God's Grace in Weights and Measures

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Abstract

The title of this paper was inspired by a phrase from Proverbs 16:11, ". . .all the weights in the bag are of his making." (NIV) The thesis of this paper is that the Lord has an unusual concern for honest measures and correspondingly has provided a generous benevolence of grace to humanity in the form of providential standards of measurement.

At the 2017 CEC John Tixier presented a paper titled, "Observations on Things Measured in the Bible," in which he recounted the Lord's great interest in honest measures and the Bible's presumption that the reader will understand the standards of measurement being used [1]. In Biblical times the maintenance of standards of measurement was the responsibility of temple priests, particularly to facilitate taxation [2]. As cultures have developed, the role of keeping standards of measurement has become a governmental function, usually via a bureaucracy of scientists who specialize in metrology. During about the last 150 years there has been a clear historical record of basing definitions on observations of nature that give universal results—natural constants as best we can understand them—artifacts of creation. Recently, in November 2018, the General Conference on Weights and Measures (*Conférence Géneral des Poids et Mesures*, CGPM) redefined The International System of Units (*Le Systèm International d'Unités*, SI) in such a way as to define all units of measurement in the SI on defined (rather than measured) natural constants. Most other systems of units refer themselves to the SI, for one example, U.S. Customary units, so the redefinition of the SI by the CGPM has fundamental importance to almost any measurement one could perform.

The nature of historical debates about measurements and standards of measurement have been remarkably peaceful. No government, no matter how corrupt or unloved, has tolerated vendors who use "differing weights," one for buying and one for selling [3]. What debate there has been about standards has been mostly confined to making the standards practical, accurate, and repeatable. Standards of measure have been mostly free from fundamentally rebellious types of conflict. This paper, partially inspired by John Tixier's paper (*ibid*), explores Biblical perspectives on metrology throughout history with emphasis on more recent developments and up-to-date attention given to the November 2018 meeting of the CGPM.

Keywords

General Conference on Weights and Measures (CGPM), grace, International System of Units (SI), measurements, metrology, providence, standards, U.S. customary units.

Introduction

The Holy Bible includes many expressions of God's concern for measurements. At the 2017 Christian Engineering Conference John Tixier elaborated in his paper [1] on the ways that God shows interest in numbers and measures and how God, in some situations, expects measurements to be made. Jesus even speaks of faith as something that can be *measured*. Tixier also describes

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how measurements are used in God's judgements on humanity. (One illustration: "You have been weighed on the scales and found wanting" [4]) Tixir's paper demonstrates that God has a strong interest in measurements.

The particular subject of *honesty in measurements* appears within many books of both the Old and the New Testament. One web site lists about 100 texts that relate to this subject [5]. Proverbs 16:11 is one such text. "Honest scales and balances belong to the Lord; all the weights in the bag are of his making" [6]. Other translations end this verse with, ". . .of his work." In the tradition of wisdom literature in which Proverbs stands, especially the phrase, "all the weights in the bag are of his making" or ". . .of his work" is intriguing and gets one thinking: Are standards of measurement in some sense a product of God's handiwork? How do standards of measurement depend on God's creation and our human response to that creation? Are standards of measurement an outflow from God's grace?

As an introductory teaser, which highlights the central difficulty with keeping standards of measurement, consider the *story of the noon-day cannon* [7, pp 13-15]. Once upon a time, before the era of radio or the internet, as a convenience to mark lunch-time, a small town set off a cannon each day at noon. One child in the town was interested in how the cannon-master knew when to set off the cannon, so he asked the cannon master. The cannon master showed the youngster a fine pocket watch that he used to demark the time for setting off the cannon. The youngster, now generally interested in how people set their clocks, asked the cannon master how he set his watch. The cannon master told the youngster that each Sunday he went to the downtown jewelry store, where there was a large clock mounted on a pedestal by the road in front of the store. Knowing that the jewelry store's clock was considered very accurate and was used by many people in the town to set their clocks, the cannon master was confident in the accuracy of setting his watch by this clock. The youngster, of course then asked the proprietor of the jewelry store how the big clock on the pedestal was set. You guessed it—the big clock was set according to the cannon shot. The youngster, now knowing how each clock in town got set, was satisfied. Every question had an answer. Yet the youngster felt some unease without being able to pin down the reason for the unease.

For much of history this story describes the situation of many standards of measurement that have been used. The main reason these earlier standards did not seem as ridiculous as the story of the noon-day cannon is that the intervals of checking the standards against (circular) references was long, obscuring the insubstantiality of the standard. There has long been a sense of unease with standards, centered on a desire to find a standard that could serve as an ultimate reference. The story highlights the desire for a standard that transcends humanity.

Definitions

Before going further, it will be helpful to digress a bit to define some vocabulary. The definition of a measurement in Tixier's paper is useful. "To measure something is to determine a certain set of its properties in reference to a standard." [1, p 140] In the literature there may be some variation in the language used to further elaborate on the definition of a measurement. In the following pages, there are seven distinguishable concepts defined for the purposes of this paper: 1) a measurement of an object, 2) a unit of measure, 3) a common standard of measurement, 4) a prototype standard, 5) an intermediate standard, 6) a natural standard, and 7) a master standard. A penny will be used as a running example to illustrate these seven concepts of measurement.

Figure 1, A souvenir penny-press. It also happens to be a type of vending machine [8].

1) The word "penny" can refer to a *measured object*—a coin. As an object it has some primary purpose, in this case the embodiment of monetary value. We can measure the value of a penny: one cent. (Similarly, we can measure the value of a dime: ten cents.) Aside from the penny's functional value (one cent) we can measure the diameter and mass and other aspects of a particular penny. Maybe one particular penny was run through a souvenir penny-press (Figure 1), making the measurement of it particularly interesting. Or we can measure aspects of objects inserted into a penny-press in payment. This way the penny-press can recognize a penny and reject a slug. A penny is an object that can be measured, in fact numerous aspects of a penny can be measured.

2.) There is a *unit* associated with a penny, the cent. Sometimes we confound the value with the unit. If one says that a certain candy costs, "two pennies," then one dime would purchase five pieces of the candy—no pennies involved. It would have been more correct to say that one piece of the candy costs two cents, but people use language in various ways. Sometimes such confusion is normalized. For example, mileage measured in miles, voltage, measured in volts. We need to distinguish the units from the measured quantity when language is used that way.

3.) One could quantify mass in "pennies" as a *common standard* of measurement. For example, the mass of a package of sugar could be measured by balancing the sugar with the mass of several pennies drawn from the normal circulation of pennies. Then the price of the sugar could be stated in cents per penny! That is, penny-coins (or monetary equivalent) per penny-mass; or one could also use "the penny" as a unit of length (the diameter of a penny); or "the penny" could be a unit of volume; or a penny can be used to measure tire-tread depth (Figure 2.), etc.

Figure 2, A penny can be used to measure the tread-depth of a tire.
The penny is a common standard *of measurement in this context.*

4.) A *prototype standard* penny might be held at the mint to judge the proper manufacturing of pennies. One particular penny could be held in reserve as being exemplary of a properly manufactured penny. This penny would be the standard by which all other pennies are judged. Only one prototype standard object may be designated; otherwise no unique authority is established. If by some accident the prototype standard should be lost or destroyed (war, earthquake, carelessness, vandalism, "moths and rust" [9], etc.) an existing penny could be selected and promoted to the role of prototype. This hints of the noon-day cannon story since the choice of penny to promote can have no fundamental assurance of being the ideal penny upon which to standardize.

Interestingly, an important prototype standard, the international prototype kilogram, has been kept for about 130 years as a prototype standard from 1889 [10] until just a little over a month ago, as of the presentation of this paper [11].

*Figure 3, "*Le Grand K*," The international prototype kilogram, under three nested bell jars, maintained by the* Bureau International des Poids et Mesures*, Sèvres, France* [10].

5.) A *natural standard* is a set of instructions. The instructions describe the process for building an intermediate standard (defined below). These instructions must have two properties: The first property is that if the natural standard is followed with state-of-the-art technique, the objects produced will always be comparably identical—as measured to the state-of-the-art. Any one of the resulting built objects will be suitable to serve as an intermediate standard. In the case of a penny, a natural standard might be a written description of dimensions, materials, design for the face and obverse sides, etc. The second defining element of a natural standard is that one must be able to make functionally identical copies *of the instructions* for making the intermediate standard. Non-substantive variations *of the instructions* such fading ink, yellowing paper, shrinkage of paper, coffee stains, minor typographic errrors (such as the one you just read) and so forth must have no effect on the ability to carry out the instructions with state-of-the-art precision.

Hints of the noon-day cannon problem may arise when natural standards are devised. How does one specify instructions for making something without reference to the measurement being standardized? However, should a natural standard be achieved, then it of course will demote any prototype that may have been previously recognized. If that does not happen immediately upon creation of a natural standard, it will happen eventually due to the difficulty of maintaining prototypes and the undesirable variations found in common standards.

6.) An *intermediate standard* is an accurate copy of a prototype or it is an object produced from a natural standard. It is used expressly for the purpose of geographic distribution and practical use of the standard while minimizing the risk of losing or damaging a prototype standard or minimizing the expense and time required to apply a natural standard. An intermediate standard may also be an accurate copy of another intermediate standard, so long as there is a traceable record of comparisons back to a prototype or natural standard.

In the analogy of a penny, if a country has several mints, one mint might be charged with maintaining the prototype standard penny and the others may be equipped with intermediate standard pennies.

7.) The most authoritative standard that exists for a measurement is called the *master standard*. It may be a common- a prototype- or a natural standard.

Crease's Properties of Standards

Robert Crease defines three "important properties" of a measurement standard. While each important property is important of its own accord, in practice they get traded off against each other simultaneously in the determinacy of the over-all acceptance of the standard. The three important properties Crease defines[†] are: [7, pp 19-20]

1.) A*ppropriateness* to the intended task. If one desires to measure the distance between cities, the use of a finger-width would be less appropriate to the task than the use of the length of a person's stride. Different units and standards for the same physical phenomenon may be used for different tasks. In our present era the relationships between such units as kilometers and miles (or even mils for that matter) are now precisely defined and refer to a single master standard, making the conversion of units a simple mathematical maneuver and the choice of units is fundamentally moot—a mere convenience. That has not always been the case through history. Some units had been optimized for particular purposes in ways making compatibility with other applications impractical, the relationships between the different standards being unknown at the time. At any rate, the standard chosen (not just the units) will have a degree of appropriateness to the task.

2.) A*ccessibility*. Some natural standards such as "fist-full" or "pinch" are highly accessible since practically every person embodies the standard and can easily follow the instructions. If the standards are rare in occurrence or more difficult to maintain or produce, accessibility declines. The use of the standard and measurements derived therefrom should be able to be widely repeated without undue labor or cost.

3.) A*ssurance* of a satisfactory result. A measurement needs to reliably deliver the accuracy needed for the intended tasks and the tools involved need to be sturdy enough to maintain their accuracy and usefulness for some practical duration.

[†] Crease presents them in the order of Accessibility, Appropriateness, Assurance. They are re-ordered here to align them with the norms for technology mentioned in Monsma *et al*'s book, *Responsible Technology*[12]

Multi-Aspectual Normativity Theory

In Monsma *et al*'s book, *Responsible Technology: A Christian Perspective* (RT) [12] a Biblically responsible holistic approach to technology is described. Chapter 5 of RT develops the case that the simultaneous consideration of six *aspects* of technological design offers a holistic perspective. Christians can anchor their evaluation of these aspects with respect to *norms* derived from one's understanding of the Bible. Norms are essentially rubrics by which one may qualitatively measure the aspects. In Chapter 7 the authors of RT propose norms for each of the six aspects they have proposed. In other words, In RT the Bible is treated as a natural standard by which technology can be qualitatively measured, using norms as tools. This theory of aspects and norms has been used in other engineering contexts, for one example, in the evaluation of complexity theory [13]. Even standards of measurement can be measured by this theory as measurable objects. The Bible is much more than this of course! But RT holds that this is an appropriate use of the Bible. The multi-aspectual normativity theory of RT will be used here to evaluate standards of measurement in various eras of history. To begin this process, Crease's concept of "properties of standards" will be related to the theory, as set forth in RT.

Crease's Properties of Standards Related to Multi-Aspectual Normativity Theory

In Chapter 5, RT puts forth the case for six aspects of technology needing consideration: Cultural appropriateness, stewardship, delightful harmony, justice, caring, and trust. The outcomes of a technology should be considered in terms of each of these aspects. The norms (rubrics) chosen to evaluate these aspects reflect a person's religious convictions. In Chapter 7 the authors of RT develop norms based on Biblical principles for each of these aspects, one norm per aspect except two norms for the cultural aspect. Those are the norms of "cultural appropriateness" and "openness and communication." For practical purposes, RT presents seven norms, displayed in Figure 4.

Trust
Caring
Justice
Delightful Harmony
Stewardship
Cultural Appropriateness
Openness and Communication

Figure 4, Seven norms described in Responsible Technology [12].

RT advocates that all seven norms need to be considered simultaneously because technology exists holistically. In addition to this RT advocates that the norms have an order of dependence in that each norm shown in Figure 4 depends to a degree on the norms below it. For one simple example of these dependencies, if justice is not achieved, caring and trust must be compromised, whereas if caring and trust are not achieved, justice is not necessarily compromised, though they may be compromised for other reasons. This suggests an order of development for a technology in which the earlier norms (lower ones in Figure 4) receive an initial priority of consideration in the development of a technology, followed later by giving increasing priority to the consideration of the later norms (higher ones in Figure 4) as time passes and technology is developed.

Now, compare Crease's important properties of measurement standards with the norms for technology mentioned in RT, working from the bottom of Figure 4 upward.

Cease's important property of *appropriateness* corresponds well with RT's norm of *cultural appropriateness*. Especially with regard to the technology associated with maintaining a standard of measurement, in RT the need for a "balance of scale" is specifically mentioned as one of five characteristics of cultural appropriateness.

Crease's important property of *accessibility* corresponds with the norm of *stewardship*, found in RT, particularly regarding the, "amount of energy and materials to be deployed in the fabrication and use of technological objects" (e.g. a measurement standard) discussed in RT.

The important property of *assurance* corresponds with RT's norm of *justice*. The norm of justice is defined in RT as assuring that each person gets their due. As far as standards of measurement go, that is the essential point of the standard. Steve Vanderleest has written considerably more on this norm. In the context of technology, he calls it the norm of technological justice. He explains that technological justice is more than the absence of injustice. Justice needs to be intentional because humans are fallen creatures, "naturally inclined to choose evil. Only by the grace of God can we counter this inclination." Standards-of-measurement need to achieve a "fair and equitable treatment of others." [14]

What of the other norms for technology presented in RT? Although Crease does not mention them, the application of these norms to standards-of-measure seems relevant. They are:

Openness and Communication: RT describes this as having no secrets about the value judgements being expressed, the knowledge being used, or the side effects that are known about a technology. The point of a measurement standard is especially to enable proper expression of value judgments. The Bible's imperative of not *secretly* keeping differing weights [15] is describing exactly this type of openness, in addition to matters of justice.

Delightful harmony has three factors to assess that relate to aesthetics. Is there a sense of joy achieved in the operation or application of the technology? Is there a melding of function and beauty? Does the technology enhance shalom? By "shalom" the authors of RT are referring to a webbing together of God, people, and all of creation in right relationships. Later in this paper, as we consider various prototype and natural standards, we will see that this norm is motivational for moving away from prototype standards and toward natural standards. There is something intrinsically appealing and delightful about natural standards. Crease writes much about this in a general way, without formally recognizing it as an identifiable "important property" or "norm" of a standard.

Caring. Technology should promote interactions among people that promote care and love for one another. Technology should not place needless barriers between people or promote manipulation of people. While this design norm has, for example, obvious relevance to technology (e.g. social media) it is perhaps not such an "important property" of a standard of measure beyond the simple observation that measurements are helpful in many acts of caring. For example, medical prescriptions involve measurement. Care for the sick is enhanced by having agreed-upon measurement standards. Stating a drug-dose in SI units while providing a measurement tool calibrated in U.S. customary units would be a careless act.

Trust. With appropriate reliability, a technology should do what it is supposed to do, and not do what it is not supposed to do. The distinctive issue here is the fullness of the consideration of what should not be done by the technology. This question needs to be answered with depth that goes beyond the obvious purpose(s) of the design. As an example, it is not good enough that the brakes on my car work reliably. (If I merely get what I paid for, that's justice.) It is also necessary that the brakes on my car can be serviced efficiently and without exposing the service technician to a dangerous material such as asbestos. The general trust shown for a technological design should ideally be an outcome of design work faithfully done in response to God's Cultural Mandate [16]. There needs to be a recognition of the finite human ability to fully model and understand a situation and a respect for our duty to our Creator that is reflected in corresponding real-world testing and refinement of the design and experience with the design. Crease's important property of assurance would satisfy this norm to the extent that the standard delivered on these broader matters of what the standard should *not* do.

One more: Humility. Steve VanderLeest has proposed one more norm for technology, that of humility. "Engineers should design technology with a certain modesty, knowing that (as created beings) we are finite, and thus cannot predict all the ways our technology might be used or abused."[17] The choice of a new standard for measurement is usually fraught with very intentional humility in the sense of understanding with as much foresight as possible, the limits of uncertainty that the standard will entail.

Standards of Measurement Through the Ages

How do standards of measurement depend on God's creation and human response to that creation? We can find answers by considering who sets standards and how people have judged standards. We can also consider who challenges standard-makers and why. We can compare measurement-standards-making to the process of making other standards, such as railway track standards for an example. This will be discussed in three broad eras: 1.) ancient through modern, 2.) the advent of the SI system, and 3.) the recent meeting of the CGPM in November 2018.

Standards from Ancient Through Modern Times

At the most ancient times of standard-setting activities, things we take for granted now were not available. Arabic numerals as symbols, and the concept of symbol-place-significance related to a consistent base (e.g. decimal), and the numerical concept of zero, were not yet developed. Counting objects was the foundation of measurement. Fundamentally, the ability to count remains the primary enabler of measurement-standards. These days counting may be performed with the assistance of electronic tools that can count billions of items or events per second.

The oldest surviving accounts of measurements and standards of measurement begin in the era of the Mesopotamian and especially the Babylonian era. Standards of measurement then were typically natural standards that were thought to be repeatable and stable. For example, certain plant seeds have an astonishing uniformity of weight and invite one to use them as a common standard. The jeweler's unit of the carat, for example, owes its origins to the carob seed, once used as a common standard [18]. Units of length were often standardized by comparison to human bodies such as a finger, forearm, stride, or foot [19].

Crease points out that there is "nothing unscientific" per-se about the great amounts of local variability and regional incoherence of ancient standards of measurement, often common standards, "as long as they are accessible, appropriate, and assured." [7, p21] Specifically, they supported observation and reasoning, commerce, taxation, and religious practice. In a somewhat post-modern sense, one could say that a useful standard is merely one that gains popularity and has not been refuted. Standards are not a problem per se unless they are unpopular!

In these ancient standards a combination of cultural appropriateness and stewardship seems to have had priority. Those who set the standards were usually government officials, soldiers, or priests. The differences between government, military, and religious leadership were not well-defined or differentiated, complicating the achievement of the later norms of trust, caring and justice. The purposes of the standards were both practically and religiously oriented.

Contrary to some stories of the amazing accuracy of ancient astrological observations, there was little or no conception of a science of metrology in Babylonian times. In fact, in some ancient religions there was a deification of certain aspects of the natural creation [20]. Speculatively, this combination of primitive representation of numbers, little mathematics beyond arithmetic, and the deification of the sun, moon, stars, etc. may have motivated the choice of natural standards. Ancient calendars with their various counts of days for measuring the seasons to support agricultural activities and to establish times for religious rituals exemplify this era of natural standards based on counting seeds, days, new moons, and similar common objects or natural events.

In Biblical times there is evidence that the temple priests maintained the standards of measurement. There is also evidence that common standards and natural standards were being supplanted by prototype standards, probably to provide more accuracy, which would enhance development of later norms such as justice, or as Crease puts it, the important property of assurance. The shekel, a unit of weight and simultaneously a coin is frequently mentioned in the Pentateuch. The sanctuary shekel, in the sense of a prototype standard, is specifically mentioned several times [21]. It has been observed that the association of the prototype shekel with the temple and the temple priests is an appeal to the fixed standards of God in contrast with the fickleness of humanity [22]. Associating the prototype shekel with the temple enhanced its delightful harmony in the sense of establishing right relationships. This was a development of a later norm than simply cultural appropriateness. The presumed repeatably of the results gained by standardizing on the prototype shekel of the sanctuary is also an appeal to further development of the norm of justice.

By the late 1700s and the time of the French Revolution most natural standards had been replaced by myriads of prototype standards. Unfortunately, like the story of the noon-day cannon, these standards were all self-referential or otherwise arbitrary, coming and going in influence along with the rise and fall of the tribes, feudal lords, and nations. Crease recounts this quite colorfully including stories of the tediousness of conducting a transaction when the buyer and seller bring their own intermediate standards to the venue of the deal, possibly with all intermediates secretly corrupted to each's advantage [7, Ch. 3].

The Advent of the SI System

In the 1700s the world was in the early ascent of the Industrial Revolution, which was especially focused in Great Britain, but also beginning in France and elsewhere in Europe. Simultaneously there was political upheaval as the last vestiges of feudalism were in their final death-throes and nation-states emerged with central governance having broad geographic reach. Scientific thought had also changed. The prior Aristotelian theories of different regions (earth, air, sky) having different properties and requiring different theories had been abandoned. Nature was coming to be understood by making theories with respect to "observation," implying the primacy of measurement.

This nexus of industrial development, political upheaval, and scientific emphasis on observation was notably present in France during the time leading to the era of Napoleon. Crease maintains that this nexus created the conditions for a dramatic longing for a renewal of natural standards from which to derive intermediate standards. It was proposed that a meridian of the earth could serve as a natural standard for length. Once length was defined, a specified volume of water could serve as a natural standard for mass. A pendulum of a defined length could serve as natural standard for time differential. This was the initial conception of what became the meter-kilogram-second system (mks) and eventually morphed into the SI system. These proposed natural standards quickly gained appeal.

Earlier in this paper the norm of delightful harmony was mentioned. In the context of new perspectives on observationally-based science and political turmoil, the promise of standards that transcend the past are grippingly appealing. The appeal of natural standards is their ability to promote "right relationships," which is a concept at the heart of the norm of delightful harmony. The French Revolution was not uniformly a good thing of course. In addition to providing fertile ground for new laws and standards such as the mks system, the French Revolution also popularized the guillotine. After some brief nascent developments in new measurement standards that pointed to the future mks system in the 1780's, the concept languished in the 1790's because of the chaos of the French Revolution. Then in the early 1800s development gradually resumed [7, Ch. 4].

On May 1, 1851, the British Empire sponsored The Great Exposition of 1851. This was an international event showcasing the world-wide influence of the British Empire. By this time France, the United States, and England had all been doing work along the lines of the earlier proposed mks system based on natural standards, but none of these efforts had flourished amid the competition of entrenched local systems. The Great Exposition solidified an international recognition that the situation needed to change. In 1853 the first International Statistical Congress was convened. In 1863 the National Academy of Sciences brought the cause to the United States Congress and petitioned to adopt the "metric system." In 1866 the U.S. Congress did enact the metric system into law as a system suitable to serve in any court of law throughout the country. Initially this hardly changed any practice since it did not forbid any prior practice. But for the first time the mks system had gained legal recognition by a nation. This produced a flurry of advocacy for the system in other countries. Long story short—on May 20, 1875 a treaty creating an International Metric Commission was signed by seventeen countries, including the United States. France not only signed the treaty, they gave the newly established commission land on the outskirts of Paris. The land contained some buildings affording the commission a place to do its work [7, Ch. 6].

The events of 1875 established a remarkable convergence of talent into the hands of only a few metrologists, now holding international authority with legal standing. The legacy of the treaty of 1875 continues to this day. The norm of trust, the latest norm in RT's list, had a reached a new level of achievement—or at least so it seemed. The initial enthusiasm for natural standards resulted in the manufacture of some objects based on the natural standards and intended for use as intermediate standards. However, it was found that the natural standards could not be employed with adequate accuracy to repeatedly manufacture usefully precise additional prototypes for use as intermediate standards. Crease recounts one event in which an accidental fire destroyed an intermediate standard. Having been derived from a natural standard, work immediately started to replace the intermediate standard. But it could not be remanufactured satisfactorily [7, p130]. This event could be related to a loss of humility within the community of metrologists. They placed unfounded confidence in their new natural standards prior to adequate real-world experience with them.

Out of practical necessity, the work of the International Metric Commission changed to the preservation of the initially manufactured objects, originally derived as intermediate standards from natural standards, but now being used as de-facto prototype and master standards. The SI system became, for all practical purposes, just another set of prototype standards. The formerly attempted natural standards (meridian, volume-of-water, pendulum,) were now mere window dressing as far as their true functionality was concerned, yet their continued presentation as the conceptual basis for the mks system surely added a measure of delightful harmony to the mks concept. Prototype standards (actual objects) such as the prototype meter stick, prototype kilogram, and a prototype set of clocks, adjusted on occasion—leap-years, seconds, etc.—via astrological observations, maintained by the British Royal Observatory became the master standards of the SI system [11][23][24].

The first unit of measure in the SI system to get a functional natural standard of sufficient accuracy to propel science forward was the meter. Near the dawn of the twentieth century, Charles Sanders Peirce, at various times a professor at Harvard and Johns Hopkins Universities, a founder of the philosophical school of pragmatism, and a metrologist, proposed that the natural standard for the meter be tied to the wavelength of a particular color of light from a noble gas. Initially his ideas were overlooked, possibly due to his unpleasant personality. However, his proposal marks the start of the SI's transition to natural standards that actually work [7, Ch 9]. One-by-one, the base units of the SI system were converted from prototype standards that were originally inspired by a goal of natural standards to truly functional natural standards. The official change from a protype meter bar to the standard based on the wavelength of a particular type of light was made in 1960. In 1983, the natural standard used to define the length of a meter was changed again, this time to depend on the speed of light in a vacuum [24][25].

Consider that the first SI natural standard of practical usefulness was a standard based on light—then the wavelength of light, now the speed of light. Jesus said, "I am the light of the world. Whoever follows me will never walk in darkness, but will have the light of life" [26]. From the context in John's Gospel it is clear that Jesus was proclaiming his authority to lead us to eternal life. Could Jesus also have known that measurements would someday be standardized by the wavelength of light? If Jesus is the light of the world, could the SI standard of the meter ultimately be referencing Jesus? Consider that a rhetorical teaser, not necessarily deserving an answer. . . yet!

The November 2018 Meeting of the CGPM

The last SI prototype standard to be deposed by a natural standard was the international prototype kilogram. (Figure 3 on a previous page.) After years of discussion, and as an outcome of the November 18, 2018 meeting of the CGPM, the international prototype kilogram, was deposed, effective on May 20, 2019, by a natural standard based on a definition of Plank's constant and the technological tool called a watt balance (also known as a Kibble balance) [27]. Now all seven of the SI base units have natural definitions. The seven natural definitions use seven constants of the universe as their foundation. (See Figure 5.)

The seven SI base units defined from these standards are the meter, kilogram, second, ampere, kelvin, mole and candela. All the other SI units that have been defined are derivatives of these seven. For example, the unit of force, the newton, is a kilogram-meter per second squared. A coulomb is an ampere-second, and so forth. The historic units of most nations, for example the U.S. Customary units, are now standardized by reference to SI units by law. For example, a U.S. inch is defined as 25.4 mm exactly.

The unperturbed ground state
hyperfine transition frequency of the caesium 133 atom
$\Delta V_{Cs} \triangleq 9\,192\,631\,770$ Hz

The speed of light in vacuum
$c \triangleq 299\,792\,458$ m/s

The Planck constant
$h \triangleq 6.626\,070\,15 \times 10^{-34}$ J·s

the elementary charge
$e \triangleq 1.602\,176\,634 \times 10^{-19}$ C

The Boltzmann constant
$k \triangleq 1.380\,649 \times 10^{-23}$ J/K

The Avogadro constant
$N_A \triangleq 6.022\,140\,76 \times 10^{23}$ mol^{-1},

The luminous efficacy of monochromatic radiation
of frequency 540×10^{12} Hz,
$K_{cd} \triangleq 683$ lm/W,

Figure 5, The seven constants of the universe, the foundation of the SI's natural standards. Notice that the symbol "≜" means "is defined to be equal to." [28]

More Aspects—But No Associated Norms

The Dutch philosopher Herman Dooyeweerd provides a description of fifteen modal aspects of reality. The six aspects of technological design elaborated in RT are derived from the last (top) eight of Dooyeweerd's fifteen aspects of reality. RT amalgamates Dooyeweerd's Social, Lingual, and Historical aspects into one aspect, in this paper named "Cultural." RT then proposes two norms for the cultural aspect, "openness and communication" and "cultural appropriateness." That leaves seven of Dooyeweerd's aspects that have not yet been considered in this paper. Listing them from the later (upper) to the earlier (lower), these seven of Dooyeweerd's aspects of reality are: analytic, sensitive, biotic physical, kinematic, spatial, and arithmetic [29]. Dooyeweerd posits that norms arise only for the later (top) eight aspects of reality. It is in these aspects that humans have been given choice and creativity in responding to God's call to obedience. In the earlier (bottom) aspects, our lives are governed by the inescapable laws of the creation rather than by humanly devised norms. As some examples, we encounter no choice beyond matters of efficiency and technique in making rules for counting of several objects. The count is self-evidently correct or not correct. A count of objects just, "is what it is." As another example, we do not debate the validity of arithmetic. We write "1 + 1 = 2" and there is no question about it. We cannot defy gravity (physical aspect) either. We are subject to the creation in all of Dooyeweerd's early (lower) seven aspects of reality, whereas we have freedom bounded by responsibility to be Biblically obedient to God's intent for the creation in the later (upper) eight aspects of reality. See Figure 6 for a tabular summary of this paragraph.

Dooyeweerd's 15 aspects of reality	**RT's aspects of technology**	**RT's norms for technology**
Pistic	Pistic	Trust
Ethical	Ethical	Caring
Juridical	Juridical	Justice
Aesthetic	Aesthetic	Delightful Harmony
Economic	Economic	Stewardship
Social	Cultural	Cultural Appropriateness
Lingual		Openness and communication
Historical		
Analytic		*All of life is subject to God's law in these lower aspects of reality*
Sensitive		
Biotic		
Physical		
Kinematic		
Spatial		
Arithmetic		

Figure 6, Dooyeweerd's aspects of reality, RT's aspects of reality, and RT's norms for engineering related to each other. [12][29]

The seven natural constants that now define the SI system have their principle functions in the lower aspects, especially the physical, kinematic, spatial, and arithmetic aspects. These are aspects that are not normed by humanity. We are simply subject to these aspects of reality, and thus subject to the constants of the universe, and ultimately subject to our Creator-Redeemer—Jesus Christ.

God’s Common Grace in Standards-of-Measurement

The Oxford English Dictionary provides many phrases to describe the meaning of grace. In this paper the phrase *God’s grace* is intended to represent, “something received from God by the individual: benevolent divine influence acting upon humanity to impart spiritual enrichment or purity, to inspire virtue, or to give strength to endure trial and resist temptation.” [30] This *common grace* is what is meant by the phrase *God’s grace* in this paper. (In contrast to a *saving* grace.)

David Chi has discussed the relationship between common grace and engineering in a paper from 2013. He shows how Christians participate in the activities of engineering with a different quality of insight and discernment than others. He also points out that sin is a common reality for all. He distinguishes some different classifications of sins such as sins of individuals and sins of institutions. As an example of the need for God’s grace in technological matters he mentions the possibility of clothing brands intentionally being labeled with smaller size-numbers than are conventional—“vanity sizing”—as an example of institutionalized sin. He concludes that, “The only solution to this problem is the redemptive work of Jesus Christ.” [31]

The seven natural constants upon which the SI now rests are something received from God by His creative and sustaining acts. Their existence and significance to humanity is something beyond the control of humanity. Even people who do not have a Christian faith, generally have faith in these constants. And what else can it be but faith that tells us these are truly constant constants? Any attempt to measure these constants using the present SI system of standards is just as ridiculous as the noon-day canon story. And what better set of standards of measurement could be proposed?

The natural standards that have been defined in the SI system positively serve humanly devised norms for the higher aspects of reality. The SI system and the work of the CGPM have served to inspire virtues such as honesty, justice, and trust. It is in this sense that God, through Christ, has extended a generous measure of grace to humanity through the provision of the creation with natural constants.

The Bible states that, “For in him all things were created: things in heaven and on earth, visible and invisible, whether thrones or powers or rulers or authorities; all things have been created through him and for him. He is before all things, and in him all things hold together.” [32] Jesus Christ conducts himself with self-conscious authority consistent with this perspective. As an example, consider Jesus’ statement that, “In your own Law it is written that the testimony of two witnesses is true. I am one who testifies for myself; my other witness is the Father, who sent me.” [26] Also in his conversations with Pilate before his crucifixion, Jesus displays remarkable self-awareness of his authority and the purposes of his authority.

> “You are a king, then!” said Pilate.
>
> Jesus answered, “You say that I am a king. In fact, the reason I was born and came into the world is to testify to the truth. Everyone on the side of truth listens to me.”
>
> “What is truth?” retorted Pilate. [33]

In this ironic scene Pilate does not understand that he is looking into the face of Truth personified but reading between the lines we can see that Jesus perceives himself as the creator and sustainer of truth. These examples are fully consistent with a Jesus who created light in such a way that it could serve as a natural standard for measuring length. The Bible presents Jesus to us as the Creator-Sustainer-Redeemer of all things, including all "authorities," which seems now to very logically include the seven constants of the universe upon which the SI depends.

Here is an answer to the rhetorical question asked earlier, "could the SI standard of the meter ultimately be referencing Jesus?" Obviously, there is no direct reference to Jesus in the SI standard. But the Bible does make it clear that the SI standard, like all of creation, finds its ultimate foundation in the Creator-Sustainer-Redeemer, Jesus Christ. This is not to claim that the SI—a human invention—has reached the ultimate *sine-qua-non*. Further progress will likely be made in refining the SI. But Christians can see that the foundations of such standards of measurement, including earlier standards such as the *shekel of the temple* and the *international prototype kilogram*, are gifts to us from the Creator.

Max Deffenbaugh points out that, ". . .there is little difference between how Christians and those of other faiths or no faith do engineering." He points out that considering engineering as a "common grace activity" offers a reason for the similarity and simultaneously points out a difference between engineers of Christian faith and other engineers. Both groups receive the same gift of an orderly creation, a sense of right and wrong, and even the ability to read the Bible. On this common ground, both groups, given they agree to the same assigned task, generally will produce similar results by similar methods. However, Christians have a sense of vocation in relationship to what Deffenbaugh terms, "common grace ministries." Through our work, be it technological work, engineering work, or other work, we seek to minister to those around us. Deffenbaugh argues that Christians should be especially sensitive to directing their engineering work toward common grace ministries. He ends his paper with a quote from the hymn *Come Thou Fount of Every Blessing*, "O to grace, how great a debtor daily I'm constrained to be." [34][35] Our understanding that measurement standards rest on the bedrock of Jesus Christ is just one facet of how common grace does constrain us and tells of the debt we owe for this benefit. As will be described later in this paper, the "constraint" (or the "fetter") that the hymn-writer mentions should be given a positive connotation of guidance toward a fulfilling life in a superior relationship to the negative connotation of a list of "thou shalt nots," though it is, of course, both at the same time.

The Depth of God's Grace in Standards of Measurement

Imagine the confusion that might result if there was a competing measurement-standard-making authority working to supplant the SI system. Recall the old VHS vs. Beta video-tape marketing wars. There are real issues of path dependence and lock-in which one can manipulate to various advantages [36]. In fact, when making standards there usually seems to be a very serious competition between several competing standards. Railway track gauge is an example of competing standards. In spite of the advantage a uniform track-gauge would offer for convenient international travel and shipping, to this day a plethora of incompatible track-gauge standards limit train travel [37]. The story is similar in many other technological standards such as building codes, electrical powerline standards, telecommunication standards. Everywhere one looks there are regional variations which have complicated stories.

Sometimes the competition in standard-setting proceeds even to the point of nullification of any value an accepted standard could have brought. Even beyond that, standards-wars can lead to the complete disadvantaging of an entire technology.

The standards competition over AM stereo broadcasting comes to mind as an exemplary disaster in standards-making. About a half-dozen incompatible standards for AM-stereo broadcasting were permitted by the FCC simultaneously. In television broadcasting when UHF channels were added, and again when digital TV was standardized, the FCC created a transition period during which receivers could be optionally equipped to receive the new standards, followed by a date when all new receivers sold had to be capable of the new standards. In contrast, when AM-stereo was introduced, it was explicitly stated that there would be no date by which receivers had to be capable of the new standard. The resulting lack of buy-in from broadcasters (no date to target and plan for) and the extra costs for receivers (for the standard-detection and demodulators capable of handling at least several of the variety of standards instead of just one) hobbled the introduction of AM stereo broadcasting and eventually brought the entire technology of AM broadcasting to the point of world-wide marketplace failure. This happened only on account of competition in standards-setting that was left unchecked [38][39]. Technically, any of the half-dozen or so standards would give superior service compared to the present situation. Instead, each entity involved being fearful of disadvantage and too weak to gain a majority of support, each entity augured for the status quo. Unlike FM broadcasting which has enjoyed a number of upgrades to its standards over the years, (stereo, subcarrier authorized ancillary services, radio-data services, etc.) AM broadcasting has become moribund in standards that are substantially unchanged since the 1930s, save for some transmitting power reductions and other minor tweaks to enable additional channel allocations. In recent years, “FM fill-in translation” and “AM-HD” modulation (also known as “In-Band On-Channel Digital” or just “IBOC”) has been permitted by the FCC in the hope of returning vitality to the AM band, but it may be too late considering the present poor opinion the public has regarding AM and the apparently glitchy performance of the AM-HD modulation [40][41][42]. The FCC certainly did not act deliberately to throttle the life out of AM broadcasting, but by the time the disaster was realized, irreparable harm was done. The point of this paragraph: Standards-making entails the risk of disaster of a scope beyond initial credibility.

In contrast, what competitions there have been in the making of standards-of-measurement have quite progressively and consistently enhanced, rather than nullified or even attenuated, the benefits derived from the standards. Louis Berkhof notes that, “[Common grace] curbs the destructive power of sin, maintains in a measure the moral order of the universe, thus making an orderly life possible, distributes in varying degrees gifts and talents among men, promotes the development of science and art, and showers untold blessings upon the children of men.” [43, as quoted in 31] In contrast to some other standards-making activities, standards-of-measurement seem to have enjoyed a very generous record of common grace throughout history.

Dooyeweerd points out that it is by means of “Law” that the creation exists. It is the Law that establishes the boundary between the Divine and the creation. Dooyeweerd described “Law” not as a mere code of restraints but rather as that activity of God by which meaningful things are enabled to happen [44]. The seven universal constants and the peacefulness of standards-making activities through history are tangible evidences of Dooyeweerd's positive conceptualization of Law as the boundary between the Divine and the creation, through which meaningful things are enabled to happen.

Ethan Brue has suggested that, "The nature of engineering (and STEM) education is uniquely resistant to grace." [STEM: Science, Technology, Engineering, and Mathematics] He argues that grace is not something that can be taught, but is best explained by telling stories [45]. There is a story behind every measurement. Every measurement rests in Christ's faithful upholding of the creation. The history of the creation of various standards, and especially standards-of-measurement, and how these standards rest in Christ's faithfulness to us, ought to accompany the related instruction on instrumentation and measurement techniques, uncertainties, sensitivities, and traceable calibrations. The activities of the recent CGPM are part of that story of God's common grace to all of humanity.

Conclusion: God Gracefully Provides Standards-of-Measurement

Earlier in this paper it was stated that a standard of measurement is itself a measurable object. A list of six aspects of reality and another list of seven norms, plus one more, by which to assess the aspects was described. A further set of seven lower aspects of reality set forth by Dooyeweerd was described with their relationship to standards-of-measurement. For these aspects we have no choice but to follow. By considering measurement standards against these aspects and their norms (if applicable) a standard of measurement can itself be compared (measured) against themes of the Holy Bible, at least in qualitative rather than quantitative terms.

Ancient standards were frequently natural standards satisfying norms of cultural appropriateness, openness and communication to a much greater degree than the later norms such as justice, delightful harmony, and trust. Humanity has progressed from there. Refinement of measurement standards can be related to the achievement of the higher norms for technology.

The advent of the SI was centrally a call back to natural standards. This call was an attempt to enhance the norm of delightful harmony, especially in respect to establishing "right relationships."

The November 2018 meeting of the CGPM was a long-anticipated milestone in the SI system in which the final plans were laid for the retirement of the last prototype standard. All the master standards of the SI system are now natural standards.

It is challenging to educate students in STEM disciplines regarding God's grace. The best way to do it is by telling stories. There is a story behind every measurement. These stories should be told in the curriculum when measurement techniques are discussed.

Consider what the CGPM has accomplished in relation to what God has accomplished. Max Plank commented that via natural standards we can achieve units of measure that, "necessarily retain their significance for all cultures, even unearthly and non-human ones." [46] But the point of this paper is that by the grace of God, constants of the universe imply much more than that. It is not so much that the SI system is of significance even to "non-humans." It is more like the other way around! God's unchanging nature and perfect faithfulness bring us to the point of recognizing seven universal constants. From this we realize that even the humanly-devised SI system is an outcome of God's common grace and we recognize the significance and generosity of it to all of humanity. The seven natural constants of the universe are part of a boundary line between the Divine Creator and the creation. They tell of our subject-to-God nature and simultaneously enable the flourishing of culture. They tell of God's grace to us.

Lord, you have been our dwelling place
throughout all generations.

Before the mountains were born
or you brought forth the whole world
from everlasting to everlasting you are God.
…

May your deeds be shown to your servants,
your splendor to their children.

May the favor of the Lord our God rest on us;
establish the work of our hands for us—
yes, establish the work of our hands [47].

…

Honest scales and balances belong to the LORD;
all the weights in the bag are of his making [6].

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