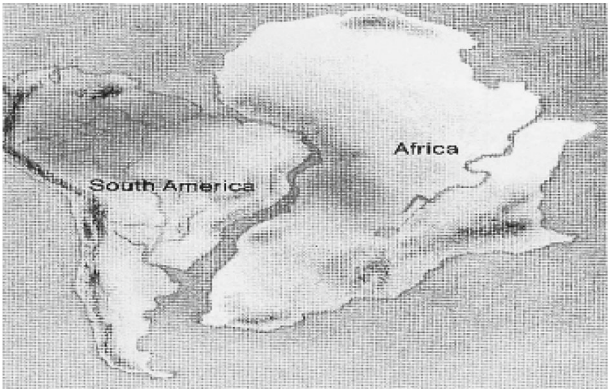

Fig. 2 The fit of the continental profiles: the western coast of Africa and the eastern coast of South America (from Fronk and Knight 1994, p. 12)

Fig. 3 The principle of reconstructing continents is not so different from rejoining the headlines from this torn newspaper (from Fortey 2004, p. 138)

> Wegener first conceived of continental drift in 1910 while examining a world map in an atlas. However, it took two years for him to *assemble sufficient data* to propose the idea in public. Wegener's evidence went far beyond the congruence in the shapes of the continents. He proposed that the similarities between unusual fossils found only in certain parts of South America and Africa indicated that these two continents were joined at one time (Franknoi et al. 2004, p. 158).

Whewell required a hypothetical theory to "explain phenomena which we have observed" and "foretell phenomena which have not yet been observed." We sufficient data consider for Wegener to assemble as data which were observed rather than foretell data.

At first:

Simple Abduction,

…… apparent "fit" between the coastlines of Africa and South America

(If) papers would be once joined,

(then) the edges of the already torn all papers fit together,

Therefore (Hence), there is reason to believe that two continents were once joined.

Wegener stated his continental drift theory to persuade others thus:

(If) the edges of the already torn newspaper fit together in everyday life (and) the close fit between the coastlines of South America and Africa on opposite sides of the Atlantic Ocean are like this, (then) the continents were once joined, after which they drifted apart.

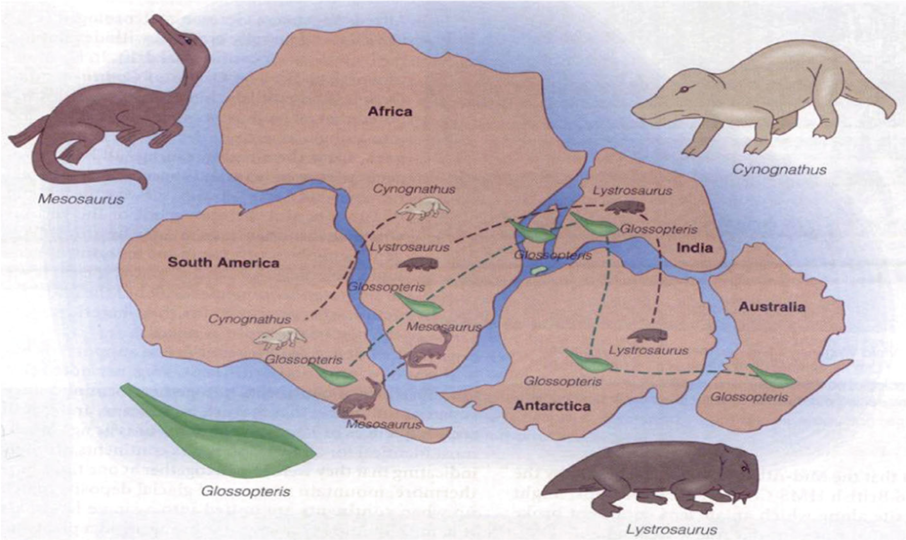

Fig. 4 Geographic distribution of plant and animal fossils with the same geologic age (from Wicander and Monroe 2006, p. 32)

"**Selection of Hypotheses**"

Retroduction is testing hypotheses only with previously gathered data. It is the best selection methodology for all probable hypotheses based on previously collected data and facts, as a kind of eliminated inference (Lawson 2010) (Fig. 4).

Next:

(If) the continents were once joined and then drifted apart, **(and)** the remains can be tracked, **(then)** the remains of similar plants and animals could be found in Africa and South America as well as other continents. **(And)** the remains of similar plants and animals have been found in Africa and South Africa as well as India, Australia, and Madagascar; **(therefore),** the continental drift hypothesis is supported.

'However Wegener's claims were not support by his geological contemporaries, because of twofold. First, geology as a science was still beholden to the uniformitarian assumption inherited from the work of Charles Lyell in the 1830s. Continental drift seemed to be an affront to the motion of a fixed and regular Earth surface. Second, Wegener had no plausible mechanism for drifting the continents" (McMenamin 2007, p. 165). It is thus possible that an alternative claim for this "Continental Drift hypothesis" was called the "continental bridge hypothesis". This view was as essential as the one that asserted that the vertical movement of the earth's crust determines the land and ocean distribution thus:

(If) the continents have always been separated, then they were connected with continental bridges (and) these bridges facilitated plant and animal movement from one place to another. If these bridges later subsided below sea level, the remnants of continental bridges should be observed. (Then), the remains of similar planets and animals could be found in Africa and South America as well as the other continents. (And) the remains of similar plants and animals have been found in Africa and South Africa as well as India, Australia, and Madagascar, (therefore), the continental bridge hypothesis is supported.

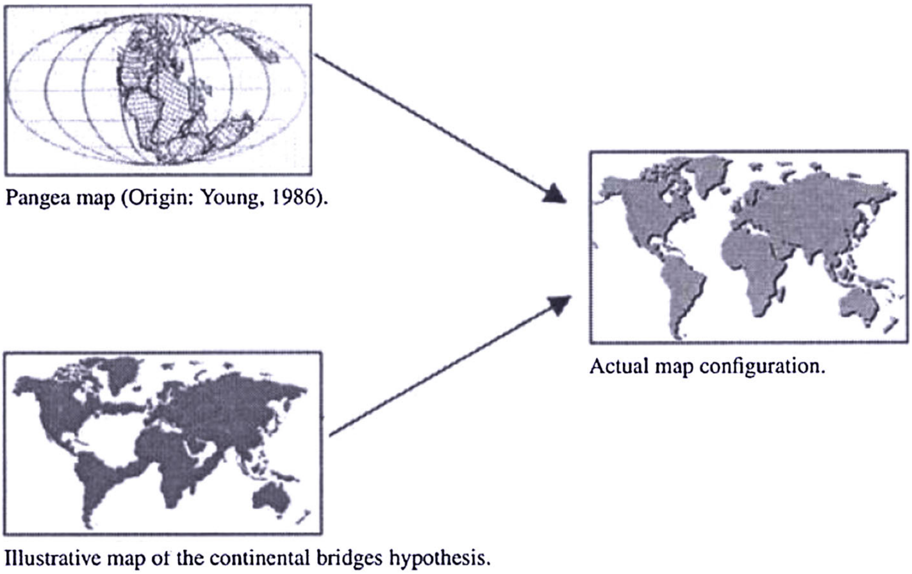

Fig. 5 The present configuration explained according to each hypothesis (from Paixão et al. 2004, p. 206)

Few scientists in 1915 regarded Wegener's hypothesis as even remotely plausible because no one could provide a suitable mechanism to explain how continents could move over the Earth's surface. Many years ago, there were continental bridges linking some continents, which facilitated plant and animal movement from one place to another. This shows how the same facts may lead to distinct hypotheses, e.g., the continental drift and continental bridge hypotheses.

Simplicity handles the problem of the conceptual complexity level of hypotheses with equal consilience. "This evaluation is strongly influenced by Ockham's razor: simplicity also can be highly relevant when discriminating between competing explanatory hypotheses" (Magnani 2001, p. 26) (Fig. 5).

These two competing hypotheses may give rise to the same prediction by adding to auxiliary hypotheses.

But this is the fundamental difference between the two hypotheses. Continental bridges of this magnitude and continuously additional numbers did not exist, and the auxiliary hypothesis of Wegener's Mobilism is simpler than that of the continental bridge hypothesis. Thus, Mobilism is a more plausible explanation than the continental bridge hypothesis.

> Although most of Wegener's contemporizes opposed his views, a few considered his ideas plausible. For these few geologists who continued the research for additional evidence, the exciting concept of continents in motion held their interest. Others viewed continental drift as a solution to previously unexplainable observation (Lutgens and Tarbuck 1998, pp. 318–319).

3.2.1 Updating Existing Hypotheses

The "selection of hypotheses" stage provides hypotheses of some justifiable plausibility, whereas the "updating existing hypotheses" stage increases the plausibility of a hypothesis based on the coherence of the background knowledge.

As*Rule-forming abduction strategies*, hypotheses to be generalized should inductively be compatible with existing and well-established theories to update hypotheses towards new theories. These hypotheses are then updated to generate new theories.

At first, Rule-forming Abduction strategy: Holmes' thermal convection theory

Wegener's efforts to explain how the continents moved across the surface did not prove convincing.

Using the assumption that the thermal convection theory can be applied based on the already known Curio's radio decay energy theory in earth's interior under surface:

If x is a huge continent above the mantle, there are y called radioisotopes in this mantle, x is pulled apart and then drifts; to generate it, there are y called radioactive elements

For a huge continent's drift, there are y called radioactive elements. A new thermal convection theory for the mantle can be formed to connect and explain them.

> Wegener did not live long enough to solve the geophysical problem. In December 1927, Holmes read a paper to the Edinburgh Geologist Society, where he revealed his drift colors. It was an extraordinary presentation and anticipated much of what was to come. Not only did he accept that "drift" had occurred, but he also suggested its elusive mechanism. Holmes' work with radioactive elements had made him aware of the possibility that they could be a source of heat (Fortey 2004, p. 140).

The Second Rule-forming Abduction strategy, Sea Floor Spreading Formation

Unfortunately, Holmes' thermal convection theory was not untestable.

On the assumption that there are hot spots in the middle of the seafloor, a new seafloor generated at the hot spots spreads out equally on all sides.

If outward from x, the hot spots, there is y, another deep ocean crust, then the crust spreads outward from x; and then there must be y, young age crust, equally on either side.

Therefore, there are young crusts equally on either side outward Cross-section of the mid–ocean ridge, and then to explain them, the term "seafloor spreading" was coined by Ditz.

The 1960s was a time of extraordinarily rapid progress in the understanding of continental mobility. Hess (Wicander and Monroe 2006, p. 35) in 1962 explicitly stated why the most obvious aspect of the Mid-Atlantic Ridge was so: it was median "because the continental areas on each side of it have moved away from it at the same rate…" This is not exactly the same as continental drift. The continents do not plough through the oceanic crust propelled by unknown forces; rather, they ride passively on mantle material as it comes to the surface at the crest of the ridge and then moves laterally away from it. Continents are part of processes that also involve the oceans. Thus, at last, the criticism of the physicist Harold Jeffreys was answered regarding the impossibility of the continents sailing across the basalt oceans like huge, granitic basques. They did not; they were at one with the oceans. New oceanic crust was added at the ocean ridge, where it was known that heat flow was high and that there were submarine volcanic activities (Fortey 2004, p. 147).

3.3 Testing Hypotheses: Corroborating Hypotheses

Generated hypotheses deductively lead to expected results for testing. If the model is correct, the history of the Earth's magnetic field for millions of years would be laid out on the ocean floor in strips parallel to the oceanic ridges. Moreover, there should be a correspondence between these alternating magnetic stripes and the alternating magnetic layers found in lava flows near volcanoes (Giere 1997).

3.3.1 Deduction

(If …) the seafloor separates at oceanic ridges where new crust is formed by upwelling magma, and formed crust moves laterally away from the ridge **(alternative hypothesis),**
(and …) a magnetic survey is possible away from the ridge for fluent and continuous times, and the Earth's magnetic field has completely reversed itself numerously times during the geologic past, **(test conditions and auxiliary hypotheses),** (then …) magnetic surveys of the oceanic crust could reveal striped magnetic anomalies in the rocks that are both parallel to and symmetric with the oceanic ridges **(Expected Result).**

3.3.2 Induction

(If…) the new observations match with the predictions, based on the seafloor separating at oceanic ridges where new crust is formed by upwelling magma, and formed crust moves laterally away from the ridge **(alternative hypotheses),** as they do in this case (e.g., magnetic surveys of the oceanic crust revealed striped magnetic anomalies in the rocks that were both parallel to and symmetric with the oceanic ridges **(Observed Result),**
(Then…) the seafloor-spreading hypothesis is supported **(Conclusion).**

3.3.3 Expected Observations

In the fall of 1965, an oceanographic research ship operated by the Lamont Geological Observatory at Columbia University was recording magnetic effects across the Pacific-Antarctic Ridge in the southeastern Pacific ocean. By dragging a magnetometer near the sea floor, the researchers measured the changes in magnetic intensity in the floor as one moves perpendicularly across and away from a major ridge. When the data were analyzed early in 1966, a pattern of increasing and decreasing magnetic intensity was revealed that matched the pattern of magnetic reversals found in minerals on land (Giere 1997).

3.4 Recycles

3.4.1 Route A: Updating Existing Hypotheses-Deduction-Induction Recycles

For cases where the observation outcome corresponds with the expected result, More data should be predicted deductively by further advanced hypotheses. By returning to the stage of updating hypotheses to form new advanced hypotheses, these new hypotheses lead to predictions deductively by repeating the updating-deduction-induction cycle; thus, this cycling procedure results in further developed theories.

3.4.2 Rule-Forming Abduction: Plate Tectonics

As the theory of seafloor spreading required, If new ocean crust is continually created along the mid-ocean ridge, the Earth must be expanding and the oceans must be getting larger.

On the assumption that there are different plates in earth crust, seafloor destruction turns out at each plate margins.

If at x plate margins, there is y destruction zone of the plate,

at x, ocean plate margin, and then there must be y, slanting zones cased the ocean plate destruction,

Therefore, there are y slanting zones toward continental plate from a kind of ocean plate margin, a trench, and then to explain them, the term “Plate tectonic” was formulated.

> If, as the theory of seafloor spreading required, new ocean crust is continually created along the mid-ocean ridge, either the Earth must be expanding and the oceans must be getting larger, or an equal amount of old crust must necessary be destroy in order to maintain an Earth of constant size. The clue was provided by the previously unexplained Benioff Zones (the Subduction Zones discovered by H. Benioff). These slanting zones of deep earthquake foci are the places where old, cold lithosphere is sinking back into the asthenosphere. In this way, cool and still brittle lithosphere can sink to great depths (Skinner and Porter 2000, p. 379).
>
> The reaction of the geological community was immediate and dramatic. Nearly everyone embraced mobilist models. During the next few years, geologists developed the idea of seafloor spreading into what is now called plate tectonics. According to the theory of plate tectonics, the Earth’s surface consists of several “plates” that slowly move about the surface, constantly changing the configuration of continents and oceans. Much of geological research now involves working out the details of this general theory (Giere 1997).

It should be noted that the ocean plate is younger than the continental plate because the origins of the two plates are different.

Route B: Abduction based on updating new dada-Deduction-Induction recycle

Non-monotonic Inference

The “Plate Tectonic” hypothesis has been supported because it is relatively simple. But recent studies indicate that the Lithosphere is necessary for thermal convection, rather than the movement caused by mantle thermal convection *(Unexpected data by the “Plate Tectonic” hypothesis).*

In addition to some type of thermal convective system driving plate movement ***(Revision of “Plate Tectonic” hypothesis***), some geologists think plate movement is also aided by “ridge-push” or “slab-pull” mechanisms ***(a newly revised hypothesis)***. Geologists are fairly certain that some type of convective system is involved in plate movement, but the extent to which other mechanisms, such as ridge-push and slab-pull, are involved is still uncertain (Wicander and Monroe 2006, pp. 46–47).

4 The Relation Between the Work of Šešelija and Weber (2012) and That of This Research

Recently, Šešelija and Weber (2012) did the evaluation of Drift by means of an account of theory evaluation suitable for the context of pursuit, develop in Šešelija and Straβer (in press). They say that a research tradition (Laudan 1977) is initially worthy of pursuit in a strong sense (WPSS) if it satisfied the following criteria. This research discusses their prior work, then compare with my work as follows:

4.1 Presence of Significant Explanation

By significant explanations in the context of pursuit, they mean those that address the phenomena for which the dominant rival has either no explanation, or has a very week explanation.

Rival Draft-contractionism can in this case be regarded as offering either a weak explanation for the two significant types of similarities between the continents or no explanation at all. First, the paleontological similarities, not only was there an overall resemblance of fossil forms indicating that continents must have been somehow connected in the past, but there was also an evidence of distribution of certain organisms, such as earthworms, and certain species of snails, unlikely to have crossed all the way across the land bridges. Second, there were an evidence of nearly identical stratigraphic sequence and structural pattern on the coastlines of the mating continent (modified from Šešelija and Weber 2012).

My Work argues the follows:

Stage (3) "Selection of a hypothesis" covers all phenomena that are present. The preliminary test stage then occurs, where tests are developed to select or eliminate hypotheses by *retroduction*. "Retroduction is testing hypotheses only with previously gathered data, and the best selection methodology for all probable hypotheses based on previously collected data and facts, as a kind of eliminated inference" (Lawson 2010). *Simplicity* handles the problem of the conceptual complexity levels of hypotheses with equal consilience, where consilience indicates a more significant explanation.

4.2 Inferential Density

Šešelija and Weber's standard consisted of the following two sub-criteria:

Their standard contained the following two sub-criteria:

1. Internal inferential density: A theory should not have a less unified core of hypotheses than its dominant rival.

   In regard to internal inferential density, neither rivaling theory was specially unified. Drift could not provide the precise mechanics for drifting, but it could account for many geological phenomena using the same hypothesis. In contrast, contractionism had to introduce an additional hypothesis, e.g., land bridges. Wegener's theory thus did not have a less unified core of hypothesis than its rivals (Šešelija and Weber 2012)

My work argues the follows:
Stage (3) "Selection of a hypothesis" covers all phenomena that are present. The preliminary test stage occurs, where tests are developed to select or eliminate hypotheses by *retroduction. Simplicity* handles the problem of the conceptual complexity levels of hypotheses with equal consilience and increases the internal inferential density.

"The degree of coherence of a hypothesis with what it explains and with its cohypotheses is inversely to the numbers of cohypotheses. For example, H1 is preferred to H2 and H3 because it accomplishes the explanation with no cohypotheses" (Thagard 1992, p. 77).

2. External inference density: A theory should be at least as inferential connected with established theories from other scientific domains as its dominant rival or it should be able to address the lack of such connections by means of its programmatic character.

Drift will be shown that it had inferential links with the theory of radioactive and isostasy. In contrast to contractionism that was not well connected with them. Thus it will be clear that Wegener's theory satisfied the criterion of external inferential density as well (Šešelija and Weber 2012).

My work argues the follows:

Stage (4) Updating existing hypothesis: Updating and selecting hypotheses involves updating or recreating existing hypotheses based on newly available information (Peng and Reggia 1990, p. 6) to develop more plausible hypotheses.

Rule-forming abduction thus produces rules that explain other rules, is important for generating theories that explain laws, and increases external inferential density

Programmatic character: a theory must have a programmatic character that addresses the major problems of the theory (e.g., explanatory anomalies, inconsistencies). Their criteria of pursuit worthiness were compatible with the updating stage in this research. The " selection of hypotheses" stage provides hypotheses with some justifiable plausibility, whereas the " updating existing hypotheses" stage increases the plausibility of a hypothesis based on the background knowledge coherence. As rule-forming abduction strategies, hypotheses to be generalized should inductively be compatible with existing and well-established theories for updating hypotheses towards new theories, and these hypotheses are updated to generate new theories, e.g., the At first Rule-forming Abduction strategy, Holmes's thermal convection theory, and the As Second Rule-forming Abduction strategy, Seafloor Spreading formation.

Theoretical growth and the growth of the programmatic character : a theory must exhibit a theoretical growth that occurs as a development in the previously mentioned WPSS standards.

Therefore, we will argue that pursuing the hypothesis of continental drift was rational than rival, the hypothesis of contrationism are consistent with our work, compatible with previous Šešelija and Weber (2012). Specially pursue procedure of the abduction which is suggested in this research. Kapitan (1997) claims that the form of the conclusion of Peirce's abduction is also misleading, to assert the truth of its conclusion would be too much, the aim of every abduction is to recommend a course of action. One might suppose that its conclusion implies there is reason to suppose that H is worth pursuing (examining further) (Oh 2010).

5 Conclusions and Implications

We have explored and proposed a scientific inference procedure based on various kinds of abductive strategies for the criteria of theory selection, and we have examined our procedure's validity by applying it to the question of continental drift, which revolutionized Earth science.

First, we suggested a scientific inference procedure based on abductive inference strategies to generate hypotheses; this procedure involves the deduction-induction method for the evaluation of hypotheses. The term "abduction" is usually applied to the evaluation of explanatory hypotheses, although it sometimes also includes processes for generating them (Josephson and Josephson 1996). The processes as suggested by this research above drive patterns of if/then/therefore reasoning used to test these explanations, which is based on Magnani's research (2001).

Second, the role of creativity in the invention of hypotheses is very important because hypotheses invented by analogical abduction from other domains to explain puzzling phenomena are tentative hypotheses of argumentation claims. However, if new information suggests hypotheses that have not previously been considered, a new cycle begins again by revising the existing hypotheses; this is what we refer to as "non-monotonic" character.

Third, through the work of Šešelija and Weber (2012), recent article with interest. we will argue that the hypothesis of continental drift was rational than that of rival, the hypothesis of contrationism are consistent with our work, specially the generalized pursue procedure of the abduction inference in this research.

Finally, Geography, one of the natural sciences, is subject to methods of inquiry that drive causal explanations for historical evidence of natural phenomena. Therefore, they are statically valid, based on abductive inference.

Originality may be the capacity to look at the same facts and see new explanations. Much of the same evidence that had been used for a previous abduction was paraded again by Wegener to draw an utterly different map and to make predictions as different from drowned continents as could be imagined. Just as Suess' theory died by its predictions, so the theory of Gondwana and Pangaea finally lived by virtue of facts that were still to be uncovered. Process of theories formation from Continental Drift to Plate Tectonics Theory are involved with all abduction strategies: simple, analogical, existentential, rule-forming abduction.

Hintikka (1999) maintains that regarding the theory of logic and reasoning, especially at the level of introductory textbooks and courses, the study of excellence in reasoning is often forgotten, and the emphasis is on the avoidance of mistakes in reasoning. The focus has been on definitory rules, and strategic rules have largely been neglected. No one is good at logic and reasoning based on knowing only the definitory rules of logic; one must also master the strategic rules.

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