SCIENCE, CRITICAL THINKING, MULTI-ATTRIBUTE DECISION MAKING

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Science is the pursuit and application of knowledge and understanding of the natural and social world following *a systematic methodology based on evidence.* Science includes scientific methods such as *objective observation*, which refers to measurement and data (possibly, although not necessarily, using mathematics as a tool), evidence, experiment, critical analysis, and verification. The four major branches of science are: *mathematics and logic, biological science, physical science, and social science.* The key words that best define science are thus:

objective observation + evidence-based approach + application of scientific methods = general truths

The basic problem of such an explanation of science lies in the very definition of what *general truths* are, what kind of evidence is required to prove them, and how to arrive to this kind of evidence through *objective observation.* The simplest premise to answer these questions would be: through *logic* and *critical thinking.* But let us start at the beginning, with a fundamental question: *what is truth*? *What is a general truth in this context*?[1] Let us analyse a generally accepted fact: water boils at 100 degrees Celsius, as a general truth. It soon becomes clear that while this statement may be true in a broad sense, it is not a general truth, since this depends (at least) on the pressure (or on the altitude), at which the measured water is located. The conclusion is that the truth is a complicated or *multi-attribute problem.* Let us consider this issue on the example of artificial intelligence (AI).

Talking about AI has become one of the most topical subjects of the moment, although many people who think they know a lot about this subject, in fact know almost nothing at all (Aberšek, 2021). Others, who know a lot, are convinced that they know nothing (remember the Socratic paradox, "*I know that I know nothing*"). However, the underlying problem lies in the very definition of the term artificial intelligence, because at least two types of AI exist: artificial general intelligence (AGI) or strong AI, and weak or narrow AI. We also have to ask ourselves the question of who we are, and how we perceive the world around us? We may either be experts, pseudo-experts, or laymen, operating at different levels of consciousness. With regard to this division, one may start from the basic pedagogical premise – the three-level scale of knowledge acquisition:

1. The basic starting level is: *I do not know that I know nothing!*
2. The next level is: *I know that I know nothing!*
3. Only after one realizes this (Level 2), they may shift to the next hierarchical level by performing a personal (first-person) analysis of one's competence and come to the conclusion: *I know that I can!* But the Dunning–Kruger effect which is a cognitive bias whereby people with low ability, expertise, or experience regarding a certain type of a

1 *General truths:* the present simple is used to express facts that are always true or events that always happen. This use is often described with the term "general truth": *The sun* ***rises*** *in the east or Water* ***boils*** *at 100 degrees Celsius.*

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task or knowledge tend to overestimate their ability or knowledge[2] also must be taken into account.

4. Finally, there is the execution level, where an individual's interest (motivation) comes into play, for example: *I can, and I want to;* or *I can, but why should I?*

Unfortunately, the majority of those who have mastered the first three levels often show a lack of interest or motivation to *actually do something.* Even more people too often stay only at the first level *(I do not know that I know nothing,* or worse, an attitude of general ignorance – *I already know everything there is to know)* and skip the second and third levels. In many fields of science there are very *few scientists who do understand and who are able to do something,* and then there are many different pseudo-scientists (we could call them 'preachers') who do not understand the problem at hand (they don't possess the knowledge) and who do not understand that they are not able to resolve it (because they don't have the basic intellectual capacity) – but so often these people do have interests and they take the right to preach and explain the truth. And this is the essence of the difference between science and pseudo-science (faith): science requires *knowledge* and *understanding* alongside a great deal of personal *skepticism.* With faith, one needs only an interest (motivation) in order to proclaim some kind of 'truth', which does not require scientific evidence. Considering the level of intellectual abilities of these preachers, "proclaimers of the truth", these "truths" are more or less simplified and adapted to the level of the target audience. And unfortunately, in the world of science, the balance is tipped more and more towards such preachers, who always seem to be in the majority. And if we don't believe them, it will be our own fault (unconditionality is the essence of faith: only if you truly believe, X will happen; if X doesn't happen, it is because you did not have enough faith – in other words, the fault always lies with the believer and never with the expositor of the faith), whether the matter at hand is environmental changes, a pandemic, global warming or any out of a number of other complex problems. This means that science tends to lean towards an increase in entropy and the negation of science (Aberšek, Flogie, 2022). In short, to provide a scientific explanation, we need knowledge about the complexity of the problem, and we need critical thinking to be able to judge (assess, evaluate) a problem and its possible solutions.

Experts generally analyse problems by breaking complex problems into more knowable parts. The quality and accuracy of such analysis depend on the strength of the science used to assess each part. Science is reasonably strong for well-known phenomena (our awareness – we believe that we understand), such as environmental problems, ecological footprint, or nuclear power. Still, it is a different story for new technologies such as AI, physical cybernetics systems (robots), self-driving vehicles or Covid. When scientific understanding is incomplete, analysis shifts from reliance on facts to expert judgment, and studies of those judgments find that they are often quite good – but only when experts get good feedback.

However, with new technologies such as the self-driving car or AI algorithms, feedback will be a long time coming. Until it does, we will be unsure – and the experts themselves will not know – how accurate their risk estimates are. How, then, can researchers in this area fulfil their duty to inform people about accurate ways to think about events and choices that are beyond their experience? Scientists can accomplish this if they follow two fundamental lessons from studies of decision-making: critical evaluation and thinking, and multi-attribute decision making.

Critical Thinking

Critical thinking is the intellectually disciplined process of actively and skilfully conceptualizing, applying, analysing, synthesizing, or evaluating information gathered from,

2 for more see: https://www.britannica.com/science/Dunning-Kruger-effect

or generated by, observation, experience, reflection, reasoning, or communication, as a guide to belief and action (Elder & Paul, 2009). The top five critical thinking skills could be: Observation, Analysis, Inference, Communication and Problem Solving.

Critical thinking is self-guided, self-disciplined thinking which attempts to reason at the highest level of quality in a fair-minded way with the use of the intellectual tools that critical thinking offers – concepts and principles that enable them to analyse, assess, and improve thinking. Critical thinkers must avoid thinking simplistically about complicated and complex issues (pseudo-science) and appropriately consider the rights and needs of relevant others. They recognize the complexities in developing as thinkers. They embody the Socratic principle: *the unexamined life is not worth living, because they realize that many unexamined lives together result in an uncritical, unjust, dangerous world* – which is the result of the situation in the world today.

Problem Solving – Multiparameter Analysis

Let us now turn our focus on the minority that understands and is motivated to take action – on scientists and the scientific interpretation of truth. The basic premise must be that problems are always complex (i.e., non-complex problems are not real problems) since it is obvious that the world is becoming increasingly complex and interconnected, and that some of our biggest challenges have begun to seem intractable. How will climate change play out? How does AI work? Our traditional approaches to these problems are often qualitative and disjointed and lead to unintended consequences. To bring scientific rigor to the challenges of our time, we need to develop a deeper understanding of complexity itself. A high complexity of problems requires a highly complex approach, which is most often described in science using the Theory of Complex Systems[3]. In general, the decision-making problem can be defined as (Bohanec, 2020) which developed DEXi[4]:

1. *Given* a set of alternatives $Æ = \{A_1, A_2, \ldots A_n\}$ and (somehow expressed) aims or goals of the decision maker(s), and
2. *find* alternative $A_i \in Æ$ that best satisfies the goals.

In the field of science, multiparametric analysis involves collecting data from a range of inputs to make an accurate diagnosis. Based on multiparameter analyses, we can make multi-attribute decisions. Utility functions are the components of multi-attribute models that define the aggregation aspect of option evaluation. In multi-attribute decision making, the decision problem is decomposed into a number of smaller, less complex subproblems. Alternatives are decomposed onto different dimensions, usually called attributes, criteria, goals, etc. These are evaluated independently. For each aggregate attribute *Y*, whose descendants in the tree of attributes the corresponding utility function *f* defines the mapping according to equation:

$$f: X_1 \times X_2 \times \ldots \times X_n \rightarrow Y$$

3 When a whole is greater than the sum of its parts, it is considered a complex system. Traditional thinking would analyze each individual component, but this method also includes the *relationships* between all components. By studying how the parts of a system relate to each other, we can predict the likelihood of certain outcomes.

4 DEXi is a computer program for multi-attribute decision making - https://kt.ijs.si/MarkoBohanec/dexi.html

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And each decision rule can be interpreted as an *if-then* rule of the form:

if X_1 = value 1 and X_2 = value 2 ... X_n = value n then Y = attribute (or value interval)

Problems of this kind can be found in almost any field of human activity. They range from everyday personal decisions to more complex problems like selection of the most appropriate technology, project management and planning and many others. Alternatives are ranked according to utility values, where a higher value means a better alternative. In multi-attribute terms, the decision problem is therefore described by:

1. a set of alternatives $A = \{A_1, A_2, \ldots A_n\}$;
2. a set of criteria $X = \{X_1, X_2, .., X_n\}$; each criterion $X_i \in X$ is further described by its name, x_i, and the domain D_i of values it may hold;
3. partial utility functions $f_i : D_i \rightarrow R_i$, i = 1,2,...,n;
4. a global utility (aggregation) function $F: R_1 \times R_2 \times \ldots \times R_n \rightarrow R$.

Summing-up

In complex systems, there is not just one single scientific truth, just as there is not just one, unified science. Even from a rough division of science, one can see that a wide variety of experts participate in the interpretation of the truth, who can all have very different views on the same problem, since they observe it from different angles. For example, if we consider the Covid pandemic from the perspective of medicine (as a natural science) or from the perspective of sociology (as a social science), we arrive at different scientific truths. In the case of complex systems, however, we must always look for some generalized truth, which is not really anyone's entire truth, but it can be the lowest common denominator (which we are all able to live with). Therefore, in complex systems, the scientific truth is always a kind of generalized truth that has no simple answers. If someone preaches the truth in a simple way, such truth is definitely doubtful. To illustrate, let us borrow the words of some of the most eminent scientists in the field of quantum mechanics:

- *If you are not completely confused by quantum mechanics, you do not understand it.* (John Wheeler)
- *It is safe to say that nobody understands quantum mechanics.* (Richard Feynman)

In these two quotes lies the whole story of truth and science, and the Socratic paradox is made patently clear.

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