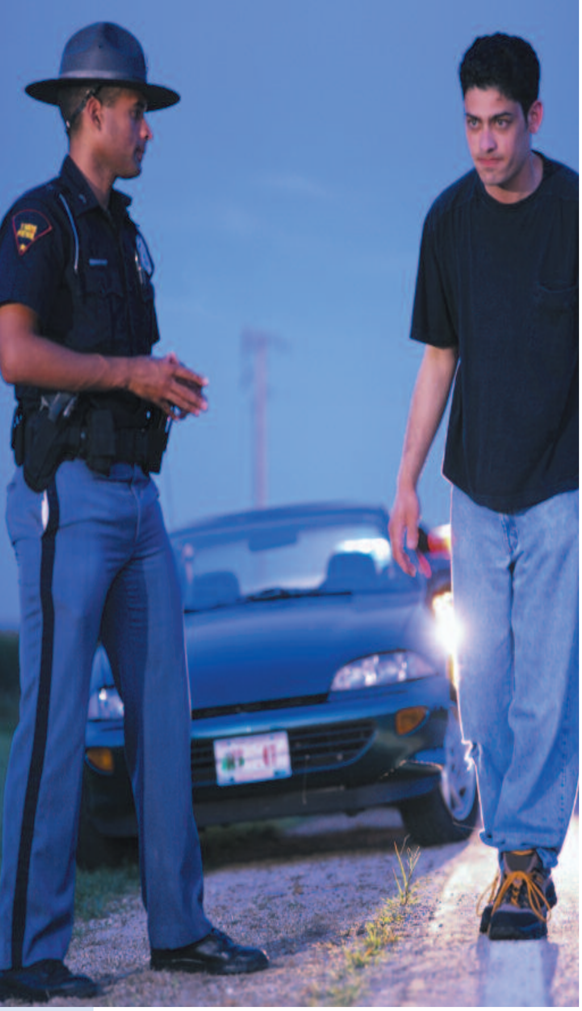

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BY TED VOSK

Trial by Numbers

Uncertainty in the Quest For Truth and Justice

"All results for every forensic science method should indicate the uncertainty in the measurements that are made, and studies must be conducted that enable the estimation of those values."[1]

On Aug. 5, 2010, prosecution expert Rod Gullberg was handed a breath alcohol test ticket with the values 0.081 and 0.080 printed on it. Assuming the lab followed proper quality assurance procedures and testing protocols, all parties agreed that these were the results of an accurate and reliable test. Gullberg was then asked, given these results and the fact that this was an accurate and reliable test, could he state beyond a reasonable doubt that this individual's breath alcohol concentration (BAC) exceeded a 0.080 (the *per se* limit in the state of Washington). Gullberg responded: "I would have to say yes based on these results here."

Similar evidence and testimony, concerning a range of forensic measurements, are introduced in courtrooms around the country every day. And based on such evidence and testimony, citizens accused of all manner of crimes are found guilty. In the context of a prosecution for driving under the influence of alcohol, where guilt may be based on a number alone and a machine is the only way to determine an individual's breath or blood alcohol concentration, many simply plead guilty in the face of such evidence. But what if the results from an accurate and reliable test do not actually mean what most of us presume?

Despite the fact that the test under consideration was agreed to be accurate and reliable, within 10 minutes of his testimony Gullberg reversed himself, stating that he could not conclude based on the test results that the individual's BAC was in excess of a 0.080. In fact, he conceded that while the test

Figure 1

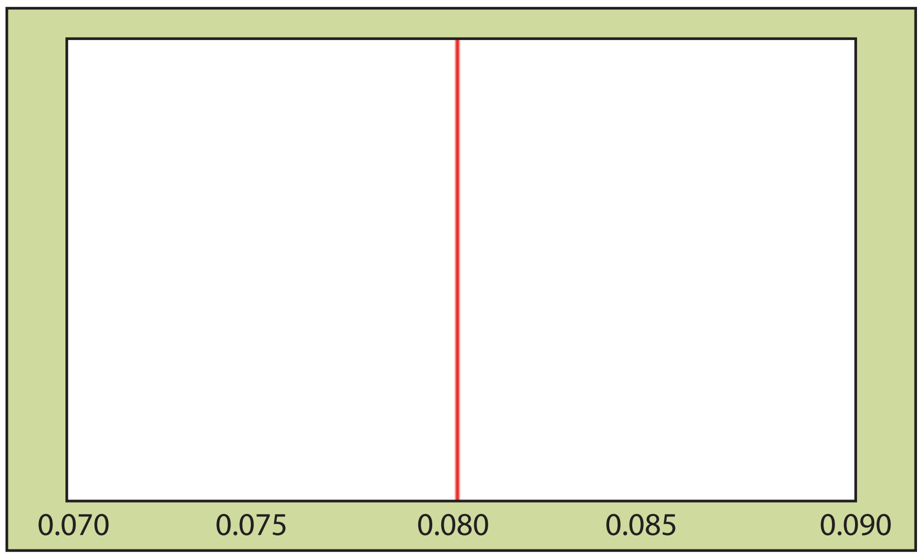
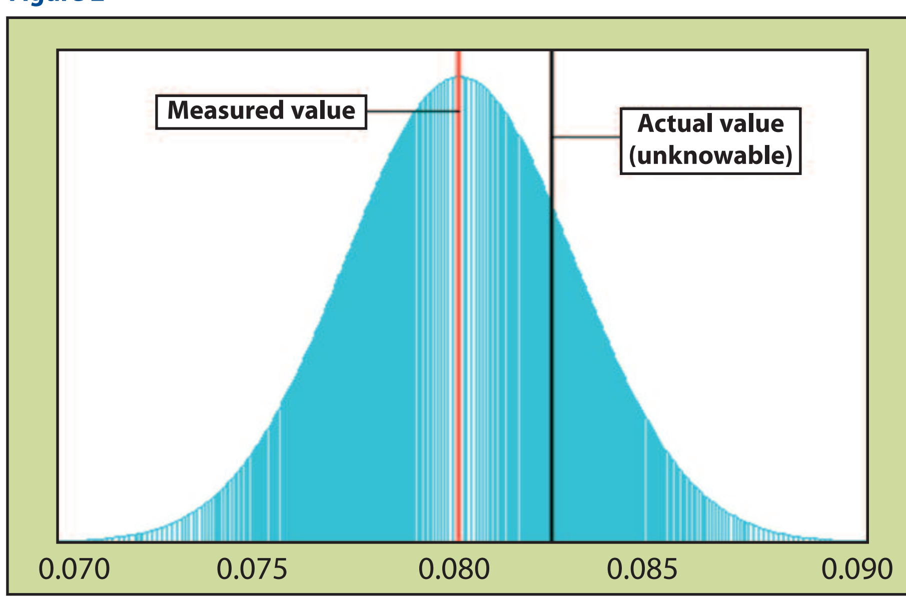


Figure 2



was accurate and reliable, there was actually a 44 percent likelihood that the individual's BAC was below a 0.080! Far more than a reasonable doubt, these "accurate and reliable" test results barely established the conclusion as more likely than not! Absent those critical 10 minutes, an innocent citizen could have been convicted based on evidence that meant something very different from what the state presented it to establish.

What happened in those 10 minutes to change Gullberg's opinion? Did he lie? Were the wrong values printed on the breath test ticket? Was there something wrong with the test?

Measurement Uncertainty

To many, the result of a measurement represents a singular, well-defined property of a thing being measured (the "measurand"). In such a world, a breath test result of 0.080 would be interpreted as representing an individual's true and specific breath alcohol concentration.[2] (See Figure 1.)

Unfortunately, reality is not quite so simple. For even the most carefully performed measurement, the value of a thing being measured can never be known exactly; all that can ever be given is an estimated value.[3]

> [F]or a given measurand and a given result of measurement of it, there is not one value but an infinite number of values dispersed about the result that are consistent with all of the observations and data and one's knowledge of the physical world, and that with varying degrees of credibility can be attributed to the measurand.[4]

Thus, in the real world, a breath test result of 0.080 is more appropriately represented as a packet of values, any of which could actually be attributed to an individual's BAC. (See Figure 2.)

If the illustration in Figure 2 is reminiscent of the familiar Bell Curve, it is no coincidence. The information obtained from a measurement, which we call its result, is actually a probability distribution that characterizes our knowledge of the measured quantity.[5] That we can never know the singular true value of the thing being measured is due to many factors including "measurement error" and imperfect information concerning the measuring system and thing to be measured.

Measurement uncertainty "reflects the lack of exact knowledge of the value of the measurand."[6] It provides a quantitative statement characterizing the dispersion of values that can actually and "reasonably be attributed to the measurand."[7] It is well-recognized that "the result of a measurement is only an approximation or estimate of the value of the specific quantity subject to measurement and thus the result is complete only when accompanied by a quantitative statement of its uncertainty."[8] For example, "[n]umerical data reported in a scientific paper include not just a single value (point estimate) but also a range of plausible values (e.g., a confidence interval, or interval of uncertainty)."[9]

The most common way of expressing measurement uncertainty is as a coverage interval. It consists of a range of values that can be attributed to the measurand as well as a level of confidence that the "true" value is contained within that range. Assuming a measured value of y and an expanded uncertainty U determined to have a 95 percent likelihood of containing the true value of a measurand, a complete measurement result X and the accompanying coverage interval would be expressed as follows:

Measurement Result = Value ± Uncertainty

$$X = y \pm U \ (95\%)$$

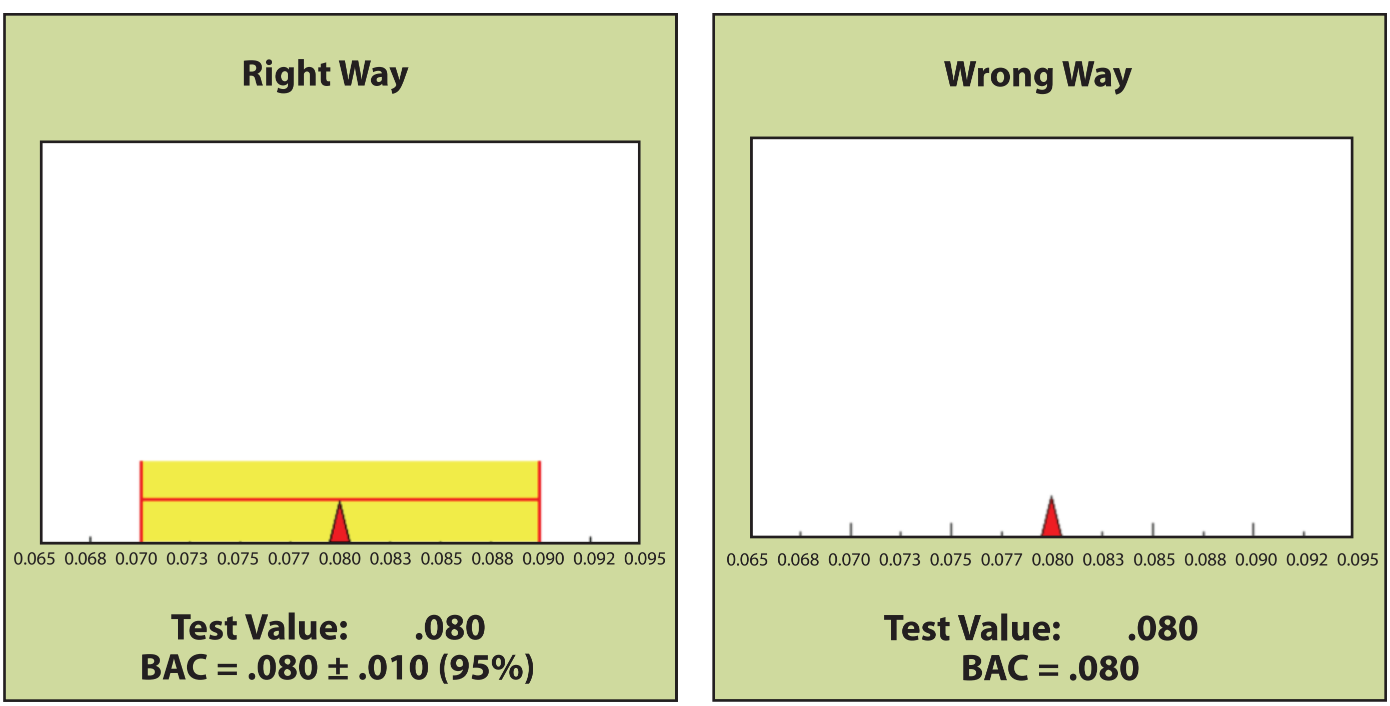
Coverage Interval

$$y - U \leq X \leq y + U$$

Returning to the example of a breath test result of 0.080, and assuming an uncertainty of ± 0.010 with a 95 percent level of confidence, the right and wrong way to conceive of and report the result of the BAC measurement is shown in Figure 3.

Thus, despite the fact that the value reported is a 0.080, all we can really say is that the values that can actually be attributed to the BAC in question range

Figure 3



from .070 to .090 with a 95 percent level of confidence. This applies to all forensic measurements. Whether it is measuring the level of blood alcohol in an individual, the heroin content of a sample or any other quantity subject to measurement, the quantities of interest can be determined "only within a confidence interval of possible values."[10]

Although there are different approaches for determining uncertainty,[11] the same general principles and tools utilized are applicable to all measurements.[12] First, all sources of uncertainty that may affect the use to which the result is put must be taken into account.[13] A common way to document sources of measurement uncertainty, as well as their relationship to each other and the final result, is a cause and effect diagram. (See Figure 4.)

Figure 4: Cause and Effect Diagram

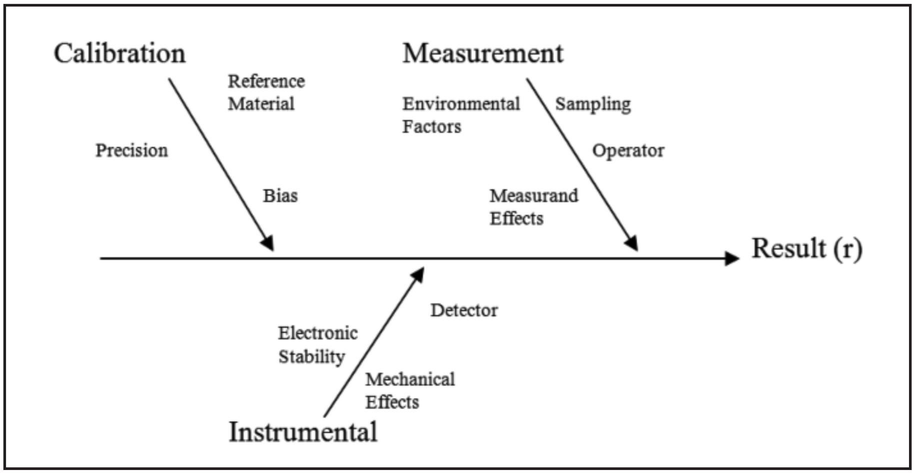


Figure 5: Uncertainty Budget

Uncertainty Source	Type A	Type B	
Calibration			
Ref. Mat.		.052	
Precision	. 080		
Bias	.068		
Combined Uncertainty by Type	.105	.052	
Combined Uncertainty Calibration			.117
Instrumental			
Mechanical Effects	.064		
Electronic Stability	.055		
Detector		.041	
Combined Uncertainty by Type	.084	.041	
Combined Uncertainty Instrumental			.093
Measurement			
Environmental Factors	.101		
Sampling	.112		
Operator	.064		
Measurand Effects		.055	
Combined Uncertainty by Type	.164	.055	
Combined Uncertainty Measurement			.173
Total Uncertainty			
Combined Uncertainty			.229
Expanded Uncertainty (*k*=2)			±.458

Once the relevant sources of uncertainty have been identified, the amount of uncertainty contributed by each must be determined.[14] These values are then added together to yield the combined uncertainty, μ_c.[15] Multiplying the combined uncertainty by an appropriate coverage factor, *k*, generates the expanded uncertainty, $U = k\mu_c$, discussed above.[16] This information is commonly documented in an uncertainty budget.[17] (See Figure 5.)

The coverage factor, shown in Figure 6, is important because it determines how large the coverage interval will be and the level of confidence associated with it. The actual level of confidence associated with a given coverage factor depends upon the probability distribution associated with the measurement. For most real world situations, the underlying distribution will be approximately normal[18] so that $k = 2$ yields a level of confidence of approximately 95 percent and $k = 2.576$ gives a level of confidence of approximately 99 percent.

Coverage Interval[19]

$$y - k\mu_c \le X \le y + k\mu_c$$

One important thing to note is that the uncertainty associated with a measurement is likely to differ when the measurement comes from two different sources. Accordingly, even where two measurements from distinct entities report identical values, the results may have very different meanings. For example, assume two individuals submit to a breath test but on different breath test machines, and that each test yields a value of 0.095.[20] Given that the uncertainties associated with each test are likely different, the values reported may give a clear indication that one of these individual's BAC is over a 0.08 while revealing that the values that could actually and reasonably be attributed to the other's BAC include those under the *per se* threshold. (See Figure 7.)

Here, identical test values but with different uncertainties yield different results[21] and different interpretations. Depending on which circumstance applies, a jury may come to a very different conclusion. Clearly, "considering or not the uncertainty of a critical result can make the difference between acquittal and a guilty sentence."[22] Again, the same thing applies to all measurements, not just those pertaining to forensic alcohol analysis.[23]

> Knowledge of the uncertainty associated with measurement results is essential to the interpretation of the results. Without quantitative assessments of uncertainty, it is impossible to decide whether observed differences between results reflect more than experimental variability, whether test items comply with specifications, or whether laws based on limits have been broken. Without information on uncertainty, there is a risk of misinterpretation of results. Incorrect decisions taken on such a basis may result in unnecessary expenditure in industry, incorrect prosecution in law, or adverse health or social consequences.

Measurement uncertainty is "fundamental to the interpretation and reporting of results."[24] Absent a statement of uncertainty, a result "lacks worth [and] credibility"[25] and may be considered "meaningless."[26] In particular, "[a]ll results for every forensic science method should indicate the uncertainty in the measurements that are made."[27] When the result of a forensic measurement is reported simply as "'a number,' it does not reflect the accuracy of the measurement and cannot be properly interpreted."[28] "Estimating and reporting measurement uncertainty with the number completes the picture and allows us to properly use the result to make reliable and defensible decisions."[29]

Some Answers

What happened in those critical 10 minutes to change Rod Gullberg's opinion? When he was initially presented with the "results" of the breath test in question, they were incomplete because they did not include any information concerning their uncertainty. (See Figure 8.) As already shown, the picture created by such incomplete results is rather simplistic. (See Figure 9.)

Without more information, the breath test ticket clearly seems to communicate that the BAC of the individual in question exceeded the legal limit.

It was only after Gullberg had declared that he could conclude that this individual's BAC exceeded a 0.080 beyond a reasonable doubt that he was provided with the test's uncertainty. To a 99 percent level of confidence, the coverage interval was defined as 0.0731 to 0.0877. That means the values that could actually and reasonably be attributed to the BAC in question ranged from 0.0731 to 0.0877 with a 99 percent level of confidence. This creates a very different picture indeed.

In fact, by visual inspection alone

Figure 6: Distributions, Coverage Factors and Coverage Intervals

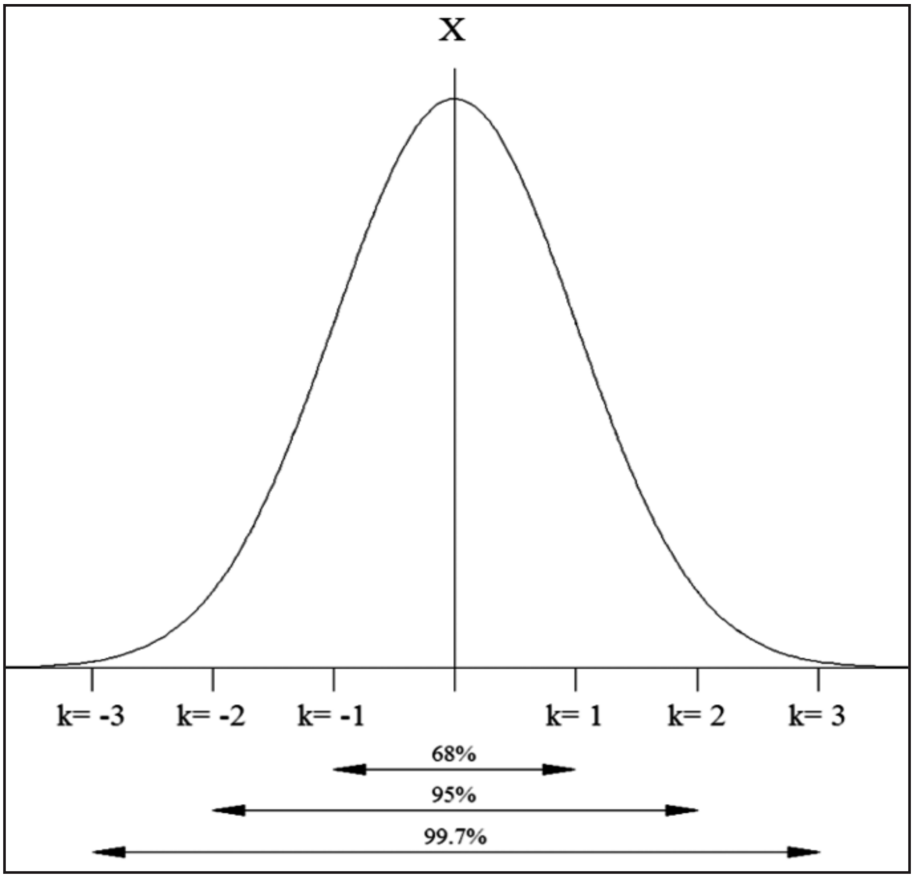
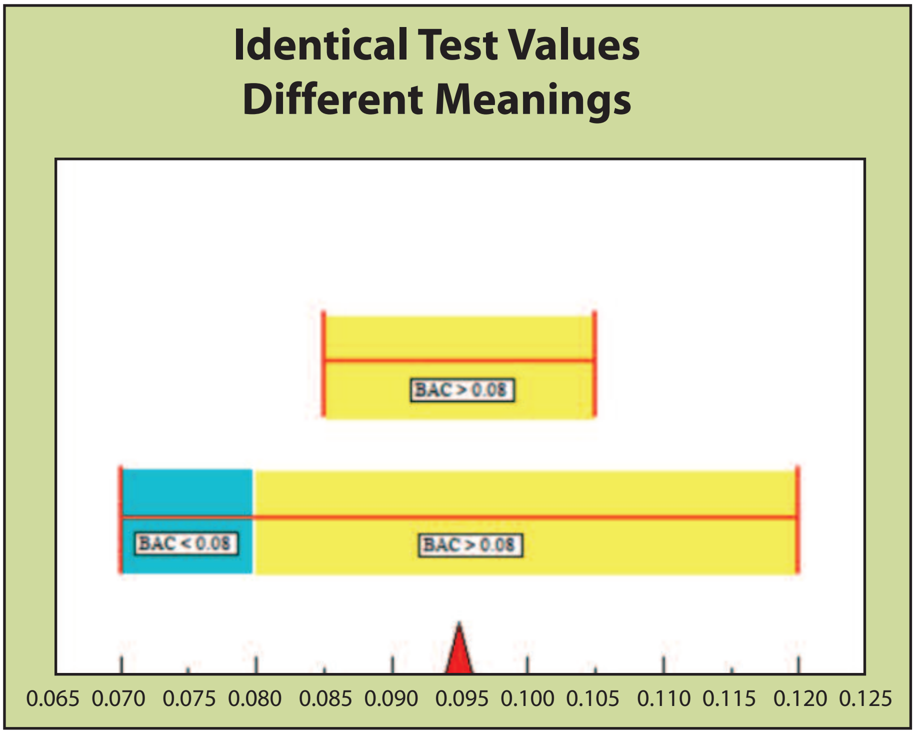


Figure 7



(Figures 10 and 11) we can determine that it is almost as likely that this individual's actual BAC is under the legal limit as it is over.

And given the coverage interval, Gullberg was easily able to confirm that the likelihood that this individual's true BAC was under a 0.080 was 44 percent.[30] To understand how this could be determined from the coverage interval, remember that the test result, and hence the coverage interval itself, is characterized by a Gaussian probability distribution, i.e., the Bell Curve. (See Figure 12.)

Figure 8: Breath Test Ticket

Breath Analysis		
Blank Test	.000	02:32
Internal Standard	Verified	02:32
Subject Sample	.080	02:33
Blank Test	.000	02:34
External Standard	.082	02:34
Blank Test	.000	02:35
Subject Sample	.081	02:37
Blank Test	.000	02:37

Figure 9

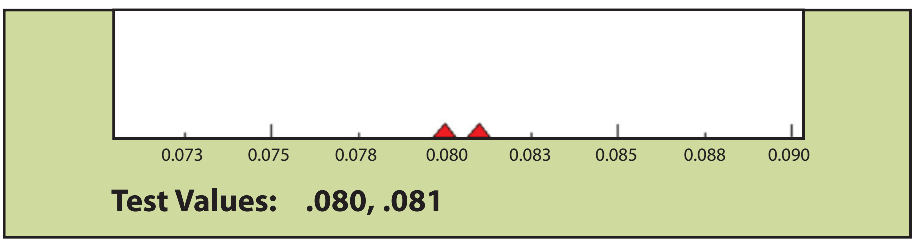


Figure 10

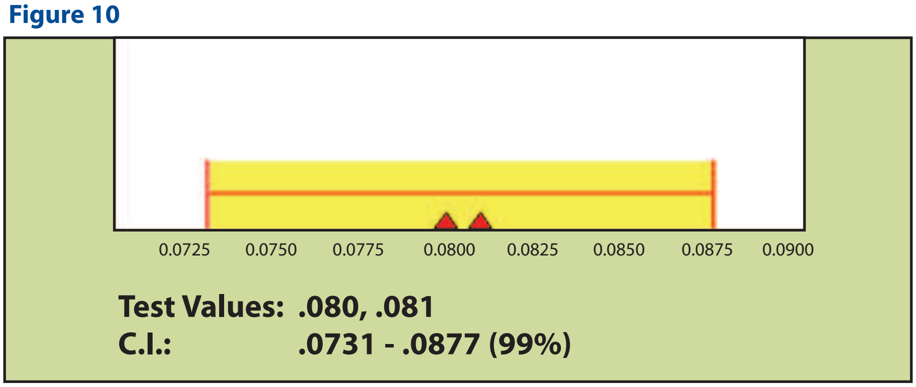
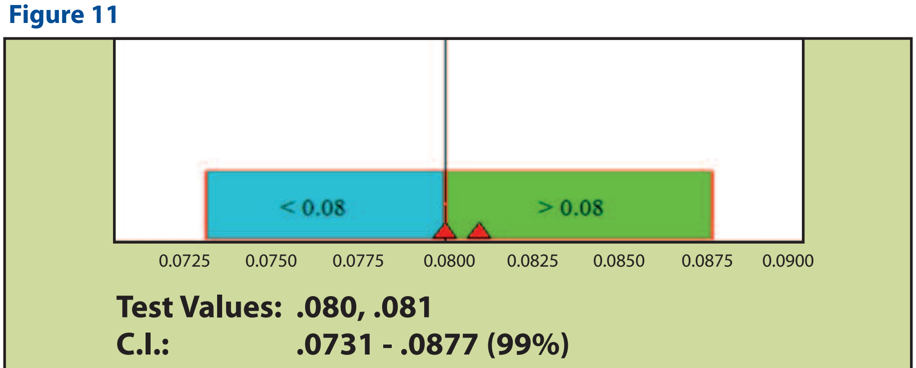


Figure 11



If the total area under the Bell Curve is defined so as to equal 1, the probability that the result lies within any range of values is simply given by the area under the curve contained within that range. Hence, the probability that this particular BAC was actually less than the legal limit is given by the area under the curve within the range from 0.0 to 0.079. (See Figure 13.)

At this point it should be recognized that the inclusion of uncertainty is not a "get out of jail free" card for those charged with DUI or any other crime. Just as the uncertainty may demonstrate a high likelihood that an individual with test values above the legal limit is actually below that limit, it can go the other way as well. It may show that there is a high likelihood that an individual with test values below the limit is actually above that limit. In general, the uncertainty favors neither party. It simply facilitates the discovery of truth by enabling proper interpretation of the evidence. Moreover, except in those cases where the evidence of guilt consists solely of a measurement result, measurement uncertainty does not dictate a particular outcome. Although necessary for the proper interpretation of a measurement result, it is simply another piece of the evidence for the jury to consider and weigh with the rest of the evidence in arriving at a verdict.

Rod Gullberg did not lie. The wrong values were not printed on the breath test ticket. There was nothing wrong with the test. Gullberg simply had not been provided sufficient information upon which to base a reliable and defensible opinion. State Toxicologist Fiona Couper and Quality Assurance Manager Jason Sklerov faced similar lines of questions. Predictably, they were also unable to properly interpret the state's breath test results absent information concerning each test's measurement uncertainty. Each of the state of Washington's top three experts had been asked to interpret the results of breath tests obtained by their own program. And each was unable to do so absent information concerning each test's uncertainty.

Uncertainty in the Quest For Truth and Justice

The aforementioned testimony was obtained during a week-long evidentiary hearing before a panel of three King County District Court judges.[31] The primary subject of the hearings was whether the state could offer *breath* test results as evidence in prosecutions for

DUI without providing both the defendant and jury the uncertainty associated with those results.

Six months earlier, a similar question was raised before Commissioner Paul Moon of the Snohomish County District Court with respect to the admissibility of a *blood* test result absent its uncertainty. The commissioner found the blood test inadmissible under Washington Rules of Evidence 702 and 403. With respect to the first evidentiary provision, the court found:[32]

> If an expert testifies that a particular blood alcohol content measurement is value A, without stating a confidence level, it is this court's opinion that the evidence is being represented as an exact value to the trier of fact … [and] that presenting to the trier of fact the result of a blood test as an exact numerical value without stating a confidence level, is not generally acceptable in the scientific community and misrepresents the facts to the trier of fact. … This court holds that the result of the blood test in this case is not admissible under ER 702 in the absence of a scientifically determined confidence level because it misrepresents the facts and therefore cannot be helpful to the trier of fact.

Addressing Evidentiary Rule 403, the court explained:[33]

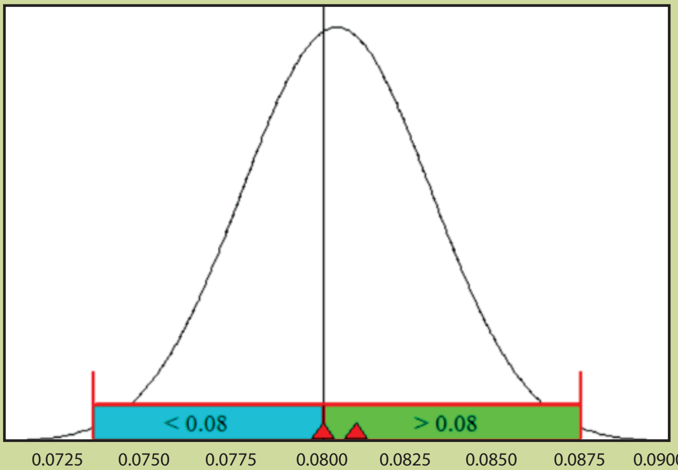
> It has been this court's experience since 1983 that juries it has presided over place heavy emphasis on the numerical value of blood alcohol tests. To allow the test value into evidence without stating a confidence level violates ER 403. The probative value of this evidence is substantially outweighed by its prejudicial value. Therefore this court holds that the result of the blood test in this case is not admissible under ER 403 in the absence of a scientifically determined confidence level.

The prosecution chose not to present any witnesses at this earlier proceeding.[34] With this as prologue, however, the prosecution presented testimony from the state's three top *breath* test experts at the King County hearings.[35] These experts proved of little benefit to the prosecution.

King County prosecutors[36] were forced to acknowledge that their own experts were unable to properly interpret the breath test results presented absent information concerning each test's uncertainty. They also acknowledged that it was unlikely that the typical defendant or juror would fare any better and may be misled by such results as easily as the prosecution's experts were. Nonetheless, the state argued that it had no duty to provide the uncertainty of breath test results to either the defendant or jury, and that the court had no power to require it to do so. It maintained that even though it knew that its evidence was incomplete and subject to being misleading and misinterpreted when unaccompanied by measurement uncertainty, the justice system was intended to permit whatever results such evidence might engender — even if it meant that innocent citizens would be deprived of their liberty and guilty individuals set free as a result.

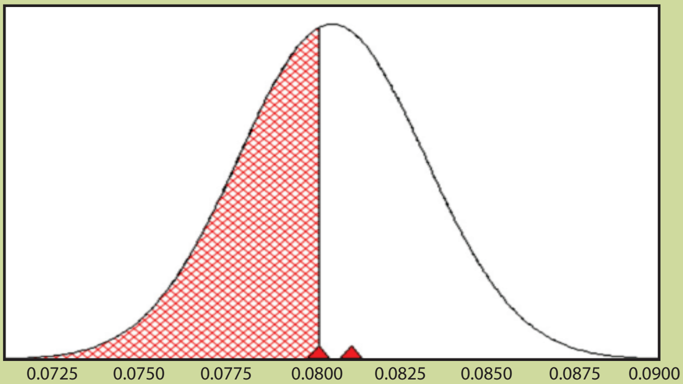
Washington prosecutors are not alone in this mindset. Although a few forensic labs properly account for uncertainty in the results they report, "most [forensic] reports do not discuss measurement uncertainties or confidence limits."[37] Yet it is exactly this type of incomplete and often misleading evidence that is offered by prosecutors around the country every day. What is more alarming is that courts around the country permit this very evidence to form the basis for depriving citizens of their liberty on a daily basis as well. Such practices not only threaten individual liberty, but strike at the integrity of the justice system itself by hindering its ultimate mission of determining the truth. As the King County Court noted:[38]

Figure 12



Test Values: .080, .081
C.I.: .0731 - .0877 (99%)

Figure 13



Test Values: .080, .081
C.I.: .0731 - .0877 (99%)
P < 0.08: ~44%

A prosecutor is a participant in a system of criminal justice which is, by design, adversarial. Yet, a good prosecutor will never let the desire to "win" overcome his or her sense of justice. A trial court will follow precedent when it rules on matters before the court, but precedent will never be allowed to overcome the determination of a good judge to do justice in each and every case. What was trustworthy and reliable yesterday may not be today. As concepts of justice advance through each generation of police, criminal justice practitioners, attorneys and judges, we aim to provide better justice than was provided by those before us. As concepts of science change, we also need to be ready to move forward with those new, better practices. Nor should the court allow an instrument or a machine to determine an element of a criminal offense — unless there are appropriate safeguards to ensure that the evidence provided by the machine is what it purports to be. It bears repeating that these safeguards are foundational to our criminal justice system.

In the end, what this issue boils down to is plain and simple truth. The defense in this hearing was not asking for something that would derail prosecutions or preclude convictions. It was simply asking the court to require the state to report the results of its forensic measurements in a complete and accurate manner so that both defendants and jurors could properly interpret that evidence and would not be misled by it. The court saw the issue the same way:[39]

> When a witness is sworn in, he or she most often swears to "tell the truth, the whole truth, and nothing but the truth." In other words, a witness may make a statement that is true, as far as it goes. Yet there is often more information known to the witness, which if provided, would tend to change the impact of the information already provided. Such is the case when the state presents a breath-alcohol reading without revealing the whole truth about it. That whole truth, of course, is that the reading is only a "best estimate" of a defendant's breath-alcohol content. The true measurement is always the measurement coupled with its uncertainty.

The court subsequently recognized that "a breath-alcohol measurement without a confidence interval is inherently misleading."[40]

Neither the lab nor the prosecution provided the court with any reason why uncertainty either was not or could not be provided with the result of every test.[41] In Washington, the uncertainty of every breath test that will be conducted on an instrument over the course of a year can be determined in five minutes at the time of the instrument's annual calibration using an Excel spreadsheet. Thus, whether it is one test, 100 tests, 1000 or tens of thousands, the uncertainty of all these tests together can be determined in five minutes, once a year, and then printed up in a table to be supplied to every defendant and jury along with the test results. Given the ease with which the uncertainty can be determined and supplied, one is left wondering why the state would not *want* to supply this information.

The panel concluded that for breath test results to be admissible in prosecutions for DUI, both the defendant and jury must be provided with the uncertainty associated with those results. First, under principles of Due Process and the rules governing discovery, it stated:[42]

> [W]e now place the state on notice that every discovery packet supplied to defendants must contain the confidence interval for any breath-alcohol measurement the state intends to offer into evidence in that case. Should the state fail to comply with this discovery order, then upon objection, such breath-alcohol measurement will not be admitted at trial.

Then, under Evidentiary Rule 702, the court found:[43]

> Once a person is able to see a confidence interval along with a breath-alcohol measurement, it becomes clear that all breath-alcohol tests (without a confidence interval) are only presumptive tests. The presumption, of course, is that a breath-alcohol reading *is* the mean of two breath samples. This answer, however, is obviously incomplete. (Put another way, a breath-alcohol measurement without an uncertainty measurement does not tell the "whole truth." RCW 5.28.020.) As discussed above, a breath test reading is only a "best estimate" of an individual's breath-alcohol level. The determination of a confidence interval completes the evidence. Therefore, upon objection, a breath-alcohol measurement will not be admitted absent its uncertainty level, presented as a confidence interval.

Thomas Bohan, immediate past president of the American Academy of Forensic Sciences, hailed the King County Court opinion as a landmark decision, engendering a huge advance toward rationality in our justice system and a victory for both forensic science and the pursuit of truth.

Conclusion

"The ultimate mission of the system upon which we rely to protect the liberty of the accused as well as the welfare of society is to ascertain the factual truth."[44] "Complete, competent, and impartial forensic science investigations can be that 'touchstone of truth' in a judicial process that works to see that the guilty are punished and the innocent are exonerated."[45] Given the potential consequences to individuals and society alike, however, reliance upon forensic science "is not a matter to take lightly, or to trust to luck."[46] Accordingly, "[i]n this age of science we must build legal foundations that are sound in science as well as in law."[47] This can be achieved "only by requiring scientific evidence to conform to the standards and criteria to which scientists themselves adhere."[48] If we are to follow this path, then we must understand that science can never tell us what is and is not true: "It is scientific only to say what is more likely and what is less likely."[49]

Notes

1. National Academy of Sciences (NAS hereinafter), Strengthening Forensic Science in the United States: A Path Forward 184 (2009).

2. All graphic illustrations were created utilizing ProStat Software.

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3. BIPM (Bureau International des Poids et Mesures), *Evaluation of Measurement Data — Guide to the Expression of Uncertainty in Measurement (GUM)*, § 3.1.2, Appendix D.4 (2008); Kirkup, *An Introduction to Uncertainty in Measurement* 33 (2006); NIST, *Guidelines for Evaluating and Expressing the Uncertainty of NIST Measurement Results*, NIST TN 1297 § 2.1 (1994); Kristiansen, *An Uncertainty Budget for the Measurement of Ethanol in Blood by Headspace Gas Chromatography*, 28(6) J. ANAL. TOX. 456 (2004).

4. BIPM, *Evaluation of Measurement Data — Guide to the Expression of Uncertainty in Measurement (GUM)*, § 5.2 (2008); BIPM, *International Vocabulary of Metrology — Basic and General Concepts and Associated Terms (VIM)*, § 0.1 (2008); Ehrlich, *Evolution of Philosophy and Description of Measurement* 12 ACCRED. QUAL. ASSUR. 201, 208 (2007).

5. Estler, *Measurement as Inference: Fundamental Ideas* 48(2) ANNALS CIRP 611, 623 (1999).

6. BIPM, *Evaluation of Measurement Data — Guide to the Expression of Uncertainty in Measurement (GUM)*, § 3.3.1 (2008).

7. BIPM, *Evaluation of Measurement Data — Guide to the Expression of Uncertainty in Measurement (GUM)*, § 2.2.3 (2008); BIPM, *International Vocabulary of Metrology — Basic and General Concepts and Associated Terms (VIM)*, § 2.26 (2008); EURACHEM, *Quantifying Uncertainty in Analytical Measurement* CG-4, § 2.1.1 (2000); Hofmann, *Common Sources of Error in Measurement*, Handbook of Measuring System Design V.1, p. 289, 293 (Sydenham & Thorn ed., 2005).

8. NIST, *Guidelines for Evaluating and Expressing the Uncertainty of NIST Measurement Results*, NIST TN 1297 § 2.1 (1994); JCGM, *Evaluation of Measurement Data — Guide to the Expression of Uncertainty in Measurement (GUM)*, § 3.1.2 (2008).

9. NAS, STRENGTHENING FORENSIC SCIENCE IN THE UNITED STATES: A PATH FORWARD 116 (2009).

10. NAS, STRENGTHENING FORENSIC SCIENCE IN THE UNITED STATES: A PATH FORWARD 116-117 (2009).

11. These include the top-down, bottom-up and total-error approaches. EURACHEM, *Measurement Uncertainty Arising From Sampling: A Guide to Methods and Approaches* §§ 6.1, 9.1.1, 10.1.1, 12.1 (2007); Gullberg, *Statistical Applications in Forensic Toxicology*, Medical-Legal Aspects of Alcohol 490 (James Garriott ed., 5th ed. 2009).

12. BIPM, *Evaluation of Measurement Data — Guide to the Expression of Uncertainty in Measurement (GUM)* (2008); EURACHEM, *Measurement Uncertainty Arising From Sampling: A Guide to Methods and Approaches* §§ 6.1, 9.1.1, 10.1.1, 12.1 (2007); ISO, *General Requirements for the Competence of Testing and Calibration Laboratories*, ISO 17025 § 5.4.6.3 Note 3 (2005); NIST, *Guidelines for Evaluating and Expressing the Uncertainty of NIST Measurement Results*, NIST TN 1297 §§ 1.2, 1.3 (1994); EURACHEM, *Quantifying Uncertainty in Analytical Measurement* CG-4, § 1.1 (2000); A2LA, *Guide for Estimation of Measurement Uncertainty in Testing*, § 1.0 (2002); UKAS, *The Expression of Uncertainty and Confidence in Measurement*, M3003 (2007); ILAC *Introducing the Concept of Uncertainty of Measurement in Testing in Association With the Application of the Standard ISO/IEC 17025*, ILAC G-17 § 5.2 (2002); NIST, *National Voluntary Laboratory Accreditation Program: Procedures and General Requirements*, NIST Handbook 150 § 5.4.6.3 (2006); NATA, *Assessment of Uncertainties of Measurement for Calibration and Testing Laboratories* 8 (2d ed. 2002).

13. ISO, *General Requirements for the Competence of Testing and Calibration Laboratories*, ISO 17025 § 5.4.6.3 (2005).

14. *The Metrology Handbook* 306 (Bucher ed., 2004).

15. For reasons beyond the scope of this article, uncertainties are not added like normal numbers. Instead, they are combined in the same manner standard deviations are combined: each value is squared, the squares are added and then the square root of the sum is determined. The result is the measurement's combined uncertainty:

$$\mu_c = \sqrt{s_1^2 + s_2^2 + \cdots + s_i^2}$$

16. Expanded uncertainty:

$$U = k\mu_c$$

With this information, a complete result and coverage interval can be expressed as:
Result:

$$X = y \pm U\ (95\%) = y \pm k\mu_c\ (95\%)$$

Coverage interval:

17. *The Metrology Handbook* 311-315 (Jay Bucher ed., 2004).

18. This is due to the Central Limit Theorem. BIPM, *Evaluation of Measurement Data — Guide to the Expression of Uncertainty in Measurement (GUM)*, App. G.2 (2008); Kirkup, *An Introduction to Uncertainty in Measurement* 143-150 (2006); Rabinovich, *Measurement Errors and Uncertainties: Theory and Practice* 68 (2005); Estler, *Measurement as Inference: Fundamental Ideas* 48(2) Annals CIRP 611, 623 (1999); Halaj, *General Charicterization of Systematic and Stochastic Errors*, Handbook of Measuring System Design V.1, p. 295, 297-8 (Sydenham & Thorn ed., 2005).

19. See note 15.

20. Example adapted from Gullberg, *Estimating the Measurement Uncertainty in Forensic Breath Alcohol Analysis*, 11 Accred. Qual. Assur. 562, 562 (2006); Gullberg, *Common Legal Challenges and Responses in Forensic Breath Alcohol Determination*, 16(2) Forens. Sci. Rev. 92, 93 (2004).

21. Remember, a test result consists of both the test value and its associated uncertainty.

22. Bich, *Interdependence Between Measurement Uncertainty and Metrological Traceability* 14 Accred. Qual. Assur. 581, 581 (2009).

23. ISO, *Guidance for the Use of Repeatability, Reproducibility and Trueness Estimates in Measurement Uncertainty Estimation*, ISO/TS 21748 draft revision, v (2009); ISO, *Guidance for the Use of Repeatability, Reproducibility and Trueness Estimates in Measurement Uncertainty Estimation*, ISO/TS 21748, v (2004).

24. SWGDRUG, *Recommendations*, Part IV-C § 1.1 (5th ed. 2010).

25. NATA, *Assessment of Uncertainties of Measurement for Calibration and Testing Laboratories* 8 (2002).

26. A2LA, *Guide for Estimation of Measurement Uncertainty in Testing*, § 1.0 (2002).

27. NAS, Strengthening Forensic Science in the United States: A Path Forward 184 (2009).

28. Bono, *ISO/IEC 17025:2005: Section 5.4.6: Estimation of Uncertainty — Is Anyone Certain What This Means? at* 7, Presentation at the 61st Annual Meeting of the American Academy of Forensic Sciences (2/17/2009) (emphasis added).

29. Bono, *ISO/IEC 17025:2005: Section 5.4.6: Estimation of Uncertainty — Is Anyone Certain What This Means? at* 7, Presentation at the 61st Annual Meeting of the American Academy of Forensic Sciences (2/17/2009).

30. The determination is based upon the assumption that the underlying distribution is Gaussian (i.e., normal, a Bell Curve).

Confidence Interval: .0731 — .0877

$\bar{Y}_{bc}$ (bias corrected mean):

$$\frac{(b_l + b_u)}{2} = \frac{(.0731 + .0877)}{2} = .0804$$

U (expanded uncertainty — 99%):

$$\bar{Y}_{bc} - b_l = .0804 - .0731 = .0073$$

μ_c (combined uncertainty):

$$\frac{U}{2.576} = \frac{.0073}{2.576} = .00283$$

$z_{\bar{Y}_{bc} \to .08}$ (z-factor):

$$\frac{(\bar{Y}_{bc} - .08)}{\mu_c} = \frac{(.0804 - .08)}{.00283} = .141$$

$P_{bac < .08}$ (probability BAC less than 0.08):

$$\sim 44\%\ [z_{.141 \to tail}\ Table]$$

The use of this particular example should not be taken as an indication that the uncertainty can only impact the outcome at values very near a critical limit. The evidence showed that when uncertainty was included, results with mean values of 0.030 greater than a particular limit could actually be shown to include values below the limit in question. Moreover, these values were shown to be conservative so that even results in excess of these may be found to include values below a particular limit contained within their associated coverage interval.

31. King County District Court judges David Steiner, Darrell Phillipson and Mark Chow.

32. *State v. Weimer*, No. 7036A-09D at 3 (Snohomish Co. Dist. Ct. March 23, 2010); *available at* http://www.waduicenter.com/wp-content/uploads/2010/04/Snohomish-County-District-Court-Cascade-Decision-Moon-032710.pdf.

33. *State v. Weimer*, No. 7036A-09D at 4 (Snohomish Co. Dist. Ct. March 23, 2010).

34. The only testimony was that of University of Washington Metrologist Dr. Ashley Emery.

35. The state's experts were the former head of the Washington State Breath Test Section Rod Gullberg, State Toxicologist Fiona Couper, and State Toxicology Lab Quality Assurance Manager Jason Sklerov.

36. The King County Prosecutor's Office is headed by prosecutor Dan Satterberg.

37. NAS, Strengthening Forensic Science in the United States: A Path Forward 186 (2009).

38. *State v. Fausto*, No. C076949, at 22-23 (King Co. Dist. Ct. Sept. 21, 2010); *available at* http://www.waduicenter.com/wp-content/uploads/2010/09/Ahmach-II-3-Judge-Panel-Ruling-012210.pdf.

39. *State v. Fausto*, No. C076949, at 23 (King Co. Dist. Ct. Sept. 21, 2010).

40. *Id.* at 28.

41. *Id.* at 17.

42. *Id.* at 26.

43. *Id.* at 28-29.

44. *Commonwealth of Northern Mariana Islands v. Bowie*, 243 F.3d 1109, 1114 (9th Cir. 2001).

45. Peterson, *The Evolution of Forensic Science: Progress Amid the Pitfalls* 36 Stetson Law Rev. 621, 660 (2007).

46. P. Kirk, The Ontogeny of Criminalistics, 54 J. Crim. Law & Police Sci. 235, 238 (1963).

47. Justice Stephen Breyer, in *Reference Manual on Scientific Evidence* 4-8 (2d ed. 2000).

48. Black, *Evolving Legal Standards for the Admissibility of Scientific Evidence*, 239 Science 1508, 1512 (1988).

49. Feynman, *The Character of Physical Law* 165-166 (1965). ■

About the Author

Ted Vosk is licensed to practice in the states of Washington and Massachusetts, as well as in the federal district, circuit and Supreme Courts. His primary areas of practice are criminal defense, appeals, and consulting. He is a graduate of Harvard Law School and has degrees in both physics and mathematics. Vosk has been named a Goldwater Scholar for his work in physics and mathematics, a Rising Star in criminal law by *Washington Law and Politics* magazine, and is a member of MENSA.

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