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ABDUCTIVE REASONING: A CONTRIBUTION TO KNOWLEDGE CREATION IN EDUCATION[1]

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Abstract

Based on an epistemological discussion, this paper aims to show the contribution of abduction as a scientific procedure in the educational field. To that end, I explain how scientific research approaches and processes are founded on the three types of logical inference: deduction, induction and abduction, all of which underpin knowledge building and the role of both science and researchers. Firstly, I describe the specific features of abduction according to Peirce's philosophical system. Then, I illustrate its implementation in a study on teaching. Finally, I underscore how abduction could contribute to build a broader scientific project in the intercept between basic and praxeological research.

EPISTEMOLOGY • RESEARCH • KNOWLEDGE • METHODOLOGY

RAZONAMIENTO ABDUCTIVO: UNA CONTRIBUCIÓN A LA CREACIÓN DEL CONOCIMIENTO EN EDUCACIÓN

Resumen

Basado en una discusión de carácter epistemológico, este artículo pretende mostrar el aporte de la abducción como procedimiento científico en el campo educativo. Para ello, se plantea cómo los enfoques y procesos de investigación científica se estructuran desde las tres clases de inferencia lógica: deducción, inducción y abducción, los cuales fundamentan la construcción de conocimiento y el rol de la ciencia y del investigador. La abducción es descrita con sus especificidades al interior del sistema filosófico de Peirce, para luego ilustrar su implementación a través de una investigación sobre el trabajo docente. Finalmente, se destaca cómo la abducción podría aportar en la construcción de un proyecto científico más amplio, en el cruce entre la investigación fundamental y praxeológica.

EPISTEMOLOGÍA • INVESTIGACIÓN • CONOCIMIENTO • METODOLOGÍA

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RAISONNEMENT ABDUCTIF: UNE CONTRIBUTION À LA CRÉATION DES CONNAISSANCES EN ÉDUCATION

Résumé

Cet article, basé sur une discussion à caractère épistémologique, vise à montrer ce que l'abduction peut apporter à la procédure scientifique dans le domaine de l'éducation. Pour ce faire, il verifie comment les approches et les processus de recherche scientifique se structurent à partir de trois types d'inférence logique: la déduction, l'induction et l'abduction, qui étayent la construction de la connaissance et le rôle de la science et du chercheur. L'abduction et ses spécificités seront d'abord décrites à partir du système philosophique de Peirce, et son application illustrée par moyen d'une recherche sur le travail enseignant. Finalement est mise en avant la contribution de l'abduction pour l'élaboration d'un projet scientifique plus vaste, à l'intersection de la recherche fondamentale et praxéologique.

ÉPISTÉMOLOGIE • RECHERCHE • CONNAISSANCE • MÉTHODOLOGIE

RACIOCÍNIO ABDUTIVO: UMA CONTRIBUIÇÃO PARA A CRIAÇÃO DO CONHECIMENTO NA EDUCAÇÃO

Resumo

Baseado em uma discussão de caráter epistemológico, este artigo pretende mostrar a contribuição da abdução como um procedimento científico no âmbito educacional. Com essa intenção, pergunta-se como os enfoques e processos de pesquisa científica são estruturados a partir dos três tipos de inferência lógica: dedução, indução e abdução, que fundamentam a construção de conhecimento e o papel da ciência e do pesquisador. A abdução é descrita com suas especificidades no seio do sistema filosófico de Peirce, para depois ilustrar sua implementação através de uma pesquisa sobre o trabalho docente. Finalmente, destaca-se como a abdução poderia contribuir para construir um projeto científico mais amplo, na interseção entre a pesquisa fundamental e praxeológica.

EPISTEMOLOGIA • PESQUISA • CONHECIMENTO • METODOLOGIA

A DÚRIZ-BRAVO (2005) POINTS OUT THAT ONE OF THE MOST FREQUENT COGNITIVE processes is to infer consequences from available data. When these data are expressed in linguistic models, it is called a reasoning. Reasonings are usually deductive and inductive; however, abductive reasoning has a crucial role in scientific modeling processes. Therefore, reflecting on scientific approaches and on the knowledge-building process is key for any investigation. Nevertheless, the logical reasoning that structures investigative processes, as well as their epistemological implications, do not seem to be not very explicit, and even less conceptualized, particularly regarding the various views about science, knowledge and the role of the researcher. In other words, we must assume that scientific procedures have a significant logical and epistemological dimension. This is critical when it comes to praxeological research, which aims to combine knowledge-building processes and the processes involved in changing human and social realities.

In educational research, knowledge and scientific reflection emerge most often from approaches in which theoretical frameworks and hypotheses are imposed *a priori* –hypothetical-deductive logic –, followed by an exploration of the empirical world in order to validate/invalidate them. Although less generalized, studies arising from grounded theory (GLASER; STRAUSS, 1967) have influenced research that starts with observation and field work to allow the emergence of explanatory theories and hypotheses or, in some cases, a comprehensive reflection

– holistic-inductive logic. Thus, the hypothetical-deductive and holistic-inductive approaches provide the framework for most of the research in pedagogy and education, usually as opposite approaches.

However, there is a third, less popular and even unknown possibility: abduction, a notion developed by Aristotle in his Organon (1995) and later resumed by Peirce (1965). Abduction is an approach that works from a comprehensive theory of reality which prepares the empirical work and narrows the study field. The hypothesis is not given *a priori*; it emerges from data to then be verified. The purpose of this paper is threefold: a) to show the logical scope of the different approaches; b) to present their epistemological implications; and c) to highlight the importance of abduction for overcoming the opposition between deduction and induction. This will be done in three sections as described below.

The first section develops further the logical and epistemological issues underlying the inductive and deductive approaches, so as to prepare the way for abduction. Here, the main goal is to show how the hypothetical-deductive approach assumes an epistemology formed by already-existing paths as it seeks to validate an *a priori* hypothesis. Likewise, I point out how the holistic-inductive approach implies an epistemology of heuristic subjectivity, since the researcher ends up concretizing the real from his/her own knowledge, which is unconsciously mobilized. Finally, I introduce abduction as a logical inference. The second part deals in greater detail with abduction as a central element of Peirce's philosophical system (2002). This perspective, to which management sciences (DAVID, 1999) and semiotics (ECO, 1989) have also contributed, interprets abduction both from its logical and epistemological viewpoint, i.e., as something at the origin of a process: the abduction/deduction/induction spiral cycle. This is how I propose to overcome the dichotomy/antagonism that is often thought to characterize the deduction-induction relationship. Finally, the third section presents an implementation of this cycle, which allows, on the one hand, to think about a more complex research project (MORIN, 2008) comprehending both research and intervention, and, on the other hand, to present a mechanism for analyzing teachers' work.

LOGICAL INFERENCES AT THE HEART OF SCIENCE

Researchers always conduct their work according to the logic of some scientific method. In human and social sciences in general, the method consists of some classic phases, i.e., problematization, epistemological or theoretical frameworks, hypotheses, empirical data collection, analysis and validation/invalidation of the hypothesis, and conclusions; sometimes, in other, more inductive models, the disposition of phases begins with problematization and collection of empirical data to end with a theory and a hypothesis, which may be explanatory or comprehensive. Therefore, the two most frequent approaches in educational research are the hypothetical-deductive and the holistic-inductive. Despite their frequent use, they seldom include a logical and/or epistemological reflection. To

make this point evident, I am going to head beyond the pure field of human sciences, since research methodologies, though specific to the various disciplines, have the same structure in a logical and epistemological sense. Based mainly on Peirce (1965, 2002), I will use references from both the natural sciences and the "sciences of the spirit", thus resuming Dilthey's (1992) well-known distinction. To defend the idea that inferences have a double logical-epistemological dimension, I will describe how this manifests both in deduction and induction. Then, I will introduce abduction as a third possible type of inference.

ABOUT DEDUCTION

From the deductive approach to the logical aspect

The hypothetical-deductive method can be defined as the "mental operation which consists, primarily, in starting with a proposition or set of propositions of universal (or at least general) reach, from which emerges a hypothesis or a set of hypotheses referring to particular cases"[2] (GAUTHIER, 1986, p. 522). The type of reasoning behind this approach was posed by Aristotle (1995) in the Prior Analytics, an integral part of his Organon;[3] in his theory of sign, this reasoning is called *apodeixis*. The following table shows (on the left) the research approach, with its corresponding research phase (middle column) and logical structure (right column):

TABLE 1
DEDUCTIVE REASONING

RESEARCH APPROACH	PHASE/ PREMISE	DEDUCTIVE SYLLOGISM
Theory/Hypothesis	Rule	A. All the marbles in package X are white
Empirical study	Case	B. These marbles are from package X
Validation/Invalidation	Result	C. These marbles are white

Source: Prepared by the author.

Deduction – in Table 1, the A-B-C formula, the "deductive syllogism" column – works with the purpose of "obtaining a consequence (C) from a general rule (A) and an empirical observation (B)" (DAVID, 1999, p. 3). This type of syllogism has marked the whole history of humanity: it comprises the Cartesian method and, from then on, all of science. The hypothetical-deductive approach, established from this type of inference, is to this day – it must be stressed – the most used in scientific research (i.e., articles, observations, thesis, etc.).

2 In original: "opération mentale consistant avant tout à prendre pour point de départ une proposition ou un ensemble de propositions de portée universelle (ou du moins générale) dont on tire une hypothèse ou un ensemble d'hypothèses portant sur des cas particuliers".

3 Prior Analytics, one of Aristotle's most important texts, is also one of the most important works on logics as it presents the theory of syllogism: the analysis of arguments according to their forms, i.e., according to the various figures and modes of syllogism. It is worth noting that, to Aristotle, there is only one science – the science of the general and the necessary. Syllogism is the organon of science, i.e., its instrument.

From the logical aspects to the epistemology of deduction

The logical aspect, however, has consequences at the epistemological level. Deductive research seeks to build true knowledge. Thus, the research project is structured from a theoretical framework with a fixed view of reality; from theoretical elements established a priori, an explanatory or comprehensive hypothesis is proposed for the phenomenon studied. The empirical world will then be the guarantor of the hypothesis validity (or invalidity). The "conservative" nature of the hypothetical-deductive approach comes from the fact that the hypothesis is subjected to the possibilities offered by the theoretical framework used – the more restricted it is, the less it allows data to "speak". For example, if we propose a socio-cognitive theory of learning, the comprehensive or explanatory hypothesis will not consider the genetics of the individual. What is sought in this approach is, in the best of cases, to validate the scientific work, even if it follows a Popperian logic.[4] The use and goals of deduction are shown in the table below:

TABLE 2
DEDUCTIVE APPROACH IMPLEMENTATION

DEDUCTIVE APPROACH	OPERATIONALIZATION	GOAL
Theory/Hypothesis	*A priori* theoretical framework	Proposing a theoretical-empirical relationship
Empirical study	Methodology according to the theory and pertinent to the empirical context	Finding indicators of that relationship
Validation/Refutation	Interpretation and argumentation favoring the hypothesis/theory	Proving the hypothesis/theory to be consistent

Source: Prepared by the author.

In deduction, the status of thought is a static one, since what the researcher does is reproduce a theory, either to validate it or refute it. Scientific knowledge is simultaneously an existing knowledge and, to a lesser extent, an object to be developed under the shadow of existing theories, since deduction does not add new discoveries – its result is already contained in the rule.[5] Thus, it is an epistemology whose paths are already drawn, and this, it must be said, has some scientific interest – e.g., to test the resistance of a theory, to use it in other contexts, etc. In the hypothetical-deductive method, scientific theories can never be deemed true, but, at best, not refuted. Thus, knowledge and the researcher's role can be viewed as reproductive, because the theory – rule – is resumed both in the framework of the empirical study – cases – and in the validation/refutation of the hypothesis – results –, these last two elements being knowingly contained in the theory (DAVID, 1999). And the conclusion reached is paradoxical: the hypotheses can be refuted, but not verified. Moreover, the nature of science is

4 This means recognizing that the work of a hypothetical-deductive thesis, for example, is too valuable not to validate the initial hypothesis after results. Therefore, one may say that either the hypotheses in these works lack boldness, or that the falsifiability applied is rather moderate. It is worth remembering that, to Popper, falsifiability is the property a universal proposition has when it involves at least one statement that is logically possible and deductible from it that can be proved false by empirical observation. If it is not possible to imagine an empirically verifiable statement that contradicts the original proposition, then such a proposition will not be falsifiable.

5 This criticism is closely related to Peircean thinking about meaning. To learn more about this criticism, see Peirce (2006).

that its claims are refutable on principle: they can be refuted by experience when put to the test.

ABOUT INDUCTION

From the inductive approach to the logical aspect

The second type of reasoning is one that, without relying on pre-existing knowledge, addresses its subject of study from experience, from what is observed in particular cases. This holistic-inductive procedure[6] seeks to make theory emerge from the empirical world, *a posteriori*. It is used mainly by grounded theory (GLASER; STRAUSS, 1967), in which experience occupies a critical position. Accepting subjectivity, grounded theory calls forth the researcher's sensitivity and creativity to arrange the real and theorize about it using a procedure that ensures scientific rigor.[7] The stages of this approach (Table 3, left column) can be seen in the Aristotelian syllogism called *apagoge*, whose logical construction is shown in Table 3 (right column):

TABLE 3
INDUCTIVE REASONING

INVESTIGATION APPROACH	PHASE/PREMISE	INDUCTIVE SYLLOGISM
Empirical study	Cases	B: These marbles come from package X
Analysis/Arrangement of reality	Result	C: These marbles are white
Theory/Hypothesis	Rule	A: All the marbles from package X are white

Source: Prepared by the author.

This second way of reasoning corresponds to a permutation of the deductive syllogism A-B-C into the form B-C-A. It consists in finding a rule (A) that could account for the result (C) if the empirical observation were true (B). For Aristotle, induction does not imply generality because, according to him, it is not licit to conclude a general rule from two particular premises. In table 3, the marbles case is examined considering the known facts that they are white and can be confirmed to come from package X; but establishing the rule that "all the marbles in package X are white" cannot be accepted; therefore, Aristotle's rejection of this reasoning applies to all induction-based scientific research. This is resumed in the following observation by Hume:[8] "What entitles one to pretend that what we infer from cases observed will continue to hold for cases not yet observed?" (cited in DELEDALLE, 1990, p. 160). However, according to Peirce

6 At this point, it is worth noting that there are several inductive studies which, in principle, would not seek rules, but a singular comprehension of phenomena. Peirce's (2002) interpretation refers to the inductive-logical inference that aims to create rules.

7 For more information on "grounded theory", see Raymond (2005) and Weick (1989).

8 HUME, David. Tratado de la Naturaleza Humana: Ensayo Para Introducir el Método del Razonamiento Humano en los Asuntos Morales. México City: Porrùa, 2005.

(1965, 2002), research approaches built on inductive reasoning can produce a rule in the long-term by contrasting the hypothesis with the empirical world.

From the logical aspect to the epistemology of induction

The project of inductive research, more particularly of grounded theory, is primarily an exercise of disciplined imagination (WEICK, 1989):

TABLE 4
INDUCTIVE APPROACH IMPLEMENTATION

INDUCTIVE APPROACH	OPERATIONALIZATION	GOAL
Empirical study	Methodology built in the empirical world	Establishing pathway indicators
Analysis/Arrangement of reality	Interpretation and identification of comprehensive/explanatory elements	Finding logical relationships that connect phenomena
Theory/Hypothesis	*A posteriori* theoretical framework	Stabilizing an explanation in the form of a hypothesis/theory

Source: prepared by the author.

Inspired by American sociology and phenomenalism,[9] the inductive approach carries a legacy that is both complex and full of extensive debates (RAYMOND, 2005). Researchers who adhere to this approach are divided, in ontological and epistemological terms, between pro- or post-positivists and pro-constructivists;[10] the flexible nature of this approach allows placing it between these two paradigms. With regard to its epistemological scope, this approach implies a dynamic view of thought in which the researcher mobilizes his/her capacities towards creating categories to arrange the real and eventually generate knowledge. The latter will take place in a discovery as it is not already contained in a theory employed to capture the real: it emerges from empirical data arranged by the researcher. However, capturing the world is not an act we perform "with our bare eyes" as there is always some angle of apprehension of phenomena in place (GUILLEMETTE, 2006; ANADÓN; GUILLEMETTE, 2007). Aware of this problem, researchers who follow the inductive paradigm reaffirm the place of subjectivity in treating empirical data *a posteriori*. Nevertheless, the criticism about the presence of a permanent "classification" of phenomena by reason seems to remain valid. The inductive-approach epistemology may be understood as one of heuristic subjectivity, in which the researcher arranges and gives meaning to the

9 Phenomenalism is a positivist current that seeks relationships between phenomena based on verifiable facts, without resorting to metaphysics by any means. According to this current, essence and phenomenon are the same thing (KOLAKOWSKI, 1966).

10 On the positivist side, pro-positivists argue that the properties of social reality – external to man – can be captured by methods that ensure objectivity, with knowledge being viewed as based on measurable data, whereas post-positivists reject that the science of the spirit should have the same structure as the natural sciences to explain human phenomena, leading them to use mixed methods: behavioral observation, interpretation of values and other, unobservable elements. In both cases, reality is objectifiable. In contrast, the pro-constructivist current argues that reality is perceived hermeneutically, i.e., as a subjective interpretation of the world. See Bryant (2002) and Raymond (2005) for more details on the different positions related to grounded theory.

empirical world, in a search "for intuitions to be validated by data" (ANADÓN; GUILLEMETTE, 2007, p. 33).

DEDUCTION, INDUCTION, A PLACE FOR ABDUCTION?

From a historical viewpoint, Aristotle (1995) had pointed out the three types of reasoning: *apodeixis* or deduction, *apagoge* or induction, and *epagoge* or abduction. According to him, with the last of these, one may "approximate science" (p. 317), but one is not fully in science as abduction is but probable or possible knowledge. As said earlier, because the Aristotelian project aims at true knowledge, abduction ends up excluded from this desired scientificity.[11] It was not until two thousand years later that Peirce resumed Aristotelian abduction, integrating it into his philosophical system in an unprecedented, totally renewed way: Peirce devoted himself mainly to studying the logic of science, understood here, on the one hand, as abduction, i.e., the formation of hypothesis to explain surprising facts, and on the other, as induction, i.e., the generalization of hypotheses by means of tests. His core proposal consisted in establishing induction and abduction firmly and permanently beside deduction in the very concept of logic (RODRÍGUEZ, 2005, p. 88). Much of the criticism (REILLY, 1970; ECO, 1990) of the Peircean notion of abduction is solely focused on its logical aspect, thus prolonging the Aristotelian idea of an "invalid" syllogism and discarding the epistemological aspect of abduction without any reference to the ontosemantic question – a topic I will briefly address in the second part of this paper – Abduction: an inference, a method. But Peirce's project goes further:

> Abduction has the role of introducing new ideas into science: in one word, creativity. Deduction extracts the necessary, verifiable consequences from whih should derive that the hypothesis is correct, and induction experimentally confirms the hypothesis in some cases. However, these three types of reasoning do not work independently or in parallel, but in an integrate, cooperative manner over the successive stages of the scientific method.[12] (GÉNOVA, 1996, p. 59, free traduction)

In other words, as logical inferences, abduction, deduction and induction play a precise role in the development of science. However, the case we make here is that these three phases form a more complex method, understood as a "cycle" (DAVID, 1999); it is precisely a project to overcome the deduction-induction dichotomy, a

11 For a more detailed explanation of this type of syllogism in Aristotle, see Quine (1973) and Aristotle (2001).

12 In original: "A la abducción corresponde el rol de introducir las ideas nuevas en la ciencia: la creatividad, en una palabra. La deducción extrae las consecuencias necesarias y verificables de las que se debería seguir que la hipótesis es cierta, y la inducción confirma experimentalmente la hipótesis en una porción determinada de casos. Pero estas tres clases de razonamiento no funcionan de modo independiente o paralelo, sino integrado y cooperando en las fases sucesivas del método científico."

path towards "a recursive abduction/deduction/induction cycle" (1999, p. 1). In short, abduction is both a stage, as it introduces a new idea, and a method, i.e., a cycle that combines abduction, deduction and induction in a recursive process.

ABDUCTION: AN INFERENCE, A METHOD

> *Living doubt is the life of investigation. When doubt is set at rest inquiry must stop.* (CP 7. 315)[13]

According to Peirce (2002), one may say that abduction is the only way to arrive at a new idea. Based on the amazement before an unexplained event (a feature in common with induction), abduction embodies an approach in which doubt in all its forms – i.e., the questioning of theories, the search for explanations and valid arguments, etc. – is at the core of investigation.[14] Reducing abduction purely to terms of logical inference is a mistake: therefore, at least two epistemological senses can be established for the term abduction. Definition 1: the inferential process through which plausible hypotheses are generated – we can call it creative abduction. Definition 2: the inferential process through which the best explanation is established and hypotheses are evaluated – we can call it evaluative abduction (MAGNANI, 1998, p. 1,[15] cited in RODRÍGUEZ, 2005, p. 93-94).

Understanding abduction in Peirce is not limited to following its evolution over his thought, since it is a major notion in the whole of his philosophical system, as will be seen below.

THE ORIGIN AND PLACE OF ABDUCTION IN PEIRCEAN THOUGHT

The initial question

At the outset, Peirce (1965) acknowledges a rivalry – concerning formal logic – with other thinkers, including Kant.[16] However, it is Kant's reflection on *a priori* synthetic judgments that raises one of Peirce's main scientific concerns:

> According to Kant, the central question of Philosophy is "How are synthetic judgments *a priori* possible?" But antecedently to this comes the question how synthetic judgments in general,

13 I will henceforth use canonical citation for Peirce's works.

14 In this respect, Peirce sides with the Descartes of the Metaphysical Meditations about the "methodical doubt" procedure. Furthermore, according to Peirce, a hypothesis never gets to have the status of knowledge, but that of belief, and since abduction consists of a recursive loop that is always returning to its own assumptions, Peirce may be said to have provided clues on the concept of falsifiability fifty years before Popper (ALISEDA, 1998).

15 MAGNANI, Lorenzo. *Abduction and Hypothesis Withdrawal in Science*. Boston, MA: 20th World Congress of Philosopy. Available on: http://www.bu.edu/wcp/Papers/Scie/ScieMagn.htm. Access on: March, 20, 2016.

16 "We have in mind three men of great strength, Aristotle, Duns Scotus and Kant. Our greatest enemies, were, in antiquity, Pythagoras, Epicurus, and in the modern world, Descartes, Locke and, I should add, Hegel" (PEIRCE, 2006, p. 17).

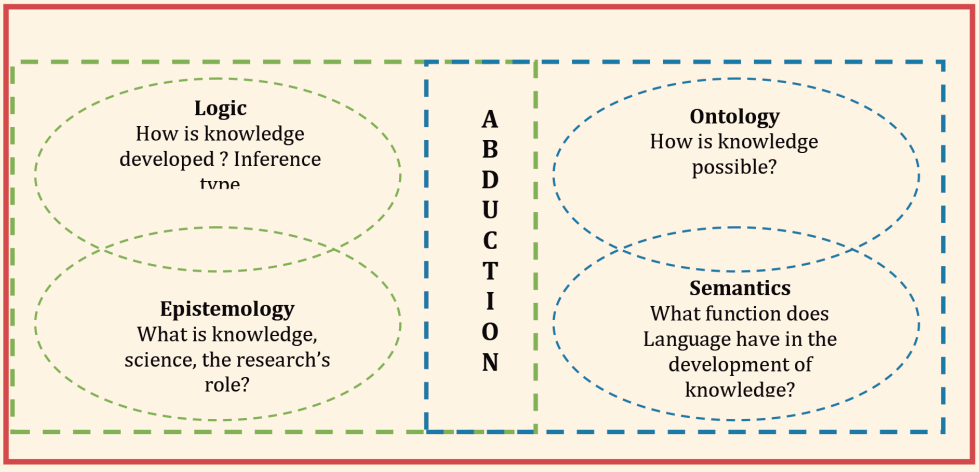
> and still more generally, how synthetic reasoning is possible at all. When the answer to the general problem has been obtained, the particular one will be comparatively simpler. This is the lock upon the door of philosophy. (CP 5. 348)

The possibility of *a priori* synthetic judgments, i.e., propositions that increase knowledge and are prior to experience,[17] is a problem with greater appeal to Peirce than the possibility of reasonings that increase knowledge. Aliseda (1998) says that, following Kant, Peirce shows two different faces of his own project, both of which are interrelated (as will be seen): justifying the possibility of synthetic reasoning and developing a method for acquiring reasoning.

Abduction in Peirce's philosophical system

In response to the challenge of finding a method to acquire knowledge, Peirce develops abduction.[18] Abduction occupies a central position in the Peircean system as it is a notion that bears a logical-epistemological question, with a double ontosemantic dimension (SOTO, 2005). Its epistemological level concerns the proper attitude towards science, knowledge and the researcher's role. The logical level regards the formal argumentative reasoning structure used to generate knowledge (inferences). The semantic level shows language's meaning and role in creating knowledge. Finally, the ontological level focuses on what makes knowledge possible (SOTO, 2005).

FIGURE 1
ABDUCTION IN PEIRCE'S PHILOSOPHICAL SYSTEM



Source: Prepared by the author.

17 *A priori* synthetic judgments differ both from analytic judgments, which are true propositions that do not involve anything new, and from *a posteriori* synthetic judgments, which, while adding new knowledge, require experience. This set of judgments is comprised in Kantian logic, which aims to establish the possibility of objective knowledge of phenomena – i.e., pure, intellectual and rational knowledge that allows knowing objects a priori.

18 Pierce outlined his proposals in a series of articles published from 1877 to 1878 in the popular Science Monthly, under the general heading of Illustrations of the Logic of Science. The last one, "Deduction, Induction, and Hypothesis", contains an explanation of the three inference modes (CP, 2.619-644).

Abduction is a response to the question initiated by Kant (2001) about how synthetic knowledge is possible. Likewise, it is a notion that ensures the systemic relationship between both dimensions, as shown in the scheme above. Consequently, the role of abduction is that of a hinge at the crossroads of a system, shaping a scientific method. This division between the double logical-epistemological and ontosemantic dimensions builds on the distinction between logic and ontology. The former refers to a logical generality, i.e., a representation, and the latter, to an ontological generality, i.e., what is represented by the representation. Thus, abduction has an ontosemantic element connected to the question of how to ensure that

> [...] beliefs are about something, about a fact or an object of the world, including the possibility that some beliefs may be about others, and that they may be something real, thus possessing the ability to change the flow of experience.[19] (SOTO, 2005, p. 5)

For the sake of consistency with the goals of this paper, I will only address the double logical-epistemological dimension. To that end, I will now describe how the notion of abduction evolved in Peircean thought.

DEVELOPMENT OF THE NOTION OF ABDUCTION IN PEIRCE

Understanding abduction implies, firstly, becoming aware of the difficulty created by the existence of different versions of this notion in Peirce's works. To overcome this issue, we can identify two non-opposite phases which, in fact, can be understood as complementary: abduction as inference and abduction as a method.

Abduction as inference

In this first phase of Peircean thought, abduction is viewed in terms of logical inference. The three reasoning modes – deduction, induction, and "hypothesis" (as Peirce calls abduction in this phase) – are independent procedures in the search for statements' veracity. Therefore, the logical structure of abduction is:

TABLE 5
ABDUCTIVE REASONING

RESEARCH APPROACH	PHASE/PREMISE	ABDUCTIVE SYLLOGISM
Theory/Hypothesis	Rule	A: All the marbles in package X are white
Analysis/Arrangement of reality	Result	C: These marbles are white
Empirical study	Case	B These marbles come from package X

Source: Prepared by the author.

19 In original: "las creencias son sobre alguna cosa, sobre un hecho o un objeto del mundo, incluyendo la posibilidad de que ciertas creencias sean sobre otros, y que ellas mismas sean alguna cosa real y, en consecuencia, que ellas poseen la capacidad de modificar el flujo de la experiencia".

Abduction can be understood as the inference of a case (B) from a rule (A) and a result (C). It has a poor degree of veracity or, as Peirce puts it, something may be the "case" (CP 5.171) if it is a belief accepted by inference from knowledge pre-established in the premises – i.e., rule and result. Thus, the three types of reasoning can be classified as explanatory, when they make clear what is already contained in the premises, and expansive, i.e., reasonings that increase knowledge (CP 2. 623).

TABLE 6
EXPLANATORY AND EXPANSIVE REASONING

INFERENCE	Explanatory or analytic	Deduction
	Expansive or synthetic	Induction
		Hypothesis (Abduction)

Source: Prepared by the author.

The explanatory character of deduction is clear, but what difference is there then between induction and abduction? The point is addressed by Peirce as follows:

> In induction, we conclude that facts, similar to observed facts, are true in cases not examined. By hypothesis [abduction], we conclude the existence of a fact quite different from anything observed, from which, according to known laws, something observed would necessarily result. (CP 2.636)

Strictly speaking, induction posits that something that has been verified is highly likely for cases not verified, while abduction concludes, through observation, something new but different from everything that has been observed.

Abduction as a method

Later in his reflections, Peirce begins to see "the hypothesis" as a more complex procedure and decides to rename it "abduction". In this period, he comes to consider the three types of reasoning as elements that serve a much more complex procedure in which abduction is:

> [...] the process of forming explanatory hypotheses. It is the only logical operation which introduces any new idea; for induction does nothing but determine a value, and deduction merely evolves the necessary consequences of a pure hypothesis. Deduction proves that something must be; induction shows that something actually is operative; abduction merely suggests that something may be. Its only justification is that from its suggestion deduction can draw

> a prediction which can be tested by induction, and that, if we are ever to learn anything or to understand phenomena at all, it must be by abduction that this is to be brought about. (CP 5.171)

Thus, the process begins with a surprising fact, which could be explained from a hypothesis whose strength relies on empirical data (CP 5.189). A fact is surprising if it is new or abnormal in relation to beliefs (ALISEDA, 1998). For Peirce, doubting beliefs is the engine that drives the search for, or the investigation of a new belief. Therefore, the role of abduction is to propose a hypothesis capable of appeasing the doubt before a surprising fact, i.e., it must facilitate returning to the state of belief. The intellectual exercise that abduction requires is of a dual nature or, more specifically, an operation of "rational instinct" (AYIM, 1974,[20] cited in ALISEDA, 1998, p. 4): on the one hand, abduction is instinctive as it appeals to creation and to choosing one among several possible hypotheses; on the other, it is subject to argumentative reason criteria. In turn, an abductive hypothesis must meet two complementary requirements: it must be proven in the empirical world, and it must be economic – i.e., ensure the shortest possible path.

Abduction as an epistemic change

As an approach arising from a deep reflection on knowledge building, abduction can bring about change with powerful epistemic consequences: a) concerning knowledge, that it does not have the status of truth, but one of belief, so that it can develop or even be replaced by more consistent knowledge; b) concerning knowledge creation, that its starting point should be both the empirical world and a pre-established theory, without denying beliefs; c) concerning the role of the researcher and of science, that it should contribute to viewing thought in a dynamic process towards an epistemology of true scientific discovery and rational instinct; d) and concerning the dichotomous view that opposes deduction and induction, that it must evolve towards a collaboration between the various inference methods established in research. This set of consequences will occur if abduction becomes operational as an approach that is total, contextualized and applied to a particular study.

USING ABDUCTION TO ANALYZE TEACHERS' WORK: AN IMPLEMENTATION EXAMPLE

In this third section, I will treat abduction as a complex process that can be applied to a complex research object. Thus, abduction and the role of each inference type (i.e., abduction, deduction, induction) will be treated here as a scientific approach focusing on a praxeological analysis of teaching. To that end,

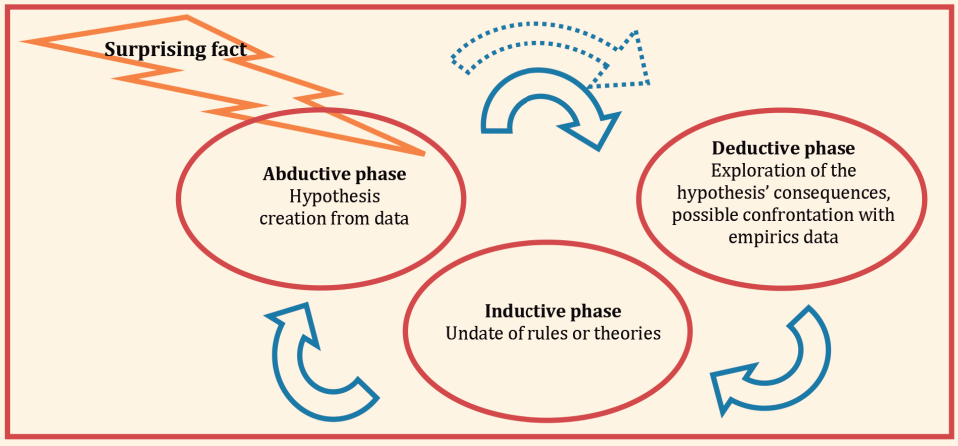
20 AYIM, Maryann. Retroduction: the rational instinct. *Transactions of the Charles S. Peirce Society*, Indiana, v. 10, n. 1, p. 34-43, 1974.

I propose, on the one hand, to understand abduction as a cycle that synthesizes the key points of each type of reasoning and, on the other, to see more concretely how to implement the project in a particular investigation.

BUILDING THE APPROACH: THE ABDUCTION/DEDUCTION/INDUCTION CYCLE

According to David (1999): "deduction allows generating the consequences (C), induction, establishing general rules (A), and abduction, building the hypothesis (B) [...] Most reasonings, and, particularly, scientific reasoning, combine these three forms of reasoning"[21] (p. 4-5, free traduction). From this viewpoint, the author proposes "to understand the whole abductive process as a recursive abduction/deduction/induction cycle"[22] (p. 1). The three stages of the abduction/deduction/induction cycle – henceforth, "adi cycle" – are relatively autonomous in the sense that each involves a specific procedure – and formal requirements to be met – and can be executed at different times and in different research projects. The following scheme illustrates the process:

FIGURE 2
THE ABDUCTION/DEDUCTION/INDUCTION CYCLE



Source: Prepared by the author.

This scheme shows the three phases of the adi cycle. Faced with a surprising fact – a research problem –, the researcher engages in the scientific challenge in the first abductive phase. After conducting an exploratory study, the researcher proposes a theoretical framework that fulfills three characteristics: (1) being flexible enough not to "stifle" the hypothesis creation – this primarily means comprehensive, non-explanatory theories; (2) being adjusted enough so the researcher will not "drown" in empirical data; and (3) being an exercise of

21 In original: "la déduction permet donc de générer des conséquences (C), l'induction d'établir de règles générales (A), et l'abduction de construire des hypothèses (B) [...] La plupart des raisonnements, et en particulier les raisonnements scientifiques, combinent les trois formes de raisonnement".

22 In original: "comme une boucle récursive abduction/déduction/induction".

awareness of the notions used – the critical function. It is worth highlighting that this theoretical framework should not already contain an underlying explanation, but rather it should be a guide for empirical work. As said earlier, in this phase, data should be gathered using unrestrictive tools – interviews, observations – that can also be modified according to the needs of the researcher – i.e., evolutive tools. Finally, the resulting hypothesis must be fed by existing theories that allow it to drive an expansion of understanding towards explanation[23] in the form of clues to be explored. Subsequently, the second deductive phase aims to develop the theoretical aspect so as to reinforce the hypothesis obtained by abduction in order to return it to the empirical world. The hypothesis is now posited a priori, in the form of a device – either analysis or intervention – that seeks the consequences and the breadth established by the explanation/comprehension. Through analysis, the classical elements of hypothetical-deductive research are mobilized – i.e., the theoretical and empirical phases, the discussion of results, etc. –, whereas through intervention the hypothesis and the set of results of the abductive stage can be "translated" into clues – always adapted to the research context – either to transform the phenomenon (FAVERGE, 1968) or to understand it (CLOT; LEPLAT, 2005). From that transformation will result specific, concrete guarantees of the good path the hypothesis has followed – or bad path, in cases of failure. In other words, this phase is supposed to be a rational formalization of the previous approach: instinct, which played a crucial role in the emergence of the hypothesis, is now put aside. If the hypothesis fails the deductive test, the researcher must return to the abductive phase. However, if it passes this phase, then the researcher can move on towards induction. The third inductive phase consists in returning the results of contrasting the hypothesis with the empirical test. From the perspective of the rule-establishing process, this phase is an update: searching for and analyzing a case with relatively similar features to the case already studied – where the abductive hypothesis emerged –, analyzing in detail the consequences of the hypothetical explanation, and determining the rule and its limits. Likewise, in Figure 2 the dotted arrow indicates that it is possible for the cycle to resume all phases, a supplementary process linked to the hypothesis refutation or to a later evolution towards another explanation. In this case, "new explanatory [or comprehensive] hypotheses must be formulated – through abduction – and the cycle begins again"[24] (DAVID, 1999, p. 5). After this general and theoretical description of the adi cycle, I will now show its use in an investigation about teaching.

23 I agree with Weisser's (2006) view that the explain-understand dichotomy can be overcome through Ricoeur's "hermeneutical arch" model.

24 In original: "il faut reformuler – par abduction – de nouvelles hypothèses explicatives [ou compréhensives], et le cycle recommence".

USING THE ADI CYCLE TO ANALYZE TEACHING

The research project and the adaptation of the cycle

The research project discussed here builds on the adi cycle, adapting it to the context in which it is developed. Its main goal is to analyze the difficulties faced by teachers at an agricultural secondary vocational school (for students aged 13-17) in identifying their own teacher education needs. An instance of intervention research, the study has two specific features: it gives prominence to the actors – management and teachers – and claims the autonomy of the heuristics (knowledge pursuit) and praxeological (change pursuit) dimensions of research (NUNEZ MOSCOSO, 2012), both features being combined by a "translation" procedure in which the knowledge acquired in the heuristic process migrates into the transformative interface (MARCEL; NUNEZ MOSCOSO, 2012). The problem that represents an instance of Peircean "amazement" is that these teachers have no initial teacher education in pedagogy and, frequently, no continuing education adapted to their work context, yet they resourcefully manage to succeed in their activities. How do they manage to overcome their difficulties? What can be done to train them? To address both questions, I combined the three stages of the adi cycle with the study's phases and instruments. The various elements involved are explained in the following table:

TABLE 7
ADI CYCLE IMPLEMENTATION.

STAGES	PHASES	RESEARCH DIMENSION	INSTRUMENTS
ABDUCTION	Developing a hypothesis from the analysis of empirical data	Fundamental or heuristic	- Problematization - Theoretical orientations - Methodological device - Data collection - Analysis and hypothesis emergence
DEDUCTION	Dialogue/comparison between the hypothesis and existing theories		- Discussion of theories conflicting or in line with the hypothesis - Analysis of the hypothesis implications and consequences
	Transformative interface	Praxeological or transformative	- Translation of some elements of the fundamental research dimension to support intervention - Clues for training (support for political decision-making)
INDUCTION	Implementation of the training device		- Awareness raising for, and negotiation with decision makers and teachers - Creating the training device - Actors' feedback - Analysis and comparison of results - Possibility to generalize the device or initiate the loop again

Source: Prepared by the author.

The three stages of the cycle and their instruments

The three stages of the cycle and their instruments are conceived as follows:

a. regarding the abductive stage of the adi cycle, once the problematization of teaching in the context of the agricultural school and the people related to it has been conducted – school and students characteristics, data on agricultural technical education in Chile –, the notion of teaching used is that of a system of professional practices, expanding through the three dimensions of teaching: activity, status and experience (TARDIF; LESSARD, 1999). These two guiding elements – comprehensive theories – are used in building the methodological device, and they allow the creation of data collection instruments – interviews, observations. Next, the various empirical resources are qualitatively explored; it is in this stage that the rational instinct intervenes, from the perspective of the emergence of an *a posteriori* comprehensive/explanatory hypothesis – one that provides answers to the problem of these teachers' professional difficulties and training needs. In more concrete terms, it is a reflection on the possible hypotheses, using an argumentative analysis to preserve the most complete one.

b. In the deductive stage of the adi cycle, the hypothesis is contrasted with existing theories –particularly explanatory ones – to detect potential conflicts and complementarities. Then, in a systemic and complex manner (MORIN, 2008), the process moves towards the praxeological dimension. In this stage, some elements of fundamental research are "translated" so as to provide support for educational policy decision-making, i.e., recommendations with a view to improving teacher education for these teachers.

c. Finally, the inductive stage will begin by raising s of and negotiating with the decision-makers and teachers – to induce change in the latter's teacher education – so as to create the conditions for building the teacher education process. Strategically, the partial results of the research process are presented at the outset to facilitate the training device implementation. This phase proceeds to include a period of collaborative work with the teachers so they can be updated on data from the study, and the needs that progressively emerge can be incorporated. Once the training has begun, a permanent apprentice/trainer/coordinator feedback system is implemented. This last element will feed a training device evaluation phase, which is prolonged by mediate/immediate results – teachers' post-training feedback – and by the possibility to replicate the device in other contexts – the search for generalization. At the end of this stage, if the device is found not to be adaptable or found to be susceptible to improvement, it will be necessary to resume the cycle process – the adi cycle's recursive dimension.

CONCLUSIONS

In conclusion, it is fair to say that abduction provides four new, potentially valuable elements for education and pedagogy, particularly for the analysis of teachers' work: the idea of knowledge, the role of science, overcoming the deduction-induction dichotomy, and using the research-intervention approach, in the logic of a praxeological process.

With regard to the idea of knowledge, the character of belief that Peirce ascribes to it brings about a completely new and dynamic condition. Deduction, taken as an isolated approach, puts us before a science of established theories, in which the researcher is a mobilizer of existing theoretical frameworks, and knowledge is a domain to be verified – or to falsified, in the sense of Popper (2007). Induction, on the other hand, considers science as a motor to be fed in which theories must be created from the researcher's subjectivity, and where knowledge is to be developed with focus on the subject – always looking for general rules or local explanations. However, abduction, with its critical perspective, is interested in probable knowledge, bearing in mind that it is always a matter of relative, evolutive probability. At the same time, this has powerful consequences on the role of science. In the adi cycle, abduction's mission is to find the hypothesis, the deduction and to think of its consequences from an *a priori* approach; induction's mission is to give it the status of a rule. The adi cycle has a logical dimension, but it also has an epistemological dimension that sets it up as a true epistemology of discovery. Thus, the abductive approach appears as a scientific development project that introduces new ideas and in which the research community confronts its studies to advance knowledge, which is dynamic by definition. This approach is, in my view, a clear possibility of making research complex: understanding phenomena, explaining them, but also transforming them by venturing out in new paths. Abduction contributes to overcome the deduction-induction dichotomy, integrating them as part of a more global process – the adi cycle. Each of its phases is relatively independent, and this favors collaborative research, which can be conducted even at different temporalities. Finally, with regard to using the abductive approach to analyze teaching, one can understand it concomitantly as an implementation and a contribution for creating a merging point between investigation and intervention; the heuristic dimension of search for knowledge (or "beliefs", in the sense of Peirce) and the praxeological dimension of search for change (NUNEZ MOSCOSO, 2012) give the actors – policy decision-makers, teachers – a space that is facilitated by the different stages of the adi cycle. At the intervention level, abduction allows engaging the actors in the creation and implementation of the training device, as well as in its evaluation phase, the latter being a key element for the adi cycle dynamics. For the purposes of this study, the limits of the abductive approach are mostly related to the characteristics of the research world: such a project is very expensive – funding, length –, researchers adhere to mainstream theoretical frameworks that may not be compatible with those adhering to deductive or inductive approaches. Similarly, it is necessary to continue defining and developing the different elements of abduction as a

research method, particularly those elements of a methodological nature. This, however, is fare beyond the modest goal of this paper, which is to arouse interest in abduction and in a critical dialogue in the scientific community.

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