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Teaching SI Units in Engineering and Technology Programes

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TEACHING SI UNITS IN ENGINEERING AND TECHNOLOGY PROGRAMES

Abstract

As technology and economy gain global integration, the use of SI units (*Systeme Internationale d'Unites*) has become common place. About 95% of the world population is familiar with the system with a vast majority using it as the primary units of measure. In fact, the only countries today that are not fully metricated are United States, Liberia, Myanmar (formerly Burma), and Brunei. So the English units are still the popular units in the United States and it is the preferred units of instruction in our colleges and universities, especially in engineering and technology programs.

This paper discusses an approach in teaching SI units in engineering and technology programs. The approach is based on a M20-50 strategy for Junior Colleges in technical and vocational education. The prefix "M" stands for Metric and the numbers 20 and 50 represent the minimum percentage Metric content in assignments for first-year and second year-students, respectively. A M20-40-60-80 strategy is used for 4-year colleges and universities in engineering, engineering technology, and technical education. This requires that the assignments for students should have 20%, 40%, 60%, and 80% minimum metric content for first-, second-, third-, and forth-year students.

From our experience, most of the students claim it is easier and faster calculating in Metric units than English. They think fewer mistakes are made in metric calculations compared to English; especially when working with fractions in English units. We have found that many industrial and engineering technology students are not well grounded in the units of fundamental quantities like area, volume, pressure, stress, flow rates, etc. Though they talk about these quantities regularly, they fail to capture their proper units. Hence teaching units, in general and SI units in particular, is imperative not just for metrication purposes but also for sound education.

Introduction

A unit of measurement is a standard for measuring a physical quantity that may be defined through voluntary agreement, adopted by convention or defined by law. Measurement units and standards are developed and managed by professional organizations (e.g. ASME: American Society of Mechanical Engineers, ASTM: American Society for Testing Metals, ASQ: American Society for Quality, IEEE: Institute of Electrical and Electronic Engineers, SAE: Society of Automotive Engineers, etc.); national and international bodies such as the American National Standards Institute (ANSI) and International Standardization Organization (ISO). The ISO develops and manages SI units and standards. The metric system is defined as the current version of SI units and standards. ANSI coordinates the adoption and management of United States National Standards. The United States is the only industrialized nation where English or United States Customary units are in common usage though English units have been defined using metric standards since 1893[1].

A system of units is a group of fundamental units and their combinations that constitute a language of measurement. The magnitude of a physical quantity is completely specified by a *number* and a *unit*. The *number* gives the *size* of the quantity while the *unit* identifies the *type* of quantity. The unit gives the number a context so that it can be properly understood and interpreted. Lord Kelvin in 1883; captured the importance of measurement units when he said "…when you can measure what you are speaking about and express it in numbers, then you know something of your subject; when you cannot express it in numbers, your knowledge is of a meager and unsatisfactory kind" [2, 3]. Unit systems can be divided into two groups; namely base units and derived units. Base units are standardized with respect to fundamental physical quantities, the choice being somewhat arbitrary. They measure basic physical quantities such as length, mass and time. Derived units are obtained by combining two or more base units. Many derived units can be expressed in more than one form but it is professional to adhere to conventions, especially standards.

In the United States, the SI and English units and standards are in use. The SI Units is as a result of 17th and 18th centuries' proposals for a uniform standard of units. This standard is continuously being revised and the United States has been participating since 1875. The metric system was first suggested by Simon Stevin in 1585 but was adopted in 1790 by the French Academy of Sciences which started to develop it into a practical system. Thomas Jefferson recommended the use of the metric system in 1790, but in hindsight, his advice appears not to have been taken seriously. In 1795, France officially adopted the metric system and by 1900, 35 more countries had adopted it. In 1866, by an Act of Congress, the metric system became lawful throughout the United States in all contracts, dealings and court proceedings. After many decades of debates, Congress passed the Metric Conversion Act (P. L. 94-168) in 1975 [1, 4]. This Act made the metric system the legal units of weights and measures in the United States, but actual adoption by business and public has been somewhat slow. SI units and standards are the most widely used measurement units system today. About 95% of the world population is familiar with the system with a vast majority using it as the primary units of measure.

The United States customary units have their roots in the English System which developed from the system used by early American Colonists. Several versions of the units are in use but the popular ones are the foot-pound-second (fps) system and the inch-pound-second (ips) system. United States customary or English units are managed by the National Institute of Standards and Technology (NIST). In English units, some quantities have multiple unit variants that seem unrelated. For instance, energy can be measured in BTUs (British Thermal Units), foot-pounds, kWh (kilowatt hours), kilotons (explosive energy), etc. Also, the English units system has many conversion factors, making them more complicated to remember. For example, there are 8 ounces in a cup, 2 cups in a pint, 12 inches in a foot, 3 feet in a yard, and 5280 feet in a mile.

The growth of worldwide science and commerce has greatly accelerated the adoption of SI units of measurement throughout the world so that the metric system, (the current version of SI units and standards), is now the world's measurement language for trade and science. Therefore, it has become necessary for technicians, technologists, designers, and engineers in the United States to become competent in the metric system. Since the global economy is here to stay and metric is the international language, it seems obvious that full conversion to SI units is a matter of time! Full conversion to metric system will ensure that the United States stays at the leading edge in scientific and technological innovation.

In the United States' academia, the SI units and standards are popular in the scientific community while the English units and standards are popular in the engineering and technological communities. Because English units system is used in training the vast majority of our engineers, technologists, and technicians, they are probably ill equipped for the global stage where the SI units system is the measurement language of trade and science. For instance, when companies from different countries work on the same technical project(s), the use of a common unit of measure is necessary. Since the SI units system is international, this is often the preferred choice. According to Euler [5], all new USA standards (ASTM, ANSI, SAE, IEEE, ASME, etc.) are now written in metric. This is because, the lead engineers in these organizations recognize the importance of trying to get the USA on track with technically advanced countries, in an effort to regain lost USA competitiveness in a global economy. The global market for English unit products is continuously shrinking and American industries using them forfeit industries and jobs to third-world countries that use the simple SI units and fulfill business needs efficiently. If our engineering and technology graduates are to lead the global technological enterprise, they must be highly competent in the use of the SI Units system. In addition, engineering and technology degree graduates competent in SI and Metric units would have greater employment opportunities as expertrates in other countries. The rise of China, India, and Brazil as technological powers will further increase the need for our graduates in technology and engineering to be more competent in the use of SI units and standards. Training our students for competence in the job market is important to all of us. In fact, job placement rate is one of the assessment criteria of various Accreditation bodies of programs. SI literacy and competence are factors that will be relevant in getting employed in a global economy which can influence placement rates.

This paper discusses strategies for accelerating the training of engineering and technology students in the use of the SI units system in post-secondary technical education system. This will eventually help in metricating the whole economy due the predominance of graduates literate and competent in SI usage. A M20-50 strategy is proposed for junior colleges in technical and vocational education system. The prefix "M" stands for "metric" and the numbers 20 and 50 represent minimum percentage metric content in assignments for first-year and second year-students, respectively. A M20-40-60-80 strategy is proposed for 4-year colleges and universities in engineering, engineering technology, and technical education. This requires that the assignments for students should have 20%, 40%, 60%, and 80% minimum metric content for first-, second-, third-, and forth-year students. It is hoped that engineering and technology faculty members in our colleges and universities would join in the efforts of rapidly transforming the United States economy into a metric based one through effective teaching of the metric system. A metricated technological community is needed to accelerate the metrication of the economy because technology has a profound impact on the quality of life and directly influences the economy. The technological academia needs to accept the fact that the *Metric Conversion Act*, first passed in 1975 and amended in 1988, is the law of the land. Hence the need to embrace a strategy or strategies for metrification of technological education should be of interest to the community.

SI Units System

As mentioned earlier, the SI units system is an international system. There are seven base units in the SI Units and two supplementary units [5, 6]. These include the meter (length), kilogram (mass), second (time), ampere (electric current), degree kelvin (temperature), radian (angles), and candela (luminous intensity). Though the base units of the SI units are somewhat arbitrary like other systems of units, but they have sound scientific bases. The most common of the SI base units are the meter (for length), kilogram (for mass), and second (for time) and these provide the current meter-kilogram-second (mks) metric system. The meter is defined as the distance light travels through a vacuum in 1/299,792,458 of a second. The kilogram is defined as the mass of the International Prototype Kilogram, a platinum-iridium cylinder kept at Sèvres, near Paris in France. Weight standards in other countries can be adjusted to the Paris standard kilogram with an accuracy of one part per hundred million (10^{-8}). The second is defined as the 9,192,631,770 periods of vibration of the radiation emitted at a specific wavelength of cesium-133 atom. Table 1 shows the base units of the metric and English units systems while Table 2 shows some derived units.

The SI units system is based on the decimal number system with sub units derived through multiples of ten or division by ten. For instance one kilometer (km) is a thousand times larger than a meter (m) and one millimeter (mm) is a thousand times smaller than a meter. It has a simple set of conversion factors that are positive or negative powers of ten which is consistent

Table 1: Fundamental units of SI and English Units Systems [6, 7, 8]

Quantity	SI (Metric) Units	EnglishUnits
	BASE UNITS	
Length	meter (m)	Inch (ft)
Mass	kilogram (kg)	Slug
Time	second (s)	second (s)
Current	ampere (A)	ampere (A)
Temperature	kelvin (K)	Rankine (^oR)
Luminous intensity	candela (cd)	Candela (cd)
Amount of substance	mole (mol)	Pound mole
	SUPLEMENTARY UNITS	
Plane angle	radian (rad)	Degree
Solid angle	steradian (sr)	-

Table 2: Some derived SI units [7, 8, 9]

Quantity	SI (metric) Units	English Units
Force	newton (N)	Pound (lb)
Voltage	volt (V)	volt (V)
Resistance	ohm (Ω)	ohm (Ω)
Capacitance	farad (F)	farad (F)
Inductance	henry (H)	henry (H)
Pressure or Stress	pascal (Pa)	psi (pound per squared inch)
Energy	joule (J)	foot-pound; Btu (British Thermal Unit)
Power	watt (W)	hp (horse power) or Btu/hr

across all unit types. The metric system is continuously evolving. There have been different versions such as millimeter-newton-second (mns) system; centimeter-gram-second (cgs) system; meter-tonne-second (mts) system; and meter-kilogram-second (mks) system. The current metric system is the mks system which was adopted in 1960 at the 11st General Conference on Weights and Measures. In practice, the units may be grouped into standard and conventional. The standard units are those adopted by ISO and recommended for usage. The conventional units are the commonly used SI units in certain industries or cultures but can be derived from the base units of standard SI units. For example pascal (Pa) is the standard unit of pressure or stress. However, megapascal (MPa) is commonly used in metallurgy, bar (100 kPa) is commonly used in Meteorology, and millimeter of Hydrogen (mmHg) in Medicine. Similarly kelvin (K) is the SI standard unit of temperature but the celsius (^oC) is in common usage. Thus MPa, bar, mmHg, and ^oC are conventional units but can be derived from the SI base units.

It is not uncommon to deal with very large or very small quantities in science and technology. In such situations, symbols help in concise representation. About 20 orders of magnitude symbols, called metric or SI prefixes have been approved by ISO. Table 3 gives the symbols and their order of magnitude values in metric system.

Table 3: SI order of magnitude values [8]

Name	Symbol	Factor	Name	Symbol	Factor
yotta	Y	10^{24}	yocto	y	10^{-24}
zetta	Z	10^{21}	zepto	z	10^{-21}
exa	E	10^{18}	atto	a	10^{-18}
peta	P	10^{15}	femto	f	10^{-15}
tera	T	10^{12}	pico	p	10^{-12}
gigi	G	10^{9}	nano	n	10^{-9}
mega	M	10^{6}	micron	μ	10^{-6}
kilo	k	10^{3}	milli	m	10^{-3}
hecto	h	10^{2}	centi	c	10^{-2}
deca	da	10^{1}	deci	d	10^{-1}

Table 4: Preferred Numbers

First Choice (R10)	Second Choice (R20)		Third Choice (R40)			
1.00	1.00	1.12	1.00	1.06	1.12	1.18
1.25	1.25	1.40	1.25	1.32	1.40	1.50
1.60	1.60	1.80	1.60	1.70	1.80	1.90
2.00	2.00	2.24	2.00	2.12	2.24	2.36
2.50	2.50	2.80	2.50	2.65	2.80	3.00
3.15	3.15	3.55	3.15	3.35	3.55	3.75
4.00	4.00	4.50	4.00	4.25	4.50	4.75
5.00	5.00	5.60	5.00	5.30	5.60	6.00
6.30	6.30	7.10	6.30	6.70	7.10	7.50
8.00	8.00	9.00	8.00	8.50	9.00	9.50

SI Preferred Numbers

In engineering design, sizes such as length, diameter, area, volume, power, etc. may be estimated on the basis of functionality, usability, safety, cost, etc [10]. However, actual values are often chosen based on standard guidelines (Table 4). To minimize variety and promote harmonization and compatibility of interfaces, preferred numbers or values are adopted. The ISO preferred numbers are a geometric series of numbers that have been adopted worldwide for standardization purposes. They were first proposed by Charles Renard, a French army captain and engineer in the 1870s [18]. They are therefore known as the Renard's series, and designated as R5, R10, R20, etc. Each R-value represents the root of 10 and R5, R10, R20 and R40 are recommended. Table 4 shows standard SI preferred sizes. Values in Table 4 can be increased by multiplying by 10 or reduced by dividing by 10 to obtain any desired value. Observe that in Table 4, R20 contains all values of R10, and R40 contain those of R20. The ISO preferred numbers are recommended for use when selecting metric sizes. It should be noted that metric preferred sizes hardly have identical English sizes.

Teaching SI Units

The main motivation for this study is the perceived potential that teaching has as an aid in transforming our country into a metric-based economy and society. Most high school graduates today would have been taught or introduced to the metric system. Hence one approach to accelerating metrication of the economy and the nation is to metricate the post-secondary educational system curricula. This is based on the premise that graduate from our post-secondary schools will be more likely to continue the use of metric units in living and at the workplace if they were properly trained in the units while in school. The workplace will of necessity become metricated due to foreign trade pressures, but public and private living may take longer to metricate. Elementary and secondary school systems spend a lot of money in units' education. The post-secondary education system needs to augment the metrication instructional efforts of the elementary and secondary school systems by providing adequate instructions with SI units and standards. SI units and standards need to be taken more seriously in technological and engineering academia.

In order to have a coordinated and structured approach to metrication education in our tertiary institutions, we present M20-50 teaching strategy for Junior Colleges in technical and vocational education. The prefix "M" stands for Metric and the numbers represent percentage Metric content in assignments. We also present M20-40-60-80 teaching strategy for 4-year colleges and universities in engineering, engineering technology, and technical education. Table 5 summarizes the M20-50 strategy and Table 6 summarizes the M20-40-60-80 strategy. Such strategies should ensure that graduates from technology and engineering programs are capable of solving problems and communicating in SI units. Non-technical graduates should be given a minimum of two year exposure to SI units, with the goal that they understand the commonly

Table 5: M20-50 Teaching Strategy

Level	SI Content (%)	Topics
100/1000	20	SI Base Units, Conversion Problems. Master measurements in primary base units of length, mass, and time. Physical feel of units by guessing distances (length, circumference, perimeter) and masses to be emphasized. 20% of assignments should be SI based.
200/2000	50	Problem-solving with SI/Team assignments in SI. Able to define and recognize units and measurements in all base and supplementary units. Able to recognize and use derived units in problems within Major. Units of energy, power, temperature, force and weights, volume, area, densities, pressure and stress should be understood. 50% of assignments should be SI based.

Table 6: M20-40-60-80 Teaching Strategy

Level	SI Content (%)	Topics
100/1000	20	SI Base Units, Conversion Problems. Master measurements in primary base units of length, mass, and time. Physical feel of units by guessing distances (length, circumference, perimeter) and masses to be emphasized. 20% of assignments should be SI based.
200/2000	40	Problem-solving with SI. Able to define and recognize units and measurements in all base and supplementary units. Able to apply and use derived units in problems. Units of energy, power, temperature, force and weights, volume, area, densities, pressure and stress should be understood. 40% of assignments should be SI based.
300/3000	60	Team assignments in SI. Able to recognize and use derived units in problems, especially in defined majors. 60% of assignments should be SI based.
400/4000	80	Individual SI Based Project assignments. Competent in the use of SI in problem solving. Easily make conversions between SI and United States customary units. Can formulate and solve problems in SI in defined majors or disciplines. 80% of assignments should be SI based

used units such as the meter, kilogram, pressure, liter, etc. If our graduates are competent in SI units usage, then employability is widened into international stage and they become more highly competitive.

Though most high school graduates today would have been taught or introduced to the metric system, the depth may be in question. The metric system is probably taught without concrete applications; e.g. comparing kilogram mass with real objects or comparing the meter length with the size of real objects. Such comparisons can help translate concepts to practical activities that are relevant to real life and work. Now, new students in colleges and universities (especially colleges) will include some that have long graduated from high school and may have forgotten most of, if not all, of metric knowledge. This raises the need of reviewing the base metric units and their divisions. It will be prudent in such reviews to focus on metric units in popular usage such as the units of length, time, mass, temperature, area, volume, pressure, energy, and power because technical and non-technical people deal with these quantities on a daily basis. We are tempted to suggest that a course in SI units and standards in post-secondary educational institutions be mandatory for technology and engineering students in their freshman year. This can then be followed up with the strategies presented above in other courses.

In our view, academia in the technological community needs a stronger commitment to the metric system. Many of us in this community may need some retooling in the SI units in order to be effective in helping the metrication process through teaching. Updating our notes may not be out of place, in fact, it is a good idea attending a seminar on metrication. We should learn to do measurements in metric: acquire metric measuring devices (meter sticks, kilogram scales, Newton scales, Celsius thermometers, etc.). As instructors, we should always use and teach the latest version of the SI units, otherwise called the metric system [8, 11]. We need to be diligent in distinguishing metric units from acceptable conventional SI units and promote the use of standard metric units. In problem solving, we should do all computations in metric. If customary units are used in a problem, it is recommended to first convert initial problem values to SI units before doing the computations.

As Instructors in technology and engineering, we should learn to rigorously implement the use of preferred sizes (Table 4) in design of components and products. Functional sizes should be chosen from preferred metric sizes and if this is not acceptable or practical, they should be rounded up to whole numbers in millimeter. Decimal millimeter size *must never* be allowed. Sizes such as 10 *mm*, 12 *mm*, 15 *mm*, 17 *mm*, 20 *mm* with 5 *mm* increments above 20 *mm* are standard bore sizes of cage (ball and roller) bearings. These are alternatives to preferred sizes for shaft cross-sectional diameters. Using preferred sizes in design reduces component varieties and minimizes production cost. It also maximizes the benefits of standardization of components and products. Adopting metric prefer sizes at the design phase ensures that subsequent planning and decisions will be metric based. Design Instructors (technical and non-technical) in our colleges and universities thus have the greatest leverage in accelerating metrication if they would choose to "go metric". If graduates of technology and engineering are competent in SI units before graduation, they can make a profound impact on the economy and country due to the fact that technology drives modern economies. The standard and quality of life is heavily tied to technological development.

Conversion between Units

Conversion of quantities from Metric to English units or verse versa; is in most cases, a scaling problem. That is, units in different measurement systems are related by proportion, so a factor can be used to multiply or divide a quantity in one unit to obtain its equivalent value in the other unit. The exception to this rule is temperature units due to the temperature values for the freezing and boiling points of water that were assigned arbitrarily. It is somewhat a wonder that the Celsius temperature scale has the same rate (change per degree) as the Kelvin scale since the freezing and boiling points of water were arbitrarily assigned also! Please refer to Tables A1 and A2 for conversion factors from English to SI units for some physical quantities.

To convert from English to Metric:

$q_M =$ quantity in metric unit $\quad$ $q_E =$ quantity in English unit

$k_E =$ conversion factor from English to Metric unit

$$q_M = k_E q_E \tag{1}$$

Examples:

a) Convert 180 lb to newton.

$q_E = 180$ lb; $k_E = 4.448$ N/lb (Table A1)

$q_M = k_E q_E = 4.448\text{x}180 = 800.64$ N

b) Convert 150 psi to pascal.

$q_E = 150$ psi; $k_E = 6.895$ kPa/psi (Table A1)

$q_M = k_E q_E = 6.895\text{x}15 = 1034.25$ kPa = 1.034 MPa

To covert from Metric to English:

$k_M =$ conversion factor from Metric to English unit

$$q_E = k_M q_M = \frac{q_M}{k_E} \tag{2}$$

$$k_M = \frac{1}{k_E} \tag{3}$$

Examples:

a) Convert 200 MPa to psi.

$q_M = 200$ MPa $= 200\text{x}1000$ kPa

$k_E = 6.895$ kPa/psi (Table A1)

$$q_E = \frac{q_M}{k_E} = \frac{200\text{x}1000}{6.895} = 29,006.5 \text{ psi}$$

b) Convert 1500 mm to feet.

$q_M = 1500$ mm $= 1.5$ m

$k_E = 0.3048$ ft/m (Table A1)

$$q_E = \frac{q_M}{k_E} = \frac{1.5}{0.3048} = 4.92 \text{ ft}$$

Some Experiences

The authors have tried in the past three years using the strategies outlined above in the following courses: MFG 333, MFG 231, CONS 333, DRFT 333, DRFT 336, and DFTG 2308. MFG 333 is an introductory course in strength of materials for 4-year Industrial and Engineering Technology students. MFG 231 is a course in manufacturing technology for 4-year Industrial Technology students. CONS 333 is a course in quantity survey concerned with the estimation of building quantities for 4-year Industrial Technology students. DRFT 333 is a machine design course for 4-year Engineering and Industrial Technology students. DRFT 336 is a CAD course for 4-year Industrial and Engineering Technology students. DFTG 2308 is an instrumentation drafting course for 2-year design drafting students. MFG 333 and DRFT 333 have afforded the greatest opportunities for applying SI units and the students have shown likeness for it. Definitions, conversions and applications in problem solving are covered. Use of preferred numbers is demonstrated in these courses. Due to numerous instrument types that are covered in DFTG 2308, only definitions and readout applications are treated. However, few conversions are done.

Definitions and some conversions are treated in MFG 231. But CONS 333 and DRFT 336 have presented the most challenges because the available texts and examples in these courses are largely in English units. So focus has been on definitions and few examples in conversion. It has been possible to meet the 60% metric assignment content requirement in MFG 333 and DRFT 333 and 40% of MFG 231. The 50% for DTFG 2308 is not yet achieved (40%). The achievement in CONS 333 and DRFT 333 is not very encouraging, being about 30%. As mentioned above, current textbooks in CONS 333 and DRFT 336 are largely in English units.

In discussion sessions on Metric units, most of the students said it is easier and faster calculating in Metric units than English. They think fewer mistakes are made in Metric calculations compared to English, especially when working with fractions in English units. A few of them that are working in the industry expressed the view that some older workers are resistant to metrication. This resistance seems more prevalent in small and mid-sized companies producing mainly for local markets. But companies involved in international businesses are embracing metrication and sometimes prefer applicants with SI skills. A veteran student revealed that military personnel are given SI training in a two-week program in Germany and South Korea when they are deployed to these countries. In the opinion of the student, using SI units consistently took two to three months. The experience of this veteran suggests that transition to SI units may not be as costly or "inconveniencing" as is commonly believed.

During a recent oversea site training program at an LNG plant being built by companies from different countries, one of the authors found in a datasheet, a gas flow rate given in "MMSCM". The last three letters (SCM) was easily interpreted as "Standard Cubic Meter", a SI unit. The first two letters "MM" initially caused confusion, since "M" represents mega (10^6) in SI, and "MM" would probably be interpreted as 10^{12}! Because "M" in Roman numerals represents 10^3, "MM" is most likely 10^6, since "MM" is a non-standard SI representation. In SI, 10^{12} is represented by T (tera, Table 3). It is clear that using mixed units leads to confusion in joint project ventures and the Mass Rover tragedy of 1999 [12] should not be forgotten so easily. Mixed units application may be the cause of untold frustrations and project delays in the engineering and manufacturing industries, not just only in oil and gas.

We have found that many industrial and engineering technology students are not well grounded in the units (Metric or English) of fundamental quantities like area, volume, pressure, stress, flow rates, etc. This opinion is based on the fact that when they provide solution values to problems, they often fail to provide the correct units. The proportion of students with this issue may be higher than 30%, especially in classes with small number of students. This is certainly disturbing since they talk about these quantities regularly, but fail to internalize their proper units. Therefore teaching measurement units and standards in general, and SI units and standards in particular, is important not just for metrication purposes but also for sound education. The knowledge of weights and measures, according to John Quincy Adams in his Report to Congress in 1821, is among the first elements of education. Perhaps a most profound statement on this point is that of W. B. Yeats in 1938, "Measurement began our might …". Certainly, graduates of technology and engineering must be literate in the units of physical quantities.

Conclusions

The global economy and technological integration are current realities with metric as the international language. It is obvious that rather than decline, adoption of metric units will become common place. Therefore, there is an urgent need to accelerate the metrication of post-secondary technical education system. This will eventually help in metricating the whole economy due to a workforce that is literate and competent in the use of the metric system. We have presented M20-50 teaching strategy for Junior Colleges in technical and vocational education and M20-40-60-80 teaching strategy for 4-year colleges and universities in engineering, engineering technology, and technical education. We believe that faculty in the engineering and technological communities have the greatest potential in helping to accelerate the metrication process through effective teaching of the metric system. For example, adopting metric prefer sizes at the design phase ensures that subsequent planning and decisions will be metric based. Design Instructors (technical and non-technical) in our colleges and universities thus have the greatest leverage in accelerating metrication if they would choose to "go metric". Therefore, a renewed commitment to the goal of metrication is thus required in our community. The scientific community is metricated and so should be the technological and engineering communities.

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Appendix: Metric Conversion Factors

Table A1: Some general conversion factors (exact value underlined)

Quantity	English Units	SI Units	Conversion Factor
Length	in.	mm	<u>25.4</u>
	ft.	m	<u>0.304 8</u>
	yard	m	<u>0.914 4</u>
	mile	km	<u>1.609 344</u>
Area	in^2	mm^2	<u>645.16</u>
	ft^2	m^2	92.903×10^{-3}
	sq. yd.	m^2	0.836 127
	sq. mi.	km^2	2.589 988
	acres	hectares (ha)	0.404 687 3
Volume	oz	mL	29.57
	in^3	mm^3	$16.387\ 064 \times 10^{3}$
	ft^3	m^3	$28.316\ 85 \times 10^{-3}$
	gallon	L	3.7854
Mass	oz	g	28.351 418
	slug	kg	14.589 569
Force	oz	N	0.278 014
	lb	N	4.448 22
	lb	kgf	0.4536
Mass density	$Slug/in^3$	kg/m^3	$0.890\ 310\ 13 \times 10^{-3}$
	$slug/ft^3$	kg/m^3	515.225 767
Weight density	lb/in^3	N/m^3	$0.271\ 144\ 704 \times 10^{-3}$
	lb/ft^3	N/m^3	157.087 407
Energy	kWh	MJ	3.6
	Btu	J	1 055.056
	ftxlb	J	1.355 82
	calorie	J	4.182
Power	Heat ton	kW	3.517
	Btu/s	kW	1 055.056
	Btu/h	W	0.293 071
	hp	W	745.699 87
Pressure	lb/in^2 = psi	Pa = N/m^2	6.894 758 kPa
	lb/ft^2 = psf	kPa= 10^3 Pa	1 bar = 100 kPa
	1 tor = 1 mmHg	MPa = 10^6 Pa = N/mm^2	1 atm = 760 mmHg
	1 atm =14.7 psi	1 atm =101.3 kPa	
Temperature	^oF	^oC	$5/9(^oF - 32)$
	^oR	K	$^oC + 273.15$
Plane angle	degree	degree	<u>1.0</u>
	degree	rad	$17.453\ 3 \times 10^{-3}$

Table A2: Some common units in mechanical engineering (exact value underlined)

Quantity	English Units	SI Units	Conversion Factor
Moment of area or Section modulus	in^3	mm^3	$16.387\ 064 \times 10^3$
Area moment of inertia	in^4	mm^4	$416.231\ 426 \times 10^3$
Weight/length Spring rate	lb/in lb/ft	N/mm N/m	$175.126\ 771 \times 10^{-3}$ 14.593 898
Bending moment Twisting moment (Torque)	lb-in lbxft	Nmm Nm	112.984 788 1.368 003
Velocity; Speed	ft/s	m/s	0.3048
Acceleration	ft/s^2	m/s^2	0.3048
Volume flow rate	ft^3/s cfm cfm gpm (U. S.)	m^3/s m^3/s L/s L/s	$28.316\ 847 \times 10^{-3}$ $0.471\ 947\ 4 \times 10^{-3}$ 0.471 947 4 $63.083\ 333 \times 10^{-3}$
Modulus of elasticity	lb/in^2 (psi)	MPa = N/mm^2	$6.894\ 758 \times 10^{-3}$
Stress intensity	$ksixin^{0.5}$	$MPa\text{-}m^{0.5}$	1.100 11
Heat flux	$Btu/(hxft^2)$	W/m^2	3.152 481
Heat flow rate	Btu/s Btu/h	kW W	1.055 056 0.293 071
Thermal conductivity (k-value)	Btu/ftxhx°F	W/mK = W/m°C	1.730 73
Thermal conductance (U-value)	$Btu/ft^2xhx°F$	$W/m^2K = W/m^{2o}C$	5.678 263
Thermal resistance (R-value)	$ft^2xhx°F/Btu$	$m^2K/W = m^{2o}C/W$	0.176 110
Heat capacity; Entropy	Btu/°F	kJ/K = kJ/°C	1.899 1
Specific heat capacity Specific entropy	Btu/(lbx°F)	kJ/(kgK)=J/(kg°C)	4.186 8
Latent heat, Specific energy	Btu/lb	kJ/kg	2.326
Vapor permeance	Perm (23 °C)	$ng/(Pa\text{-}sm^2)$	57.452 5
Vapor permeability	Perm/in	ng/(Pa-sm)	1.495 29
Momentum	lbxft/s	kgm/s	0.138 255
Angular momentum	$lbxft^2/s$	kgm^2/s	$42.140\ 11 \times 10^{-3}$
Moment of mass	slugxft	kgm	4.446 900 6
Mass moment of inertia	$lbxft^2$	kgm^2	0.413 253 2