were due to massive objects exerting their force of gravity on the space–time continuum, very similar to bowling balls placed on an outstretched blanket. Einstein's proposed theory was not initially accepted, but after years of tests and experiments, his theory gained acceptance.

This is the true nature of science. Laws are discovered. Theories are invented to explain them. The laws and theories are tested by experiments, observations, and hypothesis testing. Hypotheses are woven together into the theories as the theories are modified. Theories are never proven, only continually tested and updated. Theories can be accepted for hundreds of years, but with the advent of newer technology, theories are subjected to new tests and rigors, and eventually outdated or incomplete theories give way, absorbed into new, mature theories. The science of friction ridge skin has experienced exactly such trials.

14.2.3 Laws and Theories in Friction Ridge Examination

If we accept the definition that a scientific law is a generalized description of patterns and phenomena in nature and a scientific theory is the explanation for that law, then what theories and laws exist within the discipline of friction ridge science?

The two most basic laws are:

1) Human friction ridge skin is unique.

> Each individual possesses a unique arrangement of friction ridge skin. Specifically, the ridge arrangements, the robust arrangements of the minutiae within the ridge patterns, and the shapes and structures of the ridges all combine to form a unique arrangement of friction ridge skin in the hands and feet of each individual.

2) Human friction ridge skin is persistent (permanent) throughout the individual's lifetime.

> Specifically, what is meant by persistence is that the sequence of the ridges and the arrangement of the robust minutiae do not change throughout a person's lifetime. This is not to say that the friction ridge skin does not change over time. It does. Friction ridge skin expands as people grow from childhood to adulthood. Skin cells constantly slough off. The substructure of the skin changes over time and ridge heights decrease (Chacko and Vaidya, 1968). The number of visible incipient ridges increases as we age (Stücker et al., 2001). Hairline creases and wrinkles proliferate as we age. All these factors describe a dynamic and changing friction ridge skin. Yet the arrangement of the minutiae and the ridge sequences is very robust and reproducible. There is evidence to support that third-level details (e.g., ridge shapes and pore locations) are persistent; this is explored later in the chapter (see section 14.3.2.2).

The next question of interest is, Are these scientific laws? According to Popper, to satisfy the criteria for scientific laws, these laws must be falsifiable. Clearly, both laws are easily falsifiable. One must simply find instances where different individuals have indistinguishable friction ridge skin or instances where the arrangement of the ridges in friction ridge skin is observed to naturally change over time (excluding injury or trauma, of course). However, in the history of this discipline, no such instances have been demonstrated.

Suppose one individual, in the entire world, actually did have a fingerprint that matched someone else's fingerprint. Obviously, the forensic community would be shocked, and the verity of the law would be questioned. But in a purely Popperian view (Thornton, 2005):

> No observation is free from the possibility of error—consequently we may question whether our experimental result was what it appeared to be. Thus, while advocating falsifiability as the criterion of demarcation for science, Popper explicitly allows for the fact that in practice a single conflicting or counter-instance is never sufficient methodologically to falsify a theory [or law], and that scientific theories [or laws] are often retained even though much of the available evidence conflicts with them, or is anomalous with respect to them.

Thus, Popper advocated constant testing to refute a theory or law. A single instance of falsifiability should spawn additional testing.

Fundamental theories exist that explain the two laws of uniqueness and persistency. Uniqueness is explained by biological variations (genetic influences and random localized stresses) within the developing fetus. Persistence is maintained by the substructural formations of the developing skin (hemidesmosomes, papillae, and basal layer).

These are theories that explain the laws. These theories have empirical evidence and testing that support, but do not conclusively prove, them. Additional information may be learned that will cause these theories to be adjusted and incorporate the new data. Thus, science is evolving and dynamic.

14.2.4 Hypothesis Testing

Theories and laws are commonly challenged through hypothesis testing. The results of testing a hypothesis can support or refute a theory or law. In some instances, the results will call for modifications to be made to a law or theory, which in turn leads to further hypotheses to test under the new or modified law.

Although there are no rigorous formulas or recipes for testing hypotheses and designing experiments (nor should there be), a generic model for hypothesis testing can be described. The steps of this model are often referred to as "scientific method". Huber and Headrick (1999) noted that the term scientific method is a misnomer. They stated that scientific method is derived from epistemology (the study of knowledge and justified belief, according to the *Stanford Encyclopedia of Philosophy*). Francis Bacon defined a basic approach to scientific method encapsulated in four steps: (1) observe, (2) measure, (3) explain, and (4) verify (Huber and Headrick, 1999). This description in modern times has been modified into a hypothesis testing model. The basic steps of the hypothesis testing model have been described as:[1]

- Observation.
- Hypothesis formulation.
- Experimentation.
- Data analysis and conclusion.
- Reproducibility.
- Communication of results.

The researcher must first make a specific observation or note a general problem or query. Then a hypothesis is formulated (often referred to as the "null hypothesis"). The hypothesis is testable and falsifiable. A counterhypothesis is also formulated. A suitable experiment is designed to test the specific hypothesis. Data from the experiment are collected. These data may be qualitative or quantitative. The data are evaluated, often statistically (though not a requirement), and conclusions are drawn whether to accept the hypothesis or reject the hypothesis and accept the null hypothesis. The results of the experiment should be reproducible by another scientist following the methodology. Finally, the results should be communicated to others. This is not only important for sharing the knowledge, but also for peer review and critical analysis.

14.2.5 Comparison Methodology and Theory

As an extension of the law that friction ridge skin is unique, if during the deposition of a latent print, the details of the friction ridge skin are sufficiently recorded on a surface via residues on the friction ridge skin, then theoretically *the latent print image can be individualized to the source friction ridge skin.*

This is what Hempel and Oppenheim (1948) refer to as a derived theory (as opposed to a fundamental theory). The derived theory allows application of the principle to specific objects or individuals that would be prohibited by the universality and generality requirements of a law or fundamental theory. However, the theory that latent prints can be attributed to a unique source of friction ridge skin raises some questions that are difficult to answer.

Even if the friction ridge skin is unique down to the cells and ridge units, this issue is secondary to whether a latent print (which will not contain all of the information in the source skin) can be correctly attributed to its source. How much information must be transferred for the examiner to reliably individualize the latent print? What happens to the reliability of the details when subjected to distortions? What tolerances are acceptable regarding distortions and the flexibility of skin?

Ultimately, the latent print will be compared to a source (via known standard reproductions) by an expert. The comparison methodology generally accepted in the United States is the ACE-V methodology. This is an acronym for analysis, comparison, evaluation, and verification. The stages of ACE-V methodology are defined as *Analysis*—Assessment of the quantity and quality of ridge detail present in an impression; *Comparison*—A side-by-side comparison of the two

[1] This basic model can be found in most elementary collegiate science texts in various forms.