

The Extra-Theoretical Dimension of Creativity. Extracting and Manipulating Information by Abduction

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Abstract Science is one of the most creative forms of human reasoning. The recent epistemological and cognitive studies concentrate on the concept of *abduction* as a means to originate and refine new ideas. Traditional cognitive science accounts concerning abduction aim to illustrate discovery and creativity processes in terms of *theoretical* and “internal” aspects, by means of computational simulations and/or abstract cognitive models. A neglected issue, worth of a deepest investigation inside artificial intelligence, is that “discovery” is often related to a complex cognitive task involving the use and the manipulation of external world. Concrete manipulations of external world is a fundamental passage in the process of knowledge extraction and hypotheses generation: by a process of *manipulative abduction* it is possible to build prostheses for human minds, by interacting with external objects and representations in a constructive way, and so by creating *implicit* knowledge through doing. This kind of embodied and unexpressed knowledge holds a key role in the subsequent processes of scientific comprehension and discovery. This paper aims to illustrate the close relationship between external representations and creative processes in scientific explorations and understanding of phenomena.

1 Theoretical and Manipulative Abduction

Science is one of the most explicitly constructed, abstract, and creative forms of human knowledge. In the twentieth century Kuhnian ideas about irrationality of conceptual change and paradigm shift (see [1]) brought philosophers of science to distinguish between a *logic of discovery* and a *logic of justification*, and to the direct conclusion that a logic of discovery, and then a *rational* model of discovery, cannot exist. Today researchers have by and large abandoned this attitude by concentrating on the concept of *abduction* pointed out by C.S. Peirce as a fundamental mechanism by which it is possible to account for the introduction of new explanatory hypotheses in science.

Theoretical abduction (see [2,3]) is the process of *inferring* certain facts and/or laws and hypotheses that render some sentences plausible, that *explain* or *discover* some (eventually new) phenomenon or observation; it is the process of reasoning in which explanatory hypotheses are formed and evaluated. There are two main epistemological meanings of the word abduction: 1) abduction that only generates “plausible” hypotheses and 2) abduction considered as inference to the best explanation, which also evaluates hypotheses. To illustrate from the field of medical knowledge, the discovery of a new disease and the manifestations it causes can be considered as the result of a creative abductive inference. Therefore, creative abduction deals with the whole field of the growth of scientific knowledge. This is irrelevant in medical diagnosis where instead the task is to select from an encyclopedia of pre-stored diagnostic entities. Both inferences, selective and creative, are ampliative because in both cases the reasoning involved amplifies, or goes beyond, the information incorporated in the premises.

Theoretical abduction certainly illustrates much of what is important in creative abductive reasoning, in human and computational programs, but fails to account for many cases of explanations occurring in sciences when the exploitation of environment is crucial. It fails to account for those cases in which we can think to a “discovery through doing”, cases in which new, before unexpressed, information is codified by means of manipulation of some external object (*epistemic mediators*). The concept of *manipulative abduction* (see [2]) captures a large part of scientists thinking where the role of action is central, and where the features of this action are implicit and hard to be elicited: action can provide otherwise unavailable information that enables the agent to solve problems by performing a suitable abductive process of generation or selection of hypotheses.

2 Manipulating World to Extract Information

2.1 The “internal” side of discovery

Throughout his career it was C.S. Peirce that defended the thesis that, besides deduction and induction¹, there is a third mode of inference that constitutes the

¹ Peirce clearly contrasted abduction to induction and deduction, by using the famous syllogistic model. More details on the differences between abductive and inductive/deductive inferences can be found in [2,4].

only method for really improving scientific knowledge, which he called *abduction*. Science improves and grows continuously, but this continuous enrichment cannot be due to deduction, nor to induction: deduction does not produce any new idea, whereas induction produces very simple ideas. New ideas in science are due to *abduction*, a particular kind of non-deductive² inference that involves the generation and evaluation of explanatory hypotheses.

Many attempts have been made to model abduction by developing some formal tools in order to illustrate its computational properties and the relationships with the different forms of deductive reasoning (see, for example, [5]). Some of the formal models of abductive reasoning are based on the theory of the *epistemic state* of an agent (see [6]), where the epistemic state of an individual is modeled as a consistent set of beliefs that can change by expansion and contraction (*belief revision framework*). These kinds of logical models are called *sentential* (see [2]).

They exclusively deal with selective abduction (for example, diagnostic reasoning)³ and relates to the idea of preserving *consistency*. Exclusively considering the *sentential* view of abduction does not enable us to say much about creative processes in science, and, therefore, about the nomological and most interesting creative aspects of abduction. It mainly refers to the *selective* (diagnostic) and merely *explanatory* aspects of reasoning and to the idea that abduction is mainly an inference *to the best explanation* (see [2]): when used to express the creativity events it is either empty or replicates the well-known *Gestalt* model of radical innovation. It is empty because the *sentential* view stops any attempt to analyze the creative processes: the event of creating something new is considered so radical and instantaneous that its irrationality is immediately involved.

For Peirce abduction is an *inferential process* that includes all the operations whereby hypotheses and theories are constructed. Hence abduction has to be considered as a kind of *ampliative* inference that, as already stressed, is not logical and truth preserving; indeed valid deduction does not yield any new information, for example new hypotheses previously unknown.

If we want to provide a suitable framework for analyzing the most interesting cases of conceptual changes in science we do not have to limit ourselves to the *sentential* view of theoretical abduction but we have to consider a broader *inferential* one: the *model-based* sides of creative abduction (cf. below).

From the Peirce's philosophical point of view, all thinking is in signs, and signs can be icons, indices or symbols. Moreover, all inference is a form of sign activity, where the word sign includes "feeling, image, conception, and other representation" ([7, 5.283]), and, in Kantian words, all synthetic forms of cognition. That is, a considerable part of the thinking activity is model-based. Of course model-based reasoning acquires its peculiar creative relevance when embedded in abductive processes, so that we can individuate a *model-based abduction*.

² Non-deductive if we use the attribute "deductive" as designated the classical logic.

³ As previously indicated, it is important to distinguish between *selective* (abduction that merely selects from an encyclopedia of pre-stored hypotheses), and *creative* abduction (abduction that generates new hypotheses).

Hence, it is in terms of *model-based abduction* (and not in terms of sentential abduction) that we have to think to explain complex processes like scientific conceptual change. Related to the high-level types of scientific conceptual change (see, for instance, [8]) are different varieties of *model-based abductions* (see, for examples, [9]).

Following Nersessian (cf. [10] and [11]), the term “model-based reasoning” is used to indicate the construction and manipulation of various kinds of representations, not mainly sentential and/or formal, but mental and/or related to external mediators.

Although it is controversial as to whether there is any form of representation other than strings of symbols, it is possible, following Johnson-Laird (see [12]), to assume the existence of at least three kinds of *mental* representations:

1. *propositional representation* (strings of symbols such as “the pot is on the table”);
2. *mental models* (structural analogs of real world or imagined situations, such as a pot being on a table);
3. *images* (a mental model from a specific perspective, such as looking down on the pot on the table from above).

Obvious examples of model-based reasoning are constructing and manipulating visual representations, thought experiment, analogical reasoning, but also the so-called “tunnel effect” (see [13]), occurring when models are built at the intersection of some operational interpretation domain - with its interpretation capabilities - and a new ill-known domain.

Manipulative abduction ([2]) happens when we are thinking through doing and not only, in a pragmatic sense, about doing. So the idea of manipulative abduction goes beyond the well-known role of experiments as capable of forming new scientific laws by means of the results (the nature’s answers to the investigator’s question) they present, or of merely playing a predictive role (in confirmation and in falsification). Manipulative abduction refers to an extra-theoretical behavior that aims at creating communicable accounts of new experiences to integrate them into previously existing systems of experimental and linguistic (theoretical) practices. The existence of this kind of extra-theoretical cognitive behavior is also testified by the many everyday situations in which humans are perfectly able to perform very efficacious (and habitual) tasks without the immediate possibility of realizing their conceptual explanation. In the following sections manipulative abduction will be considered from the perspective of the relationship between unexpressed knowledge and external representations.

2.2 External mediators

The power of model-based abduction mainly depends on its ability to extract and render explicit a certain amount of important information, unexpressed at the level of available data. It also has a fundamental role in the process of transformation of knowledge from its *tacit* to its *explicit* forms, and in the

subsequent knowledge elicitation and use. Let us describe how this happens in the case of “external” model-based processes.

As pointed out by M. Polanyi in his epistemological investigation, a large part of knowledge is not explicit, but tacit: we know more than we can tell and we can know nothing without relying upon those things which we may not be able to tell (see [14]). Polanyi’s concept of knowledge is based on three main theses: first, discovery cannot be accounted for by a set of articulated rules or algorithms; second, knowledge is of course public but also to a very great extent personal, as constructed by humans (and so linked to their emotions); third, an important part of knowledge is tacit.

As Polanyi contends, human beings acquire and use knowledge by actively creating and organizing their own experience: tacit knowledge is the practical knowledge used to perform a task. The existence of this kind of cognitive behavior, not merely theoretical, is also testified by the many everyday situations in which humans are perfectly able to perform very efficacious (and habitual) tasks without the immediate possibility of realizing their conceptual explanation. In some cases the conceptual account for doing these things was at one point present in the memory, but now has deteriorated, and it is necessary to reproduce it, in other cases the account has to be constructed for the first time, like in creative experimental settings in science.

Hutchins [15] illustrates the case of a navigation instructor who for 3 years performed an automatized task involving a complicated set of plotting manipulations and procedures. The insight concerning the conceptual relationships between relative and geographic motion came to him suddenly “as lay in his bunk one night”. This example explains that many forms of learning can be represented as the result of the capability of giving conceptual and theoretical details to already automatized manipulative executions. The instructor does not discover anything new from the point of view of the objective knowledge about the involved skill; however, we can say that his conceptual awareness is new from the local perspective of his individuality.

We can find a similar situation also in the process of scientific creativity. Too often, in the cognitive view of science, it has been underlined that conceptual change just involves a *theoretical* and “internal” replacement of the main concepts. But usually researchers forget that a large part of this processes are instead due to *practical* and “external” *manipulations* of some kind, prerequisite to the subsequent work of theoretical arrangement and knowledge creation. When these processes are creative we can speak of manipulative abduction (cf. above).

Scientists need a first “rough” and concrete experience of the world to develop their systems, as a *cognitive-historical* analysis of scientific change (see [16] and [17]) has carefully shown.

The prevailing perspective among philosophers is that the processes of discovery and the consequent new incoming scientific representations are too mysterious to be understood. This view receives support from numerous stories of genius’ discoveries, such as Archimedean Eureka experiences. Such accounts ne-

glect periods of intense and often arduous thinking activity, often performed by means of experiments and *manipulative* activity on external objects; these are periods that prepare such “instantaneous” discoveries. It is also important to understand that the scientific process is *complex* and *dynamic*: new representations do not emerge completely codified from the heads of scientists, but are constructed in response to specific problems by systematic use of heuristic procedures (as pointed out by Herbert Simon’s view on the “problem-solving process” [18]).

Traditional examinations of how problem-solving heuristics create new representations in science have analyzed the frequent use of analogical reasoning, imagistic reasoning, and thought experiment from an internal point of view. However attention has not been focalized on those particular kinds of heuristics, that resort to the existence of *extra-theoretical* ways of thinking (*thinking through doing*, cf. [19]). Indeed many cognitive processes are centered on *external representations*, as a means to create communicable accounts of new experiences ready to be integrated into previously existing systems of experimental and linguistic (theoretical) practices.

It is possible to achieve some further interesting insights on these problems studying them from a different contrasting approach, which moves away from Simon’s paradigm, but which can offer a rational solution to the problem of creativity and conceptual change in terms of mathematical models: the *dynamical* approach ([20]). The traditional computational view treats cognition as a process that computes internal symbolic representations of external world. But this approach is considered too reductive⁴, since it is based on the functionalist hypothesis (which cannot render the *external dimension* of cognition), and on a computation of static entities. It is useful to integrate it with a dynamical modeling of cognition, which is able to describe abductive processes as *dynamical entities* “unfolding” in real time (we can also gain a better *cognitive-historical* perspective) (see [21]). From this point of view it is possible to model the terms (objects or propositions) that constitute abduction in terms of *attractors* in a dynamical system, specifying topologically the *semantic* content of the inferential process by the spatial relations between its defining attractors. We can therefore consider the process of progressive development of “new” concepts and of replacement of old ones in terms of temporal evolving patterns defined by interactions between topological configurations of attractors.

Moreover, a central point in the dynamical approach is the importance assigned to the “whole” cognitive system: the cognitive activity is in fact the result of a complex interplay and simultaneous coevolution, in time, of the states of mind, body, and external environment. Even if, of course, a large portion of the complex environment of a thinking agent is internal, and consists of the proper software composed of the knowledge base and of the inferential expertise of the individual, nevertheless a “real” cognitive system is composed by a “distributed cognition” among people and some “external” objects and technical artifacts

⁴ However, we do not have to forget the computational approach led to important results, for instance by integrating cognitive studies and robotics [?].

(see [15] and [22]). For example, in the case of the construction and examination of diagrams in geometrical reasoning, specific experiments serve as states and the implied operators are the manipulations and observations that transform one state into another. The geometrical outcome is dependent upon practices and specific sensory-motor activities performed on a non-symbolic object, which acts as a dedicated external representational medium supporting the various operators at work. There is a kind of an epistemic negotiation between the sensory framework of the geometer and the external reality of the diagram ([3]).

This process involves an external representation consisting of written symbols and figures that for example are manipulated “by hand”. The cognitive system is not merely the mind-brain of the person performing the geometrical task, but the system consisting of the whole body (cognition is *embodied*) of the person plus the external physical representation. In geometrical discovery the whole activity of cognition is located in the system consisting of a human together with diagrams.

An external representation can modify the kind of computation that a human agent uses to reason about a problem: the Roman numeration system eliminates, by means of the external signs, some of the hardest parts of the addition, whereas the Arabic system does the same in the case of the difficult computations in multiplication. The capacity for inner reasoning and thought results from the internalization of the originally external forms of representation. In the case of the external representations we can have various objectified knowledge and structures (like physical symbols - e.g. written symbols, and objects - e.g. three-dimensional models, shapes and dimensions), but also external rules, relations, and constraints incorporated in physical situations (spatial relations of written digits, physical constraints in geometrical diagrams and abacuses) (see [23]). The external representations are contrasted to the internal representations that consist of the knowledge and the structure in memory, as propositions, productions, schemas, neural networks, models, prototypes, images.

The external representations are not merely memory aids: they can give people access to knowledge and skills that are unavailable to internal representations, help researchers to easily identify aspects and to make further inferences, they constrain the range of possible cognitive outcomes in a way that some actions are allowed and other forbidden. The mind is limited because of the restricted range of information processing, the limited power of working memory and attention, the limited speed of some learning and reasoning operations; on the other hand the environment is intricate, because of the huge amount of data, real time requirement, uncertainty factors. Consequently, we have to consider the whole system, consisting of both internal and external representations, and their role in optimizing the whole cognitive performance of the distribution of the various subtasks. It is well-known that in the history of geometry many researchers used internal mental imagery and mental representations of diagrams, but also self-generated diagrams (external) to help their thinking.

3 The Extra-Theoretical Dimension of Discovery

We have introduced above the notion of *tacit knowledge*. Now we propose an extension of that concept. There is something more important beyond the tacit knowledge “internal” to the subject - considered by Polanyi as personal, embodied and context specific. In many cognitive and epistemological situations, we can also speak of a sort of implicit information “embodied” into the whole relationship between our mind-body system and suitable external representations. An information we can extract, explicitly develop, and transform in knowledge contents, to solve problems (as it is manifest, for instance, in the geometrical problem contained in the *Meno* [24] (see [2, chapter 1] – even if it is well-known that Plato considered this activity just as the result of reminiscence and not of discovery).

As we have already stressed, Peirce considers inferential any cognitive activity whatever, not only conscious abstract thought; he also includes perceptual knowledge and subconscious cognitive activity. For instance in subconscious mental activities visual representations play an immediate role. Peirce gives an interesting example of model-based abduction related to sense activity: “A man can distinguish different textures of cloth by feeling: but not immediately, for he requires to move fingers over the cloth, which shows that he is obliged to compare sensations of one instant with those of another” [7, 5.221]. This surely suggests that abductive movements have also interesting extra-theoretical characters and that there is a role in abductive reasoning for various kinds of manipulations of external objects. *All* knowing is *inferring* and inferring is not instantaneous, it happens in a process that needs an activity of comparisons involving many kinds of models in a more or less considerable lapse of time.

All these considerations suggest, then, that there exist a creative form of thinking through doing,⁵ fundamental as much as the theoretical one: *manipulative abduction* (see [2] and [3]). As already said *manipulative* abduction happens when we are thinking *through* doing and not only, in a pragmatic sense, about doing.

Various templates of manipulative behavior exhibit some regularities. The activity of manipulating external things and representations is highly conjectural and not immediately explanatory: these templates are hypotheses of behavior (creative or already cognitively present in the scientist’s mind-body system, and sometimes already applied) that abductively enable a kind of epistemic “doing”. Hence, some templates of action and manipulation can be selected in the set of the ones available and pre-stored, others have to be created for the first time to perform the most interesting creative cognitive accomplishments of manipulative abduction.

Some common features of the tacit templates of manipulative abduction that enable us to manipulate things and experiments in science are related to: 1. sen-

⁵ In this way the cognitive task is achieved on *external* representations used in lieu of an internal ones. Here action performs an *epistemic* and not a merely performatory role, relevant to abductive reasoning.

sibility to the aspects of the phenomenon which can be regarded as *curious* or *anomalous*; manipulations have to be able to introduce potential inconsistencies in the received knowledge (Oersted’s report of his well-known experiment about electromagnetism describes some anomalous aspects that did not depend on any particular theory of the nature of electricity and magnetism); 2. preliminary sensibility to the *dynamical* character of the phenomenon, and not to entities and their properties, common aim of manipulations is to practically reorder the dynamic sequence of events into a static spatial one that should promote a subsequent bird’s-eye view (narrative or visual-diagrammatic); 3. referral to experimental manipulations that exploit *artificial apparatus* to free new possible stable and repeatable sources of information about hidden knowledge and constraints (Davy’s set-up in term of an artifactual tower of needles showed that magnetization was related to orientation and does not require physical contact); 4. various contingent ways of epistemic acting: *looking* from different perspectives, *checking* the different information available, *comparing* subsequent events, *choosing*, *discarding*, *imaging* further manipulations, *re-ordering* and *changing relationships* in the world by implicitly *evaluating* the usefulness of a new order (for instance, to help memory).

Gooding [17] refers to this kind of concrete manipulative reasoning when he illustrates the role in science of the “construals” that embody tacit inferences in procedures that are often apparatus and machine based. The embodiment is of course an expert manipulation of objects in a highly constrained experimental environment, and is directed by abductive movements that imply the strategic application of old and new *templates* of behavior mainly connected with extra-theoretical components, for instance emotional, esthetical, ethical, and economic.

The whole activity of manipulation is devoted to building various external *epistemic mediators*⁶ that function as an enormous new source of information and knowledge. Therefore, manipulative abduction represents a kind of redistribution of the epistemic and cognitive effort to manage objects and information that cannot be immediately represented or found internally (for example exploiting the resources of visual imagery).⁷

From the point of view of everyday situations manipulative abductive reasoning and epistemic mediators exhibit very interesting features (we can find

⁶ This expression is derived from the cognitive anthropologist Hutchins (see [15]), who coined the expression “mediating structure” to refer to various external tools that can be built to cognitively help the activity of navigating in modern but also in “primitive” settings. Any written procedure is a simple example of a cognitive “mediating structure” with possible cognitive aims, so mathematical symbols and diagrams: “Language, cultural knowledge, mental models, arithmetic procedures, and rules of logic are all mediating structures too. So are traffic lights, supermarkets layouts, and the contexts we arrange for one another’s behavior. Mediating structures can be embodied in artifacts, in ideas, in systems of social interactions [...]” [15, pp. 290–291].

⁷ It is difficult to preserve precise spatial and geometrical relationships using mental imagery, in many situations, especially when one set of them has to be moved relative to another.

the first three in geometrical constructions): 1. action elaborates a *simplification* of the reasoning task and a redistribution of effort across time (see [15]), when we need to manipulate concrete things in order to understand structures which are otherwise too abstract (see [25]), or when we are in presence of *redundant* and unmanageable information; 2. action can be useful in presence of *incomplete* or *inconsistent* information - not only from the “perceptual” point of view - or of a diminished capacity to act upon the world: it is used to get more data to restore coherence and to improve deficient knowledge; 3. action enables us to build *external artifactual models* of task mechanisms instead of the corresponding internal ones, that are adequate to adapt the environment to agent’s needs. 4. action as a *control of sense data* illustrates how we can change the position of our body (and/or of the external objects) and how to exploit various kinds of prostheses (Galileo’s telescope, technological instruments and interfaces) to get various new kinds of stimulation: action provides some tactile and visual information (e.g., in surgery), otherwise unavailable. Also natural phenomena can play the role of external artifactual models: under Micronesians’ manipulations of their images, the stars acquire a structure that “becomes one of the most important structured representational media of the Micronesian system” [15, p. 172]. The external artifactual models are endowed with functional properties as components of a memory system crossing the boundary between person and environment (for example they are able to transform the tasks involved in allowing simple manipulations that promote further visual inferences at the level of model-based abduction). The cognitive process is *distributed* between a person (or a group of people) and external representation(s), and so obviously *embedded* and *situated* in a society and in a historical culture.

An interesting epistemological situation we have recently studied is the one concerning the role of some special epistemic mediators in the field of non-standard analysis. We maintain that in mathematics diagrams play various roles in a typical abductive way. Two of them are central:

- they provide an intuitive and mathematical *explanation* able to help the understanding of concepts difficult to grasp, that appear obscure and/or epistemologically unjustified, or that are *not expressible* from an intuitive point of view;
- they help *create* new previously unknown concepts.

In the construction of mathematical concepts many external representations are exploited, both in terms of diagrams and of symbols. We are interested in our research in diagrams which play an *optical* role – microscopes (that look at the infinitesimally small details), telescopes (that look at infinity), windows (that look at a particular situation), a *mirror* role (to externalize rough mental models), and an *unveiling* role (to help create new and interesting mathematical concepts, theories, and structures).⁸

Optical diagrams play a fundamental explanatory (and didactic) role in removing obstacles and obscurities and in enhancing mathematical knowledge of

⁸ The epistemic and cognitive role of mirror and unveiling diagrams in the discovery of non-Euclidean geometry is illustrated in [3].

critical situations. They facilitate new internal representations and new symbolic-propositional achievements. In the example we have studied in the area of the calculus, the extraordinary role of the optical diagrams in the interplay standard/non-standard analysis is emphasized. In the case of our non-standard analysis examples, some new diagrams (microscopes within microscopes) provide new mental representations of the concept of tangent line at the infinitesimally small regions. Hence, external representations which play an “optical” role can be used to allow us a better understanding of many critical mathematical situations and, in some cases, to discover (or rediscover) more easily and nicely sophisticated properties. The role of an “optical microscope” that shows the behavior of a tangent line is illuminating (see Figure 1 and, for details, [26]).

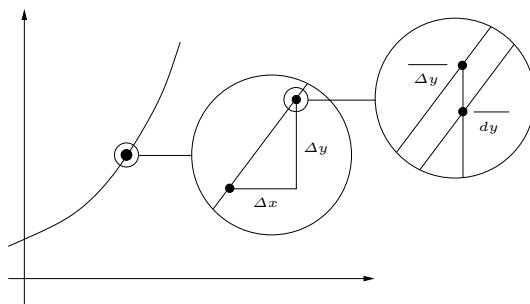


Figure 1. An optical diagram shows an infinitesimal neighborhood of the graph of a real function.

Some diagrams could also play an unveiling role, providing new light on mathematical structures: it can be hypothesized that these diagrams can lead to further interesting creative results. The optical and unveiling diagrammatic representation of mathematical structures activates *direct perceptual operations* (for example identifying how a real function appears in its points and/or to infinity; how to really reach its limits).

We stated that in mathematics diagrams play various roles in a typical abductive way. We can add that:

- they are *epistemic mediators* able to perform various abductive tasks in so far as
- they are *external representations* which are devoted to providing explanatory abductive results.

4 CONCLUSION

It is clear that the manipulation of external objects helps human beings in knowledge extraction and in their creative tasks. We have illustrated the strategic role

played by the so-called traditional concept of “implicit knowledge” in terms of the recent cognitive and epistemological concept of manipulative abduction, considered as a particular kind of abduction that exploits external models endowed with delegated cognitive roles and attributes. Abductive manipulations operate on models that are external and the strategy that organizes the manipulations is unknown *a priori*. In the case of creative manipulations of course the result achieved is also *new*, and adds properties not contained before. If we simply look at the birth of modern science, an epistemological situation corresponding to that one delineated in the previous section is immediately evident. Already in the *Dialogues Concerning the Two Chief World Systems* (see [27]), accentuating the role of observational manipulations, Galileo presents an anatomist that, “manipulating” a cadaver, is able to get new, not speculative, information that goes beyond the “world of paper” of the Peripatetic philosophy.

In scientific practice there is a lot of procedural, extra-sentential and extra-theoretical aspects indispensable to provide knowledge and information otherwise hard to grasp. By making them explicit we can rationally and positively integrate the previously existing scientific encyclopedia. The enhancement of the analysis of these important human skills can increase knowledge on inferences involving creative, analogical, spatial, and simulative aspects, both in science and everyday situations.

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