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SHORTCOMINGS IN SCIENCE COMMUNICATION AND EDUCATION: POSSIBLE REMEDIES AT THE DARWIN-DOHRN MUSEUM

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Abstract

Formal education, in most countries, is based on abstractions that are inflicted to young humans with the intention of providing them with interpretative keys to understand the world… later. The approach is eminently deductive: rules first, facts later. Our natural way of learning, however, is inductive: we learn to speak (facts) first and only later we learn the rules. Furthermore, nature is almost absent in formal programs: the natural curiosity of young humans for natural things (biophilia) is discouraged. To cope with this shortcoming, scientific communication focuses on amazing things (the ohh strategy) that never provide awareness (ahh) about natural patterns and processes. Nobody knows that diatoms and copepods are the most important plants and animals that allow for the functioning of planetary ecosystems. The Darwin-Dohrn Museum is an attempt to merge the ohhh and the ahhh strategies.

Keywords

Biodiversity, Ecosystem Functioning, Education, Scientific Communication, Induction, Deduction

1. *The humanities and science: the odd couple contributing to our culture*

Our species is not endowed with genetically transmitted "knowledge"; each individual must be exposed to long periods of training, often delivered by a formalized education system: school. The accumulation of knowledge, generation after generation, and the impetuous progress of what we collectively know, require a lifelong cultural update that continues after school. "Culture" is usually split into two main branches: the humanities and the sciences. Humanities (e.g. art, literature, music, history, philosophy and religion), on the one hand, characterize the collective culture of each nation, whose schools usually focus on the national culture, with a biased representation of human achievements: the humanities of other countries are not covered with the same accuracy, promoting a prejudice towards other nations, since "we" have a culture, "they" do not. Sciences (from mathematics to biology), on the other hand, tend to be more universal. In every country, in fact, all science programs deal with the same topics, even though each country might praise own achievements in the history of science. France, for instance, considers Jean Baptiste Lamarck as the founder of the theory of evolution, whereas Anglo-Saxons reserve this glory to Charles Darwin. Some "foreign" achievements can be belittled: the western world, for instance, used Roman numbers for centuries, and the passage to Indo-Arabic numbers signed a cultural regime shift that opened a new era and that is not properly recognized. The pervasive influence of other cultures in promoting the development of western sciences and humanities is usually understimated. With the Enlightenment, however, the western world gave a prominent position to science as a way to conceive and understand the natural world and, at present, even the countries that recognize the preminence of religion have embraced western science and technology, if only to develop weapons. Democracies are based on knowledge-based public consensus, hence, even if there is no alternative to science to acquire knowledge, popular science communication, not only aimed at young people but at the public at large, is crucial for the cultural upgrade of informed citizens, also due to the limited space that natural sciences are given in education curricula. The various branches of science, then, are engaged in public outreach, so as to convince citizens that it is worth while investing public money in scientific enterprises. Outreach strategies, however, have contrasting effects.

2. *Some people do not wish to know*

Increasingly high numbers of humans, in fact, deny the importance of science as a way of knowing, and oppose their beliefs to scientific facts. In his last editorial for Nature, the prominent scientific journal he directed for 25 years, John Maddox complained about the widespread distrust for science (Maddox, 1995). Maddox praised several scientific achievements and expressed surprise about the attitude of high numbers of individuals that do not believe in scientific discoveries. The mistakes of science are often used to discredit it, while forgetting that only science can correct its mistakes, proceeding by trial and error.

The popular disbelief in scientific evidence is paralleled with the belief in scientific proposals that are far from being proven. If, on the one hand, climate deniers refuse to accept proven facts (Mendy, Karlsson & Lindvall, 2024), on the other hand the belief in the existence of intelligent extraterrestrial life is very strong, in spite of the zero factual evidence in support of mathematical models that consider the probability of the emergence of life in some exoplanets. Paradoxically, then, people (and also many decision makers) tend to believe in unproven facts, and deny proven facts. The Flyeye project of Space Surveillance (Föhring et al. 2024), and several other projects with similar aims, is a further example of the investment of enormous public funds in projects based on highly hypothetical assumptions such as: an asteroid impacted the Earth 66 million years ago and led dinosaurs to extinction, hence we must be ready for another collision that might threaten our very existence. Of course, if the killer asteroid will be identified, it is feasible that a reaction system is designed, with further costs.

The probabilities of such events as the discovery of extraterrestrial life and our extinction due to asteroid impacts are very small and should not deserve such enormous expenses, especially because similar supports are not invested to face much stronger threats to our survival, such as climate change, ecosystem deterioration, biodiversity erosion and other stringent emergencies that are actually taking place.

How is it possible that people believe more in little grey men such as Roswell aliens (Borzellieri, 2011) than in the reports on climate change signed by hundreds of scientists, including Nobel Prizes? How is it possible that proven facts are denied (such as biological evolution and the climate crisis) whereas pure speculations are accepted as true? These irrational attitudes are probably due to lack of science literacy in the general public, highlighting serious faults in both formal education and science communication, hindering the emergence of critical thinking in vast public portions.

3. *Scientific illiteracy about our body*

Two decades ago I realized that first-year students in biological and environmental sciences don't know the difference between excretion and elimination. So I conducted an experiment during the first lesson of every university first-year course I taught since then. I often happened to be the first person the students met at university, after thirteen years of pre-university education.

Without saying anything, I would write on the board '*Pee*' and '*Poop*,' and then ask: Who can tell me how *pee* and *poop* are formed? I refrained from citing excretion (*pee*) and elimination (*poop*) because I was sure that most students were not familiar with the two technical words, so I deliberately used an infantile jargon. To explain further, I said: Have you seen the mineral water commercial praising how a certain brand of water makes you pee a lot? Everyone had seen it. Great, what path does water take inside our body to become pee? Raise your hand, if you know it. In more than twenty years, no one ever raised their hand. Knowing how pee is formed means knowing how our entire body functions.

Everyone had the information to answer, but they weren't able to turn it into knowledge. The answer, in fact, requires knowledge of the digestive, circulatory, respiratory, and excretory systems, along with cell metabolism. Each topic is covered in pre-university courses, but one at a time. To answer the question about pee, you need to know how to connect them, so as to "link the dots" represented by the single bits of information, so as to transform information into knowledge. The troubling part is that no one had ever asked the question, under the illusion that they knew an answer that wasn't within the reach of their education.

Not knowing how our body works is just the tip of the iceberg, as we will see later for the functioning of planetary ecosystems (Boero, 2024).

These, and other scientific facts, should be the foundation upon which the rest of our knowledge is built. So, we are missing the basics. Casual interviews with colleagues from the science faculty made me realize that, apart from the biologists, my colleagues didn't know the answers. When asked to evaluate the students' level of preparation after the first lesson, I could only respond that their knowledge level was below zero and that we needed to start from scratch.

4. The scientific approach

Once, a girl raised her hand and explained the path of water into our body in this way:

'*... we have two digestive systems, one for liquids and one for solids; what we drink goes into the liquid system, and the waste product is pee, while what we eat goes into the solid system, and from there comes poop; if something goes wrong, it means what we ingested went the wrong way*.'

Everyone laughed, but no one knew the answer. The girl, of course, was the brightest of the entire class, the most inclined toward science. According to Faber and Proops (1993), science is based on three steps: the first is the identification of ignorance, the second is the formulation of hypotheses to reduce it, and the third is the verification of these hypotheses. The girl understood that she didn't know, identified her ignorance, so she formulated a hypothesis that, obviously, wouldn't hold up under scrutiny and would therefore need to be reformulated. But if you don't realize that you don't know, becoming aware of your ignorance, you will never reduce your ignorance. The student was convinced to be the only one to ignore the functioning of her body, and was afraid to ask, since many education systems train students to answer questions rather than posing them.

Educational systems are almost invariably boring. The reason is simple: they are based on abstractions that students must learn while sitting still in their desks or bent over their books, a sort of alienation from the outside world that surrounds them and that they wish to know. Edward Wilson (1984) coined the word biophilia to give a name to the natural inclination of young humans toward the living world. At school, instead of being encouraged, biophilia is ignored and is replaced by abstractions that have little to do with the real world. We learn to speak our mother language through an inductive procedure: first we speak, then we learn the rules of grammar and syntax. Learning the rules first, with a deductive approach, with the assumption that "then" we will use them in practice is the main problem of formalized education.

5. The ontogeny of culture must recapitulate its phylogeny

Haeckel formulated his biogenic law (ontogeny recapitulates phylogeny) arguing that the develpmental stages of each individual, from the fertilized egg to the reproductive adult (i.e. its ontogeny) passes through the evolutionary stages that recapitulate its evolutionary history from ancient to recent ancestors (i.e. its phylogeny). Even human embryos would pass through these stages during their development. This concept has been questioned by many authors (e.g. Gould 1977), but is is useful to plan effective teaching. The ontogeny of culture takes place in every human individual: we are born ignorant and acquire knowledge during our entire existence, if we want to. The phylogeny of culture comprises the origin of culture in our ancestors and all the steps that led to present-day culture: the evolution of culture.

Cave paintings, mostly representing animals and humans, are the first known signs of culture. They merge a scientific and an artistic culture, since they are fine pieces of art that represent portions of reality, demonstrating a full understanding of the structure and often of the behavior or natural objects, such as animals. Only later we started to develop abstractions, such as the translation of natural phenomena into mathematical terms, leading to physics, or the understanding of the properties of different materials, leading to chemistry and geology. The "stories" told by cave paintings evolved into poetry and literature.

Wilson's biophilia is a sign of recapitulation: the ancient eagerness to know nature remains in our inherited feelings: almost all children are attracted by natural objects, especially living ones, and want to know about them. A child in a wood or on a beach, wants to know as much as possible about natural things, s/he brings them to the adults around and asks questions about what they are, what are their names. Once told, the transmitted knowledge is retained and used in future natural trips: the curiosity for nature is innate in most individuals.

Once brought to school, this curiosity is not cultivated and the proposed "culture" focuses on abstractions, on general rules that must be learnt and that will prove useful... later. Induction is our natural way of learning, but schools are far too often based on deductions. This shift in the communication of knowledge, and the topics that are treated (from grammar to syntax to theorems and their demostrations) are cumbersome and usually do not nurture children's cusiosity. Children want to fulfil the desires of adults and accept to retain portions of knowledge that are not attractive for their young minds. "Later" they understand the importance of what was inflicted to them, even if, once grown up, they often admit that that "later" never arrives and that what they received at school had no impact on their future life.

If school were to nurture human nature by cultivating biophilia, learning would be a fascinating pleasure. Only later, it would be natural to move from observing the facts around us to developing abstract concepts, just as has occurred over the course of the evolution (phylogeny) of our shared knowledge. Since biophilia is not encouraged in school curricula, the curiosity for nature remains also in many adults, and the lack of nature in school is compensated by books, movies, tv programs, exhibits that deal with nature, but this is usually done just by eliciting wonder and surprise.

6. *The OHHH Strategy*

Popular science communication dealing with nature engages people by focusing especially on animals. Natural history museums, an evolution of the wonder rooms of the 16th and 17th centuries, are largely dedicated to animals, first displayed as taxidermy in cabinets, then placed in reconstructions of their natural habitats.

Museums, however, tend to amaze the public, so as to make them go 'OHHH'. The same thing happens in aquariums and zoos. Nature also enters our homes through television documentaries. But, also in this case, the primary purpose is entertainment linked to amazement. Charismatic animals, usually large vertebrates, are shown, along with exotic habitats like coral reefs and tropical forests. In all cases, animals and habitats are shown with the purpose of evoking the amazement I mentioned earlier: 'OHHH'. (Boero, 2021).

But if you ask what are the most important plants and animals in determining the functioning of planetary ecosystems... the answer doesn't come (just as in the case of the path of water into our bodies, leading to urine production). Someone might say bees, but the terrestrial portion of the biosphere is small compared to the ocean, and there are no insects there.

Thousands of hours of documentaries and impressive buildings and structures dedicated to nature, and yet no one knows which plants and animals are most important for the functioning of planetary ecosystems. And, like with the question about pee, the most serious issue is that no one is aware they don't know things of such pervasive importance, feeling secure in their narrow scope of knowledge—a knowledge that does not include how their own body or the ecosystems that sustain our lives work. These are obviously considered trivial matters, insignificant details. How can they be compared to theorems with proofs and poems to memorize?

Don't get me wrong. I'm not saying that it's useless to know theorems and poems; I'm just saying that maybe it's also necessary to know our bodies and the ecosystems.

7. *The Darwin-Dohrn Museum: from ohhh to ahhh*

To answer questions about the structure, functioning, and evolution of marine ecosystems (90% of the space inhabited by life), together with three young colleagues, with the collaboration of architects and artists, we designed a museum unlike any other.

A museum where the 'OHHH' of wonder leads to the 'AHHH' of awareness. The museum is called Darwin-Dohrn (DaDoM), and it is in Naples, next to the Zoological Station Anton Dohrn and its Aquarium, which in 2024 celebrates 150 years.

The DaDoM occupies the Casina del Boschetto, built in 1948 by architects Luigi Cosenza and Marcello Canino: an example of the post-war rationalist style. The building was abandoned since the mid-1990s, in 2015 the City of Naples loaned it to the Anton Dohrn Zoological Station, that completed the restoration in 2019. The exhibition project respected the original plan, also taking into account the safety regulations required in premises open to the public.

Dedicated to the two giants of ecology and evolutionary biology, Charles Darwin and Anton Dohrn, the Darwin-Dohrn Museum - DaDoM – promotes the knowledge of the evolution and ecology of marine biodiversity.

Inside the DaDoM, visitors voyage through the oceans through time in the footsteps of Darwin and Dohrn and many other scientists, discovering how organisms became adapted to all marine environments. In this journey, the public will understand the importance of the oceans in determining the conditions on the planet, will encounter the primordial forms of life that appeared in the oceans over 3 billion years ago, will discover evolutionary theories, and will encounter a series of fossils that show the evolution of forms and functions over the geological eras (walk through time).

Works of art, and historical biological samples will show how marine organisms move, feed, and reproduce, and the mechanisms that led to current life forms, in a gallery of biodiversity, from the simplest to the most complex organisms, to arrive at the multipurpose room of the DaDoM, housing a large skeleton of a sperm whale (beached along the Campania coasts and recovered by researchers), enriched by models of the organisms that feed on the cetacean carcasses that sink to the bottom of the sea. The multipurpose room is dominated by a six-meter high wall that houses ten thousand preparations of animals from the Gulf of Naples, set up by the genius of Salvatore Lo Bianco and by those who followed his footsteps in the art of conservation.

The multipurpose room is designed to host thematic exhibits to explore topics of great scientific and popular interest, but also for scientific conferences and seminars, and is available to the cultural world for other initiatives of public interest, such as shows, concerts, exhibitions and film broadcasts. The museum itinerary also includes a journey through the studies and ancient maps of the Gulf of Naples, the discoveries of the over 20 Nobel laureates who conducted their studies in the SZN, up to the current research updated and exhibited month by month.

The Museum includes a large educational laboratory for students of all types and levels designed to carry out practical observation and study activities aimed at discovering the secrets of marine life. The upper floor of the building includes the staff offices, laboratories and organizations hosted by the Center. The Museum garden hosts two scientific submersibles made available by the MareAmico Cultural Association and which have also been used for the exploration of the deep sea environments of the Mediterranean.

With the aim of strengthening the so-called "third mission", i.e. the activities of dissemination of scientific discoveries, as well as the opening of research facilities to citizens, with their direct involvement, the Darwin-Dohrn Museum offers opportunities for scientific and educational collaborations, training of teachers and specialists in the sector, educational workshops, cultural meetings, and guided tours for citizens and tourists. It is a Scientific, Educational and Cultural Pole in the Heart of the City of Naples.

The Museum was inaugurated on December 9, 2021 but its layout will be continuously enriched with new material and new initiatives (see https://szn.it/index.php/en/darwin-dohrn-museum)[1]

A detailed description of the Darwin-Dohrn Museum can be found at https://www.pro-natura.it/lettore-news/il-museo-darwin-dohrn-dadom.html (Boero, 2022).

The Museum, through a sequential exhibition, leads the visitor to ask questions and then to find different answers (AHHH) with various moments of wonder (OHHH). Awareness and beauty, beauty and awareness!

I won't explain how pee is formed but I will explain how the Biological World Works, using a graphic diagram created with the usual skill by the artist Alberto Gennari.

The planet's surface is 71% covered by the ocean, which is not a surface: it's a volume!

More than 90% of the space inhabited by living beings is made up of the oceanic water column. Land is an exception. The oceanic volume is the rule.

It is the ocean that keeps the biological world functioning.

Figure 1 shows a diagram of how the marine ecosystem works.

(Top right) The marine landscape is dominated by carnivores. The shark eats the tuna, which eats the mackerel, which eats the sardine. They're all carnivores, but where are the herbivores? Where is the grass?

(Top left) Algae and marine plants live in the illuminated zone of the sea, along the coast, and are eaten by herbivores, but their contact with the vast ocean volume is minimal.

[1] For more information and to book a visit: https://fondazionedohrn.it/home/dadom/

(Top center) Fish begin their lives as tiny eggs that become embryos, then larvae, and then juvenile stages. In the first part of their life, all fish feed on small planktonic crustaceans: copepods. These are the herbivores and feed on microscopic unicellular algae that make up the phytoplankton: the 'grass'! All organisms die and are decomposed by bacteria, which, in turn, become resources for viruses. Decomposition creates nutrients that will support phytoplankton growth. The oxygen produced on the surface is carried to the depths by descending currents. Ecosystems function thanks to microbes (i.e. bacteria, single celled algae, and tiny animals)!

(Bottom center) Organisms in the illuminated zone die and sink into the darkness toward the seabed. They are broken down by bacteria into particulate organic matter: marine snow. This is eaten by suspension feeders, like crustaceans living in deep waters and bottom-dwelling fauna, such as worms and sea cucumbers.

(Bottom right) Detritivores take the place of herbivores and support a food web of carnivores. Large carcasses sink to the seabed and become islands of food for multitudes of scavengers. Much of the space inhabited by living beings is in darkness. The descending currents that bring oxygen to the depths generate ascending currents that bring nutrients to the surface, supporting the phytoplankton.

A more accurate description of Figure 1 can be found in the Video 'Gli animali più importanti - The Most Important Animals', accessible at https://vimeo.com/870710767/50f21de9de.

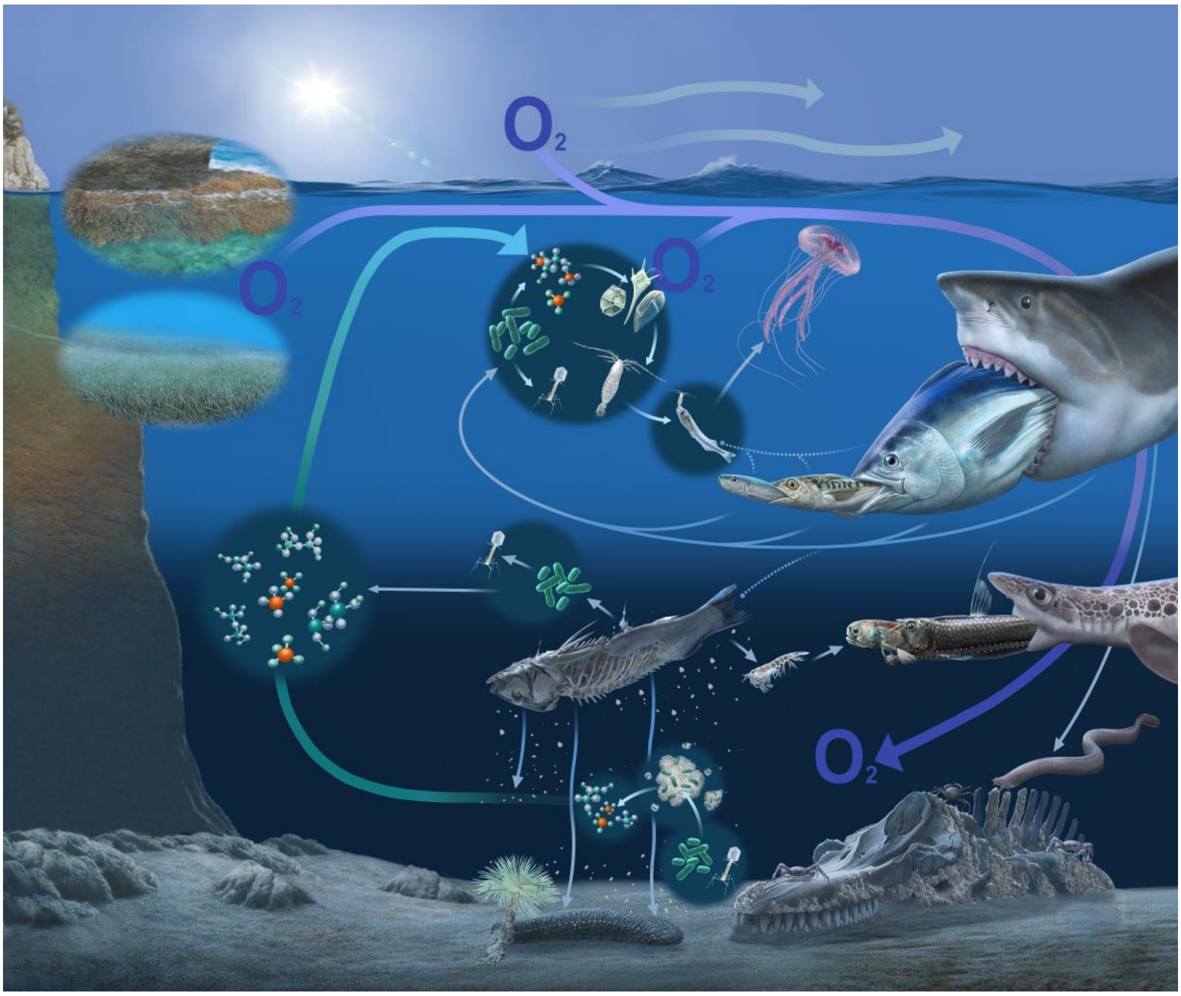

Fig. 1: The functioning of oceanic ecosystems. See text for explanation. (concept: F. Boero, art: Alberto Gennari)

8. Ocean literacy

The European Union promotes ocean literacy, being aware of the rampant illitteracy of the public at large.

Recognizing one's ignorance, if ignorance exists, should trigger the desire to learn and is the first step toward a culture that understands the most important things. If you're among the few who 'already know,' I hope you'll be eager to better share your knowledge, because most people 'don't know', while not knowing that they don't know.

All the visitors of the Darwin-Dohrn Museum have fun learning these things: why don't naturalistic entertainment programs (and museums, zoos, and aquariums) explain them? The answer is simple for documentaries: documentary filmmakers are technically excellent, they know perfectly well HOW to communicate, but they don't know WHAT to communicate, stopping at the most obvious and flashy things: charismatic species and habitats. Curators of museums, zoos, and aquariums may know the necessary information, but they're usually dazzled by their specific area of scientific interest, unable to connect it with the rest of the natural world, focusing on details and losing sight of the whole, the interactions. The result of all this is ocean illitteracy.

9. From reductionism to holism

Science has always adopted the reductionistic approach: complexity is broken down, and portions of it are analyzed, while the rest is considered insignificant or constant. Each specialist, therefore, knows their subject inside out but is unaware of other fields or, at best, doesn't know them as deeply as own specific research area. Since the whole is more than the sum of its parts, reductionistic analyses must then lead to a holistic synthesis where the parts interact to form a whole—from the systems of our body to the components of biodiversity and ecosystems.

Education and communication systems are eminently reductionistic but, to truly understand the world, we need the transition from reductionism to holism. Ecology and evolutionary biology are the most holistic fields in science. They identify parts in a reductionistic way and then make them interact holistically.

10. Induction and deduction, separate twins

If formal education programs are eminently deductive, providing rules that are not connected with facts, science communication is eminently inductive, exposing people to amazing facts without leading them to understand the general rules that link the bits of information and transform them into knowledge. From the functioning of our body (excretion vs. elimination) to the functioning of planetary ecosystems (based on interactions among microscopic organisms such as bacteria, diatoms and copepods) the essentials of knowledge are missing even in most cultured individuals.

The recent awareness of our links with the rest of nature calls for both the ecological transition and the one-health approach (our health depends on the health of both biodiversity and ecosystems). The need for this cultural regime shift is the best proof that both education and dissemination systems have failed to meet the challenge of pursuing a knowledge-based approach to sustainability and well being. Italy, for example, only recently introduced biodiversity and ecosystems in its Constitution, but their importance is just enunciated and is not yet recognized by stringent policies, just as it happens in the European Union (Boero, 2024) whose Directives set very ambitious objectives that are seldom met.

It will not be easy to reform current culture-building systems since those that should reform them are biased by their education and are reluctant to recognize its inadequacy.

It is sterile to argue about what is best: induction or deduction? Both are conducive to build up our culture. Induction is a corpse without deduction, but deduction is a ghost without induction.

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