Chapter 12

Intuitions in Science Education and the Public Understanding of Science

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Abstract

Although science builds on ordinary, intuitive reasoning, its results can be highly counterintuitive. This tension between the intuitive, cognitive basis of science and its counterintuitive results offers both opportunities and challenges for those who are involved with taking science to the public, in particular science educators, communicators, and popularizers. On the one hand, they need to engage with people's intuitive understanding by resorting to appealing metaphors, imagery, or narratives as tools to facilitate the understanding and acceptance of scientific concepts. Because of their intuitive appeal, these representations can become popular, bringing scientific concepts to large parts of the public. On the other hand, however, these tools can also be highly misleading, creating or sustaining unscientific representations that, because of their intuitively appealing nature, are more likely to become popular within the culture at large than the underlying scientific concepts the educator or communicator is trying to convey. Furthermore, as science educators, communicators and popularizers do not have minds that differ markedly from any ordinary human mind, they themselves are not entirely immune to the powerful seduction of intuitively appealing representations, thus enforcing their misleading effect. As such, science educators, communicators, and popularizers should be careful about the educational, communicational, and rhetorical strategies and tools they employ. Some can become highly

successful, but this might come at the expense of their own understanding of science and, especially, that of their audience and of society at large.

Scientific Thinking as Scaffolded Cognition

Traditionally, the philosophy of science looked at science in the abstract. Philosophers assumed that they could get at the nature of science by treating it as a collection of symbols that stood in a special formal relationship to both one another and the facts of the world. The task of the philosopher was to apply the tools of logic to lay bare these relations. The assumption was that science or the scientific method produced a special and solid type of knowledge, one that was rooted in deduction and pure induction, characterized by rational ways of reasoning and, above all, blessed by steady if largely piecemeal progress. However, this research program failed, and for good reason. Philosophers generally found that there yawns a wide gap between their models of rationality and progress and the actual process of science, whereas sociologists and historians brought to light several irrational or not so rational factors and forces in concrete cases or episodes of scientific change. Karl Popper in a way still tried to salvage the traditional, rational model of scientific progress by invoking an idealized, dialectical process of conjecture (of scientific hypotheses and theories) and refutation (or falsification) (Haack, *Defending Science*; Kitcher, *The Advancement*). It was Thomas Kuhn who showed that such ideal views on science in no way reflect actual scientific practice (*The Structure*). Science, as perceived and portrayed by Kuhn, is not about following the logical norms of induction and deduction, but about what real scientists do while trying to solve problems or puzzles under the guidance of a so-called paradigm or disciplinary matrix. One important aspect or dimension of this scientific praxis is that scientists do not work in isolation, but within social groups that can be described as cultures of science: the social nature of the scientific endeavor can hardly be underestimated (Goldman, *Knowledge*; Boudry and Pigliucci, this volume).

Several strands can be discerned in the post-Kuhnian philosophy of science. One approach focuses on its sociological aspects, and assumes that, given the failure of the traditional view, objective knowledge about the world is simply impossible. Hence, science cannot be considered a quest for objective truth, but is nothing more than sociological interactions based on power relations. Such ideas led to the development of relativism, postmodernism, and the science wars. The other approach, naturalism, accepts the idea of science in the flesh without, however, resorting to, or harboring, relativist ideas about that all too human endeavor. Instead, philosophers in the natural tradition assume, inspired by modern evolutionary theory, that scientific reasoning can and should be regarded as an activity of evolved, biological information-processing organs—human brains—that shape and constrain the ways scientists can obtain scientific knowledge about the world (Haack, *Defending Science*). As Phillip Kitcher writes:

> Science is not done by logically omniscient lone knowers but by biological systems with certain kinds of capacities and limitations. At the most fine-grained level, scientific change involves modifications of the cognitive states of limited biological systems. What are the characteristics of these systems? What kinds of cognitive states can they be in? What are their limitations? What types of transitions among their states are possible? What types are debarred? What kinds of goals and interests do these systems have? (Kitcher, *The Advancement* 59)

An important feature of this naturalistic approach is that scientific cognition is considered not to be fundamentally different from ordinary cognition. As Susan Haack puts it: "Scientific inquiry is continuous with everyday empirical inquiry—only more so" (*Defending Science* 94). This "continuity hypothesis" has paved the way for applying the methods of the cognitive sciences to the study of science itself, the results of which feed back into the research on human cognition (Nersessian, *Creating*). It also entails that philosophers of science need to be informed about the results of the cognitive sciences.

One of the main findings in cognitive science is that, in contrast to personal experience, human thinking is not limited to the mental processes over which we have voluntary control. Theoretical considerations within the field of artificial intelligence research, the cognitive sciences, evolutionary psychology, and a plethora of empirical studies have demonstrated that our thinking depends on domain-specific mechanisms that work largely under the radar of conscious awareness (Barrett, *The Shape of Thought*; Pinker, *How the Mind Works*; Tooby and Cosmides, "The Biological Foundations"). These evolved mental mechanisms provide quick and adequate solutions and responses to particular challenges, resulting in intuitive beliefs (Kahneman, *Thinking, Fast and Slow*). Luckily, we also have metarepresentational capacities that enable us to evaluate these intuitive beliefs (Kahneman, *Thinking, Fast and Slow*). Our intuitions do, in the form of systematic constraints, patterns, preferences, and biases, exert great influence on the resulting beliefs about beliefs or "reflective beliefs" (Mercier and Sperber, "Intuitive"). Nevertheless, in the course of our evolution and history, we have succeeded in overcoming the limitations of that intuitive reasoning and thus developed increasingly complex ways of living and thinking.

It is tempting to associate science exclusively with our reflective capabilities. Indeed, that is precisely the approach of the classic or standard pre-Kuhnian model. Certainly, scientists have to think hard and carefully about formulating their research hypotheses, setting up their experiments, making their analyses, and drawing their conclusions. They have to be aware of the distorting influence of perceptual, cognitive, and other biases. However, intuitive cognition plays an important part in science as well: not merely in the sense that our intuitions lead to hard-to-overcome biases, but also, and more importantly, that they enable us to reason scientifically at all. Indeed, recent cognitive approaches to science have discussed the roles of both types of cognition, the interaction between them, and their respective contribution to scientific thinking (Atran, *Cognitive Foundations*; Blancke et al., "From Ends to Causes"; Carruthers et al., *The Cognitive Basis*; Evans, this volume; Mercier and Heintz, "Scientists"; Mercier and Heintz, "The Place"; Nersessian, *Creating*; Thagard, *The Cognitive Science*).

This, however, confronts us with a paradox: if science indeed is based on, or inspired by, a natural way of knowing, how then, can it generate highly counter-intuitive results, that is, ideas and concepts that do not come naturally to mind? The solution lies in what is known as mental scaffolding (Heintz, "Scaffolding"). Scientists have managed to supersede the constraints they too have been endowed with by evolution. Mathematics, logic, and statistics discipline their reasoning and increasingly sophisticated artifacts render their experiments and observations more precise and support their cognitive processes; scientists rely on colleagues to check whether their ideas and results really match reality or express bias; analogies, models, and thought experiments enable them to explore unchartered domains on the basis of familiar, intuitive inferences and natural capacities. As such, human cognition has become extended, distributed, and social; in short, scaffolded (Sterelny, "Minds").

The Influence of Intuitions on Scientific Thinking

Intuitions as Biases

Because we are here primarily interested in intuitions, let us zoom in on them and elucidate their role in scientific thinking. Broadly, one can identify two types of influence. First, as intuitions entail naive assumptions about how the world functions, they often produce systematic distortions of, and even resistance to, scientific concepts and theories. Examples in the history of science abound. When in July 1837, Darwin scrabbled his first sketch of common descent in one of his notebooks, the image he produced looked like a piece of a coral reef. More than forty years later, however, Ernst Haeckel, German's foremost Darwinian in the nineteenth century, depicted evolution as a tree that ends with the emergence of man. He had transformed a widely diverging process without any specific direction into a purposeful progression. Such teleological representations of evolution are still popular today; think, for instance, of the chimp-like creature that gradually changes into a modern human. However, in contrast with Darwin's earliest drawing, these conceptions are not scientifically accurate, but rather reflect a strong tendency to ascribe a finalistic (and anthropocentric) purpose to natural events. This universal inclination, aptly coined "promiscuous teleology" by psychologist Deborah Kelemen, exerts, from a very young age, a strong influence on our thinking about the natural world (Kelemen, "Function"). When five-year-olds are asked why rocks are pointy, they prefer the answer that explains this property in terms of purposes rather than the answer that refers to natural causes. They believe that rocks are pointy "so that animals wouldn't sit on them" (Kelemen, "Why are Rocks"). With years of education, we learn to override the nefarious impact of our teleological reasoning—although we should immediately point out that this kind of thinking is not necessarily wrong: artifacts and, according to some philosophers, adaptations are perfectly explainable in terms of the function they serve (Ruse, *Darwin*; Kampourakis, *Understanding*). However, this does not completely immunize us against the siren song of teleological reasoning. Under speeded conditions, not only educated adults, but even professional scientists show a preference for teleological over causal-mechanistic explanations (Kelemen and Rosset, "The Human Function"; Kelemen et al., "Professional"). It is therefore unsurprising that scientists such as Haeckel also succumb to the allure of purposeful reasoning.

Haeckel's tree is but one example of the many misconceptions and representations of the evolution of life that emerged after the publication of Darwin's *On the Origin*. Historian Peter Bowler has documented how Darwin succeeded in making the idea of evolution acceptable in the scientific world, but failed to convince the majority of his colleagues of the mechanism of natural selection (*The Eclipse*). This period in the history of science is known as the eclipse of Darwinism. Scientists resorted to representations of evolution that somehow opened up space for the idea of purpose and even agency. In other words, they created, and argued for, types of evolution, such as orthogenesis and neo-Lamarckism, that aligned more closely with an intuitive understanding of the world. Perhaps the clearest example of a more intuitive representation of evolution is theistic evolutionism, which assumed that God guided and even actively intervened in evolution. One way, for instance, proposed by Asa Gray, Darwin's friend and leading Darwinian in the United States, was that God procured the right mutations so that organisms could adapt to their environment. This theory is highly intuitive for the same reason that religious beliefs are intuitive. It taps into our folk psychology. The mental capacity ("theory of mind") by which we spontaneously interpret other people's behavior in terms of mental states such as intentions, wishes, fears, emotions, and so on, evolved as an adaptation that facilitated living in ever bigger and more complex and tight-knit social groups. However, we also apply this kind of reasoning to purely natural things, processes, and phenomena or even to cultural artifacts. We kick the flat tire of our car because it ruins our plans for a trip to the countryside and curse our computer when it breaks down the moment we are about to finish our paper. Of course, we know that cars and computers do not have minds, but it is remarkable how readily we treat them as intentional beings. We also ascribe mental states to the biological world or describe and interpret it in terms of intentions and goals. Creation stories across the world imagine the origin of the world and life on it as the result of an intentional act by some powerful agent. Even in more secular surroundings, the intuitive idea that nature is designed for a purpose does not all of a sudden disappear from our thought processes (Evans, "Emergence"). Instead, it re-emerges as the idea of Mother Nature or (the strong version) of the Gaia theory, the belief that natural processes are intentionally designed to produce only good results (Järnefelt et al., "The Divided Mind"; Järnefelt, this volume).

Darwin himself contributed to the misunderstanding of his theory through his choice of metaphor. To explain the evolutionary process he had discovered, he relied upon an analogy with artificial selection. Just as breeders picked from the variation at hand in each generation the traits they were looking for, the environment "selects" those traits that add to the fitness of organisms. Hence, Darwin spoke of natural selection. However, by using the term "selection," he not only created an analogy, but also a metaphor that transferred the inferences that come with intentional thinking—that is, our folk psychology—onto people's thinking about evolution. As a result, people came to think of natural selection, not as purely natural, but as an agential process in which nature chooses the most suitable individuals or species and thus creates the diversity and complexity of nature. In fact, Darwin himself used the metaphor in exactly such a way when, for instance, he wrote:

> It may be said that natural selection is daily and hourly scrutinising, throughout the world, every variation, even the slightest; rejecting that which is bad, preserving and adding up all that is good; silently and insensibly working,

> whenever and wherever opportunity offers, at the improvement of each organic being in relation to its organic and inorganic conditions of life. (*On the Origin* 82)

The codiscoverer of the theory of evolution by natural selection, Alfred Russel Wallace, complained to Darwin that by employing such language he had misguided his audience. Darwin, however, was confident that, with time, people would understand his theory correctly. Given what we know today about people's predisposition to reason in intentional terms about natural events, it seems that Wallace had a point. By using an intentional metaphor to explain a natural process, Darwin triggered and strengthened rather than overcame people's intuitive thinking about nature (see Blancke et al., "From Ends to Causes," for a similar analysis of cladograms; Shtulman, this volume).

From an educational and communicational point of view, the metaphor is not always successful. It can realize the very goal it was intended to avoid, namely, that people think about the natural process of evolution in intentional terms. Nonetheless, from a cognitive perspective, it is understandable why Darwin chose this particular metaphor. Darwin's cognitive makeup was not basically different from anyone else's in that he shared the same predispositions as his contemporaries and these had been entrenched by the cultural environment he grew up in. Indeed, before Darwin left on his five-year voyage with the Beagle (1831–1836), he was a creationist. A series of observations and theoretical insights during his journey planted seeds of doubt about the traditional, theistic account of the origin of species that later developed into the mechanistic Darwinian theory of evolution. But in order to arrive at his radically new and counterintuitive way of thinking about nature, Darwin too had to override his intuitive inclinations. The analogy with artificial selection, with its intentional overtones, may have served to accomplish this difficult task, as it allowed him to reason about the terrain he was exploring in familiar terms, as if natural selection was an agent. In a way, he used a novel but still intuitive way of thinking (selection) to override another intuitive but traditional (creationist) way of thinking about nature.

Intuitions as Scaffolds

This story of natural selection brings us straight to the second role of intuitions in scientific thinking. Not only do they entail biases that hinder scientists in their quest for a better understanding of the world, they also function as scaffolds to attain such an understanding. Just as we depend on artifacts, rules of logic, and conspecifics to transcend our intuitive grasp of the world, we rely on our intuitions as building blocks to develop scientific knowledge (Heintz, "Scaffolding"). This is possible because intuitions not only process the type of information they evolved to process, but also any relevant piece of information that meets their input conditions. For instance, we have a face recognition system that responds to the presence of actual faces, but also to any cue in the environment that sufficiently resembles a face, from a realistic portrait or a photograph to a smiley (Sperber, *Explaining;* on the implications for the cultural evolution of portrait paintings, see Morin, "How Portraits"). Similarly, intuitive ways of thinking that generate our naive understanding of the world can be put to work on tasks they were not evolved to solve. The key thus lies in creating and providing the right cognitive environment so that our intuitions do not merely produce naive theories about the world, but scientific ones as well (for an account of the psychological faculties required for the transgression of our intuitive views, see Vlerick, "How Can Human Beings").

Such a perspective has considerable implications for our understanding of the development of science. The history of science shows that the scientific process does not merely constitute a simple and incremental accumulation of knowledge, but is characterized by deep conceptual changes (Vosniadou, *International Handbook*). The Darwinian revolution, for instance, was not simply an addition to the then extant knowledge about nature, but brought an entirely new way of looking at nature. Einstein's relativity theory and quantum mechanics depart sharply from Newtonian physics, which, in turn, contradicted even more intuitive Aristotelian physics. Such drastic changes in our understanding of the world could be easily interpreted in terms of replacing intuitive, but misleading, with counterintuitive, but more accurate beliefs, the latter being the result of reflective thinking. In this view, intuitions are overruled and replaced by a different type of reasoning. However, if intuitions remain at play even in scientific thinking, conceptual change is not a matter of replacing one way of thinking with another one, but of altering the ways in which intuitions function. Scientific thinking is not about fighting the impact of our intuitive reasoning, but about putting it to good use. We already mentioned, for instance, that teleological thinking is not bad per se. It helps us to think correctly about artifacts (that are definitely made for a purpose) and adaptations (that have been shaped by evolution to perform a particular purpose). However, it goes awry if we apply the same way of thinking to whole organisms (lions are to live in a zoo) and natural objects and events (rain falls to water plants). It also misleads us if we think that the function of an adaptation suffices to explain its existence: for instance, eyes have not come into existence with the purpose of giving us sight as natural theologians argued.

Instead, natural selection favored those mutations, which happened to enable our ancestors to make sense of light information, which gave them a bonus in terms of fitness. Teleological reasoning does not need to be eradicated from our thought processes (which would be impossible in the first place); it only has to be canalized and sanitized so that it enables us to attain a scientific understanding of the world (see Evans, this volume, for a similar argument and demonstration).

Another example of a hard-wired intuition that needs to be recruited properly is psychological essentialism. This is the spontaneous assumption that organisms contain an invisible and immutable core ("essence") that determines their identity, development, and behavior. As such, it poses serious obstacles to a scientific understanding of the biological world. Essentialist reasoning, for example, hampers a proper understanding and acceptance of evolutionary theory at several levels. For starters, it leads one to assume sharp boundaries between species and to disregard the individual variety that natural selection necessarily works on (Gelman and Rhodes, "Two-Thousand Years"). Even when students accept the concept of evolution, they tend to represent it in terms of changes of the species essence, rather than as the gradual rearrangement of properties within a particular population by natural selection (Shtulman and Schulz, "The Relation"). It also affects our understanding of genetics, as it makes us conceive of an organism's DNA as its essence. This becomes clear, for instance, in the context of the opposition to genetically modified organisms (GMOs). In one survey, when asked whether a tomato of which the genome was edited with fish DNA would taste like fish, not even half of the respondents gave the correct, negative answer. Moreover, people particularly oppose the practice when biotechnologists cross so-called species boundaries. They think it more problematic that an apple's genome would be engineered with DNA from a fish than from another race of apples (Blancke et al., "Fatal Attraction"). However, despite the fact that essentialism constitutes an enormous impediment to the understanding and acceptance of scientific theories and important technological innovations, it is not completely off the mark either. As in the case of teleological thinking, essentialism does capture several real properties of the biological world: organisms can indeed be categorized into different species. In fact, the idea that information of one typical member of a species can be extended to all members of that species forms the basis of biological studies (Shtulman and Calabi, "Cognitive Constraints"). And DNA does play a determinative part in the identity, development, and behavior of an organism. It is only when essentialism supports the belief in the fixity of species, in sudden mutations of species (to another "essence"), or the idea that a single piece of DNA contains the essence of an organism, that this intuitive way of thinking about nature distracts us. Again, whether or not essentialism has a negative impact depends on how the intuition is canalized (see also Evans, this volume).

One way to canalize intuitions in the right direction is the (correct) use of analogy. Analogies map the inferential structure of a familiar source domain unto an unfamiliar target domain, which makes it possible to fruitfully explore the unknown territory or to convey new insights with relative ease. Think of Darwin's selection analogy, which allowed him to understand and convey how nature generates adaptive biological structures and, eventually, new species. In this example, the immediate source domain is of course a cultural practice, but intuitions too can function as a source. In fact, intuitions can be considered to be inference machines that quickly and automatically provide us with enormous amounts of information without us having to store and consciously retrieve that information. Take essentialism, for instance. If one happens upon a woodpecker during a hike, it suffices to categorize the bird as such and immediately we know that it breathes, that it reproduces through hard-shelled eggs, that it flies and has a habit of banging its beak against trees in order to obtain its daily dose of small insects hiding in the bark. We do not have to observe these features, nor are we consciously aware of them. Essentialism makes it possible to generate a plethora of inferences simply on the basis of category membership. These inferences are there for the taking and available when we need them. Similarly, our intuitive psychology functions as an inference system. A 1944 classic video by Fritz Heider and Marianne Simmel features three geometric objects, two triangles and a circle, moving across the screen. Our understanding of objects is usually guided by our intuitive physics, which includes the expectation that objects do not move unless a force (by another object or an agent) is exerted unto it. The simple fact that these objects move by themselves triggers our intuitive psychology, which immediately starts to make inferences about what these objects are up to. As a result, the mind makes up a story that runs more or less as follows: two lovers, one of the triangles and the circle, are being bullied by the other triangle. In the end, the two lovers leave and the bully in anger rips the place apart (a rectangle suggesting the presence of a room). It is remarkable how little information, how little input we need to conjure up such a scenario. We do not see the love of the two objects or the anger of the bully, nor can they tell us how they feel. We simply infer their emotional states from the objects moving in particular ways. And we are able to do so because our intuitions provide us with a rich understanding of how people behave under particular circumstances. Again, the example of natural selection demonstrates how these inference systems can be recruited in scientific thinking. By coining the term "natural selection," Darwin could not only rely on the inferences that became available through the analogy with artificial selection. It is also an intentional term that elicits intuitive inferences about agents that Darwin could employ to reason about natural selection.

Analogies are of course not the only means to scaffold cognition and to put intuitions to work in scientific reasoning. In fact, scientific reasoning only becomes possible through the availability of a cognitive environment that includes both ecological and psychological scaffolds that lift up our intuitions and cognitive abilities. Professional scientists are trained to acquire a specific terminology, use and manipulate particular objects, and conduct a series of practices that are typical of their field. They have learned to memorize relevant facts about the subject they are studying, think differently about certain entities (e.g., species as a population of slightly varying individuals instead of an essence) and they keep their knowledge up-to-date by consulting the relevant literature. Moreover, they rely on colleagues whom they expect to have gone through a somewhat similar training and who will be interested in more or less the same issues and share the same epistemic background. These practices and social relations are embedded within institutional arrangements (procedures, peer-reviewed journals, organizations). The resulting shared cognitive environment prevents scientists from holding naive assumptions about the world and helps them to produce and maintain highly counterintuitive scientific concepts and theories. Without this environment, science would simply not be possible.

Educating and Communicating Science

Imagine what would happen if you introduced scientific concepts in an environment that is different from the one shared in scientific communities, an environment that lacks the scaffolds that enable scientists to push the barriers of our knowledge. What would happen to these concepts? In fact, this is not difficult to imagine at all, because it happens all the time. Through science education, communication, and popularization, scientific concepts are transmitted from the environment in which they have been developed, maintained, and become ingrained in brains that lack the necessary background and motivation to process them properly. What happens all too often is that these brains then transform these concepts into types that are easier to work with, in other words, into intuitively more appealing types. As a result, people misrepresent scientific information in systematic ways, leading to detectable patterns. For instance, surveys show that students do not distort basic concepts of evolutionary theory in any odd way, but hold misconceptions that betray essentialist, teleological, and intentional biases. Another example is that people typically expect a ball that leaves a curved tube to continue moving in a curve, instead of proceeding in a straight line as predicted by modern physics (McCloskey et al., "Curvilinear Motion"). And so on. In a cognitive environment without sufficient support, our intuitions easily play up as biases again.

The fact that scientific concepts require proper scaffolding and the right environment to flourish poses formidable challenges to science educators and communicators who transmit and explain these concepts under less suitable conditions. It does not suffice to simply communicate scientific ideas, because students and lay people will not understand them and quickly transform them into more palatable, but scientifically inaccurate versions. Thus, educators need to develop and employ practices and tools that enable people to apprehend the science correctly. One approach is to partly reconstruct some of the scientists' environment in the classroom. For instance, teachers can challenge students to develop hypotheses, test them against the facts, and discuss their results with classmates. Such experiences might induce them to revise their earlier, intuitive beliefs with scientific beliefs that are more capable of explaining what they observed. Another approach makes use of thinking aids. Analogies and metaphors are excellent examples of such aids, but they are not the only ones. Drawings and models, for instance, help us to visualize a scientific concept, which in turn assists us to understand the issue at hand. Scientists use them to clarify their thinking—Darwin's coral drawing in his 1837 notebook comes to mind—but teachers can apply them equally well in the classroom. For instance, Kelemen and her colleagues showed that picture storybooks can be used to teach the basics of natural selection to 5- to 8-year-olds (Kelemen et al., "Young Children"). Note how these educational solutions do not exclusively depend on students' reflective reasoning. Surely, they involve some reflection, as learners have to make a sustained and conscious effort to overcome their intuitive theories and to understand and accept scientific beliefs. To a large extent, however, these tools also rely upon intuitions and mental capabilities shared by all students (e.g., testing hypotheses, visualizing objects and scenarios, finding reasons). As scientific thinking depends upon intuitions, it would be truly surprising if science education did not.

The classroom setting is special in the sense—and to the extent—that it allows for the re-creation of certain aspects of scientific practices, for systematic and sustained ways of teaching, and for the continuous control and correction of misconceptions. In other words, teachers can partly reconstruct the necessary cognitive environment in which scientific concepts hold sway. Nonetheless, it is remarkable how, even under these relatively favorable circumstances, students experience great difficulties coming to terms with scientific beliefs. In the case of the public understanding of science, science communicators do not have the same opportunities to manage and control how people receive and understand the message they want to convey. When one reaches out to a lay audience, either directly or via the media, it is difficult to have the public engaged in experiments or to systematically check and correct for misunderstandings. All one can do is communicate in the hope that one will instil at least a minimal public understanding of the scientific content. However, the odds are very much against communicators, as distortions may occur at several levels. Many people are simply not interested in scientific issues, so even if the communicated message reaches them, they will at most assimilate only a fragment of the information. In the case that people do pay attention, they might have motivations other than a concern for truth that constrain the way in which they perceive and interpret scientific information. Religious, political, and ideological beliefs can seriously affect people's understanding and acceptance of scientific concepts and theories. Creationists will treat any confirming piece of information about evolution with great scepticism, argue against it, or transform it into a belief that fits within their religious framework. Such views are enforced by alternative sources of information that people consider to be authoritative but that contradict the science. Environmentalist groups, for instance, oppose genetic modification in agriculture and thereby use intuitively appealing but inaccurate representations of GMOs. Finally, even if people are genuinely interested in learning about scientific matters, they usually do not have the time and energy to acquire a full understanding and also lack the right background knowledge and institutional support to interpret the information correctly. On other occasions, people will claim to accept a scientific belief without properly understanding its content (Guillo, this volume).

Intuitions have an effect at each of these levels. Generally, people feel no need to acquire a scientific understanding, as scientific matters are often too complex to understand and are usually redundant in people's daily lives. They prefer the messages that align most closely with their intuitive understanding of the world and the ideas that are popular within their own cultural environment, giving trust to the sources that provide such information and distrusting others. Finally, intuitions bias people towards reconstructing highly counterintuitive scientific content in the direction of more cognitively palatable notions. However, intuitions not only affect the transmission of scientific ideas at the receiver's end, but also at the end of the sender. In order to make scientific concepts and theories more salient and more understandable, science popularizers lower complexity and make their message more intuitively appealing. Think, for instance, of the interactions between several different species within a particular environment. A scientific evolutionarily informed look at these ecological patters discloses a ruthless struggle for survival under harsh conditions and an endless competition for resources between individuals, not the least within the same species. Death and spoilages are distressingly common, and preying and parasitism are the most common form of interorganismic interactions, while not uncommon instances of symbiosis or cooperation are merely driven, or at the very least facilitated, by genetic "interests." Environmental factors such as predators, disease, and lack of food sources keep each species in check, thereby creating an equilibrium that gives the impression of a delicate balance. However, this balance can easily be disturbed. If an individual organism or species has the opportunity, it will exploit its environment to the fullest and flourish to the detriment of others. Maintaining the "balance of nature" would be the least of its concerns. Nevertheless, documentaries tend to present the delicate relations between and within species in a narrative of a harmonious and almost romantic play, written by nature, in which each species knows and plays it role. Such a presentation may help to convey the correct idea that species depend on one another for survival (e.g., as a food source, shelter). Moreover, it may help to raise public concern about the annihilation of valuable ecosystems. It also, however, romanticizes nature and thus misinforms people about how ecosystems function. Romantic views tap into our essentialist, teleological, and intentional biases: individual organisms are regarded as representatives of their species and can easily be replaced. Tens and tens of individual blackbirds may die, but as long as one blackbird sings in the dead of night, we behold the beauty of nature. The delicate balance between organisms is not regarded as emerging from interactions between individuals but as the very goal of such interactions, either intended by the individuals themselves, evolution, or Mother Nature. Such views, however, fail to address and emphasize the important Darwinian point that ecosystems consist of countless individual interactions in which not the conservation of the system but the survival and the reproduction of organisms, or, in ultimate (genecentric) terms, protection and spreading of genes is at stake.

Such examples make clear that it is not just the case that people distort the scientific content that they receive, but that the content itself is already distorted before it reaches them. Egil Asprem discerns two steps in which science becomes transformed through popularization, driving theories towards cognitively optimal forms ("How Schrödinger's Cat"). In the first step, the theory is translated into common language that consequently taps into our intuitions. Asprem discusses the example of genetic determinism (a gene for this, a gene for that) that thrives on our preferences for monocausal explanations. In a second step, causal explanations are warped in the cloak of intentionality by means of analogy, thus exploiting our folk psychology. As we have seen, Darwin's use of natural selection in *On the Origin of Species* stands out as an example, but Asprem himself refers to the popular concept of the selfish gene, coined by the British biologist Richard Dawkins. Dawkins has always emphasized that it was just a metaphor to facilitate the understanding of genecentrism and should not be taken literally—although he has made this mistake himself. "Nevertheless," as Asprem notes, "Dawkins opened a can of worms. The metaphor invites readers to process the science in ways that are antithetical to its theoretical content" ("How Schrödinger's Cat" 121). As Darwin had done more than hundred years before, Dawkins, unintentionally, confuses his audience by using intentional language as a communicational tool.

Conclusion

In science intuitions play a double part. As biases they tend to distract scientists from finding out how the real world functions, and they have induced scientists to develop practices, tools, and methods to counter their influence. As scaffolds, intuitions play a pivotal role in the construction of counterintuitive ideas, and hence they are essential to the progress of science. However, this is only possible given the right cognitive environment in which both psychological and ecological factors enable the development of scientific concepts. This double role of intuitions puts science educators and communicators in a precarious position. On the one hand, they need to find ways to override them if they want to succeed in instigating a conceptual change in their learners or members of the audience. On the other hand, they have to employ the very same intuitions as stepping-stones towards a scientific understanding. One way to walk this delicate line is to translate the complexity of scientific theories into more intuitively appealing notions, but the examples of natural selection and the selfish gene clearly indicate that this strategy is risky. Another option might be to use less enticing machine metaphors (Tanghe, "Robots"; but see Pigliucci and Boudry, "Why Machine-Information").

So how should teachers proceed? What educational tools and strategies can they deploy to develop a scientific understanding of the world in their students or audience but avoid the pitfalls of intuitive reasoning? Limitations of space prevent us from going into the practical details, but we will conclude with some general remarks. First, teaching science definitely requires a good understanding of the human mind. Teachers and communicators should be aware that students or lay people do not receive scientific information like a tabula rasa's inscriptions, but instead they will have intuitive expectations of how the world functions. These expectations, in combination with people's acquired beliefs, concerns, and motivations, lead people to transform scientific information in ways that they find relevant. And this is certainly not always in the direction of accuracy. Second, knowledge about the human mind should result in the design and application of educational tools, methods, and strategies that are targeted at overcoming such systematic biases and misconceptions. Teachers and communicators should not simply transmit scientific content, but think very hard about how they can accomplish this. Already there is plenty of literature available in which one can find helpful suggestions. Third, good educational tools foster a scientific understanding of the world by building on people's intuitive reasoning. Teachers and popularizers should not be afraid of using metaphor, analogy, images, models, and narratives to help their learners understand scientific theories. As we have seen, these same tools help scientists to develop their theories. However, one should always be careful that these tools do not enforce people's intuitive reasoning (see also Shtulman, this volume). And finally, ideally these tools and strategies take part in the development of a cognitive environment that raises the relevance of representing scientific beliefs correctly. This is easier said than done, especially in the context of the public understanding of science, but it is absolutely necessary if we want to live in a scientifically informed culture. Given the risks and dangers entailed in rampant irrational beliefs and practices, that goal is certainly something worth aiming for.

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