Philosophies of Scientific Testing

John Bloore
ECE department
Lafayette College
Easton, Pennsylvania
bloorej@lafayette.edu

***Abstract* – this paper aims to explain how many of the scientific testing practices and procedures stem back their philosophical origin. Several theories of two of the most important figures in the philosophy of science will be explained. First the works of Carl Gustav Hempel and his theories about logical positivism will be explained. Next, the works of Karl Popper and his theories about empirical falsification will be explained. Finally, we will discuss modern testing practices from the American Society for Testing and Materials (ASTM) and how they relate to the theories described by both Hempel and Popper.**

I. Introduction

This section will describe the philosophical theories of Carl Gustav Hempel relating to his deductive-nomological model and those from Karl Popper related to empirical falsification.

II. Content

A. Carl Gustav Hempel

Hempel is one of the most influential people in the field of philosophy of science. He was especially famous for his articulation of the deductive-nomological model, a method of determining whether certain hypothesis or claims about scientific phenomena are justifiably true. This became the standard model of scientific explanation in the 1950's and 60's.

In Hempel's deductive-nomological model, the explanation of facts are reduced to logical relationships between statements, or deductions of statements that describe the facts we want to explain. The premises in his model are the scientific laws and suitable initial conditions relating to the experiment. In order for a hypothesis to be true, not only must the explanation make logical sense, the premises must also be true. These explanations must be based on facts described by scientific laws and not based on pragmatic reasons. This model is a common method used in the broader philosophical theory of Logical Positivism.

1. Logical Positivism

Logical Positivism is a branch of philosophy that embraces verificationism; a proposition is only valid if it can be conclusively determined to be true. According to this theory, only statements that are either logically or empirically verifiable are cognitively meaningful.

For example, let us consider a hypothesis stating that the scientific laws of the universe will change after trillions of years due to major cosmic events. Verifying the truth of this would be impossible since the sun is going to super-nova way before that and wipe out the human race. Therefore, Hempel would conclude that although this may or may not be true, this hypothesis has no cognitive meaning and is useless.

According to Logical Positivisim, confirming our scientific theories does prove they are correct, rather they give us added confidence to believe the given theory is true. Some factors that increase our confidence in a theory are:

a) Repeatability – if one can repeat an experiment several times and confirm that this hypothesis is true every time, then this will increase our confidence that the theory is true.

b) Different testing conditions – one can increase the confidence in his theory by testing it in different environments and/or with different conditions.

c) Scope of tests – the more ground that each test covers, the more confident one can be when verifying a theory.

d) Different people performing tests – the more people can confirm a scientific theory is true, the more confident we can be in our theory.

e) Other scientific principles – if there are well acclaimed scientific laws or principles that back the current scientific claim, we can be more confident that it is true.

B. Weaknesses of Hempel's theory

Although the deductive-nomological model is a very popular way to evaluate if we can definitively state that a theory is true, it has been criticized by modern philosophers. One issue with Hempel's deductive-nomological model is that it allows causally irrelevant factors to be included in confirmation. This occurs because Hempel does not place enough emphasis on the scope of relevant conditions to the theory at hand. Therefore, one may be able to falsely confirm a theory based on factors that do not directly affect the problem. Additionally, Hempel runs into problems with inductive explanation of theories. According to Hempel, we are not able to prove a theory is true, rather we simply increase our confidence that the given theory is true by testing it. This is problematic because it does not allow one to definitively prove that a theory is true, rather it is based on a high degree of probability.

C. Karl Popper

Karl Popper is another one of the most influential people in the field of philosophy of science. He is famous for rejecting the use of induction when determining whether a scientific theory is true or not. This view is contrary to Hempel's theory, and instead embraces empirical falsification.

1. Empirical Falsificationism

Empirical falsificationism claims that a theory in the empirical sciences can never be proven, rather, it can only be falsified; therefore, every scientific theory should be heavily scrutinized. A strong scientific theory should be impossible, or extremely difficult to falsify. However, many scientists often claim to disprove, or falsify, popular scientific theories. If the outcome of one's experiment contradicts the theory at hand, this does not mean that the theory is instantaneously falsified. Rather, one needs to further test the theory to make sure that it is indeed false. Additionally, everybody should refrain from *ad hoc* maneuvers to avoid contradicting the scientific theory at hand, like proposing alternative explanations that only explain the current situation, or blaming irrelevant factors in the testing environment.

2. Critical Rationalism

Popper is most famous for rejecting the most popular epistemic view, or the justificationist account of knowledge. This holds that only what can be proved/experienced should be accepted as knowledge. Believing in falsificationism, Popper argues that rational explanations cannot definitively prove a theory correct. Popper believes that because scientific theories are abstract in nature, they can only be tested indirectly by referring to their implications. For example, the theory of gravity can only be proven or disproven by observing objects attract to heavier objects. Popper also believes that logically, no amount of positive outcomes in an experiment can confirm that a scientific theory is true, however, a single counterexample is logically sufficient to prove a theory false. Therefore, a scientific theory is only falsifiable, not provable.

3. Problems with Popper

The biggest problem that Popper faces is dealing with the problem of induction. In common practice, people hold inductive statements true. For example, people hold the theory of gravity true, because every time something is in air, it falls to the ground. The fact that during every test case the theory of gravity holds true does not prove it is true though. For all that we know, the laws of the universe might change in the upcoming years and alter the theory of gravity so that when I drop a pencil, it goes up instead of down. Additionally, nobody can prove that gravity holds true in every instance ever to occur because nobody will live forever to tell the tale. Even though everybody knows that the theory of gravity is true, the only way to falsify it would be to find a pencil that fell up due to gravity and no external factors.

Popper has trouble dealing with theories that are based on experience, like when a drop a pencil it will fall to the ground, or the sun will rise tomorrow. He attempts to escape these by suggesting that although we cannot logically prove that a pencil will fall to the ground or the sun will rise tomorrow, we can postulate a theory that states every day the sun will rise, or every time I drop an object it will fall to the ground. If this fails to occur in either case, we will have falsified our theory, but until this happens, there is no need to reject the assumption that the theory is true. Although Popper provides a way to escape the problem of induction, he does so in a way that weakens his theory. This work around sounds a lot more like Hempel's theory than Popper's because we are assuming scientific principles are true based on the fact that we have not experience otherwise.

D. Modern testing practices and how they relate to Hempel and Popper.

Modern scientists use test methods, such as physical tests, chemical tests, and statistical tests to produce test results for what they are studying. Scientists perform many different types of tests like, qualitative, quantitative, categorical, personal observation, output of a precision measuring instrument, etc. But properly writing a test method and also choosing the correct test method to measure the correct property or characteristic is extremely important. The American Society for Testing and Materials (ASTM) is an organization that sets the standard for appropriate testing methods and practices.

1. ASTM test method validation

ASTM contains certain criteria for writing down a proper test method, and also describes different components that are crucial for validating the results. Here I will first list the ASTM test method validation practices, and then discuss how many of these components relate to Hempel theories described above.

1. Accuracy and precision of experiment
2. Repeatability and reproducibility
3. Range over which a test method is considered
4. Curve fitting
5. Robustness or how insensitive the experiment is to environmental variables we cannot control
6. Measurement uncertainty
7. Round Robin Testing – multiple independent people performing the same test using the same test method

These test method validations are almost identical to the confidence boosting criteria that Hempel describes above. The more we can repeat an experiment or reproduce a result, the more confident we are that it is true. Performing a test over a broad range of values is just like evaluating the scope of the testing practice. A robust test will be able to produce the same results in different environments and at different points in time; this relates to an increased scope of the experiment, which increases our confidence that the result is correct. Finally, round robin testing is identical to Hempel's criteria of multiple people performing the same test the same way. All of these factors are confidence boosting criteria in affirming a scientific theory, according to Logical Positivism.

2. Software Testing Practices

This section will describe two software development approaches: The Waterfall Model and the Agile Model.

The waterfall model separates software development and testing into two different stages. After all the requirement gathering and floor planning has been done, the developers first implement or build a feature. Once this is complete the developers and pass it to the QA team for testing before the product is released.

The agile model blends the development and testing stages into one. After all the requirement gathering and planning has been done, the developers work along with the testers in development. As the developers finish features, they are tested to see if no bugs occur. If there are many issues, the project is passed back to the developers until they have been fixed. After bouncing back and forth for a while between developing and testing, the product is released.

Although these two different software development life cycles describe distinct approaches, they still test in a similar fashion. During the testing stage, the QA testers are looking to break the code to find bugs. This is exactly the approach that Popper describes in his empirical falsificationism. He believes that we are never able to prove something is true, but once we falsify it, we know it is wrong. The QA testers think this way too, they cannot prove that the software is perfect, but they continue to test it until they find flaws within the program.

E. Conclusion

Modern testing practices rely on theories developed by both Hempel and Popper and therefore should take elements from both philosophers when evaluating our theory or hypothesis, or testing a product we are developing. Hempel's theories are important to use when one is trying to evaluate how confident or reliable a scientific theory is, just like many of the ASTM test validation practices. Popper's theories are important when we are testing to see if a product works, or can withstand outside pressures or tests; we can see this often in software testing methods.

III. References

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