What is the epistemology of science

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The word epistemology is derived from two Greek words: “episteme” meaning knowledge and “logos” meaning study of. Putting these two ideas together, epistemology is therefore the study of knowledge and is often considered the “theory of knowledge” (Wenning 2009). The focus of this theory is on three particular questions: *what is knowledge?, how is knowledge produced? and what are the limits of knowledge?* (Wenning 2009). Each question will be given its own section for discussion.

What is knowledge?

Over the course of humanity many philosophers and scientists have argued about what knowledge is exactly. To say that knowledge is something we know implies that we believe it but also implies that it is true. Some argue that knowing something that is true is not enough because one can know something to be true by mere guess or coincidence. Therefore, the third and final requirement for something to be considered knowledge is that we are justified in believing it to be true. This justification requirement is the most important one and begs the question: what is proper justification? The formulation of this definition of knowledge is often phrased as: “justified true belief” (Wenning 2009). Focusing on scientific knowledge means to ask questions regarding what kind of beliefs we are dealing with, what does truth mean, and what justification methods are satisfactory.

Karl Popper, a famous philosopher of science famously came up with a well accepted answer to the first question regarding what kind of beliefs can qualify as scientific knowledge. His answer was any belief that can be falsified through empirical experimental evidence (Thornton 2022). His idea builds upon the philosophy of empiricism: the belief that knowledge

must come from experience through the senses and perception (Wenning 2009). Our entire modern approach to science is based on this philosophy and Popper's distinction between what beliefs can be considered scientific and which cannot be is extremely clear to understand, making it a well accepted basis for part of the definition of scientific knowledge (Thornton 2022). Next comes the idea of truth. In scientific knowledge, for a belief to be true would mean that there is some external rule outside of human awareness that exists and applies all across the universe and not does not change. We will discuss the idea of truth further in the *limits of scientific knowledge* section. Finally the most important restriction is regarding what is considered valid justification. As mentioned, the belief in question that has the potential to become scientific knowledge must be falsifiable experimentally. Much of the justification required for this belief to become scientific knowledge is in the fact that none of the experiments that have been performed so far falsify the theorem. If the belief is not falsified over the course of many different experiments by many different scientists it becomes well established scientific knowledge. This is a very simplified understanding of justification however because it does not discuss what kind of experiments must be performed (Wenning 2009). True scientists attempt to falsify their own theories in a noble attempt to find truth while pseudoscientists only perform experiments they know will not disprove their theory. They do not value truth but instead personal gain, fame or anything else. The authors of this paper would argue that any scientist who does not value the truth above all else is no scientist at all.

Knowing this difference between scientists and pseudoscientists is often not as easy to tell and it leads directly into the next section.

How is scientific knowledge produced?

We begin this response starting with the famous "scientific method" taught in our schools. The scientific method is defined as a process that is used to generate scientific knowledge. It begins with observations and then formulation of a question. A hypothesis answering this question is made followed by experiments testing this hypothesis. Once the experiment is completed, the data is analyzed and a conclusion is made on whether the data falsified the hypothesis. If yes, the hypothesis is altered and the process continues, if not, more experiments are done and eventually with enough experiments that do not falsify the hypothesis, it becomes scientific knowledge.

Paul Feyerabend, a 20th century philosopher of science disagrees with the idea of science having one single method of producing knowledge such as the scientific method. He famously argued

> *"every proposed methodological rule has been fruitfully violated at some point in the course of scientific advance, and that only by breaking such rules could scientists have made the progressive steps for which they are praised (1975). He concluded that the idea of a fixed, historically invariant scientific method is a myth. There are no universally applicable methodological rules. The only methodological rule that is universally applicable is 'anything goes', which buys its universality at the cost of being completely empty (1970a, 105)" (Oberheim & Hoyningen-Huene, 2023).*

The idea that "anything goes" seems contradictory to the idea of proper science but the argument stands very strongly. The method of producing a new theory does not matter, the only thing that

matters is its ability to hold up to evidence and experimentation *(Oberheim & Hoyningen-Huene, 2023)*.

Feyerabend also made claims suggesting that the development of science does not happen sequentially but rather in jumps where new theories introduce new concepts that are incommensurate with previous ones. He says "the interpretation of an observation language is determined by the theories we use to explain what we observe. When our theories about reality change, what we experience as reality changes accordingly" *(Oberheim & Hoyningen-Huene, 2023).* This is a very similar view to that of Thomas Kuhn, another famous philosopher of science, who introduced the idea of paradigm shifts in his book *The Structure of Scientific Revolutions* (Bird 2022). This idea is that scientific progress happens through large leaps in understanding called paradigms that alter our view of reality. Further, "these competing paradigms lack a common measure because they use different concepts and methods to address different problems, limiting communication across the revolutionary divide" (Bird 2022). While this view of producing scientific knowledge is supported historically, it is argued that these views neglect progress and risk relativism (the subjectivity of scientific knowledge).

Another noteworthy idea on the topic of knowledge production comes from Robert Merton who, in 1942 introduced four principles or norms that he claimed should always be obeyed when performing science. These norms are less philosophical and more practical and are guidelines for institutions that conduct scientific research. The norms are: communism, universalism, disinterestedness and organized skepticism (Macfarlane 2023). Communism refers to the idea that scientific theories and ideas belong to everyone and cannot be claimed as intellectual property; universalism refers to the idea that anyone can find truth because truth is

universal and not culturally dependent; disinterestedness refers to the idea that scientific inquiry should be pursued for the purpose of interest wonder and insight not personal gain or ego, and organized skepticism refers to the idea that we should scrutinize all beliefs and claims without bias towards any particular idea or theory. Macfarlane (2023) claims that the norms (referred to as CUDOS) are in decay in our scientific institutions. He claims that institutions profiting from scientific ideas and theories contradict the communism norm, that talk of relative and context based truths contradicts universalism norm, that egoism and seeking personal achievement contradict disinterestedness and that advocacy and social agendas contradict organized skepticism. Macfarlane (2023) presents strong evidence suggesting this decay and while this is argued to be a bad thing, one interesting counter argument is that disinterestedness is an unrealistic norm to pursue since it contradicts human nature to compete. Newton himself was very vain and had a large ego yet his ideas and work was arguably the greatest contribution ever made to our understanding of the world. Besides this norm, the authors of this paper agree very deeply with them and believe Merton's norms should be common knowledge for all scientists and science educators.

Limits of scientific knowledge

Axiom of Science

The first limitation of science that we must mention is known as the Uniformity of Nature principle. This principle states that "the laws of nature are forever constant and apply the same way to all matter across both time and space" (Wenning, 2009). Rutherford and Ahlgren (1990) add that this principle includes that those laws are knowable through investigation. This single principle summarized simply as: **the universe operates according to consistent and**

knowable laws serves as the core axiom of scientific inquiry. This is an axiom of science because it is an unproven belief that must be accepted for science to occur. If it is not accepted there would be no point in conducting science because either the laws are not knowable and it is therefore an impossible feat or there are no consistent laws and therefore nothing to discover. This axiom must be accepted for science to begin.

Uncertainty of theorems

Another limitation of the scientific pursuit is that scientific knowledge can never be known for certain. Due to the inability of humans to predict anything about the future we can never know for sure if a well established theorem will fail one day perhaps when tested with new observations. Since there is always a possibility of an established scientific fact to be disproven "Scientists therefore do not claim to possess 'truth' as such because this would constitute something that is known now and forever to be correct" (Wenning, 2009).

The demarcation problem

Another limitation we will discuss stems from the demarcation problem. This problem attempts to decipher questions that are scientific in nature from those that are not. As previously mentioned, Karl Popper developed a simple way to test this, namely whether or not the question is falsifiable experimentally (Thornton 2022). Under this assumption there are many important questions beyond the scope of science, two of which are: morals and aesthetics (Rutherford and Ahlgren 1990). Science by definition cannot prove experimentally that an action is wrong morally speaking, or whether or not something possesses beauty. This is a very important limitation to acknowledge.

The perceptible world

Finally the last limitation we will discuss is an idea that the boundaries of science depend upon the current state of science and technology. If we take as assumption the general beliefs of empiricism, we conclude that we can only know what we perceive. Since there are many physical entities beyond the reach of our natural senses like atoms, certain frequencies of electromagnetic waves … we might conclude that these entities are unknowable, however if we had technology that could measure what we expect to be present we could perceive the readings on those machines. This leads to the conclusion that what is perceivable and therefore (assuming empiricism) within the reach of scientific understanding is completely dependent on the current technology available and scientific understanding.

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