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What are Scientific Questions?

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Abstract ― In science, questions are more important than answers, but the scientific questions has not yet been clearly defined, taught, or evaluated in school systems. Here, I present the “K5 theory” to classify all conceivable knowledge, and to demonstrate that fields of potential scientific study can be described by proposition and logic, that is “logical space.” We classified scientific questions into three categories based on each question's target in logical space: (1) Questions to Close, for asking about the reliability of the proposition; (2) Questions to Extend, for asking what can possibly be deduced from the proposition; and (3) Questions to Open, for asking about what new proposition could be made from the proposition. Hereafter, I examine the expansion of K5 theory in science education, and discuss methods that can be used to evaluate scientific questions, based on these three classifications.

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1. Introduction

In science, questions are more important than answers. Albert Einstein, who developed the theory of relativity, described in his book, “The formulation of a problem is often more essential than its solution... To raise new questions, new possibilities, to regard old questions from a new angle, requires creative imagination and marks real advance in science. (Einstein & Infeld 1939)” He also answered in the interview; “If I had an hour to solve a problem and my life depended on the answer, I would spend the first 55 minutes figuring out the proper questions to ask. (Calaprice 2005)”

The importance of questions in science has also been discussed quoting Claude Lévi-Strauss, who introduced structuralism into the humanities and social sciences, “It was French philosopher Claude Lévi-Strauss who once said: The scientist is not a person who gives the right answers, he is one who asks the right questions. And he was right. Asking the right questions is the essence of good science. Insightful questions can challenge accepted models, and turn the way we think about a concept on its head. (Young 2014)”

In the well-known Programme for International Student Assessments (PISA) (OECD PISA 2019), scientific competency evaluations focus on questions, beginning with the identification of questions for scientific inquiry, then moving on to whether the questions can be scientifically verified, how they can be scientifically explored, and, finally, how the results can be evaluated.

Scientific questions are verifiable via falsifiability (Popper 2002). In general, falsifiability means that the authenticity of information can be verified or falsified by inductive reasoning based on experience, such as experimentation and observation (Friedman 1999). This

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type of falsification is termed inductive reasoning and is based on realism. Briefly, the target of the scientific question actually exists. By contrast, instrumentalism states that science only has to be logically accountable for by the scientific question. In this case, the falsifiability can be called deductive reasoning, which aims to demonstrate and falsify the contradiction of an idea via deductive reasoning based on logic. Science has been advanced and developed through the use of these two arguments. For example, the phenomenon of combustion is known to be an oxidation reaction, but until Lavoisier demonstrated this fact, the phlogiston theory had been mainstream. The phlogiston theory stated that phlogiston is released as smoke during the combustion of a substance; the combusting material was termed phlogiston because it emitted smoke during combustion. However, it was discovered that the weight of the substance increased after combustion in an enclosed space. In this example, an inductive argument was used to disprove the phlogiston theory. The defenders of the phlogiston theory added the ad hoc hypothesis that phlogiston has negative weight, which could not be disproved using a logical argument, and the phlogiston theory became impossible to disprove using an inductive argument. By experimentation, Lavoisier found that oxygen is added to the substance during combustion. Thus, the answer to the scientific question, "Why does a substance burn? "was" Because of oxidation." This information could survive both inductive and deductive reasoning because the results were repeatable. Typical examples of inductive and deductive reasoning practices in modern scientific communities include the question-and-answer session at the end of conference presentations, and the peer review of scientific papers.

Therefore, when considering scientific questions, all potential inductive and deductive arguments should be considered. A clear definition and discussion regarding scientific questions should form the very basis of scientific theory, but to date such a clear definition and discussion do not exist, despite numerous discussions regarding the definition of science. For this reason, only the evaluation of scientific answers has been taught, not the theory behind the scientific questions themselves. In this paper, scientific questions are classified into three categories dependent upon the area of knowledge that scientific questions can possibly explore using inductive and deductive reasoning. The possibility to educate students and evaluate scientific questions based on these three classifications is then discussed.

2. Classification of Knowledge: K5 Theory

In education, Bloom's taxonomy is the most famous classification of knowledge (Anderson, Krathwohl & Bloom 2001). In this taxonomy, our knowledge is classified into the four types: factual knowledge, conceptual knowledge, procedural knowledge and meta-cognitive knowledge. This classification aims to define our obtained knowledge, not to define our inquiring knowledge. Although there are some classification of experts knowledge (Collins & Evans 2007), they are all the same kind of Bloom's. We don't have categorization to define our inquiring knowledge.

So we classify our inquiring knowledge. At first, we define "worldly knowledge" as all knowledge about this world, including knowledge that humans do not have. We define "logical space" as all knowledge that can be expressed by language, including mathematical formulas (Wittgenstein 1961). Taking "X=Y" as an example, the logical space is made up of two logical consequences: cause and effect ($A \rightarrow B$ [if A, then B)) and negative relationships ($\neg A$ [not A)). This logical space includes all knowledge formed by proposition and logic, and includes all past, present, and future knowledge that can be described by language (i. e., what we can learn from science).

Human knowledge and logical space are not identical. Some worldly knowledge may be included in logical space, but some may not, since there is no guarantee that all phenomena can be expressed by language. Similarly, some knowledge may be included in both logical space and worldly knowledge, while others are not, because language is not subject to real world constraints or empirical limitations, given the selective relationship between words and the target indicated by the words (Saussure 2013).

Knowledge can be formed via inductive reasoning based on our experiences. Thus, "experiential knowledge" is defined as a subset of worldly knowledge, because the phenomena that we can experience depend on human senses. Human experience knowledge can differ from animal experience knowledge, since other species use their senses differently than humans and may even have senses that humans do not. For example, dogs primarily experience the world through their well-developed sense of smell, while dolphins rely on echolocation. Given these differences, we use "umwelt (Chang 2009)" to refer to the world as it is experienced by the biological senses that evolved in each species. Humans typically experience the world through eyes that only take in a limited field of vision and only certain wavelengths of light. Some of these limitations can be overcome by science and technology. For example, humans can observe infrared and UV light, while everything from electrons to the ends of the known universe can be observed using a microscope or a telescope. By expanding umwelt theory in this manner, science has been advanced and opened up opportunities for additional inductive reasoning. However, there is still no guarantee that humans will ever discover the entirety of worldly knowledge using science and technology.

Experiential knowledge is not identical to logical space, in the same way that is not the same as worldly knowledge. Although we have expanded the human umwelt, it is different from actual experience. For example, even if we observe the UV light emitted from the wings of a female cabbage white butterfly using equipment, we cannot experience how a male cabbage white butterfly perceives the female, since the UV light cannot be linked to the female using our human sense of perception. Our experiences in the real world are the sum total of information obtained via our various sensory organs, and any experiences we obtain from experimentation or observation using a device. By considering such information obtained from devices as single perceptual information it is possible to use this information to produce a robot that can act as an organism. For example, in modern times, walking robots are not unusual; however, a walking robot cannot necessarily experience walking in the same way as a human can, because humans experience walking as the sum total of five senses, and our thoughts. While walking can be expressed as knowledge using language (including mathematical formulas), it is impossible to verbalize the totality of the walking experience, because such an experience cannot be completely divided into parts—it is rather greater than the sum ("gestalt" (Köhler 1947)) of the individual mechanics of walking. Knowledge that cannot be divided into small enough parts using language exists, and is called tacit knowledge. Since tacit knowledge cannot be verbalized (Polanyi 1966), we cannot ask scientific questions about it; therefore, it is knowledge that can be experienced but not used to create an inductive argument.

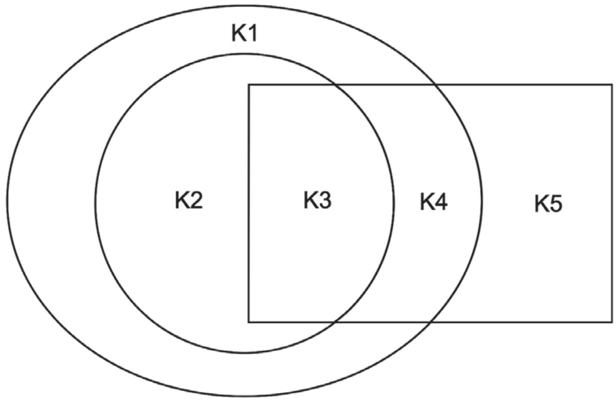

Figure 1. K5 Theory on Knowledge Categorization

Summarizing the above, all worldly knowledge can be classified as shown in Figure 1. In Figure 1, K1 to K4 represent worldly knowledge. The areas added by K2 and K3 are experiential knowledge. The area added by K3 to K5 is logical space. K1 is included in worldly knowledge, but not in experiential knowledge or logical space, and is knowledge that we cannot know (transcendental knowledge). K2 is included in experiential knowledge but not in logical space (tacit knowledge). K3 is knowledge that can be determined using inductive reasoning based on experiences, and can be verbalized (inherent knowledge). K4 and K5 include knowledge that humans cannot experience, but that can be created by language (deductive knowledge). This deductive knowledge includes K4 knowledge that exists and that we can infer, but that we cannot experience, while K5 is knowledge that we cannot experience and that does not exist. Thus, K4 is called critical knowledge in the sense that there it is no longer anything but human fantasy. K5 is beyond this critical ability, and is thus called fantastical knowledge. Figure 1 summarizes the above explanation.

- K1: Transcendental knowledge is impossible for humans to experience or think.
- K2: Tacit knowledge is possible for humans to experience, but is impossible to verbalize.
- K3: Inherent knowledge is possible for humans to verify and verbalize by experience.
- K4: Critical knowledge is impossible for humans to experience, but is possible to infer and does exist.
- K5: Delusional knowledge can be thought about by humans, but does not exist in this world.
- K1+K2+K3+K: Worldly knowledge
- K2+K3: Experiential knowledge
- K3+K4+K5: Logical space
- K4+K5: Deductive knowledge

3. The Knowledge Science can inquire

Beginning with PISA, generally, scientific inquiry targets K3 knowledge—that is, knowledge that we can actually experience by experiment and observation, and that can be expressed in language using inductive reasoning. Knowledge in this area can be disproved by experiment and observation.

Language can also be used to produce knowledge that cannot be verified or falsified via inductive reasoning, experimentation, or observation. Such knowledge cannot be proven to be untrue, and is considered K4 knowledge. For example, superstring theory assumes that the smallest unit in the world acts like a string, and covers everything from particle theory to the theory of relativity. Superstring theory can only be verified using a type of energy that humans cannot produce; therefore, superstring theory is knowledge that cannot be proven true by inductive reasoning, but it can also not be proven to be untrue, because deductive reasoning can be used to conclude that superstring theory is possible in theory.

K5 is knowledge that cannot actually exist, but is indeed human delusions. Knowledge in this area is not considered scientific knowledge. For example, phlogiston was imagined to explain combustion, and aether was said to fill the entire universe in order to allow light wave transmission. These are fantasies that cannot be proven with inductive or deductive reasoning and are not considered scientific knowledge. It is important to note that knowledge may not be scientific, but may still be worth asking questions about. For example, the phlogiston theory was disproved by Lavoisier through both inductive and deductive reasoning, but was put to another use as a treatment method called antiphlogistic bloodletting. At that time, the effects of antiphlogistic bloodletting still needed to be validated, or disproved, but could not actually be tested. In this case, the original question regarding phlogiston's role in combustion led to a new question regarding antiphlogistic bloodletting, which could be further tested.

From the above, it can be said that knowledge, which can be asked by scientific inquiry, is the sum of K3, K4 and K5 (i.e., logical space). This is to say that questions can be formulated regarding using all combinations of propositions and logic that can be created by language.

4. Three types of Scientific Questions

The subject of a question is a proposition in logical space. For example, it is said that Newton discovered universal gravitation from the question, "Why does the apple fall?" At that time, the proposition (referred to here as the potential proposition) that the moon does not fall was tied to the proposition targeted (referred to as the object proposition) by the question, "Why does an apple fall?" (Gefter 2010) These two propositions were independent, and it was not thought that these two phenomena could be connected. Forming the relationship between the two objects produced a breakthrough in

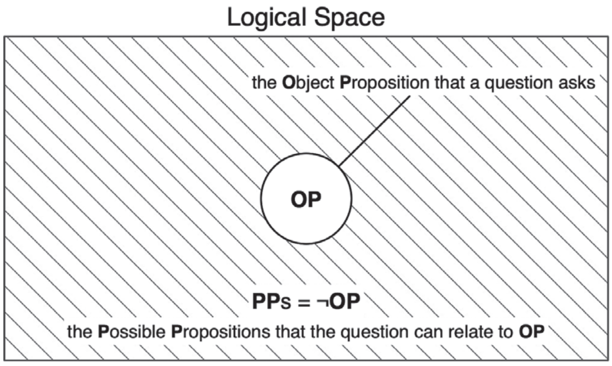

Figure 2. A possibility of questions in the Logical Space

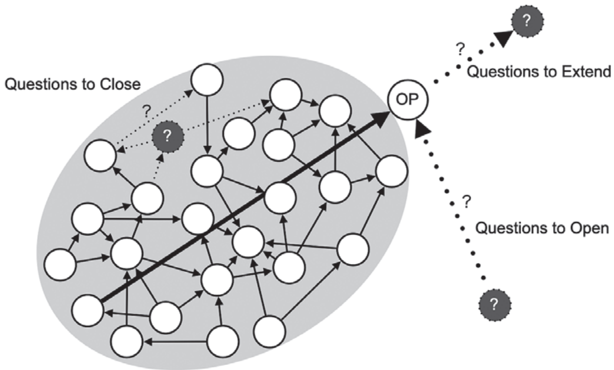

Figure 3. The relation between propositions and 3 types of questions

scientific knowledge. Other statements, such as “The sun does not fall,” or “Birds can fly,” could also have been good questions for the possible proposition, thus it can be concluded that the possible propositions that can be tied to an object proposition by a question, can include the entire logical space, excluding the object proposition (Figure 2).

Next, consider the subject of a proposition. Science tries to describe the world by analyzing and assembling the details of each substance found in the world. An electron is the smallest unit used to construct the scientific world. One theory defines the charge of one electron=$1.602176634 \times 10^{19}$ C. This value is known as the elementary charge, and was measured with high accuracy using oil drop experiments by American physicist Dr. Millikan et al. By measuring the motion of the oil droplets, which is determined by gravity and the Coulomb force acting on the charged oil droplets between two metal electrodes, the charge on the oil droplets was measured. Specifically, by changing the direction of the electric field between the two electrodes, the charge was determined from the change in velocity of the oil droplets. When this experiment was performed for multiple oil droplets, each charge was found to be an integer multiple of a certain number. This specific number is the electrical quantity. In the actual experiment, the results were not exact integer multiples, since the experimental conditions varied slightly for each test, no matter how well the conditions were controlled. Such small variations included the viscosity, air fluctuations, changes in mass and charge due to the evaporation of oil droplets, and changes in the Earth’s gravity. By ignoring such errors, the proposition charge of one electron=$1.602176634 \times 10^{19}$ C was obtained. Since this proposition is only a rule based on inductive reasoning from data obtained by a finite number of experiments and ignoring errors, inductive reasoning could be used. The above proposition (charge of an electron=$1.602176634 \times 10^{19}$ C) does not exist alone, but rather consists of propositions for various experimental conditions. That is, it consists of propositions, such as “viscosity of air=XX” and “Earth’s gravity=XX.” These types of propositions are termed conditional propositions, since they are used to establish a proposition. Some propositions are composed of a complex network of conditional propositions, and they themselves may even be conditional propositions of other propositions. The complex network of such vast propositions and their logical relationships is the logical space. The proposition X=Y is a vector with a certain regularity, or directionality, which is indicated by a set of conditional propositions related to it. For instance, an electron is a complex concept defined by various vectors, such as electrical quantity, mass, and waviness. Figure 3 shows the relationship between an object proposition and its set of conditional propositions, and the relationship among the three types of questions about the object proposition.

4.1 Questions to Close

The object propositions asked by a question are established with such a set of conditional propositions.

Since scientific knowledge is related to the real world, propositions should be based on inductive falsifiability, or in other words, based on events that can be experienced by experiment and observation. The deductively falsifiable proposition can be created by the logical combination of such inductively falsifiable propositions. Knowledge consisting only of deductively falsifiable propositions is mathematical knowledge, which should be distinguished from scientific knowledge. Considering that scientific knowledge is constituted of inductively and deductively falsifiable propositions, a scientific question could focus on the inductive or deductive falsifiability of the object proposition and the individual conditional propositions establishing it. For example, the electrical quantity example mentioned earlier could ask questions about variations in individual experimental conditions or missing conditions. We call such questions "Questions to Close" because the object propositions are too closely related to sets of conditional propositions due to their accuracy. On the right side of Figure 3, the conditional propositions marked with "?" indicate unconsidered propositions, and the "?" on the arrow in the proposition indicates questions about the logical validity of conditional propositions. Since the object proposition can increase reliability by answering such questions, I believe that such questions will lead to scientific progress.

4.2 Questions to Extend

Questions that are considered Questions to Close focus on the validity of a set of conditional propositions and the logic that produces the object proposition. These questions trace the vector opposite of the OP shown in Figure 3. We can also think of questions focused on the extension of a vector presented by a set of conditional propositions toward the object proposition, that is, about the propositions created with deductive reasoning that assumes the object proposition to be true. For example, deductive reasoning from the object proposition "charge of an electron=1.602176634×10^{19} C" can lead to the questions, "Is an ampere (unit of current) based on an electrical quantity?" "Since the charge of a quark is one-third of the electrical quantity, should the electrical quantity be one-third of 1.602176634×10^{19} C?" We call such questions "Questions to Extend" since they are possible propositions of the vector extending toward the object proposition. In Figure 3, the dotted arrow extending from the object proposition (OP) to the upper left denotes such a question. These questions could lead to the application of scientific knowledge (e.g., technology).

4.3 Questions to Open

It can be said that science has progressed gradually through Questions to Close, and that Questions to Extend have facilitated the application of science, such as the development of technology. Such questions alone could not produce the Copernican Revolution as Kant said (Kant 2007), or the paradigm shift as Thomas Kuhn pointed out (Kuhn 1962). For example, we could create a more falsifiable set of propositions called the geocentric theory using the new proposition "the earth moves," instead of introducing less falsifiable propositions to explain the phenomenon of planetary retrograde by the existing set of propositions, which are called the heliocentric theory. We can call these questions "Questions to Open," since they correspond to "Questions to Close." These questions are like asking the object proposition from a different angle than the vector presenting the object proposition, as shown in the lower right corner of Figure 3. For example, because Newtonian mechanics assumes absolute space and time, the less falsifiable hypothesis of aether had to be introduced as a substance transmitting light. The theory of relativity, in contrast, became a more generalized theory that can also explain a black hole, by questioning assumptions of Newtonian mechanics of absolute space and time. In this manner, Questions to Open can cause a scientific revolution.

5. Future Issues

In this paper, I classified knowledge and scientific questions, which can be categorized into three types. In science education, ontic, causal and epistemic questions could help to promote the formation of scientific knowledge for both students and teachers (Osborne 2011). These questions are related to the Questions to Close, because they are questions regarding the form of scientific knowledge, rather than questions based on the nature of the questions.

The classification of scientific questions in this paper allows the questions themselves to be evaluated. Due to the importance of questions, Voltaire, as a representative of the enlightenment, is reported to have said “Judge a man by his questions, rather than his answers.” In fact, this adage was described by Pierre Marc Gaston de Lévis as one of the axiom (Thompson 2016). In any case, because questions are more important than answers, it would be ideal to evaluate children’s questions rather than their answers, as is currently the case in education, since answers are easier to evaluate than questions.

“The action of appraising or valuing (goods, etc.); a calculation or statement of value (Oxford English Dictionary),” “the process of judging or calculating the quality, importance, amount, or value of something (Cambridge Dictionary),” “careful thought about something before making a judgment about its value, importance, or quality (Macmillan Dictionary)”, as the name implies, it means “to measure and judge value. (Rossi et al. 2019)” In other words, firstly we need to define “value” to evaluate (Patton 2002).

Value is also a proposition. For example, in the case of evaluating an answer, the correct answer is represented by a proposition. This proposition could be the propositional set of the correct answer together with the propositions constituting it. In contrast, a solution is also represented by a proposition, and is represented as a propositional set of solutions together with the propositions constituting it. Evaluating a solution is to compare the propositional set of the solution and the propositional set of the correct answer. When the two are the same, the solution proposition is judged to have a correct value. In such an example, the evaluation is simple, because the correct answer proposition is assumed to be the correct one.

When evaluating a question (Figure 2), the proposition that can be related to the OP by question includes all of the propositions, except the OP, from the logical space. If value of a question is being represented as a proposition (i. e., “A question is correct if it satisfies a certain condition”), then the possible propositions (PP) that can be related to a question are limited to the certain conditions of this proposition, (i. e., the evaluation criteria). For example, by defining the proposition “If a question contains the word electron, it is correct” as a value, then the propositions related by the question are limited to those that contain the word “electron” only. This is the same whether the value is “right,” “beautiful,” or “good.” Like this, representing the value of a question as a proposition, the freedom or, so to speak, the creativity, of the question could be lost.

To avoid this problem, it is possible to increase the amount of evaluation criteria that constitute value. To keep the inherent creativity of the question, the more evaluation criteria are increased, the wider the region of the PP domain becomes; however, the more evaluation criteria you add, the more ambiguous and meaningless the value becomes. For example, if a question is correct when it includes electrons, quanta, subatomic particles, photons, etc., then the more evaluation criteria you add, the more freedom you have to evaluate the question, but the more ambiguous the value becomes, and the less meaningful it becomes.

The reason why a question is more important than an answer is that the proposition related to the object proposition as a question is not as limited as the ask about the applicability or possibility of a proposition. Questions to Open ask about the possibility of reversing the proposition itself. However, many issues arise in actually evaluating these questions. When evaluating the Questions to Close, it is difficult to determine how much the object proposition is related to the missing conditional propositions and logical relationships between the conditional propositions. When evaluating Questions to Extend, we need to judge whether the proposition being asked as an extension of the object proposition is really an extension of that object proposition, which is difficult to do for outlandish propositions. When evaluating Questions to Open, it is also necessary to determine whether the proposition to which the question relates really revolve around the object proposition, which is difficult to do if it is intended to relate to an outlandish proposition. It is always difficult to evaluate a single question alone, and we need to develop methods to evaluate questions as a group about the object proposition. That is, we need to evaluate how much the distance between the proposition that we are trying to relate to the object proposition by the question and the object proposition is filled by the group of questions. In order to do this, we need to describe the logical space, or more precisely, the set of currently known knowledge, by propositions and logic. answer, herein lies the intrinsic creativity of questions. Due to this advantage, it is difficult to define the value of a question by its proposition, and it is also difficult to evaluate the question. Thus, to evaluate a question, the value of the question should not be defined by the proposition.

The three definitions of scientific questions presented in this paper are not specified by the proposition. They are not restricted to the proposition of value, as they present three ways to ask the proposition itself. Questions to Open ask about the reliability or consistency of the proposition itself. Questions to Extend ask about the applicability or possibility of a proposition. Questions to Open ask about the possibility of reversing the proposition itself.

However, many issues arise in actually evaluating these questions. When evaluating the Questions to Close, it is difficult to determine how much the object proposition is related to the missing conditional propositions and logical relationships between the conditional propositions. When evaluating Questions to Extend, we need to judge whether the proposition being asked as an extension of the object proposition is really an extension of that object proposition, which is difficult to do for outlandish propositions. When evaluating Questions to Open, it is also necessary to determine whether the proposition to which the question relates really revolve around the object proposition, which is difficult to do if it is intended to relate to an outlandish proposition. It is always difficult to evaluate a single question alone, and we need to develop methods to evaluate questions as a group about the object proposition. That is, we need to evaluate how much the distance between the proposition that we are trying to relate to the object proposition by the question and the object proposition is filled by the group of questions. In order to do this, we need to describe the logical space, or more precisely, the set of currently known knowledge, by propositions and logic.

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