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WHAT IS SCIENCE?

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ABSTRACT

We give a brief discussion of issues related to the nature of science. Our formulation is such that it applies to all scientific domains. We also present an argument which illustrates why mathematics is of fundamental importance to scientific methodology. Finally, a summary is provided of the preconditions which must be satisfied, in the physical universe, such that science is possible.

Keywords: Science, mathematics, invariance, symmetries

INTRODUCTION

In spite of the fact that most of the world's peoples are directly impacted by science and the various technologies based on its findings, few individuals have a clear understanding of the fundamental nature and meaning of science. The main purposes of this short essay are to provide a definition of science, show why mathematics plays an essential role in scientific activities, and discuss the preconditions required to exist in the physical universe for science to be possible.

The following is a summary of the major conclusions of this paper:

- 1) Science is founded on the study of patterns in the physical universe.
- 2) Since mathematics is the investigation of abstract patterns, then its mathematical structure can provide a language for science.
- 3) Science is "public knowledge."
- 4) For science to exist, certain conditions must hold and these restrictions, on the physical universe, are a direct consequence of the existence of symmetry principles.

This paper is organized as follows: The next section introduces definitions of science and mathematics, and their connections. This is followed by a section which discusses science from the perspective of it being "public knowledge." The fourth section gives a list of conditions needed to hold in the physical universe for science to be meaningful, i.e., provide understanding of past and present phenomena and predictions of future events. We conclude the paper with a general discussion of several issues related to science and mathematics education.

Finally, it should be pointed out that a number of the explanations and discussions which will be given in this essay have appeared in the writings of others and, consequently, we assume no priority for them; the relevant references will be indicated at the appropriate places in the essay. Our major task is to provide an essay for

educated laypersons who wish to have an explanation for the nature of science in a form not usually presented to the non-scientifically-trained general public.

SCIENCE AS PATTERNS

One of the critical points in human existence was the discovery of ignorance, i.e., there are things that we do not know, and the follow-on realization that we can do something about this situation (Harari 2014). This was the beginning of science (Bonner and Phillips 1957; Holton and Brush 2001; Simonyi 2012; Harari 2014). Particular examples of physical phenomena for which early humans sought explanations were as follows:

- (i) the daily rising and setting of the sun;
- (ii) collisions of two objects, one more “massive” than the other, usually resulted in more damage to the least massive object;
- (iii) heat applied to a liquid, such as water, caused it to get “hotter.”

The feature common to all these situations is the existence of certain patterns, which may be expressed as follows: if condition(s) A holds, then condition(s) B is a consequence. The generalization of this particular collection of observations leads to the following definition:

SCIENCE is the systematic observation, creation, analysis, and modeling of patterns which exist in the physical universe.

Note that this formulation of What is Science? provides a resolution to the issue of why mathematics is the language of SCIENCE. The argument is this: if mathematics is taken to be the study, creation, and analysis of patterns existing in the abstract universe of human thought and mental perception (Devlin 1994), then it should be directly applicable to the task of interpreting, understanding, and predicting the structure of patterns which occur in the physical universe. Hence, mathematics can function as a language for scientific explanation.

One consequence of this relationship between science and mathematics is that ordinary spoken or written language is insufficient to explain scientific concepts. The clarity required can only be provided by the additional use of mathematical structures and the rules of logic (Devlin 1994; Harari 2014).

SCIENCE AS PUBLIC KNOWLEDGE

An important, very significant aspect of science is that it provides us with public knowledge (Popper 1959; Ziman 1968), i.e., knowledge that is available to anyone to examine, test, criticize, and generalize.

An elementary example of the public knowledge feature of science is that if “I” perform an experiment, e.g., set up conditions A, and then find that conditions B follow, then any other (competent) individual can also carry out this same experiment, and experience shows that in the absence of errors by either party, the same results are obtained. In addition to the significance of this aspect of science, it is clearly of major import to the continuing existence of advanced technological societies.

Another consequence of viewing science as public knowledge is the elimination of the need for authority figures, whose knowledge comes solely from sacred or inspired thoughts or texts.

Note that much of general knowledge is not scientific knowledge. But it is also not “non-sense” either. Not all valuable and worthwhile knowledge is scientific. A prime illustration is the value of poetry. It is clearly not scientific knowledge, e.g., different individuals, if requested to write a poem on love, will almost certainly produce entirely different poems, based on their widely varying life experiences, writing abilities, etc. But, who would wish to give up the writing of these works?

Science is a special type of knowledge, having a very strict methodology; however, there is no general scientific method as is commonly believed by many members of the general public (Popper 1959; Ziman 1968; Holton 2001; Simonyi 2012; Harari 2014; Flammer 2015). If there exists a scientific method, then based on all of our prior experiences, its statement would read something like this: try everything, but don't be stupid!

A feature of science, sometimes overlooked by many, is this: “Science is not democratic or fair. The empirical evidence and logical critical analysis rules” (Flammer 2015). Thus, the general roles of “my opinion is ...” or the statements by authorities, in the long run, have no impacts on scientific knowledge and progress (Ziman 1968; Flammer 2015).

Finally, science is a progressive field of inquiry and, as a consequence, does not place a high premium on its prior history of achievements. The Greek understanding of atoms was replaced by Newtonian atoms, which in turn was replaced by Bohr atoms, which are presently interpreted as quantum atoms. Thus, to study and understand quantum atoms, there is no need to restudy atomic theory, starting with the Greeks. One may begin with the latest results from quantum theory and its calculational methodology (Simonyi 2012). However, if a sense of the progression of the atomic concept is wanted, then this history is very important to know. Also, it should be remarked that one measure of the validity of subjects with which to be thought of as science is to see if those who discuss them are concerned primarily with current issues or whether they take time only examining the related scientific issues of importance at a distance earlier period. If the latter is the case, then clearly they are not engaged in a scientific effort, but are only using their arguments in an attempt to “verify” an a priori set of fixed beliefs.

CONDITIONS FOR SCIENCE TO EXIST

From a strict mathematical point of view, we may consider the (theoretical) existence of physical universes having properties which differ from the actual one which we are aware of and experience. Only universes for which “locality” and “invariances” are features allow for science to be possible.

By locality, we mean that to analyze and understand any given system, bounded in space, only other nearby systems need to be taken into consideration. For example, to investigate the motion of the earth in the solar system, a very good approximation is to include only the presence of the sun; the other solar bodies have little influence. Likewise, a study of tides on the earth requires only the inclusion of the sun and moon. The effects of the other planets, the distant stars, and other objects in the galaxy are negligible. In summary, the existence of a condition of locality means that we can study

particular phenomena without knowing what everything else is doing in the physical universe. At a higher level of theoretical analysis, the locality principle places strong restrictions on the types of forces which can exist in the physical universe.

Invariances are related to symmetries. A system is said to have a symmetry if you can “do something” to it and the properties of the system do not change. For example, a book may be rotated by 360° to give the same book in its original orientation. If you closed your eyes before the rotation, then upon opening them, there is no way to determine if the book was rotated zero, one, or ten times.

Symmetry principles play important roles in science, mainly through their connection with conservation laws (Arnold 1989; Holton and Brush 2001; Simonyi 2012). In brief, if a system has a symmetry, then something is invariant or constant; if a system has an invariant, then there is a corresponding symmetry. Within the context of physics, the following such connections hold (Arnold 1989; Simonyi 2012):

Time translation \leftrightarrow Energy conservation
Space translation \leftrightarrow Momentum translation

To illustrate these principles, consider the simple experiment of heating a cup of water for tea. The experiment is this: 1) Place water in a cup. 2) Heat the water in a microwave. 3) Remove the cup with the hot water and place a teabag in the hot water. 4) Remove the teabag after 5 min and drink the tea. This experiment can be done today, tomorrow, and was done yesterday. In all cases, the results are the same, namely, a delicious cup of tea. Our conclusion is that the “experiment” gives the same outcome whenever we do it, i.e., when it is done (the time) does not play a role. In a similar manner, the tea could be made in Atlanta, New York, or Nashville, with the same expected outcome.

This experiment, while elementary, demonstrates that its end result, namely, a delicious cup of tea, is independent of both where it is done (location) and when (time). As indicated above the existence of a symmetry implies something does not change, e.g., a conservation law holds, and, likewise, if something is (always) constant for a system, then some symmetry holds for the system.

To recapitulate, science is only possible if there exists locality and invariances in the physical universe. These principles allow experiments to be repeated at different times and locations, and because of these features it is then possible to create “public knowledge,” i.e., science.

DISCUSSION

Our discussion of What is Science? differs from the usual presentations on this topic. However, we believe that this may be a better way of introducing and discussing this topic and related issues (Flammer 2015).

Finally, while the explanations given in the immediate past section are somewhat more technical than the earlier portions of this paper, it can be done or presented in such a manner that any education layperson can fully comprehend its meaning and purpose.

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