Technical Note

The Etiology of ACE-V and its Proper Use: An Exploration of the Relationship Between ACE-V and the Scientific Method of Hypothesis Testing

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Abstract: ACE-V is commonly described as the scientific methodology that fingerprint practitioners use to individualize friction skin impressions, including both tenprint and latent print examinations. This paper looks at the history of ACE-V, analyzes whether a clear understanding of ACE-V exists, gives a brief description of how ACE-V should be used, and looks at the repercussions of incorrectly using ACE-V. Recognizing the misconceptions about ACE-V is the first step in establishing a comprehensive grasp of this process, which in turn will result in practitioners reaching the best possible conclusions.

History of ACE-V

Huber initially discussed ACE-V in 1959 [1]. The purpose of Huber's message was to describe the philosophy of science and the correct use of the scientific method [2]. "The scientific method" is a phrase that has been used to describe the scientific methodology of hypothesis testing. Hypothesis testing is by no means the only way scientists arrive at their scientific conclusions [3], but its use has become so common that hypothesis testing has become labeled by some as *the scientific method*.

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Hypothesis testing is a scientific method for guiding scientific research and arriving at scientific conclusions. It entails collecting data, testing the data, arriving at conclusions, and ensuring that the data and the procedures that are used are left open for peers to review. The main purpose of hypothesis testing is to show the existence of justification to support a conclusion. Using this systematic form of reasoning ensures that the conclusions are the best conclusions possible, given the available data. To be certain that results are sound and supported, it is important to have data that are observable, testable, reproducible, and falsifiable. Using accepted practices and procedures and documenting anything that is not obvious to the average practitioner will help avoid unwanted criticism of conclusions. Diminishing potential biases will assist in making the results as objective as possible. One way to do this is to account for all the data collected, not just the data that confirms ideas or conclusions. Reproducing a conclusion alone does not equate to a scientific conclusion. For a conclusion to be considered scientific, a person must have reproducible results as well as have used sound reasoning and appropriate practices and principles to arrive at the conclusion. The overwhelming popularity of hypothesis testing is due to the reliability of the results when the process is used correctly.

Huber described hypothesis testing as it related to the comparative sciences. He used the words analyze, compare, and evaluate (better known as ACE) to describe this philosophy and also noted that verification was needed [4]. Over the years, this terminology was used by various fields but was not known to the fingerprint community until 1979, when it was introduced by Ashbaugh, who referred to it as ACE-V [5]. ACE-V was used for nearly the next twenty years on a relatively small scale. In 1998, with the advent of the first Daubert hearing on fingerprint evidence, the members of the fingerprint community recognized the need to better articulate how they arrived at their conclusions, and ACE-V gained widespread recognition.

Accepting ACE-V as a methodology came easily to the fingerprint community, but understanding it seems to be taking a little more time. This is evident by reading the various descriptions of ACE-V that have been published by different organizations [6, 7, 8]. If different organizations describe ACE-V differently, then it would follow that people are using it differently and hence may not be appropriately using it as a scientific method.

Proper Use of ACE-V

Associating ACE-V with hypothesis testing (Figure 1) demonstrates that *analysis* is the section of hypothesis testing where information or data (e.g., different levels of detail available, clarity, tolerance, distortion) are collected. The *comparison* phase is the section of hypothesis testing where a hypothesis is tested. Normally this is done by comparing different features in the known and unknown print. In science, other forms of testing are also accepted and highly valued, some of which will be discussed later. Once adequate testing is complete, a full *evaluation* of the information is done and a supported conclusion is arrived at. The final step needed to conform to an appropriate scientific method is to leave all information, data, processes, and conclusions open for peer review. Huber referred to this as verification, although he was not the first person to use this term in science [9].

Hypothesis Testing	ACE-V
Collect data	Analysis
Testing phase	Comparison
Conclusion	Evaluation
Peer review	Verification

Figure 1

Associating ACE-V with hypothesis testing.

Problems with the Word *Verification*

There are several potential problems with the word *verification*. First, the word verification can be synonymous with confirmation. The purpose of confirmation, by definition, would be to uphold the initial examiner's conclusion. Proper peer review is not about upholding a prior conclusion, even though that happens to be the most frequent outcome. The purpose of peer review is to thoroughly attempt to falsify the original examiner's conclusion or how it was arrived at [10]. The word verification may lead people to have a false sense of understanding regarding ACE-V.

Another problem with the word verification is that this word is already used in science to indicate a testing procedure [11, 12]. Some different ways of testing hypotheses include independent examinations, blind verifications, or double-blind verifications. Generally speaking, these testing methods are more useful in difficult matters that are inherently more subjective. This type of verification is done during the testing phase (the comparison stage of ACE-V) and is done prior to making a conclusion (the evaluation stage of ACE-V) [11, 12]. The use of the word verification in place of peer review confuses the testing phase with the peer review phase, eliminating peer review altogether.

The third problem with the word verification is the common belief that verification should be done blindly. The testing process, which traditional sciences use and call verification or confirmation, is a process that is done blindly. This is done to ensure an unbiased testing process and is part of the *testing* phase of the scientific method (the comparison phase of ACE-V). The verification phase of ACE-V (the peer review phase) cannot be done completely blind because this would violate the peer review process by not allowing the verifier to look at how the practitioner arrived at the conclusion.

Proper Peer Review

Peer review has a very important place in science. The main goal of peer review is to look at how a conclusion was arrived at, not merely to confirm the conclusion [13]. In order to examine whether scientific principles were used, the peer review phase requires that the peer reviewer see all the information and documentation that the initial practitioner used to arrive at his or her conclusion, even if the reviewer would not have arrived at the conclusion in this same way. The reasoning is that the goal of peer review is not to reinvent a conclusion but to assess whether a conclusion was arrived at accurately, using procedures that are tested and accepted. During the last couple of decades, the need to understand this concept has been seen at the most basic levels of science. "Show your work" has become an educational requirement, not simply a recommendation [14]. By doing so, it can be determined whether a practitioner, in any field, arrived at his or her conclusion through acceptable procedures. In order to reduce bias, the peer review process should be done from an impartial and *independent* perspective.

It is important to note that, contrary to popular belief, all scientific conclusions are not peer reviewed [15]. To ensure that conclusions conform to an appropriate scientific method, conclusions do not always need to be peer reviewed, but they need to be peer reviewable. The same can be said for other elements of hypothesis testing as well. Not all conclusions need to have documentation of how they were arrived at, especially in the case of simple and routine tasks, but they do need to be documentable if anyone should want to see this information. Documentation should always be included if any component of the data or the examination is not clearly apparent to the average practitioner. Even though peer review is not always performed in scientific discovery, it is an industry standard of the fingerprint community [6]. The fingerprint community realizes the repercussions of its conclusions and requires that this phase of the scientific method be fulfilled. The Scientific Working Group on Friction Ridge Analysis, Study, and Technology states, "All individualizations (identifications) must be verified." [6]

Hypothesis Testing / ACE-V	Components
Step 1 Collect data (Analyze)	a) Observe characteristics, contrast, smearing, pressure, amount of clarity, tolerance, orientation, double impressions, color of ridges, amount of level 1, 2 and 3 detail, etc.
Step 2 Test data (Compare)	a) Comparison phase. b) During this phase, the practitioner is forming a preliminary conclusion to test but is not coming to a definitive conclusion. This preliminary conclusion can change depending on the test results. c) All testing is done prior to making a decisive conclusion. d) Different methods can be used to test the hypothesis. These methods include, but are not limited to: - looking for common characteristics with the same spatial relationship - blind verification - predictions of new data - attempts to falsify the hypothesis
Step 3 Come to a conclusion (Evaluate)	a) Look at the entirety of information that has been collected and tested to come to a conclusion. b) Answer two questions: -Is the information observed in the prints being compared in agreement? -Is there enough information to individualize?
Step 4 Peer review (Verification)	a) Ensure that scientific principles and procedures were used. b) Try to falsify. c) Impartial/independent participant.

Figure 2

Components of the ACE-V methodology.

It may appear from Figure 2 that ACE-V is a linear process, but this is far from the truth. At various times, a practitioner may need to reanalyze the original data, perhaps collect additional data, change the hypothesis, and start the testing process over again. This cyclical course may be required several times before a conclusion is arrived at. In some cases, it is hard to tell when one step stops and another begins. Even after hypotheses are tested, peer reviewed, and universally accepted as scientific theories, they are still tested in the sense that they must hold up to the demands of practical application in our ever-changing world. An example of how the steps are intertwined is shown with Newton's Law of Gravity. Newton's Law of Gravity was tested, peer reviewed, and accepted by most people as infallible for more than 200 years. In the early 1900s, Einstein concluded that Newton's law was only true in certain situations, establishing the Theory of Relativity. Some may claim that the flaw in Newton's law was discovered well after the testing phase, the conclusion phase, and the peer review phase. It is also important to note that hypothesis testing is not always explained in four steps, as above. It can be broken down and explained in a variety of ways. Figure 2 simply compares hypothesis testing with ACE-V, which is generally described in four steps.

Different Explanations of ACE-V

Many sources have described the verification process of ACE-V to be a repeat of the ACE process done by another examiner [6, 7, 8, 16, 17]. Although the repeated application of ACE can be deemed as acceptable in science, this usually applies to very simplistic conclusions where the process used to arrive at a conclusion can be taken for granted. Although this may be applicable to many fingerprint comparisons where both the known and unknown prints are exceptionally clear and full of detail, a complete understanding of scientific methodology must be attained in order to know when the repeated application of ACE is adequate or when a complete peer review of the analysis is needed.

Other sources describe verification as a confirmation of the original examiner's conclusion [18, 19]. As discussed earlier, peer review is about scrutiny, not confirmation. Confirmation, of the process and conclusion, is just one possible result of the peer review process.

Many of these same sources indicate that verification should be done blindly, without the knowledge of the original examiner's conclusion [7, 19, 20, 21]. It is important to ensure that the verification process is done without bias, but this is accomplished by using an impartial or independent verifier, not a verifier without adequate information. It is essential that the peer reviewer be given all of the initial examiner's information and conclusions so that the reviewer can look at the process that was used to arrive at the conclusion.

Several sources proclaim that the verification stage of ACE-V is a testing stage. It is important to understand that, although the peer review process does test the conclusion, it is not a testing phase within itself. These statements not only show a lack of understanding of scientific methodology, but they also show a misunderstanding of how ACE-V relates to scientific methodology.

Consequences of Misunderstanding ACE-V

If practitioners are describing ACE-V differently, it would follow that practitioners are using it differently. If practitioners are using it differently, then the error rate may be different for each different type of application. It has been commonplace in the fingerprint industry to say that this methodology is 100% accurate if applied correctly and therefore all errors are practitioner errors. This statement should be looked at in a couple of different respects.

Rudin and Inman state, "It is impossible to separate the analyst from the method; the instrument is the examiner's brain and her decision-making process is the method." [22] It is impossible to separately test the methodology and scientifically support the assertion that the error rate of the methodology is zero when the methodology cannot actually be tested without the involvement of an examiner.

One of the problems with misunderstanding how ACE-V is synonymous with hypothesis testing is in establishing an error rate. Hypothesis testing has been used for hundreds of years (some say thousands of years) with very reliable results [23]. The success rate is so high that this type of scientific knowledge is sometimes called the supreme form of knowledge. Even if this is true, no scientist has ever claimed the error rate of hypothesis testing is zero [24]. Hypothesis testing is a self-correcting system. Science does not hold itself in such a high regard as to claim its results are absolutely conclusive [3, 4, 15]. Scientific conclusions are considered to be the best conclusions possible because they are well substantiated by the observational data available and they were arrived at through appropriate scientific practices. All conclusions are continually open to further testing and better conclusions.

Another part of this statement to analyze is "all errors are practitioner errors". If practitioners are unclear of the meaning and interpretation of ACE-V, then one cannot be sure they are using it correctly or using it as a scientific method. Practitioners can only apply this methodology correctly if they have an in-depth understanding of it. A lack of understanding will inevitably lead to mistakes. The practitioner alone cannot be blamed for these mistakes. The industry must take some responsibility in ensuring that practitioners are competently trained in scientific methodology. If different organizations describe ACE-V differently, then it can only be assumed that practitioners are being trained differently. Should the correct use of the methodology be assumed or should it be tested, as with annual proficiency testing or certification programs? Where is the correct way to apply ACE-V to be found? Even if practitioners are coming to correct conclusions, it should not be assumed that correct methodology is being used.

Conclusions

The correct way to use hypothesis testing and ACE-V has been articulated in several sources, although more so with hypothesis testing. Huber used the terms analyze, compare, evaluate, and verify to describe the philosophy of science [1, 4]. He noted that science is both a process and an end result. Giving too much weight to the conclusion and not enough weight to the process reflects a lack of understanding of the role and endeavor of experts "which shows little evidence of diminishing" [4]. More than 40 years later, this statement still holds true.

Ashbaugh stated, "Verification is a form of peer review and is part of most sciences. Many organizations erroneously use verification as a method of protecting against errors in place of adequate training. While verification may prevent the occasional error, its purpose is to verify process and objectivity as opposed to only check results. It is also an excellent vehicle for training." [13]

It would be impossible to completely describe every element of hypothesis testing in one paper. As with any scientific endeavor, one question leads to another and the process can become increasingly more difficult to understand (e.g., how the ACE-V process contains a separate hypothesis testing process within each element). This paper describes hypothesis testing at its most basic level and shows how ACE-V is synonymous with hypothesis testing. A more in-depth understanding of scientific methodology can be found by reading the works of well-known scientists and philosophers such as Aristotle, Isaac Newton, Francis Bacon, Galileo Galilei, and Karl Popper, to name just a few. The overall lack of understanding regarding scientific methodology does not only apply to the fingerprint field. McComas [3, 15] has dispelled the myths of many educated scientists who do not understand these concepts.

When ACE-V is used inappropriately, errors in individualization can and will occur [21, 25]. ACE-V is a valid scientific method *if it is used as a valid scientific method*. Practitioners in this field need a clear understanding of how ACE-V relates to hypothesis testing so they can properly use it and explain it. Acknowledging that a universal understanding of ACE-V does not exist is the first step in acquiring a comprehensive understanding of this process.

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