# Four Examples of Pseudoscience

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**Abstract** A relevant issue in the philosophy of science is the demarcation problem: how to distinguish science from nonscience, and, more specifically, science from pseudoscience. Sometimes, the demarcation problem is debated from a very general perspective, proposing demarcation criteria to separate science from pseudoscience, but without discussing any specific field in detail. This article aims to focus the demarcation problem on particular disciplines or theories. After considering a set of demarcation criteria, four pseudosciences are examined: psychoanalysis, speculative evolutionary psychology, universal grammar, and string theory. It is concluded that these theoretical frameworks do not meet the requirements to be considered genuinely scientific.

**Keywords** Demarcation Problem · Pseudoscience · Psychoanalysis · Evolutionary psychology · Universal grammar · String theory

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## 1 Introduction

The demarcation problem is the issue of how to differentiate science from nonscience in general and pseudoscience in particular. Even though expressions such as "demarcation problem" or "pseudoscience" were still not used, some consider that an early interest for demarcation existed as far back as the time of ancient Greece, when Aristotle separated *episteme* (scientific knowledge) from mere *doxa* (opinion), holding that apodictic certainty is the basis of science (Laudan 1983, p. 112). Nowadays, the issue of demarcation continues being discussed. Certainly, demarcating science from pseudoscience is not a topic of exclusive philosophical interest. Scientists and members of skeptical organizations such as the *Committee for Scientific Inquiry* also deal with this crucial theme.

The issue of how to recognize pseudoscience not only affects academia. It is well known that people spend huge amounts of money annually on alternative medicine. Adults in the United States spend $30 billion per year on alternative and complementary medicine (Nahin et al. 2009, 2016). But this is not just a problem of money. Alternative medicine can kill indirectly due to the omission of appropriate treatment (Lim et al. 2010).

Trends based on pseudoscientific beliefs, such as the anti-vaccination movement and HIV denialism, have clear negative consequences for the population. It is so important to analyze science as it is to scrutinize its imitation. Pseudoscience is a complex and influential phenomenon in society. Therefore, the demarcation problem is a theoretical matter with practical implications.

Given the fact that pseudoscience is relatively common in the non-scientific environment, it is unsurprising that pseudoscience also proliferates in academia. The scientific community adopts a tacit methodological skepticism—theories are generally not accepted without solid empirical evidence. However, sometimes unscientific approaches emerge in a science and start to be gradually accepted. In some cases, it is relatively easy to separate scientific practices from non-scientific ones. For example, there is wide consensus in the scientific community that parapsychology, scientific creationism, intelligent design, graphology or homeopathy are pseudoscientific practices. Hansson (2013, chap. 4) considers that for scientists it is generally as easy to distinguish science from pseudoscience as it is to ride a bicycle: it is a form of tacit knowledge, something that cannot be fully explained in explicit terms but it is easy to execute. Nonetheless, in certain cases it is more complicated to determine whether a discipline is scientific or not. In effect, some disciplines have created a long debate on its epistemological status since its conception.

This paper discusses the general aspects of the demarcation problem (section 2) as well as some of the pseudoscientific practices that have emerged in the past decades. In particular, four theoretical frameworks are analyzed: psychoanalysis (Section 3), speculative evolutionary psychology (Section 4), universal grammar (section 5) and string theory (section 6).

## 2 Demarcation Problem

The purpose of this section is to present and discuss the basics of the demarcation problem. Section 2.1 briefly describes some perspectives of the philosophers of science on the demarcation problem, including Popper's notion of falsifiability and the puzzle-solving criterion adopted by Kuhn. In section 2.2 the validity of four demarcation criteria is defended.

### 2.1 Historical context

The first to use the expression "demarcation problem" in the philosophy of science was Karl Popper. According to Popper himself, he started to ponder the demarcation problem in 1919, when he was only 17 years old (Popper 1962, p. 33). Popper employed the term "demarcation problem" to denote the matter of how to distinguish science from pseudoscience and metaphysics (Popper 1959/2002, p. 11, 1962, p. 33).

Popper proposed a new criterion to separate science from pseudoscience: the criterion of falsifiability. Popper argued that theories must be falsifiable to achieve scientific status. A theory is falsifiable if it can be refuted by experience (Popper 1959/2002, p. 18). Theories that cannot be refuted by counterexamples are untestable (or unfalsifiable, or irrefutable) (Popper 1962, p. 37).

For Popper, supporting evidence is the result of genuine attempts to test a theory, that is, unsuccessful attempts to falsify it (1962, p. 36). Popper (1983, p. xx) cited Einstein's

equivalence principle as an example of falsifiable hypothesis, since it can potentially be contradicted with several observations or experiments. Importantly, Popper (1962, p. 37) classified as unfalsifiable those theories that introduce *ad hoc* reinterpretations or excuses to avoid refutation when counterexamples appear. Thus, Popper considered that astrology, the Marxist theory of history and psychoanalysis are not refutable, therefore unscientific.

The historian and philosopher of science Thomas Kuhn was also interested in the demarcation debate. To differentiate science from pseudoscience, Kuhn proposed the puzzle-solving criterion: a paradigm or theoretical framework is scientific if it solves puzzles and it is unscientific if it does not solve puzzles. In his famous book *The structure of scientific revolutions*, he described puzzles in the following manner: "Puzzles are, in the entirely standard meaning here employed, that special category of problems that can serve to test ingenuity or skill in solution" (Kuhn 1970b, p. 36). In this context, puzzles are the problems that scientists face in normal or established science, such as closing the gap between observations and theoretical predictions (Marcum 2005, pp. 63-64). In a later essay, Kuhn (1970a) compared astronomy with astrology and concluded that astrology "had no puzzles to solve and therefore no science to practice" (p. 9). Kuhn (1970a) held that astronomers are engaged in puzzle-solving when they re-examine their theories as a consequence of unexpected observations, while astrologers are not involved in research puzzles since they never "attempt to revise the astrological tradition" (p. 9).

A serious objection to the puzzle-solving criterion is that some theoretical frameworks can solve puzzles despite not being falsifiable (e.g., universal grammar, as discussed in section 5.9). It is therefore a redundant criterion, since some theoretical frameworks can solve puzzles without being falsifiable, but no theory can be falsifiable without solving puzzles, so with falsifiability the puzzle-solving criterion becomes unnecessary.

Kuhn criticized Popper's notion of falsifiability. He considered that falsification does not occur with a refuting or falsifying instance, but with the replacement of a new theory or paradigm over the old one. Thus, according to (Kuhn 1970b) falsification "consists in the triumph of a new paradigm over the old one" (p. 147). The main problem is that Kuhn does not separate two related but different concepts: (1) replacement and (2) refutation. The fact that a paradigm has been replaced does not always imply that it has been refuted or falsified. For instance, psychoanalysis has been replaced by other frameworks in psychology but not fully falsified, since it is a discipline largely unfalsifiable (as discussed in section 2). Behaviorism was also largely replaced by cognitivism during the cognitive revolution that began in the mid-1950s, without being totally refuted. The principles of behaviorism remain particularly useful for clinical psychology under cognitive-behavioral therapy. In sum, the reason why a theoretical framework is unfalsifiable is because it is formulated in a way that avoids refutation, not because it does not allow new paradigms or theories.

Popper and Kuhn put, respectively, a single demarcation criterion: falsifiability and puzzle-solving. Other authors interested in the issue have adopted a multi-criteria approach and have established a list of criteria for identifying pseudoscientific practices (Bunge 1991; González 2016, pp. 11-14; Mahner 2013, pp. 41-43). The multi-criteria approach is advantageous. Science is a complex activity that cannot be identified with a single criterion. However, a very big list of demarcation criteria is unpractical, since it becomes difficult to memorize and apply. Ideally, no more than five demarcation criteria should be necessary to recognize pseudoscience.

## 2.2 Demarcation criteria

To discriminate between two different types of activities some kind of criteria or standards are necessary. It is argued that the following four demarcation criteria are suitable to distinguish science from pseudoscience:

1. **Testability.** Science must be testable. Hypotheses and theories are testable if they have the inherent capacity to generate both supporting and refuting evidence (Caldwell *et al.* 2018a). An empirical test of a theory is a rigorous procedure carried out to decide whether the theory can be accepted or not considering both supporting and refuting evidence. A theory must be falsifiable to be genuinely testable: if a theory does not admit refuting evidence it is unnecessary any kind of research, since such a theory can always be defended as plausible regardless of the observations. For instance, the hypothesis "unicorns might exist in remote planets or parallel universes" is unfalsifiable and thus unscientitic.

2. **Evidence.** Hypotheses and theories need to be supported by evidence at some point to achieve scientific status: either supported by the available evidence of its time or by evidence found some years after its inception.

   Scientists do employ working hypotheses which sometimes are found to be unsupported by evidence. But while working hypotheses are useful for science, they are not scientific until they have been supported by evidence. Ultimately, hypotheses which have never been supported by evidence are rejected and excluded from the domain of science.

   Occasionally, some theories are superseded or become obsolete when they are no longer supported by evidence or a better theory appears. To cite an example, Dalton's atomic theory has been superseded by more accurate atomic models, since it has been found that the atom is not indivisible. Even if Dalton's atomic theory is not supported by current evidence, it is still a scientific theory because it was supported by the available experimental evidence of its time.

   Testability (= falsifiability) is a necessary but not sufficient condition to have science, as it is also necessary for a theory to be supported by evidence at some point to be scientific. Some pseudosciences are indeed falsifiable. Wakefield's hypothesis that the MMR vaccine causes autism is not defended as plausible in academia since it has been falsified (Taylor et al. 2014). In other words, Wakefield's hypothesis on autism is unscientific because it is unsupported by evidence. Andrews and Thompson's hypothesis that depression is an adaptation is falsifiable but not supported by evidence and hence not scientific (more about this in section 4.1). Both astrology and phrenology are indeed falsifiable and have been falsified by empirical research (for a refutation of astrology see Carlson 1985; for a refutation of phrenology see Parker Jones 2018). Astrology and phrenology are pseudoscientific because its main hypotheses were assumed to be correct from the beginning, despite the fact that they have never been supported by rigorous evidence.

3. **Reproducibility.** Hypotheses based on experimental studies with low reproducibility are unscientific. Reproducibility is described as the capacity of separate researchers to find the same (or very similar) results when repeating an

experiment or test (Resnik and Shamoo 2016). The reproducibility of experiments is a crucial feature of modern scientific research.

4. **The 50-year criterion.** In contemporary science (from 1950 onwards), if a new hypothesis or theory fails to become scientific within 50 years and keeps being defended, then it is a pseudoscience. This criterion is new and needs a longer exposition and clarification than the other ones.

   The 50-year criterion is a practical criterion to distinguish protoscience from pseudoscience. A protoscience is an embryonic or emerging science, that is, a field which is still not scientific but eventually develops into a proper science (Bunge 1984, p. 44). On the other hand, a pseudoscience is a field which is regarded by its practitioners as scientific, even though it does not meet the necessary requirements to be a genuine science. To complicate more things, some pseudosciences can—at least in principle—become science, provided they become testable and supported by evidence.

   Following the 50-year criterion, in the context of contemporary science (from the 1950s onwards) the difference between protoscience and pseudoscience is the following: while a protoscience is a field which becomes scientific within less than 50 years, a pseudoscience is a field which fails to become scientific within 50 years and perhaps forever. The difference between pseudoscience and protoscience is better illustrated with examples. A paradigmatic example of pseudoscience is acupuncture, while a good example of protoscience that successfully became science is the Higgs Boson, first proposed in 1964 (Higgs 1964) and discovered in 2012, 48 years later (Aad et al. 2012).

   Three doubts may remain in the reader: (1) Why is the 50-year criterion specifically applied from 1950 onwards?, (2) Can a theory be regarded as pseudoscience even if 50 years have not passed since its inception? and (3) Why is it said that some pseudosciences can potentially become science? The three questions are answered in the lines below.

   (1) Why is the 50-year criterion specifically applied from 1950 onwards? Because the technology to test theories employed by scientists before 1950 was not so well developed as today and some protosciences needed more than 50 years to develop into science. For instance, Einstein's 1916 prediction of the existence of gravitational waves was initially protoscientific, since it was not testable with the technology of his time. It was tested and supported by evidence (and thus became fully scientific) more than 50 years later, when in the late 1970s strong indirect evidence of the existence of gravitational waves was found from observations of orbital decay in the Hulse-Taylor binary pulsar (Taylor et al. 1979; Weisberg et al. 1981).

   (2) Can a theory be regarded as pseudoscience even if 50 years have not passed since its inception? Yes. The 50-year criterion is applied to theories which cannot be tested with the technology of the moment and are said to be "testable in principle" or "testable in the future". If a testable hypothesis is found to be unsupported by evidence but is still being defended as plausible, then it can be regarded as pseudocientific, even if 50 years have not passed since its inception. To cite an instance, Jacques Benveniste's homeopathic hypothesis about "water

memory" was almost immediately considered pseudoscience by the scientific community (Hirst et al. 1993).

(3) Why is it said that some pseudosciences can potentially become science? The differences between chess and checkers are real, but what specifically constitutes chess and what specifically constitutes checkers is completely decided by humans. Analogously, the differences between protoscience and pseudoscience are real, but what specifically constitutes protoscience and what constitutes pseudoscience is decided by humans, since those categories are human-made. The traditional conception of pseudoscience as a field that can never become scientific should change, since it is not practical. Thus, it should be accepted that some pseudosciences can become science—at least in principle—provided they become testable and supported by evidence at some point.

This new characterization of pseudoscience is useful to abandon theories in contemporary science which fail to achieve scientific status in 50 years or more (of course this abandonment can be revised, provided that the theory has been tested and supported by evidence). With the old characterization of pseudoscience as a field that can never become scientific, scientists would hesitate to classify some approaches as pseudoscientific for millenials, if not forever, since then theories said to be "potentially testable in the future" could only be determined to be protoscience or pseudoscience *a posteriori.*

Imagine this hypothetical scenario: a new theory in a scientific field makes its first appearance in 2020. It is a theory which cannot be tested with the technology of the moment. In the year 18020 there is no empirical evidence supporting the theory, but its holders still maintain that it is a legit research field because it is testable in principle and it will be possible to empirically support it with more advanced technology. This scenario seems to be largely implausible, and the reason is clear: a theory which has not been tested and supported by evidence cannot be considered scientific (or protoscientific) forever, an emergent theory will either mature into science or not. Thus, it is useful to adopt the criterion according to which in contemporary science, if a new theory fails to become scientific within 50 years and keeps being defended, then it is a pseudoscience. Otherwise, a theory which is not supported by evidence could be defended *ad infinitum*, under the promise that it will be supported with the advent of new technology which will make new observations possible.

Any field needs to meet all these four demarcation criteria to be scientific. Based on these criteria, the four aforementioned theoretical frameworks (psychoanalysis, speculative evolutionary psychology, universal grammar and string theory) will be examined in the next sections.

## 3 Psychoanalysis

Psychoanalysis is a theoretical framework related to the study of the mind, particularly the unconscious mind, as well as a form of psychotherapy. Sigmund Freud initiated the discipline in the 1890s. During the first half of the twentieth century, psychoanalysis was the main school of psychology along with behaviorism. However, nowadays

psychoanalysis has lost much of its popularity. In the following lines, it is discussed whether or not psychoanalysis is a scientific field.

### 3.1 Unfalsifiable hypotheses

One of the most important psychoanalytic concepts is the Oedipus complex. Freud (1899/1913) said: "Perhaps we are all destined to direct our first sexual impulses towards our mothers, and our first hatred and violent wishes towards our fathers" (p. 223). The positive Oedipus complex refers to a child's unconscious sexual desire for the opposite-sex parent and jealous hatred for the same-sex parent. On the other hand, the negative Oedipus complex refers to a child's unconscious sexual desire for the same-sex parent and hatred for the opposite-sex parent (Auchincloss 2015, p. 110; Schultz and Schultz 2005, p. 65). Freud (1905/2001) argued that the Oedipus complex is a universal phenomenon which leads to neurosis when it is unresolved: "Every new arrival on this planet is faced by the task of mastering the Oedipus complex; anyone who fails to do so falls a victim to neurosis" (p. 226).

Psychoanalysts consider that repression is the psychological mechanism in which desires and impulses are kept out of consciousness (Kellerman 2009, p. 213). Therefore, the diagnosis of the Oedipus complex is essentially unfalsifiable: even when the complex is not observable, it can be said to be repressed. The Oedipus complex also exhibits problems of testability if we consider the psychoanalytic concept of reaction formation. According to psychoanalytic theory, reaction formation occurs when, in response to an initial feeling perceived to be unacceptable, an opposite emotional reaction occurs—e.g. someone can exhibit sweetness in response to an aggressive desire (Kellerman 2009, p. 209). As a consequence, the Oedipus complex is also unfalsifiable in cases where a child loves or hates both of their parents. If a child loves both of his parents, the Oedipus complex can be declared to be repressed through reaction formation: the child can be repressing his hate for the father in the form of affection. Conversely, if a child hates both of his parents, he can be said to be repressing the love for his mother in the form of reaction formation.

Another unfalsifiable assumption of psychoanalysis is penis envy. Freud proposed that penis envy constitutes a phase of development in girls. According to Freud (1905/2001) little girls "are over-come by envy for the penis—an envy culminating in the wish, which is so important in its consequences, to be boys themselves" (p. 195). Contemporary psychoanalysts still debate the penis envy hypothesis. For instance, Zepf and Seel (2016) explicitly argue that "the daughter wants to have the father's penis" (p. 415). Penis envy is considered to be an unconscious desire (Zepf and Seel 2016, p. 404). Thus, the existence of penis envy is not a testable hypothesis. If little girls are asked whether they are envious of boys' penises, it does not matter their answer, since psychoanalysts still can claim that the desire is unconscious.

Freud (1899/1913) also proposed the thesis that "wish fulfillment is the meaning of every dream" (p. 113). However, Freud was aware that nightmares seem to refute this generalization. What solution did he propose? We must differentiate "the *manifest* and the *latent dream content*" (Freud 1899/1913, p. 114, emphasis in original). If a person has a nice dream, Freud's idea is confirmed. If the same person has a nightmare, the hypothesis is also confirmed, since the psychoanalyst can reinterpret the latent dream

content as wish fulfillment. In other words, whatever a person dreams, the dream will always be a wish fulfillment. The wish fulfillment hypothesis is obviously unfalsifiable.

An additional unfalsifiable hypothesis is the existence of the id, ego and superego. Freud divided the mind in these abstract constructions. The id refers to the instincts and pleasure-seeking, the superego is related with the morality system of the subject, and the ego is the part which mediates between the demands of id, superego and reality (Yakeley 2017). Popper (1962) considered that "for Freud's epic of the Ego, the Super-ego, and the Id, no substantially stronger claim to scientific status can be made for it than for Homer's collected stories from Olympus" (p. 38). The existence of these highly abstract notions cannot be meaningfully tested: whatever is observed can be interpreted as evidence in its favor.

### 3.2 Psychodynamic psychotherapy

Pychodynamic (or psychoanalytic) psychotherapy is the form of clinical practice based on the theoretical body of psychoanalysis (Cabaniss et al. 2011, Chapter 2; Summers and Barber 2010, p. 11). There is mixed evidence with regard to the efficacy of psychodynamic psychotherapy. A number of empirical studies suggest that cognitive-behavioral therapy (CBT) is more effective than psychodynamic psychotherapy to deal with bulimia nervosa (Poulsen 2014), social anxiety disorder (Egger et al. 2016) or panic disorder (Chambless et al. 2017). In addition, many meta-analyses suggest that CBT is superior to psychodynamic psychotherapy (Canceil et al. 2004; Mayo-Wilson et al. 2014; Tolin 2010; Zhou et al. 2015). On the other hand, other meta-analyses indicate that there is no significant difference between CBT and psychodynamic psychotherapy in terms of efficacy (Leichsenring 2001; Steinert et al. 2017).

*Post hoc ergo propter hoc* ("after this, therefore because of this") is a logical fallacy that occurs when it is assumed that just because an event followed another, the first event caused the second. The fact that some patients experience symptom remission after receiving psycodynamic psycotherapy does not necessarily imply that it is a result of the psychodynamic psycotherapy in itself. It is known that patients can remit symptoms of mental disorders by means of placebo effect (Boulenger et al 2014; Mayo-Wilson et al. 2014; Zhu et al. 2014). In this regard, a large meta-analysis found no significant difference between psychodynamic psychotherapy and the placebo group (Mayo-Wilson et al. 2014). Remission of the symptoms after the psychodynamic psycotherapy can also be produced by spontaneous remission. An important percentage of people who do not receive any treatment experience spontaneous remission from depression (Whiteford 2013) social anxiety disorder (Vriends 2014) and eating disorders (Vandereycken 2012). A recent meta-analysis found no significant clinical difference between the psychodynamic psychotherapy and the waiting list (Zhou et al. 2015).

### 3.3. Neuropsychoanalysis

In 1999, the term "neuropsychoanalysis" started to be used formally, when it was introduced as the title of the house journal of the *International Neuropsychoanalysis Society* (Solms and Turnbull 2011). Neuropsychoanalysis is an approach that seeks to synthesize neuroscience and psychoanalysis, and a scientific enterprise according to its holders (Németh 2011; Schwartz 2015). Among its main representatives are Mark Solms,

Jaak Panksepp—the co-chairs of the *International Neuropsychoanalysis Society*—and Oliver Turnbull. One of the most important books of this emerging discipline is *The Brain and The Inner World*, written by Mark Solms and Oliver Turnbull. In this work, Solms and Turnbull try to reconcile what they call the "subjective" approach to mental science (psychoanalysis) with the "objective" approach (neuroscience). Solms and Turnbull (2002) lament that "Typically, neuroscientists have regarded psychoanalysis and related disciplines as 'unscientific' (how can a science of subjectivity be objective?)" (p. 6).

Solms and Turnbull are of the opinion that psychoanalytic knowledge has much to contribute to neuroscience. They argue that "Armed with the knowledge we have gained regarding the functional anatomy of the mental apparatus, it is not difficult to translate all of this [psychoanalytic concepts such as ego] into neuroscientific terms" (Solms and Turnbull 2002, p. 287). Undoubtedly, Solms and Turnbull's proposal is groundbreaking. However, it should be taken with caution. Solms and Turnbull are employing the logical fallacy known as "false analogy". This fallacy occurs when it is established an analogy between two objects, A and B, which share some properties. Then, if A has property X, we infer that B must also have property X. The analogy is incorrect if the two objects (A and B) differ in a way that affects whether they both have property X. Here is Solms and Turnbull's main argument:

> Both psychoanalysis [P] and neuroscience [N] are related to the study of mind.
>
> P postulates X.
>
> N must also postulate X.

To try to translate psychoanalytic knowledge (id, ego, super-ego, etc.) into neuroscientific terms is a very similar process to attempt to translate the knowledge behind acupuncture (*qi*, meridians, etc.) in terms of scientific medicine. Neither of these translations has succeeded.

Solms and Turnbull (2002) admit that "[We] have been in professional situations…where our interest in psychoanalysis has made it difficult to maintain the respect of our colleagues, the esteem of our students, and the willingness of journal editors to publish our work" (p. 299). One of the main problems underlying neuropsychoanalysis is its academic isolation. The three neuroscience journals with highest Impact Factor are *Nature Reviews Neuroscience*, *Nature Neuroscience* and *Annual Review of Neuroscience*. No article on neuropsychoanalysis has ever been published in any of the aforementioned journals. Papers on neuropsychoanalysis are rarely published in general journals of psychology or neuroscience. Works on the matter are usually found in a single journal: *Neuropsychoanalysis*.

### 3.5 Evaluation

Unquestionably, psychoanalysis has had historical and cultural relevance. Freud's ideas are part not only of the history of psychology, but also of the history of human culture. Freud's doctrines were highly influential in the psychology from the first half of the twentieth century. The works of Freud also influenced several artists, most notably Alfred Hitchcock and Salvador Dalí. However, psychoanalysis does not meet the demarcation criteria of testability and evidence. In effect, the theoretical basis of psychoanalysis is largely unfalsifiable. And pychodynamic psychotherapy does not have robust evidence of

being as effective as CBT, since many meta-analyses suggest the superiority of CBT (with some meta-analyses showing no significant difference between psychodynamic psychotherapy and the placebo group or the waiting list). Even the most recent psychoanalytic formulations such as neuropsychoanalysis are pseudoscientific. Neuropsychoanalysis relies on false analogies to try to revitalize discredited psychoanalytic concepts and it is almost entirely isolated from the scientific community. In sum, psychoanalysis is a clear example of pseudoscience.

## 4. Speculative evolutionary psychology

Jerome H. Barkow, Leda Cosmides and John Tooby were the first to popularize the term "evolutionary psychology" in their 1992 book *The Adapted Mind: Evolutionary Psychology and The Generation of Culture*. According to Barkow, Cosmides and Tooby (1992) "Evolutionary psychology is simply psychology that is informed by the additional knowledge that evolutionary biology has to offer" (p. 3). Thus, evolutionary psychology is a theoretical approach that studies psychological mechanisms from an evolutionary perspective. These psychological mechanisms are hypothesized to be designed to solve adaptive problems that humans had to confront throughout their evolutionary history. Evolutionary psychologists postulate that the human mind is largely composed of specific innate cognitive mechanisms or modules designed to solve adaptive problems (Cosmides and Tooby 1992, p. 166; 1997, p. 80; Pinker 1995, pp. 419-420). Several authors refer to this thesis as the "massive modularity hypothesis" (Frankenhuis and Ploeger 2007; Samuels 1998).

According to evolutionary psychologists, their framework is not merely a branch of psychology but a comprehensive approach that can contribute to the study of any region of psychology (Buss 2009; Chang and Geary 2007; Cosmides and Tooby 2013). Evolutionary psychologists study various human traits such as language (Pinker 1995), rape (Thornhill and Palmer 2000), memory (Nairne and Pandeirada 2008), art (Dutton, 2009), sport (Lombardo 2012), mental disorders (Glass 2012), or human preferences in mate choice (Buss 1989).

The philosopher of science Mario Bunge (2010) was one of the first, if not the first, to employ the expression "speculative evolutionary psychology". Here, the term "speculative evolutionary psychology" is employed to designate some areas within evolutionary psychology which are not well supported by evidence. Some cases of speculative evolutionary psychology will be examined below.

### 4.1 Evolutionary psychology and depression

The framework of evolutionary psychology has influenced clinical psychology, resulting in the so-called evolutionary clinical psychology (Buss 2009, p. 147, 2015, p. 407; Glass 2012; Starrat 2016, p. 220). It is a novel approach that is still in its early stages. However, controversial positions are already being developed. Specifically, there are works which defend that depression is an adaptation.

Paul W. Andrews is a professor of psychology who describes himself as an evolutionary psychologist (Andrews 2007, p. 48). Paul Andrews, in collaboration with

Anderson Thomson, Jr., has published some works suggesting that depression is an adaptation (Andrews and Thomson 2009a, 2009b, 2011). Andrews and Thompson argue that therapies should try to stimulate depressive meditation rather than stopping it (Andrews and Thomson 2009a). The authors defend the analytical rumination hypothesis (ARH). ARH posits that depression is an evolutionary response to complex problems. The mission of depression is to reduce distractions and analyze problems through rumination (Andrews and Thompson 2009b). According to this conception, depression promotes an analytical rumination in which the individual becomes more focused and information is processed more accurately (Andrews and Thompson 2009b, p. 622). Thus, over evolutionary time, depressive rumination often helped people to solve the problems that caused their episodes (Andrews and Thompson 2009b, p. 622).

To support their hypothesis, Andrews and Thompson (2009b, p. 621) emphasize the universality of depression: symptoms of depression have been found in virtually every human culture that has been studied. Following this logic, schizophrenia or myopia should also be considered adaptations, because both seem to be an existing feature of every human culture (Fricke et al. 2018; Jablensky and Statorius 1988; Rudnicka et al. 2016). However, it is hardly conceivable that schizophrenia or myopia are adaptations.

Andrews and Thompson (2009a, 2009b, p. 644) argue that depressive rumination may help to solve the problems that originated the depressive episode. At this point, as has been noted by Coyne (2010), there is a problem. To be considered a biological adaptation, a trait must be something more than "useful". It should enhance fitness, that is, it must increase an individual's capacity to propagate its genes. The main maladaptive consequence of depression is suicide. More than half of all people who die by suicide meet criteria for depressive disorder (Hawton and Heeringen 2009). In addition, while the cross-national lifetime prevalence of suicidal attempts is 2.7% for the overall population (Nock et al. 2008), the cross-national lifetime prevalence of suicidal attempt is about 31% for individuals with major depressive disorder (Dong et al. 2018).

Certainly, Andrews and Thompson focus their hypothesis on major depression (Andrews and Thompson 2009a, Andrews et al. 2011). Andrews and Thompson (2009a) cite a study by Kruijshaar et al. (2005) where it was estimated indirectly that 30% of men and 40% of women in the Netherlands and Australia will have at least one episode of major depression during their lifetime. According to Andrews and Thompson, this is difficult to explain given that mental disorders should not be common. Several objections can be made against their argument. First, the study they cite is likely to be overestimating the lifetime prevalence of major depression in the Netherlands, since other studies have found the lifetime prevalence of major depression to be 17.9% in the Netherlands (Bromet et al. 2011). Second, mental disorders are indeed relatively usual. The World Mental Health surveys estimate the inter-quartile range (IQR; 25th-75th percentile) lifetime prevalence of mental disorders to be 18.1-36.1% across countries (Kessler et al. 2009). Third, a common trait is not necessarily an adaptation (being common is a necessary but not sufficient condition for a trait to be an adaptation, since it must have some beneficial function as well). For instance, the global prevalence of myopia is estimated to be about 34% of the world population by 2020 (Holden et al. 2016), with East Asian countries having a high prevalence of myopia (80%-90%) among young adults (Wu et al. 2016), but it does not imply that myopia is an adaptation.

If depression is an adaptation, we would expect it to be predominant in contemporary human tribes, since they represent the closest indirect evidence we have of the Pleistocene conditions of life. In a long study that examined over 3.000 individuals from two

American Indian tribes, it was found that the prevalence of depression was very low, only about 10% (Libby et al. 2005). With that extremely low depression prevalence, the hypothesis that depression is an adaptation seems to be refuted. An adaptation is a trait which has been favored by natural selection through successive generations. Hence, an adaptation is a predominant trait in a species, meaning that the great majority of individuals of a species should have the adaptation. For instance, no one would claim that giraffes' long neck is an adaptation if only 10% of giraffes had long necks. And no serious researcher would say that human bipedalism is an adaptation if only 10% of humans walked on two legs. For depression to be an adaptation, around 80-90% of members of contemporary tribes should experience it. Of course, it can be argued that contemporary tribes differ in important ways from the Pleistocene conditions. But that would make the adaptationist hypothesis about depression unfalsifiable, thus unscientific either way.

### 4.2 The JSIM hypothesis

The jealousy as a specific innate module (JSIM) hypothesis states that natural selection shaped sexual jealousy as a psychological mechanism to prevent paternal uncertainty, and emotional jealousy as a psychological mechanism to prevent resource loss (Buss et al. 1992; Harris 2003; Lishner et al. 2008; Fussell et al. 2011). According to evolutionary psychologists, during their evolutionary history, men and women have faced different adaptive problems. Men have faced the adaptive problem of paternal uncertainty. Men could be investing resources in others' offspring. In men, an adaptive problem affecting fitness is sexual infidelity. Women meanwhile, face another risk: a man can stop investing time and resources in their offspring, by adopting a new relationship with another woman. Presumably, the emotional infidelity of a man is an indicator of the risk.

Following the evolutionary reasoning derived from the JSIM hypothesis, evolutionary psychologists predict that men are more upset than women by sexual infidelity, while women are more upset than men by emotional infidelity. In the words of David Buss (2006): "Male jealousy, more than women's, is triggered by signals of sexual infidelity….Women's jealousy, more than men's, is activated by signals of emotional infidelity" (p. 256). Evolutionary psychologists also predict that men are more upset by sexual infidelity than emotional infidelity, while women are more upset by emotional infidelity than sexual infidelity. To quote the evolutionary psychologists Buunk, Angelitner, Oubaid and Buss (1996): "As predicted by models derived from evolutionary psychology, men…exhibit greater psychological and physiological distress to sexual than to emotional infidelity of their partner, and women have been shown to exhibit more distress to emotional than to sexual infidelity" (p. 359).

Inspired by the influential article of Buss et al. (1992), evolutionary psychologists have dedicated special attention to the study of jealousy for more than 25 years, obtaining some results showing sex differences in jealousy (Bendixen et al. 2015, Buss et al. 1999, Frederick at al. 2014). Many of the empirical studies that have been conducted to test the sex differences in jealousy have used forced-choice questions, where college students had to imagine a hypothetical situation of partner infidelity. These questions are taken from Buss et al. (1992). Students are asked to imagine a relationship and identify what kind of scenario would be more distressing: (a) imagine your partner having sex with another person or (b) imagine your partner falling in love with another person. Using this forced-choice format it has been found sex differences in jealousy, where men tend to consider

more distressing sexual infidelity than women, while women tend to be more distressed upon emotional infidelity than men. These results have been reported in western and Asian countries (Buss et al. 1992, Buss et al. 1999). Evolutionary psychology predictions have also been confirmed in studies employing continuous measures (Bendixen et al. 2015).

To assess the possible limitations of the forced-choice format traditionally used, Lishner et al. (2008) conducted an interesting experiment. College students were randomly assigned to either a traditional forced-choice group or another group with a modified format. Participants in the traditional forced-choice group should mark with an X which option seemed the most upsetting of the following: (a) imagining your partner having several sexual positions with another person or (b) imagining your partner falling in love with another person. Participants in the group of the modified format in addition to the above received an additional option: (c) any of the above options would upset me equally. In the traditional forced-choice group, men found most upsetting sexual infidelity than women, and women found most upsetting emotional infidelity than men. But in the group of the modified format, most students of both sexes (62% of women and 70% men) found both forms of infidelity equally distressing. These results suggest that if participants are given the traditional forced-choice format in which they have to decide which kind of infidelity they find more distressing (sexual vs. emotional), many participants will respond randomly, since they can find both types of infidelity equally distressing.

At least 26 studies have failed to reproduce the specific sex differences in jealousy predicted by evolutionary psychologists (Buller 2005; Canto et al. 2009a, 2009b, 2011; Carpenter 2012; Costa and Silva-Barros 2008; DeSteno 2002; Dijsktra et al. 2013; Dunn 2015; Gómez-Jacinto et al. 2001; Green and Sabini 2006; Grice and Selly 2000; Harris 2000, 2002, 2003; Kato 2014a, 2014b; Larocque 2015; Leeker 2012; Lishner et al. 2008; Nannini and Meyers 2000; Penke and Asendorpf 2008; Pines and Friedman 1998; Sabini and Green 2004; Sabini and Silver 2005; Webber 2018).

Many of the articles which do not reproduce the JSIM predictions have very big sample sizes of 500 participants or more (Canto 2009b, 2011; Green and Sabini 2006; Kato 2014b; Larocque 2015; Sabini and Green 2004). In addition, while some meta-analyses do corroborate evolutionary psychology predictions on jealousy (Sagarin 2012), others do not find support for the JSIM hypothesis (Buller 2005; Harris 2003; Carpenter 2012).

The JSIM hypothesis exhibits a low degree of reproducibility, since a colossal number of studies have been unable to reproduce the specific sex differences in jealousy predicted by evolutionary psychologists. A hypothesis based on experimental studies with low reproducibility cannot be considered scientific.

### 4.3 Evaluation

Evolutionary psychology is a theoretical framework that can produce both scientific and pseudoscientific research. Evolutionary psychologists have the merit of having placed special emphasis on remembering the important role that natural selection has had in shaping human behavior. In particular, research in evolutionary psychology has made scientific and relevant contributions to the study of human preferences in mate selection (Chang et al. 2011; Sorokowski et al 2015; Zhang et al. 2014). However, in its speculative

version, evolutionary psychology is a pseudoscience. Examples of speculative evolutionary psychology include the adaptationist hypothesis about depression (which is incompatible with empirical evidence) and the JSIM hypothesis (which has a low degree of reproducibility). The field of evolutionary psychology would greatly benefit from other disciplines' constructive criticism to avoid getting stuck in speculative ideas and keep developing its more promising hypotheses.

## 5. Universal Grammar

One of the most influential notions in the history of linguistics is the Universal Grammar (UG) theory. The nativist approach to the study of language has its roots in this conception. UG is a fairly relevant issue in current linguistics. It is not without reason that UG is among the most studied and debated topics in linguistics thus far.

What is UG? This question must be addressed with caution. Some researchers consider that there is little consensus on what UG is, and what constitutes it (Dabrowska 2015; Tomasello 2004). To avoid any kind of confusion, this article refers to the definition of UG formulated by the famous linguist Noam Chomsky, because it is the standard and established definition of the concept.

Even though Chomsky's previous works already alluded to "universal grammar" (Chomsky 1965), it was not until the publication of *Reflections on Language* that Chomsky explicitly defined UG. According to Chomsky: "Let us define 'universal grammar' (UG) as the system of principles, conditions, and rules that are elements or properties of all human languages not merely by accident but by necessity—of course I mean biological, not logical, necessity" (Chomsky, 1975, p. 29). UG is defined to be "part of the genotype" (Chomsky 1980, p. 66), and thus an "innate property of the human mind" (Chomksy, 1975, p. 34).

These are the main arguments used to defend the existence of an innate UG:

1. Language as an instinct
2. Speed, ease and uniformity of language learning
3. Poverty of the stimulus
4. Linguistic universals
5. Species specificity of human language
6. Brain specialization for language
7. Critical period

All of them will be examined in the following sections.

### 5.1 Language as an instinct

An argument that can be used to hold the existence of an innate UG is to assert that language is an instinct. If language is an instinct, then children can be expected to be born with tacit grammatical knowledge. According to the *Oxford Dictionary of English*, an instinct is "an innate, typically fixed pattern of behaviour in animals in response to certain stimuli" (Stevenson 2010, p. 906). Thus, an instinct is, by definition, an innate behavior. That is, an instinct must be encoded in the genome.

Before discussing the language as an instinct hypothesis, a clarification is needed. Many linguists propose a false dichotomy between "acquire" and "learn" with regard to language. For example, Harley (2001, p. 136) suggests that children acquire their first language because they do it largely unconsciously, while they learn a second language because they do it consciously. Such a dichotomy is flawed because it implies that there is no such thing as first language learning. Indeed, learning is divided into explicit (or conscious) and implicit (or unconscious). Implicit learning is learning of information without awareness of what has been learned (Seger 1994). Children implicitly learn the first language. First language learning involves implicit learning and second language learning involves explicit learning. Thus, in this paper the world "learn" will be used—rather than "acquire"—to refer to first language learning.

Steven Pinker was the first to popularize the hypothesis that language is an instinct. In his influential book *The Language Instinct*, Pinker asserts that "people know how to talk in more or less the sense that spiders know how to spin webs" (Pinker 1995, p. 18). Pinker's analogy is striking, since it is obviously incorrect. A spider will spin webs even if it remains isolated since birth. On the other hand, a child who has been isolated since birth will not learn language. In other words, while web-spinning does not require previous experience and it is innate, language does require experience and it is learned.

The 2008 documental *A life without words* shows how two deaf siblings who grew up in a rural farm of Nicaragua did not learn any language (Isenberg 2011). They did not learn any sign language because their parents did not know sign language. It is difficult to see how language can be an instinct here. Both siblings had the stimulus of having each other to talk with, which should have been enough to spontaneously create a language. To live with a sibling should be a stimulus powerful enough for the supposed language instinct to emerge. To say that linguistic stimulus is only received when a child sees other people talking is like saying that the hunting stimulus is only received when a lion sees other lions hunting. In fact, zoo lions raised in captivity hunt birds that have accidentally entered their cage (Zachos 2018). It illustrates that a real instinct like hunting is activated as soon as a non-domesticated lion sees a prey to hunt, while a false instinct like language does not emerge as soon as a child sees another person to talk with.

Not even the strong linguistic stimulus of being exposed to speech through TV is enough to fully learn language. A prime example comes from Jim, a hearing child of deaf parents who frequently watched TV and occasionally played with some friends (Sachs et al. 1981). Jim's parents used sign language but did not directly sign to him (which is difficult to explain, since if language is an instinct, the parents should have been naturally inclined to sign to their son). When Jim was almost 4 years old, his linguistic skills were well below age level and had not learned the grammar of English. Jim was exposed to both spoken English (through frequently watching TV and occasionally playing with friends) and sign language (through seeing his parents), but did not learn either until adults started to talk directly to him.

Some authors have made an analogy between birdsong and human language (Bolhuis et al. 2010; Fehér et al. 2009). Such an analogy is flawed for the following two reasons:

1. Human language is infinitely more complex and radically different from birdsong. Language can refer to the future and the past, employ irony, communicate complex abstract ideas like morality, justice, spirit or time, and refer to every single object of the environment. Birds do not produce complex human-like semantics which

refers to basically every object of the environment, nor do they communicate complex abstract notions, employ irony or refer to the future and the past.

2. Songbirds raised in isolation produce an isolate song before being exposed to a wild-type song, while children raised in isolation do not produce an isolate syntax before being exposed to language. For instance, zebra finches which are kept alone in soundproof chambers during their development produce an isolate song different from the wild-type song (Féher at al. 2009). It supports an instinctive component of birdsong, since zebra finches produce an isolate song before being exposed to the species' typical song. On the other hand, feral children—those who have grown isolated from human contact—never exhibit an isolate syntax before being exposed to language. No feral child has been reported to create new sentences with an invented or isolate syntax when they are first found. The famous feral child Genie produced ungrammatical sentences after being exposed to English for some time, but when she was first found she was virtually speechless and did not produce ungrammatical sentences with an isolate syntax. In fact, well documented feral children like Genie, Oxana Malaya or Danielle Crockett were basically speechless when found.

Furthermore, the fact that every human society has language does not support the existence of a language instinct. Some entirely learned traits like the use of clothing items are found among all human cultures. The *Oxford Dictionary of English* defines clothes as "items worn to cover the body" (Stevenson 2010, p. 329). Following this definition, according to which clothes are items worn on the body, all human societies have some form of clothing, since no human tribe is fully naked or free from items worn on the body. And there is no known "clothing gene", nor is there any evidence that feral children lost in the wild typically create simple clothing items like loincloths. In fact, many feral children like Victor of Aveyron (Watkins 1999, p. 147), the Cambodia's "jungle girl" (MacKinnon 2007) or Traian Căldărar (Leidig 2002) were found naked in the wild, which rebuts the existence of an innate tendency to create clothing items

In definitive, the thesis that language is an instinct is not supported by empirical evidence. As derived from models from empirical linguistics (Sampson 2001; 2007), linguistic anthropology (Everett 2012) and cognitive linguistics (Tomasello 1995; 2010), language is better understood as a cultural tool.

### 5.2 Speed, ease and uniformity of language learning

Generative linguists hold that children learn language with speed, ease and uniformity, which could support the existence of an innate UG. This section discusses the plausibility of this argument.

**Speed:** generative linguists suggest that children learn language quickly (Chomsky 1959; Vikner 1995, p. 9). Nonetheless, according to Dąbrowska (2015) children do get a great amount of linguistic data. Dąbrowska calculates that, if children are exposed to language about 8 hours per day, they get 11.680 hours of exposure between the ages of 1 and 5 years (4 x 365 x 8 = 11680). 11.000 hours can be considered abundancy of stimulus. Why

are 11.000 hours of practice and exposure to language considered “fast” rather than “normal” learning? The consideration that language learning is fast rather than normal is largely subjective. And science must be objective.

Even if we were to admit that language learning occurs relatively fast, it does not suggest that there is innate knowledge of syntax. Three-year-old children can learn quickly to play both chess (Chidi 2014, p. 453; Serafica 2017) and small-sized violins (Starr 1976/2000, p. 20). With only one month of practice, some 2-year-old Asian children can play simple songs like “Twinkle, Twinkle, Little Star" on small-sized violins (Annelies 2016). No one would say that children have innate domain-specific knowledge of chess or violin skills. Therefore, the argument “X is learned quickly, so there must be innate domain-specific knowledge of X” is not correct.

Children aged 3-4 who can play chess, already know the vast majority of chess rules, even though they do not play like an adult with more experience and knowledge of strategy (Serafica 2017). Analogously, three-year-old children already have tacit knowledge of the majority of the rules of their native language, but they do not have the same vocabulary range or syntax complexity of an adult (Nippold 2004). It can be objected that language cannot be compared to playing chess or the violin, since it is a more complex ability. But that would represent an example of double standard logic. If children learn language quickly, they are assumed to have innate domain-specific knowledge of the rules of grammar. If children learn to play chess or the violin quickly, they are not assumed to have innate domain-specific knowledge of chess or violin skills. Instead of applying the same objective standard, things are judged by different standards depending on whether they favor linguistic nativism.

Another possible objection would be that language learning is a universal phenomenon, unlike learning to play chess or the violin. But language learning is only universal among human populations, not among human individuals. Feral children do not talk when they are found—unless they have learned language before being isolated—illustrating that they have not learned language. Not only feral children, but also normal deaf children raised in isolated farms do not have sign language sometimes (Isenberg 2011). Furthermore, the fact that language learning occurs in every human society does not support the existence of an innate grammar. As described before, some entirely learned traits are present in all human cultures, like the use of clothing items (if clothes are defined simply as items worn on the body, all human societies have some kind of clothing).

**Ease:** Chomksy (1975, p. 4) argues that children learn language easily since they do it without formal instruction or conscious awareness. The argument “X is learned without formal instruction or conscious awareness, so there must be innate domain-specific knowledge of X” is not valid, since children can learn many things solely from experience without formal instruction and conscious awareness. This is better illustrated with feral children examples. Vanya Yudin, nicknamed the “Russian Bird boy”, was kept isolated by his mother in a room surrounded by cages containing dozens of birds. His mother never talked to him, and when he was found at age 7 he could only communicate by chirping and flapping his arms like a bird (Cockcroft 2008). Obviously, Vanya did not have innate knowledge of bird-like behavior, yet he learned it without formal instruction or concious awareness. Oxana Malaya was neglected by her alcoholic parents and lived with dogs since she was 3 until she was found at age 8. When she was rescued, she walked

on all fours, narked and behaved like a dog (Grice 2006). Oxana learned dog-like behavior without proper instruction or awareness. There are also examples outside feral children. The chess legend José Raúl Capablanca explained that he learned to play chess at the age of 4 without formal instruction, just by watching his father's games with a friend (Capablanca 1920/1966, p. 4).

**Uniformity:** some authors have defended that language learning is remarkably uniform (Barry 2002, p. 184). However, a recent review article concluded that individual differences in language learning are the norm rather than the exception, with grammatical competence also varying across development (Kidd et al. 2018, p. 158). Dąbrowska (2015) points out that grammatical development is far from uniform since some kids begin to combine words at age 14 months, while others do not perform so until after their second birthday.

### 5.3 Poverty of the stimulus

Poverty of the stimulus is the argument that children are not exposed to enough linguistic data to fully learn language, hence the need to postulate some innate tacit knowledge of grammar (Chomksy 1986, p. 55; Dąbrowska 2015). A classic example of the poverty of the stimulus argument is the structure-dependence principle, a grammar rule which Chomsky argued to be innate in children (Chomsky 1975, p. 32-33). However, it is difficult to conceive it as innate knowledge when children do make structure-dependent errors (Ambridge, Rowland and Pine 2008), and some rules in some languages violate the structure-dependent principle (Comrie 1984, p. 100; Comrie 1989, pp. 21-22). In any case, Chomsky used the poverty of the stimulus argument to support the innateness of UG: "The argument from poverty of the stimulus leaves us no reasonable alternative but to suppose that these properties are somehow determined in universal grammar, as part of the genotype" (Chomsky 1980, p. 66).

The two main assumptions of the poverty of stimulus argument will be examined here: (1) Lack of negative evidence and (2) Children acquire the competence to produce a potentially infinite number of sentences from exposure to a limited sample of sentences.

#### Lack of negative evidence

A related issue with the poverty of stimulus argument is the supposed lack of negative evidence (Dabrowska 2015). Negative evidence in language learning is information that denotes whether a particular utterance or sentence is ungrammatical. Negative evidence is usually considered necessary since without correction, the child can overgeneralize and generate ungrammatical sentences. A distinction is typically made between direct negative evidence and indirect negative evidence. Direct negative evidence occurs when the adults explicitly correct the child's ungrammatical utterance with corrected repetitions or rejections of the utterance. Indirect negative evidence refers to the absence of particular input patterns, which can serve as evidence that those patterns are ungrammatical (Lust 2007, pp. 29-30).

A well-known study from 1970 reported that parents do not generally correct their children syntactic mistakes (Brown and Hanton, 1970). However, other studies have failed to reproduce those results. More recent evidence suggests that parents do correct

their kids' grammar mistakes with some frequency. For example, Hirsh-Pasek, Trieman and Schneiderman (1984, p. 86) found that parents repeated (with a correction of the child's error) 20.8% of the ill-formed sentences. Bohannon and Stanowicz (1988, p. 687) discovered that 34% of syntactic errors and 35% of phonological errors in children received some kind of correcting feedback from adults in form or reformulations or clarification questions. Chouinard and Clark (2003) found that (a) adults reformulate between 41% and 60% of their children's erroneous utterances (far more often than they repeat correct utterances), and (b) adults reformulate equally often all error types (phonological, morphological, lexical, and syntactic). In Chouinard and Clark's study, children regularly acknowledged adult's reformulations with terms like "uh-huh", "okay" or "yeah", and also repeated many adult reformulations. Chouinard and Clark concluded that adult reformulations offer an important source of information to correct errors in language learning.

Children also benefit from indirect negative evidence, in the form of non-occurrence of some input patterns. Thus, indirect negative evidence can be inferred from positive evidence. Children can differentiate between an accidental non-occurrence and a statistically significant non-occurrence, and deduce that the latter is ungrammatical (Regier and Gahl 2004; Stefanowitsch, 2008).

Some consider that positive evidence alone can provide enough data to successfully learn language. Hsu, Chater and Vitányi (2013) conducted a formal study and concluded that the learner has sufficient data to learn language from positive evidence alone, if the learner favors the simplest encoding of the linguistic approach.

**Children acquire the competence to produce a potentially infinite number of sentences from exposure to a limited sample of sentences.**

Hauser, Chomsky and Fitch (2002, p. 1577) argue that, given the fact that children are only exposed to a small proportion of the possible sentences, it is difficult to explain how humans acquire the ability to employ a potentially infinite number of sentences (ignoring obvious constraints such as the limited time of human existence). Due to this limitation of data, they consider that the process of learning a language cannot be explained by general learning mechanisms like imitation, generalization, analogy and statistical learning, hence the need of postulating an innate property such as UG (Hauser, Chomsky and Fitch 2002, p. 1577). However, their observation does not represent empirical evidence that there is some kind of innate knowledge of syntax, since language is not the only domain where humans produce an infinite number of possibilities from a finite number of rules. Chess is a completely learned domain were humans can potentially produce an astronomical or even unlimited number of moves from a finite number of rules.

A possible objection is that chess requires formal learning. But this is not necessarily the case. As mentioned above, Capablanca learned to move the chess pieces by observation of his father's games (Capablanca 1920/1966, p. 4). An average child exposed 8 hours per day to language has 11.680 hours of exposure and practice of language between the ages of 1 and 5 years (4 x 365 x 8 = 11680). With a similar amount of exposition and practice, any normal child would easily learn chess without formal instruction. If a child were stimulated by adults to observe two chess games per day between the ages of 4 to 5, he would have observed 1.460 chess games in just 2 years (2

x 365 x 2 = 1.460). Any normal 5 years old child would know how to move the chess pieces after having observed 1.000 chess games or less, and without needing any "formal teaching", just by observing others playing. More so, if adults correct about 20-30% of children's incorrect chess moves when they start to play, like they do when they reformulate children's incorrect sentences.

Another conceivable objection against this analogy is that chess does not really represent a system of potentially infinite moves, unlike language and its unlimited potential. Again, this is not always necessarily the case. In 2014, the FIDE/World Chess Federation added a rule that made the possible moves of a tournament chess game necessary finite, forcing automatically a draw "if any series of at least 75 moves have been made by each player without the movement of any pawn and without any capture" (World Chess Federation 2014, section 9.6). Nonetheless, before 2014 it was theoretically possible to produce a potentially infinite number of moves in a tournament chess game. There are two important rules to force a draw: the 50-move rule and the threefold repetition rule, both of which require a player to claim the draw (World Chess Federation 2014, section 9.2). Before 2014, in a hypothetical chess game where none of the players wanted to claim a draw, they could have theoretically played as long as they wanted. In effect, they could have played as long they were unable to find checkmate—which can be difficult sometimes, like in the case of the Bishop and Knight checkmate. If the players were playing fast enough, they could have remained playing without being out of time.

Crucially, in unofficial or friendly chess games played without following the 75-move rule (or even the 50-move rule and the threefold repetition rule), chess can have a potentially infinite number of moves from a limited number of rules. Whether these informal games can be considered "genuine chess" despite not following all the FIDE rules is not relevant for the present discussion. The point is that humans have domains where it is possible to create a potentially infinite number of possibilities from a finite number of rules, and it does not represent evidence of domain-specific innate knowledge.

Claud Shannon famously estimated the number of possible chess board positions to be roughly $10^{43}$. Hence, the number of possible board positions in chess is extremely big but finite. To have an unlimited number of possible moves in chess, it is necessary to repeat board positions. But the same occurs with language. The number of words in any language is finite. To have an infinite number of possible sentences in a language, it is necessary to repeat words. The number of sentences in a language would be finite if repeating words were not allowed. Unless we consider adding numbers to a sentence, which would make the set of natural numbers infinite rather than language *per se*. Indeed, some languages like Pirahã exhibit a virtual absence of words for numbers (Gordon 2004).

### 5.4 Linguistic universals

Linguistic universals are patterns which are found among all languages. Generative linguists have proposed several linguistic universals as components of UG, such as the structure-dependence principle, the Complex NP Constraint, the Island Constraint, Subjacency, Binding Conditions, constituency and syntactic recursion. However, it is disputed whether these so-called "universals" are universal conditions of grammar or constituent of all languages. There is evidence of violations of the structure-dependence principle (Comrie 1984, p. 100; Comrie 1989, pp. 21-22), the Complex NP Constraint

(Allwood 1982), the Island Constraint (Sampson 2005, p. 157), Subjacency, Binding Conditions and constituency (Evans y Levison 2009) as well as syntactic recursion (Everett 2005; Futrell et al. 2016).

Even less controversial claims for linguistic universals, such as the distinction between nouns and verbs, have found some opposition from studies from the syntax of Straits Salish (Jelinek and Demers 1994). The same applies to the proposed universality of adjectives, which has been challenged by the Northern Iroquoian languages (Chafe 2012). Anyhow, the most typical examples of linguistic universals are (1) nouns and verbs, (2) vowels and consonants and (3) interjections:

(1) **Nouns and verbs.** Proponents of the UG theory consider that the distinction between nouns and verbs is innate and part of the UG (Foley 2005, p. 47). It is true that some fMRI studies report that nouns and verbs are processed by different brain locations (Mestres-missé et al. 2010). However, other fMRI experiments made with Chinese people did not find any significant difference in the brain processing of nouns and verbs (Li et al. 2004, Yang et al. 2011). Another study found no significant difference in brain activity with abstract nouns and verbs (Moseley and Pulvermüller 2014). If the noun/verb distinction were innate, the difference in brain processing should be observable in all fMRI studies of individuals with no brain damage, which is not the case.

Interestingly, children generally learn nouns faster than verbs. It has been suggested that noun learning is easier to conceptualize than verb learning, since nouns are more individuated and refer to objects or specific entities while verbs are more relational terms which need other referents for meaning (Pulverman et al. 2006, p. 135).

(2) **Vowels and consonants.** The distinction between vowels and consonants is sometimes argued to be innate as a component of UG (Smitth and Allott 2016, p. 183; Nespor et al. 2003, p. 24). To consider the vowels/consonant distinction innate, empirical studies should show (a) different brain area activation for vowels and consonants, (b) a universal pattern of different sensitivity to vocal and consonant mispronunciations in infants and (c) same or similar sensitivity between different types of consonant mispronunciations (e.g., onset consonants with voicing change compared with coda consonants with place of articulation change).

With regard to (a), some fMRI experiments have shown different brain activation patterns for vowels and consonants (Carreiras and Price 2008). Nonetheless, other PET scans have shown that the same brain areas are activated when using either vocals or consonants during word reconstruction tasks (Sharp et al. 2005). The only difference was the amount of activation, it was greater for the consonant replacement, as we would expect, since it is a more complex task.

Concerning (b), many studies have found that 12-month-old and 20-month-old English-learning infants have no significant difference in sensitivity toward vocal and consonant mispronunciations (Floccia et al. 2014; Mani and Plunkett 2007; Mani and Plunkett 2010).

About (c), a recent ERP study found that 8-month-old infants showed brain sensitivity to onset consonant mispronunciations but not to coda consonant

mispronunciations (Von Holzen et al. 2018). In other words, the infants of this study did not support an innate brain sensitivity for consonants as a specific linguistic category, otherwise infants would have had sensitivity toward both onset and coda consonant mispronunciations.

(3) **Interjections:** interjections are sometimes cited as an example of linguistic universal (Ameka 1992), with some considering them to be innate (Ferguson 1996, p. 134). But interjections are conventionalized, as well as language-specific and need to be learned. Even though some interjections are similar across languages, the differences outweigh the similarities by far (Strange 2009, p. 60). Children learn the specific interjections of their native language because their parents and people of their environment use them. Also, feral children have not been observed spontaneously using interjections that they have not heard before.

In sum, even when all human languages do share some vanishingly few universals, it does not represent evidence that there is innate tacit knowledge of the rules of grammar. As mentioned before, some universal traits among human populations are entirely learned, such as the use of clothing items.

Also, it is difficult to explain why many feral children who have not been significantly exposed to language fail to use these universals when they are found. A well-documented case of a feral child is found in Danielle Crockett, a girl who was found at age 7 in a home where she was maintained in deplorable conditions and isolated from human contact. Danielle Crockett was absolutely unable to talk or even pronounce a single word when she was found (DeGregory 2008; DeGregory 2017). In other words, Danielle Crockett did not use any of the so-called linguistic universals. The same applies to other feral children like Vanya Yudin who had not learned to talk when he was found (Cockcroft 2008). So human linguistic "universals" are only strictly universal among human populations, rather than among human individuals.

### 5.5 Species specificity of human language

Even though other animals have communication systems, none of them is so complex as human language. Clearly, human language would not be possible without the specific human anatomy (complex brain, human-like vocal tract and a high degree of mobility of the hands). Human beings exhibit a bigger brain and have more neurons in the cerebral cortex than any of their close living relatives such as chimpanzees, bonobos and gorillas (Herculano 2011; Roth 2005). This notorious difference in the complexity of the brain could explain why nonhuman great apes have not shown to be able to fully learn human sign language, despite having great freedom of movement with hands.

Chomsky has claimed that because language is uniquely human, it must be considered innate (Chomsky 2000, p. 50). But the fact that something is exclusively human does not make it innate. The ability to play chess is also uniquely human, yet no one has claimed that chess-specific knowledge is innate. No single chimpanzee or bonobo knows how to play chess. There is no empirical evidence suggesting that chimpanzees or bonobos can correctly play chess (i.e., understanding the game, including abstract notions such as checkmate, and moving the pieces correctly). The capacity to learn to play chess is innate,

but chess-specific knowledge is learned. Analogously, the capacity to learn language is innate, but linguistic-specific knowledge is learned.

### 5.6 Brain specialization for language

Proponents of the UG theory usually defend two arguments to support the existence of a brain specialization for language: (1) Some brain structures are specifically adapted for language and (2) Dissociation between language and general cognition.

(1) **Some brain structures are specifically adapted for language**: some authors consider that certain brain structures are specifically adapted for language, which would represent evidence of the neural basis of UG (Stromswold 2000, p. 925). The most often cited brain structures traditionally considered to be only implicated in language tasks are Broca's and Wernicke's areas. However, more recent research suggests that both areas are involved in non-linguistic functions or tasks. Broca's area is involved in motor functions which include complex hand movements and manipulation of objects (Binkofskia and Buccinoc 2004). Recent fMRI data indicate that Wernicke's area is activated for musical imagery—the experience of imagining music without hearing it (Zhang et al. 2017).

Another largely linguistic area is the arcuate fasciculus (AF). Nonetheless, the AF is relevant for both language and music development (Chen et al. 2018). Musicians exhibit an increased fractional anisotropy in the AF compared to non-musicians (Halwani et al. 2011). And amusic individuals have a reduced volume in the right anterior AF compared with non-amusic individuals (Chen et al. 2018).

None of the so-called "language areas" of the brain are exclusively implicated in language-specific tasks, and so they do not support the UG theory, which presupposes that the human brain is specifically hard-wired for grammar.

**(2) Dissociation between language and cognition:** it has been proposed that there is a double dissociation between language and cognition (Curtiss 1981; Gazzaniga and Smylie 1984, Pinker 1991). The postulated dissociation comes from both (a) individuals with language impairment and overall normal cognition, and (b) individuals with impaired general cognition but overall good language skills. Let us examine both data sources.

**(a) Individuals with language impairment and overall normal cognition:** the data come mainly from children with Specific Language Impairment (SLI), a proposed condition in which language difficulty occurs in the absence of other developmental deficits. First of all, it should be noted that modularity can be a product of development, so SLI does necessarily support innateness (Paterson et al. 1999). Also, SLI has been contested, with some researchers considering SLI not specific of language but also affecting other areas of brain functioning, including memory (Hill 2001; Ullman and Pierpont 2005; Lum et al. 2010). There is evidence that people with language impairment perform significantly worse on non-linguistic tasks than people with intact language, these deficits are found in accuracy, strategy, learning rate and procedural memory tasks (Kemény and Lukàcs 2010; Lee and Tomblin 2014). Children

who satisfy the diagnostic criteria for SLI (by having a non-verbal IQ in the typical range), sometimes decline the non-verbal IQ when they get older (Botting 2005).

The nativist premise is the following: because some children appear to have a specific trouble with their linguistic performance while having normal cognition, then language is dissociated/different from cognition. To assert that because a child has a poor performance specifically in X, X is not part of cognition, is not a valid logic. Following that logic, if a child has a specific trouble with mathematics (dyscalculia), it would follow that mathematical knowledge is not part of cognition. Some children are excellent in chess, while others are horrible even after years of practice (Fraga González et al. 2018), just like we observe differences in children's reading skills or mathematical skills, yet no one has proposed that reading, playing chess or mathematical abilities are not part of cognition.

The *Oxford Dictionary of English* defines cognition as "The mental action or process of acquiring knowledge and understanding through thought, experience, and the senses." (Stevenson 2010, p. 337). As it is possible to acquire knowledge with both explicit and implicit learning, not all the knowledge or information which composes cognition is necessarily conscient. In the scientific literature, it is common to find allusions to unconscious cognition or tacit cognition (Kiefer 2012; Ray 2009; Wokke et al. 2011). Hence, both conscious and tacit components of language are part of cognition (Kihlstrom 2007).

**(b) Individuals with impaired general cognition but overall good language skills:** the most typical cited example comes from individuals with Williams Syndrome (WS) (Karmiloff-Smith et al. 2006, p. 54). Nonetheless, this example is misleading. To be a genuine dissociation, language should be fully intact in WS individuals and equal to any person who does not share the condition, not only relatively good considering WS is a cognitive disorder. Individuals with WS do not possess an intact language. There is vast evidence that individuals with WS—including adolescents and adults—do not have intact various linguistic areas such as syntax and pragmatics, and their language learning differs from typically developing children (Grant et al. 2002; Karmiloff-Smith et al. 1997, 1998; Laws and Bishop 2004; Benítez-Burraco et al. 2016). Also, there is no significant difference between linguistic tests of children with WS and children with SLI (Stojanovik et al. 2004). Therefore, it cannot be said that language in WS is almost intact, and SLI clearly affects language.

### 5.7 Critical period

A critical period can be defined as a developmental window during which certain experience has a bigger effect than at other times (Trainor 2005). Certain researchers have suggested that the existence of a critical period for first language learning supports the existence of an innate UG (Cenoz 2003, p. 61). This is usually defended with an analogy between the development of language and vision (Singleton and Ryan 2004). There is

evidence of critical periods in visual development, it has been observed that depriving a kitten of normal visual experience during a period of early postnatal life irreversibly changes neuronal connections in the visual cortex (Wiesel and Hubel 1963). But the analogy between the development of language and vision is wrong, since the visual development is not shaped by culture, unlike language. If two twin brothers are separated at birth and one of them is raised by his Russian-speaking mother in Russia while the other one is raised by his English-speaking father in England, they will learn two radically different languages despite developing the same visual system.

There are critical or sensitive periods for early brain development, since the developing brain has higher plasticity than the adult one (Hensch and Bilimoria 2012). This is clearly observable in cases of feral children. The feral child Genie was found in 1970 when she was 13, after having spent her whole childhood almost entirely isolated in a dark room. Due to her lack of human interaction, Genie did not learn language throughout her childhood. After years of reintegration and several tests, it was concluded that Genie was not able to fully learn English grammar. Genie learned a broad vocabulary, but her sentences typically lacked grammatical coherence (Fromkin et al. 2010, p. 63).

Genie's score in nonverbal tests of cognitive abilities was far below the age-appropriate level. In May 1973, when Genie was 16, she performed the nonverbal test Leiter International Performance Scale and her score was of 6-8 year level (Curtiss 1981) Genie's performance in the nonverbal test Raven's Colored Progressive Matrices was also overall poor and well below age-level (Curtiss 1977, p. 230).

Based on the available evidence, Genie showed a critical period for brain development in general, rather than for language in particular, since it affected cognition and many non-linguistic brain functions, as illustrated by her poor nonverbal tests performances. Genie never performed at a normal and age-related level in general nonverbal tests like the Leiter scale. Thus, it was a critical period for brain development, not a critical period for language in itself. The same applies to other feral children, there is no evidence that the critical period only affects language processing. As a consequence, feral children do not support the hypothesis that the brain is specifically hard-wired for grammar.

It is possible to contest that, even if the critical period is not specific to language, it does affect language, supporting nativism in that sense. Thus, the nativist logic would be as follows: "if X is affected by the critical period of brain development, then the brain is hard-wired or specifically configurated from birth for X". Following this reasoning, the human brain could be specifically hard-wired for chess. Nobody has tested feral children's abilities at chess. If Genie or Danielle Crockett cannot learn to play chess or, if compared with an experimental group of people who start playing chess, their overall chess skills are far below the experimental group, then it should be concluded that the human brain is hard-wired for chess (following the nativist logic described above). It can be objected that chess skills depend to some degree on language ability. Such an objection is invalidated by the fact that the critical period does not affect language *per se*, but brain development in general. Consequently, the fact that a particular skill or trait is affected by the critical period of brain development does not necessarily imply that such a trait is hard-wired in the brain.

### 5.8 Is UG falsifiable?

There have been solid critiques of UG: Cowie (2017), Dąbrowska (2015), Tomasello (2004; 2009); Ibbotson and Tomasello (2016), Lin (2017). None of these valid critiques have been accepted by the proponents of UG. A common criticism is that generative linguists do not require all components of UG to be universal, hence making the UG theory unfalsifiable (Dąbrowska 2015; Evans and Levinson 2009; Tomassello 2009).

Karl Popper held that to differentiate science from pseudoscience it is necessary to determine whether a theory is testable/falsifiable. Popper considered that some theories are unfalsifiable by means of introducing new *ad hoc* reinterpretations or excuses to escape refutation (Popper 1962, p. 37). The thesis that human grammar is entirely learned or created is falsifiable. The observation that all feral children which are born with a normal brain employ the same linguistic universals when they are found, would automatically refute the view that human grammar is entirely learned or created.

UG theory postulates that there is some innate tacit knowledge of the rules of grammar, including syntax. If children who have not been significantly exposed to language do not possess linguistic knowledge, then the assumption that there is innate knowledge of the rules of grammar should be refuted. The observation that Danielle Crockett and other feral children did not know any word when found, should have refuted a long time ago UG and the proposed innateness of linguistic "universals" (linguistic universals are only universal among languages, not among human individuals). Nonetheless, generative linguists make *ad hoc* excuses to avoid refutation. They argue that linguistic competence is not the same as linguistic performance (Chomsky 1965, p. 4) and subsequently assume that feral children lack a specific vocabulary rather than innate knowledge of syntactic rules. This *ad hoc* excuse saves the theory from refutation but makes it unfalsifiable. Feral children are simply assumed to have innate linguistic knowledge regardless of the observations. If feral children talk UG is confirmed, and if feral children do not talk UG is also assumed.

According to Tomasello (2009), to use the term "universal grammar" to simply denote linguistic universals or grammar across all languages but without alluding to any innate linguistic knowledge is a misuse of the term, since historically the term refers to innate linguistic-specific knowledge rather than general aspects of human cognition. Tomasello argues that it is not the notion of linguistic universals what is dead, but rather, the idea that there is innate linguistic-specific knowledge. Certainly, to claim that the UG theory does not refer to innate linguistic-specific knowledge would be a strategy to avoid falsification by creating new definitions of UG. Both traditional and contemporary definitions of UG explicitly defend the existence of innate linguistic knowledge (Chomsky 1975, p. 32-33; Vikner, 1995, p. 9).

### 5.9 UG and Kuhn's puzzle-solving criterion

Syntactic recursion has been proposed as the only uniquely human characteristic of language (Hauser, Chomsky and Fitch 2002). Therefore, it would be expected to observe syntactic recursion in all human languages as a fundamental property of UG. The work developed by Everett (2005) and Futrell et al. (2016) with the Pirahã tribe could have refuted the universality of syntactic recursion. Consequently, UG theorists can, at least in principle, make some accommodations between theoretical predictions and observations, solving puzzles in this sense. But the Pirahã tribe can only falsify the universality of syntactic recursion, not UG *per se*. Even if the universality of syntactic recursion were

refuted, the UG theory would remain unfalsifiable for three reasons: (1) UG is usually considered to be composed of more properties than merely syntactic recursion, (2) it can be argued that not all the components of UG require to be universal, and (3) the proposed innateness of linguistic-specific knowledge would remain irrefutable (it is assumed that the universality among languages of a few linguistic traits implies its innateness and the counterexample of feral children is ignored). Hence, the UG paradigm can solve puzzles, despite not being falsifiable. UG illustrates that the puzzle-solving demarcation criterion proposed by Kuhn is not useful to identify some unscientific practices.

### 5.10 Evaluation

UG theory does not meet two demarcation criteria: testability and evidence. UG is unfalsifiable, since generative linguists make *ad hoc* excuses to avoid refutation when counterexamples appear. The main arguments and observations used to maintain the existence of an innate UG have been examined here. None of these observations genuinely support the notion that there is innate tacit knowledge of the rules of grammar, therefore UG is not supported by empirical evidence. In short, UG is a pseudoscience.

Fortunately, new promising approaches are emerging in the recent years in the field of linguistics in general, and language learning in particular. The research conducted in usage-based linguistics (Diessel 2014; Ibbotson and Tomasello 2016; Tomasello 2003, 2010) is more empirically based than the UG framework. Ibbotson and Tomasello (2016) argue that it is necessary a paradigm shift in linguistics, with the UG theory needing to be changed by the usage-based linguistics approach. Usage-based linguistics can provide an empirical framework to investigate language learning as well as the use, similarities, differences and historical development of the existing 6,000 languages.

## 6. String theory

One of the ultimate goals in physics is to find a theory able to unify general relativity with quantum mechanics, since both theoretical frameworks are largely incompatible. While general relativity focuses on gravity and large scale phenomena like planets, galaxies and so forth, quantum mechanics focuses on the non-gravitational forces (electromagnetic, weak and strong forces) and small scale phenomena like sub-atomic particles, atoms, etc.

String theory has been described as a “theory of everything”, that is, a theory which attempts to unify gravity with the other fundamental forces—electromagnetic, weak and strong forces (Van den Heuvel 2016, p. 170). In other words, string theory is considered to have the potential to reconcile and unify general relativity with quantum mechanics. Thus, string theory has important theoretical implications. However, in the last years there has been an increasing number of skeptic remarks toward this theoretical framework. Some of the main methodological problems concerning string theory are discussed in the following sections.

### 6.1. The basics

The central assumption of basic string theory is that elementary or fundamental particles are not point-like particles but one-dimensional "strings", which have the dimension of length. In this theoretical framework, strings are the basic constituents of matter. These strings can vibrate in different manners and the distinct modes of vibration produce distinct types of particles. The rough estimate of the string length scale is the Planck length, about $10^{-33}$ cm (Szabo 2004, p. 3). M-theory, the modern theoretical extension of string theory, in addition to strings, has higher-dimensional objects known as "p-branes" (Gaunlett 1998).

Importantly, the theory is not considered in the normal four-dimensional spacetime (three spatial dimensions and time). Extra dimensions are required to achieve mathematical consistency. The first version of string theory, the bosonic string theory, required 26 dimensions. The bosonic string theory describes the class of particles known as bosons, but not fermions. Later, string theories that included the study of fermions and supersymmetry were called superstring theories. By the mid-1980s, there were five consistent superstring theories, and all of them required 10 dimensions. These five superstring theories were later unified into a broader theory called "M-theory". M-theory postulates the existence of 11 dimensions. In string theory, the characteristic first rough estimation of the size of extra dimensions is not much distinct from the Planck scale. However, recently some string theorists are considering the possibility of larger dimensions (Dine 2015, p. 431).

A key notion in modern string theory is supersymmetry, a proposed symmetry between the two types of elementary particles: fermions and bosons. It predicts that each of these types of particles has a superpartner, that is, every fermion has a boson superpartner and every boson has a fermion superpartner.

### 6.2 The problem of testability

The hypothesized superpartners predicted by supersymmetry have not been detected by the Large Hadron Collider at CERN. Indeed, the supersymmetry assumption cannot be falsified since string theorists do not have a definitive prediction about the mass of superpartners (Chaudhuri 2016, p. 8). Still, evidence of supersymmetry would not make string theory fully testable since the existence of extra dimensions must also be tested.
String theorists postulate the existence of tiny extra dimensions which are unobservable—at least with current technology. If extra dimensions are indeed postulated to be about the size of the Planck length, some consider that those dimensions will remain undetected in the foreseeable future, if not forever (Chaudhuri 2016, p. 8; Zwiebach 2009, p. 9). It makes the existence of extra dimensions virtually impossible to confirm. Extra dimensions are also unfalsifiable, no definitive estimation of the size of extra dimensions exists (Randall 2006). Lisa Randall, a well-known advocate of string theory, has claimed that "People have often made the mistake of believing only in what they could see. (…) String theory is another reason to believe extra dimensions might exist" (Randall 2007). It is not a very convincing assertion, extra dimensions should be accepted by empirical evidence rather than faith.

The string theorist David Gross has suggested that string theory is perfectly scientific because it is testable in principle (Castelvecchi 2015). A theory is testable in principle if it can be potentially tested in the future, and testable in practice if it has already been tested. First of all, it is far from clear that string theory is testable in principle, as it depends

on the development of new technology—particle accelerators—which could never be precise enough to test the theory with falsifying experiments. Second, and contrary to Gross's suggestion, testability in principle is not a sufficient condition to produce science. To be scientific, theories must be testable both in principle and in practice, meaning they should actually be tested. Furthermore, theories are not scientific until they have been supported by evidence at some point. Atomism was not scientific in ancient Greece, despite being testable in principle, since it was not meaningfully tested or supported by any empirical evidence. The atomic theory achieved scientific status once it was tested and supported by evidence with the works of Dalton, Thompson, Rutherford and Bohr.

### 6.3 Philosophical perspectives

The case of string theory has huge philosophical implications, especially in the context of the demarcation problem. The issue of the epistemic range of string theory is complex and has created dissimilar philosophical views. Let us briefly discuss some of the views on string theory among contemporary philosophers of science.

Mario Bunge, a physicist turned philosopher of science, is skeptic toward the epistemic value of string theory. Bunge is critical with string theory for two reasons: it is a theory protected from refutation and it has resisted experimental confirmation since its inception in 1968 (2010, p. 254). This reasoning has led Bunge to conclude that string theory is suspicious of being pseudoscience (2012, p. 6) or even science fiction (2010, p. 254).

Massimo Pigliucci has suggested that string theory is a form of mathematical philosophy (Pigliucci 2018, p. 49). Such a classification may be tempting, but it is inaccurate. String theory is not taught in departments of philosophy but in departments of theoretical physics. Researchers in the field of string theory do not promote their framework as philosophy. Rather, string theorists promote the theory as a theoretical model of physics, which is a science. Thus, string theory has always been promoted as a scientific theory, not as a philosophical doctrine.

Richard Dawid (2013), another phycicist turned philosopher, has proposed that string theory is redefining the way science should be understood. He argues that now it should be acknowledged the existence of non-empirical science. Dawid's viewpoint is undoubtedly original and interesting from an epistemological perspective, but at the same time, it is highly controversial. Dawid's notion of non-empirical science has been challenged by both philosophers (Chall 2018) and physicists (Ellis and Silk 2014). For instance, the astrophysicists Ellis and Silk (2014) claim that non-empirical science is an oxymoron, which is a correct assertion.

According to Dawid, string theory should be accepted because there is no better alternative (Dawid 2013, p. 40). Dawid's premise is debatable as there is indeed a better alternative: to stop defending string theory and similar unfalsifiable "theories of everything" and to promote research programs with testable predictions. As Ellis and Silk suggest, "there may be no need for an overarching theory of four fundamental forces and particles if gravity, an effect of space-time curvature, differs from the strong, weak and electromagnetic forces that govern particles" (2014).

String theorists should adapt to the methodology of the rest of working scientists, not the other way around. The main problem with Dawid's proposal is that it is difficult to see the clear boundaries between string theory and religion. Religion is also not supported

by any empirical evidence and unfalsifiable. Should string theory be accepted by faith rather than evidence?

### 6.4 Evaluation

Many physicists consider string theory an unscientific enterprise and are skeptic of the long-term value of research in this framework (Bunge 2006; Chaudhuri 2016; Ellis and Silk 2014). In their critique of string theory and the multiverse theories, Ellis and Silk (2014) hold that journal editors in the field of physics should generally not accept speculative and untestable work and emphasize that only testable theories should be awarded in science. Their skepticism is justified. String theory cannot become a science unless there is some experimental evidence of the proposed extra dimensions and supersymmetry. In fact, string theory should be abandoned unless the necessary technology to test it with falsifying experiments is available. Otherwise, string theory could be maintained and defended in academia forever, despite not having any empirical support.

String theory does not meet three demarcation criteria: testability, evidence and the 50-year criterion. String theory is unfalsifiable, since there is no definitive prediction of the size of extra dimensions or the mass of superpartners, and it is always possible to avoid refutation by claiming that these phenomena will be detected in the future with better technology. The main ideas of string theory—such as extra dimensions or supersymmetry—are still not supported by empirical evidence, and a theory which has never been supported by evidence cannot be considered scientific. In addition, string theory does not pass the 50-year criterion because it has not evolved into a scientific field after half a century of existence. String theory began to develop between 1969 to about 1974 (Schwarz 2000). Especifically, the idea of a one-dimensional object (or "string") first appeared between 1969 and 1970 (Schwarz 2000), and the existence of extra dimensions was postulated by string theorists as far back as 1971 (Lovelace 1971). In sum, it is safe to conclude that string/M-theory is a pseudoscience, as it does not meet the requirements to be deemed as science and it is promoted as a theoretical model of the science of physics.

## 7. Conclusion

Sometimes, the demarcation problem is discussed in very general terms, without examining any specific field in detail. Here, it was attempted to focus the demarcation problem on particular disciplines or theories. After discussing a set of demarcating criteria, four theoretical frameworks have been examined: psychoanalysis, speculative evolutionary psychology, universal grammar and string theory. It has been concluded that these theoretical frameworks are examples of pseudoscience, as they do not meet the requirements to be regarded as science.

It is important to emphasize the relevance of skepticism and critical attitude in scientific thought and academia in general. It is not enough with the rejection of easy to detect pseudosciences like astrology or ufology, which are largely ignored in academia. Occasionally, some pseudosciences can proliferate and be very well accepted in certain

scientific fields. Thus, it is crucial to adopt a critical attitude toward "high-status" pseudosciences, which are not so obvious to detect and have entered in academia.

### Conflict of Interest Statement

The author declares that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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