

## **Science and Technology: Differences, Interactions, and Their Consequences**

Ali Paya\*

Alireza Mansouri\*\*

### **Abstract**

There exists a significant conceptual distinction between science and technology. This article examines the philosophical grounds underlying the conflation of science and technology. It suggests that treating the two as identical is not merely an epistemological confusion; rather, it may lead to a range of undesirable theoretical and practical consequences. From an epistemological perspective, the paper also argues, the notion of 'applied science' may be regarded as redundant, as it falls within the category of technology.

**Keywords:** science, technology, philosophy of technology, applied science, policy-making, critical rationalism.

\* Professor of Philosophy, *Islamic College of London*; alipaya@hotmail.com

\*\* Associate Professor of Philosophy of Science, *Institute of Humanities and Cultural Studies*; (Corresponding Author), a\_mansourius@yahoo.com.

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## 1. Introduction

Some scholars, most notably those working within the critical rationalist tradition, draw a conceptual distinction between science and technology as two separate domains of human activity. In contrast, another group of researchers—particularly within the field of science and technology studies (STS), as well as certain historian-philosophers of science and the majority of postmodern writers—tend to reduce science and technology to a single category, regarding the distinction between them as largely redundant. Bruno Latour, for instance, has proposed the concept of 'technoscience' precisely on the grounds of the perceived intertwinement of scientific and technological domains. He explicitly states that the term was coined "to avoid the repetitive use of 'science and technology' (Latour, 1987, p. 29). The Society for Social Studies of Science (4S) has also adopted this expression, using it in the title of its official newsletter. The prevalence of this term in such contexts may not be merely accidental or a matter of linguistic convenience; rather, it arguably conveys the implicit message that the traditional distinction between science and technology is no longer endorsed by these intellectual movements (Niiniluoto, 2016, p. 95). It would not be unreasonable to regard this doctrine as one of the defining features of the social constructivist trend within STS, through which conclusions originally drawn about technology are intended to be extended to science as well. Instances of this line of thinking can be found in the work of Bijker and Law (1987), John Law (1992), Thomas Kuhn (1971), David Bloor (1991), and numerous others.<sup>1</sup>

This paper argues that the distinction between science and technology reflects an objective difference that constitutes them as distinct entities.<sup>2</sup> This is not to suggest, however, that science and technology lack any form of interaction. The present study aims to clarify that the relationship between the two is complex and that its pattern has changed considerably over time. For centuries, these two domains evolved more or less independently; yet in the modern era—particularly in the context of advanced sciences and technologies—their connection has become so close that distinguishing their boundaries has grown exceedingly difficult. It is arguably this very difficulty that has led some researchers to the mistaken conclusion that science and technology are reducible to one another.

To elaborate on the above argument, we first examine the epistemological difference between science and technology. We then proceed to show that the conflation of science and technology may be understood as a natural consequence of certain essentialist and instrumentalist approaches. Each of these approaches, in its own way, tends to overlook this distinction, thereby paving the way for undesirable epistemological and policy-making consequences.

## 2. The Conceptual Distinction between Science and Technology

While various scholars have attempted to differentiate science from technology

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<sup>1</sup> Parallel perspectives are evident within the Iranian intellectual milieu, notably from the Academy of Islamic Sciences in Qom. This institution posits that science does not constitute a process of *discovery*, but is instead a fundamentally *instrumental* activity (Mirbagheri, 2011, p. 151).

<sup>2</sup> The conceptualization of science and technology as 'entities' within the realm of 'reality' implies that these human constructs are ontologically situated in Popper's World 3 (Popper, 1972, ch. 3).

through definitions<sup>3</sup>, critical rationalists contend that such definitions are ultimately unproductive, as any definition inherently necessitates further definitions, leading to an infinite regress. Accordingly, the present study does not aim to formulate such definitions.<sup>4</sup> At most, definitions serve merely as initial points of departure for critical discourse and as a foundation for suggesting theories and conjectures (Popper, 1971, 1985).<sup>5</sup> Our objective here, instead, is to propose an epistemological *theory* of science and technology that elucidates the fundamental differences between the activities characteristic of these two domains.

As previously noted, the crucial components of any cognitive activity are problems, theories, and the solutions proposed for them. In essence, 'science'—or 'knowledge'—can be characterized as a designation for a category of cognitive constructs aimed at fulfilling the human drive to comprehend reality. Conversely, 'technology'<sup>6</sup> refers to products designed to address non-cognitive needs or to provide instrumental facilitation (i.e., the extension of our senses) for cognitive endeavors (Paya, 2016b, 2017a, 2017b).<sup>7</sup>

It is essential to underscore that the ultimate output of any inquiry directed toward understanding reality possesses truth value. For realists, and critical rationalists in particular, truth is defined as the correspondence between our speculative conjectures and the objective reality to which those claims refer.<sup>8</sup> Consequently, attempts to reduce knowledge to mere prediction, representation, or unification without incorporating *truth* are inherently flawed; knowledge devoid of truth, in the correspondence sense, cannot fundamentally be regarded as knowledge.

An analysis of the implications of this distinction reveals fundamental differences in the respective objectives of science and technology. Scientific or cognitive inquiry is oriented toward the attainment of true knowledge (or an approximation of truth within the constraints of current human capacity). In contrast, technological activities are directed toward solving practical problems.

While some scholars<sup>9</sup> suggest that these aims can be identified through historical induction, this perspective is grounded in a naturalistic methodology, which Popper

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<sup>3</sup> For a review of these definitions, which also include essentialist and linguistic definitions, see: (Mitcham & Schatzberg, 2009, pp. 27-64).

<sup>4</sup> Radder also regards the epistemological definition of science and technology as an essentialist definition and refers to Mitcham (1994).

<sup>5</sup> For a detailed discussion regarding 'definitions' and their place in epistemological endeavors, see the second part of Chapter 11 of the book *The Open Society and Its Enemies*, written by Karl Popper. A more concise version of this chapter can be found in: *Popper Selections*, edited by David Miller, Princeton University Press, 1985.

<sup>6</sup> It should be noted that quotation marks are utilized here to designate 'science' and 'technology' as *linguistic* labels, thereby distinguishing these names from the *actual entities* to which they refer.

<sup>7</sup> The categorization of 'science' and 'technology' as two distinct categories representing *real entities* within World 3 is consistent with *methodological nominalism*—a fundamental tenet of critical rationalism that must be distinguished from *metaphysical nominalism*. In contrast to *essentialism*, the main thesis of methodological nominalism is that linguistic labels are of little importance within an epistemological discourse.

<sup>8</sup> The "reality to which claims are referred" is itself *conjectural*. In this regard, see: (Miller, 2006, pp. 178-179)

<sup>9</sup> For instance see Radder (2009, p. 70; Kuhn 1971).

(1958/2005) warned against. Indeed, the theoretical framework underpinning the demarcation between pure science and technology rests upon a specific conception of reality in its broadest sense. Conjectures are human constructs epistemologically projected onto the objective world. Such doctrines are not derived inductively from historical observation; rather, history—much like the natural world—functions as a laboratory for the historical conjectures we have proposed (Popper, 1994, ch. 1 & 7). Moreover, these conjectures are subject to critical appraisal through the rigorous application of methodological standards and values.

When the objective of an activity is to attain truth, or at least to approach it, its product must necessarily be universal. This is because truth—as critical rationalists and other realist philosophers explain—is not relative. The relativity of truth would eliminate the possibility of knowing reality, as well as that of mutual understanding and communication among various human groups (Popper, 1963).<sup>10</sup> On the other hand, when the objective of an activity is to realize a *function*, the intention governing that activity from the outset is to fulfill that *particular* function within *specific conditions and circumstances*. This makes technologies sensitive to the context, setting, and environment in which they are realized.

To say that the aim of technology is the fulfillment of a function does not merely refer to aims that are beneficial to *society*; rather, it can also encompass the utility derived from a *personally* intended function.<sup>11</sup> Accordingly, technologies—based on the functions we embed in them to meet our instrumental and non-cognitive needs—lack an "essence". Although technological functions give technologies their distinct identity, their lack of an essence stems from the fact that such functions are intentionally embedded by human agents rather than being intrinsic properties of the entities themselves.<sup>12</sup>

Furthermore, the benchmarks for evaluating progress in science and technology are fundamentally divergent. In the scientific realm, advancement is measured by the degree of proximity to universal truth; conversely, technological progress is gauged by the increasing efficacy and success in addressing practical challenges.

There is also a distinction between science and technology regarding their

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<sup>10</sup> It is imperative to underscore that *truth* itself is not relative. Rather, what can be considered relative is human knowledge of reality, which consists of the 'candidates' and 'representations' that individuals *conjecturally* construct in their efforts to apprehend the truth concerning a specific aspect of reality.

<sup>11</sup> Radder (2009) conflates these two meanings and, in some cases, prefers to define the aim of technology as *social benefit*, whereas the aim of technology can be *personal* benefit.

<sup>12</sup> As critical rationalists explain, natural entities possess an "essence". Essence is what constitutes entities that we have played no role in creating; in this sense, all natural entities possess an essence. "Essence" is a category we have constructed conjecturally to give determination to what constitutes the consistency, existence, and source of the capacities of natural entities, which we do not fully know. In the same vein, critical rationalists speak of a "conjectural essence" for human technological constructs. Unlike natural entities, human technological constructs are not created from "nothing"; rather, all human technological constructs have emerged from bringing together components that were pre-existing. These constructs, insofar as they relate to the functions we ourselves have embedded in them, have nothing hidden from us. From here, another important difference between science/knowledge and technology becomes clear: for science/knowledge, although it too is a human construct, a kind of "essence" can be assumed. The "essence of science/knowledge" in any epistemological domain is the truth about the reality that the science/knowledge in question intends to know. Truth is not our construct, and we can only approach the knowledge of it conjecturally (For further discussion on this matter, see (Paya, 2016a; 2016c; 2017b, pp. 307–320, 343–396).

dependence on non-epistemic values. Scientists strive, as far as possible, to ensure that their scientific findings are devoid of subjective and individual aspects, as well as values originating from specific ideologies and cultures.<sup>13</sup> For scientists, the validity of scientific findings must be objective, meaning they are publicly accessible and open to criticism. In contrast, technological products are deemed more acceptable to the degree that they satisfy consumers' preferences—that is, how effectively they fulfill non-epistemic values and serve as superior pragmatic tools (Paya, 2016b, Part 2, Essay 2; pp. 394-443; 2017a, Part 2).

### 3. On the Term 'Applied Science'

Conceptual demarcations and taxonomies derive their validity from their capacity to facilitate the advancement of knowledge. Within a rigorous theoretical framework, if a specific distinction fails to provide a more nuanced or accurate understanding of the subject matter, it must be regarded as redundant and subsequently discarded. The nomenclature "applied science" represents precisely such a superfluous and fundamentally misleading classification.

To elucidate the problematic nature of this term, several preliminary considerations must be addressed. First, conceptually imprecise conceptions of "science" are largely the legacy of the philosophical framework promulgated by positivism and its successor, logical positivism (Popper, 1994, ch. 7). Second, a diachronic analysis of the history of ideas reveals that terms such as "applied sciences," "engineering sciences," and "engineering" have undergone substantial semantic shifts over time, mirroring the evolution of human knowledge (Paya, 2017b, p. 358).<sup>14</sup> Third, from the perspective of critical rationalism, linguistic designations—including specific terms, phrases, and titles—possess negligible epistemic weight regarding the substantive growth of knowledge or the resolution of pragmatic problems; rather, intellectual priority must be accorded to the underlying *theoretical* constructs that these labels are intended to signify.<sup>15</sup>

Notwithstanding the secondary status of linguistic labels, adopting specific terminology becomes intellectually untenable when it facilitates conceptual obfuscation. This is precisely the case with the term 'applied science,' which David Miller identifies as a fundamentally misleading designation (Miller, 2006/2017, ch. 5, sec. 3). This claim is clear from the arguments presented. The task of science—whether it be physics, geology, chemistry, physiology, economics, or cosmology—is,

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<sup>13</sup> The above emphasis and caution refer to the conscious advocacy of matters that have an ideological and subjective character—meaning they are completely personal and outside the reach of the public sphere and, consequently, beyond criticism. Otherwise, if scientists examine a specific thought, doctrine, or metaphysical system based on non-dogmatic considerations (and not personal or pragmatic interests) in a critical process, there is no obstacle; although its incorrectness may later be revealed through the same critical process.

<sup>14</sup> The term "applied science" was coined by Samuel Coleridge in 1817 (likely as an equivalent for the German term *angewandte Wissenschaft*). The word "engineering" also has a history full of ups and downs. In the English language, the term "engineering sciences" became common from the second half of the 19th century, but its meaning has changed significantly since then.

<sup>15</sup> In the 1960s, two physicists independently discovered the most fundamental particle currently recognized. One researcher labeled this particle a "quark," while the other referred to it as an "ace," a term derived from card games. Had an Iranian or Chinese physicist discovered this particle and assigned it other names, the choice of nomenclature would have been of minor importance. The crucial factor was the scientific accuracy and explanatory power of the model proposed to account for the behavior of this and other related particles (Paya, 2005, p. 526).

as previously stated, the discovery of truth about reality, and it pursues no objective beyond this.

In the context of the humanities and social sciences, it is imperative to recognize their dual nature, which distinguishes them from the physical and biological sciences. These disciplines function as science in one respect and as technology in another. For instance, those like Michel Foucault have designated certain aspects of these fields as "human and social technologies." However, a significant categorical mistake arises when these disciplines are reduced solely to their technological dimension—a reductionist tendency prevalent among postmodernists who conflate the pursuit of scientific truth with technological implementation. While these two facets are intertwined, they remain ontologically and epistemologically distinct. Similarly, engineering practices do not aim to acquire knowledge for its own sake, but rather to intervene in reality. Although such activities depend on some knowledge of reality to ensure practical success, their primary orientation is interventional rather than epistemic.<sup>16</sup>

An alternative conceptual framework, often prevalent among those influenced by positivist or anti-positivist paradigms, posits a tripartite division of the scientific enterprise. This view distinguishes between: (1) fundamental theories; (2) the modeling of these theories; and (3) the experimental phase. Within this restrictive framework, "pure science" is delimited solely to the first stage—fundamental theories intended to provide causal explanations for phenomena. In contrast, the modeling and experimental phases are viewed as inextricably linked to technological considerations, aiming for functional realization rather than mere knowledge acquisition. Consequently, some researchers use the term "applied science" to describe these latter activities, characterizing them as proposals to manipulate and control systems to achieve specific pragmatic objectives.

By elucidating the underlying mechanisms and procedural dynamics of phenomena, these disciplines offer prescriptive frameworks for manipulating and controlling natural or artificial systems to attain specific pragmatic objectives. This taxonomic category incorporates substantial domains such as medicine, nursing, science policy-making, engineering, and agriculture. Within this framework, proponents argue that the engineering and applied sciences—exemplified by applied physics—are neither purely scientific nor entirely instrumental. Instead, they are viewed as the theoretical study of fundamental theories under specific boundary and initial conditions (Agassi, 1966, pp. 348–366).

In response to proponents of this alternative paradigm<sup>17</sup>, it must be emphatically

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<sup>16</sup> In the field of medicine, for instance, despite the increasingly close relationship established in recent decades between research activities and clinical-therapeutic practices, a clear distinction remains between these two domains for specialists who are conscious of the nature of their work. A cancer researcher, whose efforts are directed toward producing research findings, performs a different role than a physician who utilizes those findings to treat patients. While a single individual may occupy both roles, they generally maintain an awareness of the distinction and do not conflate the two (Paya, 2016a, p. 238).

<sup>17</sup> The aforementioned conceptualization of science is not the sole model for explaining the phenomenon of science. It represents one approach developed by certain philosophers of science within the framework of critical rationalism. Another prominent alternative model has been proposed by the American-Dutch philosopher Bas van Fraassen. For an overview of his perspective and its critique, see Paya (2016b, pp. 746–925).

restated that the scientist's essential vocation is the pursuit of knowledge of objective reality. This endeavor remains ontologically independent of any pragmatic utility.<sup>18</sup> In contradistinction, the fundamental objective of the technologist and the engineer is the resolution of practical problems. Given that such problems are intrinsically context-sensitive and situational, practitioners are required to subject diverse solutions to rigorous empirical scrutiny across a wide array of conditions—including idealized or "fantasy" scenarios—to ensure functional efficacy and eliminate operational errors.<sup>19</sup>

In deliberating upon engineering, technology, and the resolution of practical problems, it is not suggested that these domains are devoid of any knowledge of reality. Fundamentally, *pragmatic success (pragma)* is contingent upon *truth*, understood as correspondence with objective reality. The fallacy inherent in the defense of "applied science" lies in the assumption that modeling and testing constitute a "scientific" phase. In contrast, "pure" or theoretical science is supposedly devoid of modeling. This conception is fundamentally flawed; fundamental theories and conjectures are themselves *models*.

Furthermore, empirical evaluation is an integral component of any scientific activity, as the identification of error is impossible without rigorous investigation. Crucially, the objective of such tests is to discover theoretical failures, which must not be conflated with experiments performed for purely pragmatic ends. Both theoretical models and practical problem-solving models require empirical assessment; in both cases, the aim remains to identify errors.

However, it is essential to recognize that the nature of 'error' differs fundamentally across these two domains. In scientific inquiry, error refers to a discrepancy in our conjectures concerning the intrinsic capacities of reality—those elements of the world that exist independently of human intervention. Conversely, in technological practice, error signifies a failure in a human-designed mechanism intended to solve a practical problem. While the primary objective of science is to gain knowledge of that which we did not construct, technology focuses on identifying and correcting flaws in our own artifacts.<sup>20</sup> Proponents of this approach mistakenly assign the evaluation of the validity of fundamental conjectures and theories to the domain of "applied science", whereas the active manipulation of reality properly belongs to the sphere of technology.

Our epistemological analysis concludes that designating "applied science" as a

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<sup>18</sup> A notable historical example involves William Herschel's nineteenth-century discovery that different parts of the light spectrum possess varying temperatures. The practical significance and application of this observation were only recognized and utilized in the twentieth century.

<sup>19</sup> A recent case is the pedestrian bridge at Florida International University, which collapsed in March 2018 under extreme or so-called "fantasy" conditions that had not been previously tested. Although the bridge's designers and engineers had prepared the structure to withstand storms, they failed to test it under the specific condition where the bridge's support cables were completely tightened while still requiring a certain degree of freedom.

<sup>20</sup> An additional clarification is necessary here to avoid misunderstanding. In theoretical pursuits, we have no means of apprehending reality other than by constructing conjectures and evaluating their deficiencies. Consequently, the epistemic process of "error elimination" regarding reality is directed toward our own constructs. However, as explained in the text, this type of error elimination pertains to a reality that we did not create. In contrast, when dealing with "errors in mechanism" within practical solutions, our focus is specifically on the defects within the constructs we have designed to address practical needs.

discrete category is fundamentally redundant, as it adds no epistemic value beyond the established science-technology demarcation. Within this framework, scientific activity is understood to involve both the generation of theoretical constructs and the instrumental use of technology. However, such technological engagement remains strictly subordinated to the critical evaluation of conjectures regarding the inherent capacities of reality, serving as a means of assessing theories rather than a mechanism for addressing practical exigencies.

#### **4. The Relationship Between Science and Technology**

As Don Ihde (1979, 1983) points out, technology has a *historical precedence* over science. While humans have existed as tool-making beings for approximately three million years, the history of the systematic pursuit of knowledge dates back only about 3,000 years.<sup>21</sup> Before this transition, human interpretations of the natural world were predominantly mythological. Thus, it cannot be cogently argued that technology is fundamentally dependent upon scientific knowledge for its existence. David Miller (2006/2017) further critiques the purported precedence of science, maintaining that scientific inquiry is neither a necessary nor a sufficient condition for technology. The traditional conception that "science discovers, and industry applies"—which posits a chronological priority for science—is therefore a fundamental misconception. (Miller, 2006/2017, ch. 5, sec. 3).<sup>22</sup>

While the aim of science is the pursuit of truth, it is epistemologically erroneous to posit that industrial advancement is monolithically dependent upon scientific discoveries. Nature provides compelling counter-examples: numerous animal species construct sophisticated artifacts—such as beavers building river dams—without possessing empirical knowledge in its modern, systematic form. Similarly, various human practices, ranging from the culinary arts to musical performance, function as technologies by addressing non-cognitive needs and modifying external reality, yet they often operate independently of formal scientific frameworks. A chef's proficiency, for example, does not presuppose an understanding of the chemical compositions of ingredients, demonstrating that such skills are not simply applied chemistry. This is further illustrated by prominent scientists like Rutherford and Lord Kelvin, who failed to foresee the technological applications of their own theoretical work; Rutherford famously dismissed the possibility of harnessing atomic energy as "moonshine." Such instances reinforce the conclusion that empirical knowledge is neither a necessary nor a sufficient condition for the emergence of technology.

From a logical perspective, Miller further substantiates the thesis that empirical knowledge is inherently insufficient for the realization of technology. Scientific laws

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<sup>21</sup> The terms "science" and "knowledge" are often used synonymously in this context. However, within this article, whenever the term "science" is used independently, it specifically refers to the empirical science.

<sup>22</sup> It should be noted that this claim by Miller must be interpreted as a logical claim. Modern technologies would certainly stop growing without the help of science, and at most, would remain within the same known fields where Kuhn's "normal scientist" (who is actually a technologist) pursues their activities. However, his claim *logically* means that these two constructs, regardless of later developments, have followed their own laws of evolution and have been independent entities. In other words, his claim refers to the fact that they are "co-evolutionary" entities. Following Popper, it can be argued that humans enter the world with at least two distinct innate capacities: one for theoretical conjecture and another for practical tool-making (Miller, 2006, pp. 178–179).

and theories generally adopt a universal logical structure, which can be represented—albeit with some simplification—through universal quantification:<sup>23</sup>

$$\forall y (Ay \rightarrow Cy).$$

In the scientific enterprise, the investigative focus is typically directed toward identifying the effects or consequences (C) that logically follow from a specific cause (A). Conversely, technological practice proceeds via an inverse methodology: while the objective is the actualization of a predetermined effect (C), the specific cause (A) required to facilitate that effect remains logically underdetermined. This asymmetry implies that selecting an appropriate cause is not a direct consequence of scientific laws, but rather a separate practical problem.

Although in rare instances one can find relationships in science that point precisely to the causes producing our desired effects, there is generally no restrictive necessity in this area; the causes required for manufacturing artifacts are not usually obtained directly from science. Even if such a possibility existed by chance, we may not be able to implement it to produce the desired artifacts. Therefore, science is devoid of technological biases—not in the sense that we are unable to explain successes based on scientific theories, but in the sense that scientific theories fundamentally do not instruct us on how to solve a practical problem or satisfy a human need.

While scientific theories may provide general inspirations for the realm of action, they do not inherently contain prescriptive instructions for solving specific practical problems or satisfying human needs. For instance, a comprehensive understanding of electromagnetic wave theory is not, in itself, sufficient to engineer a mobile phone. The transition from theoretical knowledge to a functional artifact requires creative conjectures and a rigorous trial-and-error process. From the standpoint of deductive logic, there is no direct bridge from a desired effect back to its necessary cause; therefore, as Radder (2009, p.70) observes—and contrary to the assertions of Mario Bunge (1966, p.329)—scientific laws do not provide an automatic justification for technological rules, nor is the path between them bidirectional.

Despite these logical asymmetries, science maintains a vital critical role in relation to technology. As Popper (1944, sec. 20) argues, science delineates the boundaries of the impossible<sup>24</sup>, effectively teaching technology what cannot be achieved within the realm of physical reality. It is important to emphasize that science is fundamentally descriptive rather than prescriptive; it lacks normative elements and does not dictate what "ought" to be done. Instead, it provides objective information regarding "what is" and "what is not." These scientific constraints define the limits that technological endeavors cannot transcend, serving as a safeguard against futile pursuits.

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<sup>23</sup> This should be taken with tolerance. Because scientific theories often cannot be fully formalized using first-order logic alone. To accurately represent their structure and subsequent developments, set-theoretic formalization is required (Suppes, 1967, p. 58).

<sup>24</sup> Technology, through instrument-making, also helps scientists conduct their research more precisely. A prominent example is the development of various scanners, which has revolutionized neuroscience and our understanding of brain mechanisms over the past three decades.

Despite these demarcations, many individuals, even while possessing knowledge of these scientific constraints, may choose to disregard the objective information provided by science. For instance, the law of conservation of energy physically invalidates the possibility of constructing a 'perpetual motion machine.' Likewise, the principle of entropy holds that the construction of a machine with 100% efficiency is a physical impossibility (Popper, *ibid.*). Yet, this scientific clarity has not deterred numerous individuals throughout history from squandering time, energy, and capital on the pursuit of perpetual motion or the ideal of total efficiency. In many such instances, these pursuits were promoted by charlatans who utilized these unfounded claims as a means of deception and exploitation.<sup>25</sup>

Returning to the logical structure of causal relationships in scientific theories, there is no logical path to bridge from an effect  $C$  (the desired result in the realm of action) to its cause  $A$ . However, by utilizing the logical rule of *modus tollens*, we are logically capable of arriving at the negation of  $A$  ( $\neg A$ ), which indicates the paths that cannot be followed. In formal logic, this is represented as:

$$\forall y(Ay \rightarrow Cy) \wedge \neg Cy \vdash \neg Ay.$$

Thus, engineers and technologists can utilize science—not necessarily to identify the initial causes of technological products—but rather to detect errors and eliminate practical conjectures. For instance, in the production of a cold medicine, science suggests, based on microbiological investigation, that the cause of the cold is viral, thereby eliminating all therapeutic options involving antibiotics. In short, science does not tell us how to discover a way to treat a disease; technologists carry out this task through the process of conjecture and refutation. However, science clarifies which therapeutic paths are futile and meaningless to pursue.

With the increasing complexity of the advancement and production of modern technological systems, the critical role of science in relation to technology has become more fundamental. Historically, the rectification of errors and the elimination of practical conjectures were achieved primarily through empirical testing and the material implementation of ideas. As Popper (1944) observed, determining whether a sieve is suitable for transporting water requires no scientific computation; a simple trial suffices. However, in the context of sophisticated contemporary technologies, the economic and operational costs of implementing such conjectures are exceedingly high. Consequently, scientific calculations serve as an indispensable heuristic aid, a development that has largely fostered the misconception that technology is ontologically dependent upon science.

Furthermore, a significant proportion—if not the entirety—of what is designated as scientific knowledge and technical skill is derived from the epistemic process of learning from error. Psychologically, there is a marked tendency to marginalize or forget the trajectory of failed conjectures once a pragmatic goal is realized. This retrospective clarity often fosters the illusion that scientific laws dictate the process of discovery itself. However, the act of discovery remains fundamentally autonomous and is not subject to pre-established functional instructions or algorithms; while certain prerequisites for discovery are necessary, they are consistently insufficient for

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<sup>25</sup> For a discussion on pseudo-scientific practices and charlatanism in this field, see Perelman (1970), *Physics for Entertainment*.

the actualization of innovative solutions.<sup>26</sup>

An additional factor perpetuating the fallacy of a necessary ontological link between science and technology is the pervasive failure to distinguish between scientific and technological practitioners within contemporary society. Consistent with Thomas Kuhn's (1971) conceptualization of 'normal science,' many individuals popularly identified as scientists—to whom technological milestones, such as innovative oncological therapies, are attributed—are more accurately characterized as technologists who utilize scientific theories as a heuristic resource.<sup>27</sup> The neglect of this demarcation bolsters the erroneous assumption that technology is essentially derivative of science. This conceptual conflation is further evident in Bas van Fraassen's anti-realist framework, which posits empirical adequacy rather than truth attainment as the objective of science. By marginalizing correspondence truth, such perspectives effectively reduce pure science to engineering, thereby obscuring the distinct epistemological status that separates the theoretical sciences from their technological counterparts.<sup>28</sup>

Last and most importantly, the dominance of inductivist thinking in the intellectual atmosphere leads to the critical role of science being overlooked. Inductivism seeks a way to bridge from effect to cause or from the particular to the universal. When this doctrine was introduced into the methodology of science, it sought to derive scientific theories from raw observations; in other words, it sought to ground science on observation. Similarly, in the realm of practice, inductivism emphasizes the dependence of technology on science—a view widely prevalent in society.

However, as many thinkers have clarified, the inductivist approach is fraught with numerous problems and more closely resembles a myth (Miller, 2006/2017). In fact, Miller, drawing inspiration from Popper's critique of inductivists regarding the status of observations in science, has rejected the inductivist perspective on the relationship between science and technology. Popper argued that induction is an invalid deductive method in both theoretical and practical domains and is fundamentally impossible as a method of discovery. Contrary to inductivist claims, he emphasized that observations cannot provide a firm foundation for science; instead, they serve to test conjectures and eliminate errors in our scientific theories. In a similar vein, in the realm of practice, Miller considers the role of science to be the testing of practical conjectures and the elimination of errors for engineers and technologists (Miller, 2006/2017).

## **5. Confusion of Science and Technology**

The conceptual distinction between science and technology is meaningful only within a realist framework. In this perspective, truth—defined as the correspondence between conjectural assertions and objective reality—occupies a central role. Scientific or theoretical outputs are significant to the extent that they possess truth-value. In contrast, regarding technological achievements and artifacts, the primary concern of

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<sup>26</sup> For a more detailed explanation, see Paya (2016a, 2016b).

<sup>27</sup> Regarding the nature of engineering activities, see "The Jurist as Engineer" in Paya (2017b), Walter Vincenti (1993), and the various works of Henry Petroski (1992, 1994, 1998, 2010).

<sup>28</sup> For a critical evaluation of Bas van Fraassen's perspective, see Paya (2016b, Final Chapter).

their innovators or users is not their truth-value; rather, these constructs are evaluated and judged based on their functional efficiency and pragmatic utility.

Nonetheless, it is of paramount importance to observe that the efficacy of all technological artifacts and pragmatic interventions ultimately relies on *correspondence truth*. In practice, the successful functioning of these constructs depends on the extent to which they—either explicitly or implicitly—adhere to and utilize the inherent capacities of objective reality and the nomological laws governing it. Consider, for instance, the structural integrity of a building; should an architect neglect the fundamental physical laws of mechanics and statics, the resulting edifice will inevitably fail to endure. The history of architectural practice provides sobering examples in which disregard for systemic operational laws during activities such as excavation has precipitated catastrophic structural failures and significant human and financial losses.

Furthermore, it is essential to recognize that while the primary objectives of technologists and engineers are pragmatic and functional, any theoretical framework that attempts to reduce *truth* to *success* in practice—akin to other 'theories of truth' such as consistency or redundancy theories—derives its strength from a foundational, albeit often implicit, reliance on correspondence truth. Consequently, the overarching debate concerning the demarcation between science and technology can be largely understood as an extension of the broader philosophical conflict between realists and their various adversaries, including instrumentalists, pragmatists, and social constructivists.

In taxonomizing the various perspectives concerning the demarcation between science and technology, Niiniluoto (2016, p. 95) identifies several distinct conceptual positions. One such stance posits that technology is ultimately reducible to science, implying an ontological dependency that the preceding analysis has sought to challenge. Another perspective is to consider science as reducible to technology and ontologically dependent upon it. This latter position aligns closely with the instrumentalist doctrine, which holds that what matters in science is merely its empirical adequacy or success.

The significance and status of empirical success within the scientific enterprise require a nuanced examination. While a lack of empirical success generally necessitates abandoning a scientific theory, the history of science demonstrates that many theories once considered successful were ultimately falsified and discarded (Agassi, 1966). This historical reality suggests that the intrinsic value of a scientific theory should not be evaluated solely based on its pragmatic or empirical success. As Agassi observes, anchoring trust in science to its successful outcomes is a hallmark of a justificationist paradigm. Within this framework, inductivist methods aim to justify truth claims by appealing to success. While such inductivist patterns may appear enticing for identifying effective theories, they ultimately stifle the exploratory character of science, confining its development within the limits of rigid, pre-established algorithms.

Alternatively, trust in the scientific enterprise can be sustained through a critical rationalist approach—as advocated by Popper and elaborated by Agassi—which preserves a vital role for intuition and audacious conjectures. Within this paradigm, the reliability of science is grounded in its commitment to critical methodology and

critical discussion, rather than in its practical achievements. Although in recent years the success of science is no longer regarded as final and certain, the probabilistic nature of success has been substituted within the framework of Bayesian programs. However, this path once again leads back to algorithmic processes. In sum, the instrumentalist approach, in its various forms, grounds trust in science on the *success* of science.<sup>29</sup>

The primary function of empirical success is to facilitate the rigorous evaluation of conjectures. For critical rationalists, the empirical refutation of a scientific theory is inherently enlightening, as it substantively contributes to the growth of knowledge. This perspective necessitates a distinction between *negative knowledge (via negativa)*, which informs us of what reality is not by identifying failed conjectures, and *positive knowledge (via positiva)*<sup>30</sup>, which consists of those conjectures that have successfully withstood rigorous critical assessment, albeit remaining inherently provisional (Paya, 2016b, 2017a).

Furthermore, it is important to emphasize that a theory's lack of refutation carries significant implications. The concept of *corroboration* carries substantial epistemic weight; because scientific theories are essentially bold conjectures about reality, their survival in the face of rigorous assessment signifies the attainment of a provisional and currently unrefuted knowledge of nature (Miller, 1978).<sup>31</sup> The crux of the distinction between science and technology lies in the specific role and importance assigned to empirical adequacy—a distinction that effectively evaporates within the instrumentalist approach.<sup>32</sup>

Consequently, from this perspective, Newtonian mechanics would be devoid of epistemic value if it lacked practical utility. Therefore, by marginalizing or discarding the concept of truth, instrumentalists effectively reduce science to a subset of technology. Similarly, Thomas Kuhn's (1971) philosophy, by sidelining the pursuit of truth, provides a fertile ground for instrumentalism; it is therefore unsurprising that much of the activity characterized as 'normal science' is essentially technological in nature. Furthermore, those who argue that modern science is simply a means for the mastery and conquest of nature overlook a fundamental point: science is inherently free from technological bias. Its primary objective is to understand nature and the

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<sup>29</sup> The practical success of conjectures does not necessarily change their *conjectural* status (i.e., their *epistemic status*). The primary advantage provided by such conjectures—the extent of which is also dependent on their truth value—is that they rationally permit us to utilize them to address practical needs (albeit *indirectly*, as no direct mathematical-scientific path of knowledge exists). By "indirect," it is meant that unrefuted knowledge (temporarily) defines *the boundaries of the possible* for us, thereby informing us which efforts in certain directions are futile. To transcend these boundaries, technology requires types of knowledge/capacities that can only *facilitate* (i.e. serving as a necessary but not sufficient condition.) effective solutions within the technologist's ecosystem of knowledge-skill.

<sup>30</sup> Critical rationalists categorize knowledge into two types: "negative knowledge," which refers to theories discarded after failing empirical tests—thereby teaching us what reality is not—and "positive knowledge," which consists of tentative conjectures that have successfully withstood testing thus far (Paya, 2016b, 2017a).

<sup>31</sup> See David Miller's review of the book *Science in Flux* by Joseph Agassi, published in *The Philosophical Quarterly*, Vol. 28, No. 113 (Oct., 1978), pp. 368-369.

<sup>32</sup> It is important to emphasize that the adventurism of scientists is purposeful and directed toward significant problems, rather than being an anarchic endeavor. Within the context of scientific progress, the value of this adventurous spirit lies in the fact that a scientist's failure—as noted earlier—provides negative knowledge concerning reality.

pursuit of truth, and its theoretical explanations do not, by their very nature, constitute prescriptive mandates for control or intervention.

A common counterargument may posit that, in the contemporary era, science and technology have become inextricably intertwined to the point that modern scientific inquiry is effectively impossible without the mediation of sophisticated laboratory instruments and complex technological systems. However, this assertion lacks philosophical rigor, as the defining characteristic of science remains the pursuit of truth. The fundamental distinction lies in the epistemic objective and the underlying intent behind the activity; the relative complexity or simplicity of the instrumentation employed is secondary. Moreover, the primary aim of science transcends mere phenomenological description—exemplified by empirical generalizations such as the Boyle-Mariotte Law—aiming instead at deep theoretical explanations provided by laws and theories, such as the kinetic theory of gases. To overlook the distinct epistemological status of scientific explanation is to risk conflating the aim of science with mere empirical adequacy. Such a reduction assigns a purely pragmatic status to explanation, thereby conceptually subordinating science to the domain of technology.

For example, in his early works, Habermas (1971, 1978) considered technology an inseparable part of the natural sciences and, like the positivists, viewed observation as the basis of science.<sup>33</sup> According to him, because observation and experimentation require a human agent to conduct and interpret them, technical interests necessarily intervene in the prediction and control of experiments and the production of scientific knowledge (Radder, 2009, p. 79).

This perception of the relationship among science, experimentation, and technology is fraught with confusion. While it is true that scientific laws and theories are universalizations that hold only under ideal conditions—leading us to use technologies to evaluate them—the aim of science remains the understanding of reality, or, in other words, the pursuit of truth. There are stages in the gap between theory and experience under laboratory and specific conditions that are filled with technologies. This gap is bridged by constructing theoretical models to test the claims of the initial theory (which is itself nothing more than a conjecture and a mental model), by modeling empirical data, and by utilizing laboratory instruments and statistical and probabilistic measurement tools. Notwithstanding these operational interdependencies, the fundamental epistemological demarcation between science and technology remains inviolable.

Instrumentalists typically emphasize utility and pragmatic success, thereby conflating science and technology into a monolithic domain. In these approaches, a fundamental conceptual confusion often arises between correspondence truth, understood as a semantic theory, and various other 'theories of truth'—which are more accurately characterized as epistemological approaches rather than substantive theories of truth.<sup>34</sup> By masquerading as theories of truth, these epistemological accounts have introduced profound conceptual confusion.

Since these accounts are themselves theoretical conjectures, their own validity is

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<sup>33</sup> In his later works, Habermas placed greater emphasis on the theoretical status and objectivity of theories, as well as the interactions within the scientific community.

<sup>34</sup> This type of approach is referred to as the "epistemologizing of truth."

contingent upon their correspondence with reality; thus, they remain inescapably bound by the very requirements of correspondence truth. Consequently, adopting a pragmatic interpretation of truth reduces it to mere 'success'. However, the successful execution of a technological project—such as the construction of a bridge—is inherently contingent upon its conformance to natural laws. In this sense, pragmatic success, or 'pragmatic truth,' is fundamentally dependent upon an underlying, albeit often implicit, reliance on correspondence truth.<sup>35</sup> It follows that theoretical frameworks which claim the label of 'realism' while disregarding the primacy of correspondence truth ultimately collapse into anti-realism.<sup>36</sup>

Therefore, a significant analytical point emerges at this juncture: the conflation of science and technology is not merely an incidental consequence of non-realist approaches; rather, endorsing such a conflation inexorably leads to falling into the abyss of anti-realism. In other words, there is a mutual entailment between this conceptual conflation and adopting an anti-realist stance.<sup>37</sup>

Furthermore, essentialist traditions represent another prominent intellectual trajectory that minimizes or disregards the demarcation between scientific and technological domains. Heidegger (1977, pp. 43-44), for example, assumes the essential identity of modern science and technology, implying that a specific, assertive orientation toward nature underpins science. In Heidegger's view, this 'aggressive' stance functions as a transcendental or *a priori* condition for the very possibility of modern science; thus, science is conceptualized as the derivative product of a fundamentally technological approach. This interpretive lens, which views science through the prism of its alleged technological essence, is also reflected—to varying degrees—in the perspectives articulated by the early Habermas, Foucault, and Lee Lelas.

Within several of these perspectives, the function of experimentation is reconceptualized, effectively dissolving the boundaries between science and technology and leading to the characterization of science as a subset of technology.<sup>38</sup> A fundamental premise of this approach is the primacy of practice over theory, positing that scientists, engineers, and technicians engage in some form of practice: a unified process of laboratory-based intervention, discussion, and material construction. Consequently, the resulting output—be it a theoretical conjecture or a technological artifact—is viewed as the product of a singular socio-material activity.<sup>39</sup>

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<sup>35</sup> Popper discussed the topic of "truth and pragmatism" in a scattered fashion throughout various works. Other realists—who do not belong to the school of critical rationalism—have also examined this issue. For a comprehensive discussion and additional references, see Paya (2016b, 2017a, 2017b). For an in-depth analysis regarding the reliance of epistemological theories on the correspondence theory of truth, which functions as a semantic theory, see Vision (1988, 2004).

<sup>36</sup> An instance of such seemingly realist approaches that eventually lead to anti-realist outcomes is Nancy Cartwright's perspective, which reduces all scientific activities and laws to phenomenological (technological) ones.

<sup>37</sup> Regarding these types of seemingly realist claims that conclude in anti-realism, see Paya (2016b, Section Four: Scientific Realism).

<sup>38</sup> Recent reconstructions in the field of nanoscience, such as those proposed by Don Ihde and Carl Mitcham, along with similar portrayals of the discipline, tend to obscure and render the boundaries between science and technology indistinct.

<sup>39</sup> Heidegger's thesis concerning the precedence of practice over theory culminates in the prioritization of a technological orientation over science within the context of modernity—a

This analytical focus on material processes and tangible outputs underpins the contemporary perception of science as an increasingly industrialized and organizationally mediated endeavor.

As another example, Bruno Latour rejects the fundamental distinction between science and technology by emphasizing the constructive and competitive nature of both fields (Latour, 1987, p. 131; Radder, 2009, p. 83). However, this conceptual conflation has frequently escaped the scrutiny of his critics (see, for example, Forman 2007, p. 6). Latour correctly observes that for an entity to be recognized as a specific object, it must be situated within an established semantic network; those initiated into this network perceive the object according to its intended function, an observation that underscores the epistemic distinction between mere "seeing" and 'seeing-as'. For instance, Amazonian indigenous peoples unfamiliar with modern technology might perceive a laptop merely as a "thing," lacking the semantic network to identify it as a computer. Nevertheless, Latour—and many other thinkers who conflate science and technology—neglect an ontological fact: the creation of such artifacts is predicated upon the existence of mind-independent elements in reality, characterized by inherent capacities and potentials that are not human constructions.

In the absence of these real capacities, any attempt to create a "semantic network" or distribute objects in space and time would be reduced to empty propaganda or a series of simulacra. Ultimately, even the social construction of reality relies on a reality that we did not construct ourselves.

Lee Lelas also rejects the boundary between ontology, semantics, and epistemology. He believes that observation is meant to ensure the attainment of *truth*. For Lelas, a theory is not merely a tool for calculation or prediction; it is an instrument for designing tools, encompassing both ontology and technology (1993, p. 442). He argues that the essence of scientific theories lies not in abstract mathematical or conceptual structures, but in the translations and interpretations that link theoretical concepts to the acts of observation, experimentation, and production.

Nevertheless, this reductionist perspective is fundamentally untenable; a scientific theory, *per se*, does not constitute a prescriptive blueprint for practical action or experimental intervention. For instance, the theoretical framework of quantum physics alone is insufficient to produce a laser beam, let alone to facilitate the engineering of the actual device. Furthermore, theories possess an ontological and semantic surplus that transcends the scope of any experiment. To reduce theoretical constructs to mere experimental procedures is to adopt an operationalist stance that overlooks a crucial epistemological fact: the capacity to calculate or predict the behavior of natural systems is contingent upon a prior, independent knowledge of those systems.

In this process, *calculation* essentially constitutes a mathematical articulation of our scientific knowledge, whereas prediction represents the outcome of a logical syllogism. Within this deductive framework, the major premise is our scientific knowledge of the phenomenon, behavior, or system under investigation. In contrast,

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shift that has significantly influenced French intellectuals, including Foucault. By building upon these conceptual foundations, postmodernism projects Heideggerian pessimism regarding technology onto the field of science itself (Forman, 2007, pp. 6–10).

the minor premise comprises the initial conditions or one of the testable implications derived from that knowledge. Furthermore, although the *instruments* serve to test theoretical conjectures, they properly belong to the domain of *technology*. It is crucial to observe that while both theoretical conjectures and the technological systems constructed to evaluate their practical outcomes are categorized as 'tools'—in the sense that they fulfill human needs—the term "tool" is used here as an *equivocation*. This linguistic ambiguity often leads to a categorical mistake; instruments designed to address pragmatic needs are ontologically and qualitatively distinct from those intended to satisfy epistemic requirements.

## 6. Conclusion

The distinction between science and technology ought to inform both our understanding of their respective developmental trajectories and the formulation of relevant policies. While the evaluation of scientific theories is arguably grounded in empirical evidence, explanatory power, and pursuit of truth—criteria that may be regarded as independent of human volition—technology appears to be more directly shaped by human intentions and desires.

A failure to acknowledge the distinction between technology and science, in both theoretical and practical respects, may have contributed to a number of significant problems. In particular, it can lead to a conflation between scientific institutions and science itself—understood as the body of theories, problems, and problem situations—such that judgments appropriate to the former are mistakenly applied to the latter. In historiography, this issue may also result in an insufficiently clear distinction between the evolution of science as an intellectual endeavor and that of its institutional frameworks.

Non-realist approaches to science, including instrumentalism and constructivism, seem especially prone to this confusion, often in order to bolster their own theoretical positions. In social constructivist historiography of science, for example, scientific activities tend to be restricted to, or even reduced to, exclusively social and economic factors. Consequently, such historiographies arguably lack the necessary richness to capture the full complexity of scientific practice. Reducing science to professional activities and then further reducing the study of science to the mere examination of workshops and laboratories risks obscuring many important philosophical issues about scientific theories.

It is worth noting that in these approaches, what is often emphasized as the "authority of science" is, in fact, not an inherent characteristic of science itself. Rather, it can be understood as a social construct associated with technologies and with those who exercise authority through institutions. Society, one might argue, is the primary agent that invests in technology, designs its standards, and—on that basis—applies authoritative norms, whether through legal mechanisms such as engineering or medical councils, or through other, informal means.

In the practical domain—particularly in policy-making—the conflation of science and technology may lead to ambiguities and potentially serious errors. Policies and their associated outputs, including development plans, strategic documents, and progress models, appear to be fundamentally technological in character. Unlike science, technology may be understood as a context-dependent entity; owing to this

dependence on time and place, it arguably requires continuous revision, refinement, and redesign. Civil laws and management systems can be regarded as forms of *social technology*. Confusing these with scientific laws—which are typically understood as *universal*—risks overlooking the environmental sensitivities and the social, spatial, and temporal contexts that are inherent features of technology. Such neglect could reduce or even undermine the effectiveness of these technologies, leading to highly damaging consequences.<sup>40</sup>

Science reveals certain capacities of nature to us, and philosophy plays a role in interpreting the metaphysics of science. However, the claim that the creation of science—or a philosophical foundation—necessarily gives rise to technology, or that scientific development should take priority over technological development, is not well supported. For example, versions of the "Islamic-Iranian Model of Progress" that seek to derive a specific strategy or technology directly from a proposed philosophical framework may be following an untenable approach. While philosophy and science are generally oriented toward discovering truths about reality, technology and strategy tend to propose concrete practical solutions. Nevertheless, philosophical systems may, to some extent, be useful for evaluating technologies.

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### **References**

- Agassi, J. (1966). The confusion between science and technology in the standard philosophies of science. *Technology and Culture*, 7(3), 348-366.
- Agassi, J., & Jarvie, I. (2009). *Towards a General Sociology of Science*. Retrieved from [http://www.yorku.ca/jarvie/online\\_publications.htm](http://www.yorku.ca/jarvie/online_publications.htm).
- Bijker, W. E., & Law, J. (Eds.). (1987). *Shaping Technology/Building Society: Studies in Sociotechnical Change*. MIT Press.
- Bloor, D. (1991). *Knowledge and Social Imagery* (2nd ed.). Chicago: University of Chicago Press.
- Bunge, M. (1966). Technology as applied science. *Technology and Culture*, 7, 329-347.
- Cartwright, N. (1983). *How the Laws of Physics Lie*. Oxford University Press.
- Forman, P. (2007). The primacy of science in modernity, of technology in

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<sup>40</sup> Numerous examples can be cited to illustrate this point. For instance, the healthcare system can be viewed as a form of social technology. In certain countries where many diseases that were once common have been eradicated for some time, the generation of physicians trained in those academic environments may not acquire the necessary skills and competence for diagnosing and treating such illnesses due to a lack of clinical exposure. Consequently, they may be unable to diagnose a condition introduced by a traveler from another region. To address this limitation, young physicians are often encouraged to spend a year or two gaining experience in countries where these diseases remain prevalent, enabling them to provide the necessary clinical skills upon their return.

postmodernity, and of ideology in the history of technology. *History and Technology*, 23, 1-152.

Habermas, J. (1971). *Toward a Rational Society*. Heinemann.

Habermas, J. (1978). *Knowledge and Human Interests* (2nd ed.). Heinemann.

Heidegger, M. (1998). The question concerning technology (S. Etemad, Trans.). *Arghanoon*, 1(1), 4-43. [in Persian]

Ihde, D. (1979). *Technics and Praxis*. Reidel.

Ihde, D. (1983). *Existential Technics*. State University of New York Press.

Kuhn, T. (1971). *The Structure of Scientific Revolutions* (2nd ed.). University of Chicago Press.

Latour, B. (1987). *Science in Action: How to Follow Scientists and Engineers Through Society*. Harvard University Press.

Lelas, S. (1993). Science as technology. *British Journal for the Philosophy of Science*, 44, 423-442.

Lelas, S. (2000). *Science and Modernity: Towards an Integral Theory of Science*. Kluwer.

Miller, D. (1978). [Review of the book *Science in Flux*, by J. Agassi]. *The Philosophical Quarterly*, 28(113), 368-369.

Miller, D. (2006). *Out of Error*. London: Routledge.

Mirbagheri, S. M. M. (2011). *Religion, science, and religious science in social action: The instrument for the realization of Islam*. Iranian-Islamic Model of Progress, Draft Version. [in Persian]

Mitcham, C. (1994). *Thinking through Technology: The Path between Engineering and Philosophy*. University of Chicago Press.

Mitcham, C., & Schatzberg, E. (2009). Defining technology and the engineering sciences. In *Philosophy of Technology and Engineering Sciences* (Vol. 9). Elsevier.

Niiniluoto, I. (2016). Science vs. technology: Difference or identity? In M. Franssen, P. E. Vermaas, P. Kroes, & A. W. M. Meijers (Eds.), *Philosophy of Technology after the Empirical Turn* (pp. 93-106). Springer.

Paya, A. (2005). *Philosophical analysis: Issues and perspectives*. Tehran: Tarh-e No. [in Persian]

Paya, A. (2016a). The jurist as an engineer: A response to some criticisms. *Sadra Islamic Humanities Quarterly*, (20), 224-244. [in Persian]

Paya, A. (2016b). *Philosophical analysis from the perspective of critical rationalism*. Tehran: Tarh-e No. [in Persian]

Paya, A. (2016c). The jurist as an engineer: A critical evaluation of the epistemological status of Fiqh. *Epistemological Studies in Islamic University*, 19(2), 173-198. [in Persian]

- Paya, A. (2017a). *The research of philosophers and engineers*. Tehran: Institute for Social and Cultural Studies. [in Persian]
- Paya, A. (2017b). *Paths, destinations, and customs*. Tehran: Institute for Social and Cultural Studies. [in Persian]
- Perelman, Y. (1970). *Physics for Entertainment*. Mir Publishers.
- Petrosky, H. (1992). *To Engineer is Human: The Role of Failure in Successful Design*. Vintage Books.
- Petrosky, H. (1994). *Design Paradigms: Case Histories of Error and Judgment in Engineering*. Cambridge University Press.
- Petrosky, H. (1998). *Invention by Design: How Engineers Get from Thought to Thing*. Harvard University Press.
- Petrosky, H. (2010). *The Essential Engineer: Why Science Alone Will Not Solve Our Global Problems*. Random House.
- Popper, K. (1944). The poverty of historicism II. *Economica*, 11(43), 119-137.
- Popper, K. (1958/2005). *The Logic of Scientific Discovery*. Routledge.
- Popper, K. (1963). On the sources of knowledge and of ignorance. In *Conjectures and Refutations: The Growth of Scientific Knowledge*. New York: Harper & Row.
- Popper, K. (1971). *The Open Society and Its Enemies* (Vol. 2). Princeton University Press.
- Popper, K. (1972). *Objective Knowledge*. London: Oxford University Press.
- Popper, K. (1983). *A Popper Selection* (D. Miller, Ed.). Princeton University Press.
- Popper, K. (2005). *The myth of the framework: In defence of science and rationality* (A. Paya, Trans.). Tehran: Tarh-e No. [in Persian]
- Radder, H. (2009). Science, technology, and the science–technology relationship. In *Philosophy of Technology and Engineering Sciences* (Vol. 9).
- Suppes, P. (1967). What is a scientific theory? In S. Morgenbesser (Ed.), *Philosophy of Science Today* (pp. 55-67). New York: Basic Books.
- Van Fraassen, B. C. (1980). *The Scientific Image*. Oxford University Press.
- Vincenti, W. (1993). *What Engineers Know and How They Know It*. Johns Hopkins University Press.
- Vision, G. (1988). *Modern Anti-realism and Manufactured Truth*. Routledge.
- Vision, G. (2004). *Veritas: The Correspondence Theory and Its Critics*. MIT Press.