UNIT CONVERSIONS IN THE 21ST CENTURY: INSIGHTS INTO A ROUTINE YET CRITICAL SCIENTIFIC AND ENGINEERING TASK AS MEASURED THROUGH USER INTERACTIONS WITH A MOBILE APP

Jason E. Bara and John P. McLemore
University of Alabama • Tuscaloosa, AL 35487-0203

INTRODUCTION AND HISTORY

Unit conversions are a routine yet critically important task in chemical engineering, chemistry, and virtually all other engineering and scientific disciplines. The need to perform unit conversions arises from the historical development of multiple systems of measurement that have defined units of measure using different standards. For units with singular dimensions (e.g. length), there may be dozens of possible conversion factors due to the co-existence of multiple systems of units along with the persistence of non-standard units, some of which originate from the Middle Ages and antiquity. When working with units that have multiple dimensions (e.g. velocity [=] length time^{-1}), there are potentially hundreds of possible conversion factors, although it is likely that only a small subset of these units is actually in use.

Within chemical engineering, unit conversion exercises are most heavily emphasized in the sophomore-level Mass and Energy Balance courses, and the importance of performing accurate conversions is continuously echoed throughout the curriculum. Students are often reminded that failure to properly convert units can have dangerous and/or unintended consequences. The 1999 Mars orbiter crash was attributed to Lockheed Martin performing calculations in American Engineering System units while NASA was using metric units.[1] Christopher Columbus is purported to have arrived in the Caribbean due to miscalculations relating to the distance to Asia in Roman, rather than Persian, miles.[2]

The example of Columbus also serves to illustrate that many familiar units trace their roots back to Rome, Greece, Egypt, Israel, and other well-known ancient locations and originate from approximations to dimensions of the human body. For example, the "cubit," defined as the length of a man's arm from the elbow to the tip of the middle finger, features prominently in the design of the biblical Noah's Ark. Table 1 provides some units of length from various civilizations and their conversions to the modern meter and foot, the latter of which is nearly equal to several of these.

While the units in Table 1 fell into disuse long ago, a number of units originating within non-harmonized systems of measurement developed in the Middle Ages and Renaissance still persist today. Units of mass from the Avoirdupois sys-

Jason E. Bara *is an associate professor in the Department of Chemical & Biological Engineering at the University of Alabama. Jason earned a BS in Chemical Engineering from Virginia Commonwealth University and a PhD in Chemical Engineering from the University of Colorado at Boulder. He won the 2018 ASEE Ray W. Fahien Award for excellence in chemical engineering education and the 2017 AIChE David Himmelblau Award for Innovations in Computer-Based Chemical Engineering Education Award.*

John Patrick "JP" McLemore *received BS and MS degrees in Chemical Engineering from the University of Alabama. While a student at UA, McLemore worked with Bara to develop a number of iOS mobile apps and software modules for chemical engineering and other STEM disciplines. JP currently works as a Sustaining Engineer for Schlumberger in the Houston, TX area.*

tem (e.g. ounces, pounds, tons) are formally incorporated into the American Engineering System. Units from the Troy (troy ounce and troy pound) and Apothecaries' systems (pint, fluid ounce, teaspoon, cup) as well as units not originating from any particular system such as carat (ct) are still in regular use, likely due to familiarity and convenience, even though such quantities could also be conveniently described in terms of milliliters or milligrams.

Compendia such as *Encyclopaedia of Scientific Units, Weights and Measures: Their SI Equivalences and Origins*,[3] *Units of Measurement*,[4] and *A Dictionary for Unit Conversion*[5] contain tables of conversion factors (as well as some definitions and interesting facts) for virtually all modern, ancient, and obsolete units. The information contained in these books can still be found on the shelves of university libraries or more conveniently through Wikipedia.[6]

TABLE 1
Length units from antiquity and their conversion factors to the modern US foot.

Origin	Name	Meters per	Feet (US) per
China	Tchi	0.32 m	1.05
India	Hasta	0.457 m	1.499
Egypt	Djeser	0.30 m	0.98
Persia	Zereth (Persian foot)	0.32 m	1.05
Israel	Cubit / Sacred Cubit	0.555 m / 0.640 m	1.821 / 2.100
Greece	Pous	0.30856 m	1.012
Rome	Pes	0.2944 m	0.9659

Although the metric system was conceived as early as 1586 by the Flemish mathematician Simon Stevin in his pamphlet *De Thiende* ("The Tenth"),[7] France was the first nation to practically implement the metric system in 1799 during the French Revolution, and it soon spread thereafter to areas annexed by Napoleon. However, the development of the various temperature scales occurred during the 18th and 19th centuries, and these efforts were essentially independent of the unit systems.

Global "metrication" is nearly complete, as all countries except the United States, Liberia, and Myanmar (Burma) have officially adopted the metric system,[8] and the old nation-specific unit systems have been all but forgotten. Although metric units can be found in many aspects of life and business in the United States, efforts to officially legislate metrication have failed. Vestiges of the imperial system of units are still in regular use in the United Kingdom,[9] Canada, Australia, and other countries that were formerly part of the British Empire. Interestingly, Myanmar still uses its own national system of units, although the government utilizes a mixture of imperial and metric units, and the country is moving toward official metrication.

Even for those not studying or working in technical disciplines, unit conversions are frequently encountered. Almost everyone will likely perform some unit conversions on a regular basis when cooking, baking, mixing drinks, or traveling abroad (e.g. temperature and/or currency conversion). However, some of this work typically deals with units that are seldom relevant to engineering practice such as teaspoons (tsp), tablespoons (Tbsp), jiggers, etc., yet are familiar in the kitchen. Numerous standardized measuring devices are sold specifically for these purposes, although they would be of little to no use in a chemistry lab. These are relics of the Apothecaries' system and have slightly different definitions based on location. For example, in the US, 1 tsp = 4.929 mL, but is equal to 5 mL elsewhere. While 1 Tbsp = 3 tsp in the US, 1 Tbsp = 15 mL in the metric system, except in Australia where 1 Tbsp = 20 mL.

Throughout the 20th century, performing unit conversions required either an excellent memory, textbook appendices, or reference cards and a calculator (in addition to a pencil and paper). In 1961, *Industrial & Engineering Chemistry* (a journal of the American Chemical Society) published a "Unit Converter" that could be removed from the print edition of the journal, along with instructions for cutting, folding, and taping so the user could find the conversion factor in a window by sliding the card through the holder.[10] Many engineers and scientists currently in the workforce have, for most of their careers, relied on such tables, although due to physical size constraints, these tables provide a limited set of conversion factors and still leave the actual calculation to the user and are thus prone to errors.

In earlier times, or in the absence of such media, everyday objects, such as the handle of a walking stick, might feature unit conversions, such as the one shown in Figure 1 that appears to be engraved with temperature scale conversions.

In the 1990s the advent of personal computers and the internet facilitated access to unit conversions with software and websites designed for this purpose, and eventually search engine queries were able to directly return unit conversion calculations. However, it is without question that over the past decade mobile devices have "changed the game" by providing rapid access to unit conversions within arm's reach and thus eliminating the "inertia" associated with accessing conversion factors that were not committed to memory. Hundreds, if not thousands, of mobile applications ("apps") for Apple (iOS®) and Android smartphones and tablets have been developed for this specific purpose, facilitating access to a much larger array of unit conversions and conversion factors as well as further streamlining unit conversion tasks.

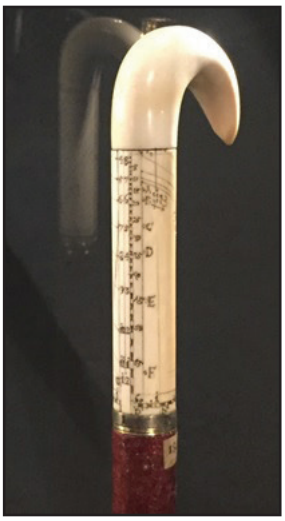

Figure 1. *Handle of walking stick engraved with what appears to be temperature scale conversions (19th Century?) Photo taken by author (JEB) at Rosenborg Castle treasury, Copenhagen, Denmark.*

With mobile apps comes the power of *analytics* -- in-app frameworks that developers can add to measure user actions along with anonymous demographic data. Such analytics allow developers to visualize app use and probe the data in order to answer questions as to how the app is being used. With respect to unit conversions, the following questions might begin to be addressed through analytics:

- Which unit categories are of greatest interest/utility and which pairs of units are most often converted? Furthermore, which units are less frequently used than might be expected?
- How do unit conversion activities in the United States compare to the rest of the world?
- How much time is spent performing unit conversions, and how does it impact employees' work and productivity?

However, among the broad offerings of unit conversion apps as well as search engines and other tools available to perform these actions, we are not aware of any prior efforts by developers (whether companies or individuals) to collect and share data on how users perform unit conversions. If such data were available, the questions above could begin to be answered, and for the first time in history, a picture of how unit conversions are performed might to come into focus. Here, we share data and insights from the analytics embedded within a unit converter app we have developed for iOS devices. This unprecedented data collection effort reveals several insights relating to the use of unit converters worldwide and suggests that a small fraction of unit categories (and the individual units within those categories) account for the vast majority of use. This knowledge can be of value to engineering educators given the intrinsic importance of unit conversions throughout undergraduate curricula. The underlying data are available upon request by emailing the author at jbara@eng.ua.edu.

ANALYTICS AND INSIGHTS FROM A MOBILE APP

Engineering Unit Converter & Calculator (v. 3.0) (referred to hereafter as *Engineering Unit Converter*) is an iOS app (developed by the authors of this manuscript) that performs unit conversions in 53 categories and includes additional functionalities and reference materials. In earlier versions of the app, a currency converter was included but has been disabled as the data source for the real-time currency conversions was terminated. Example screenshots depicting the unit conversion process are shown in Figure 2.

Through the use of Google Analytics™ for iOS, the app measures unit conversion events based on the category (e.g. length) and unit of the input value (e.g. ft). However, it does not capture the unit(s) to which the user is converting, since all calculated conversion values within the category are shown to the user.

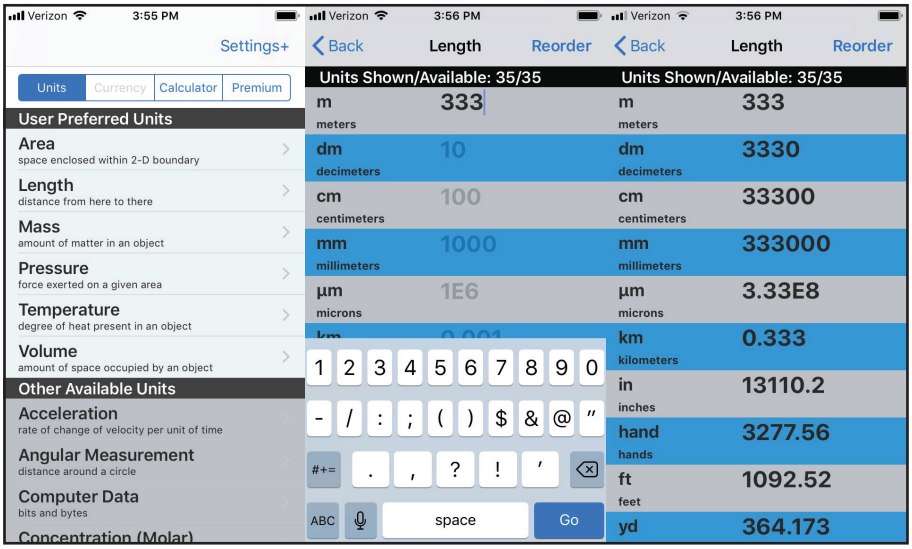

Figure 2. *Screenshots of "Engineering Unit Converter" taken on an iPhone 7. Left: app main menu; Center: user input of value of length unit being converted (333 m); Right: table of results calculated by the app.*

Over a five-year period (March 1, 2014 – February 28, 2019), *Engineering Unit Converter* was launched by 48,656 iOS users a total of 427,264 times in 210 countries to perform a total of 869,723 unit conversions in addition to the use of other features within the app. In a "typical" session a user performs 2.04 unit conversion activities. The average session duration is 2 min 53 s, meaning that cumulative global use of the app over this 60-month period was 20,532 hours (= 855.5 days = 2.34 years). As mentioned earlier, *Engineering Unit Converter* is just one of many unit converter apps for mobile devices that exist, as well as web-based modules (Google, Wolfram Alpha, etc.) and the traditional "pen-paper-calculator" method. The data from just this one app suggest that the magnitude of time spent on unit conversions worldwide is undoubtedly very large.

Table 2 presents global usage in terms of the respective number of users and number of sessions (i.e. instances of use) in the top 10 countries and aggregate data for the next 15 and all remaining countries.

Table 2 shows that the United States accounts for the greatest number of users and sessions, with ~6x and ~7x as many than the next closest country respectively. This is perhaps not unexpected as *Engineering Unit Converter* is only available as an iOS app, and the United States has a much larger number of iOS devices than in other countries.[11] Positions 2-9 are occupied by essentially the same countries in terms of user and sessions, although the ordering is slightly different, with Iraq being replaced by Malaysia. Interestingly, Malaysia, which was #12 is terms of total users, is #4 in terms of the number of sessions. The "Next 15" includes Iran, Malaysia, Singapore, Pakistan, Brazil, Mexico, Turkey, Indonesia, Myanmar, Egypt, China, Germany, Qatar, Kuwait, and New Zealand. Just ten countries accounted for ~63% of users and 76% of sessions, and 25 countries accounted for ~83% of all users and over 89% of all sessions.

While Table 2 establishes a broad geography of usage with significant representation of users and activity in countries that have adopted the metric system, the analytics can provide much deeper insights as to which unit categories are most frequently converted. Table 3 presents the most frequently converted unit categories.

Although 53 unit categories are offered within the app, Table 3 reveals that just ten unit categories account for nearly 92% of all conversions performed, with the top five accounting for 78.3% and conversions of length accounting for more than one-third (34.4%) of all actions performed. Again, perhaps it is not surprising that length is the most converted unit category as it is an intrinsic dimension of seven of the other top nine unit categories shown in Table 3.

Going a level deeper, the data obtained from Google Analytics help to develop an understanding of the most frequently converted units within each category, which can give deep insight into which measurements are more (and less) utilized. Until now, the design of printed unit conversion tables with limited space, such as those found in textbooks, had to rely on assumptions as to which unit conversion factors might be of

TABLE 2
Users and sessions of *Engineering Unit Converter* by country during March 1, 2014 - February 28, 2019.

Rank	Country	Users	Sessions
1	United States	15,540	203,170
2	India	2,572	12,231
3	United Kingdom	2,348	20,416
4	Canada	1,621	28,184
5	Philippines	1,560	9,027
6	Saudi Arabia	1,528	9,344
7	Australia	1,389	11,908
8	United Arab Emirates	1,382	8,279
9	Thailand	1,309	9,465
10	Iraq	1,274	5,540
11-25	Next 15	9,650	60,858
26-210	All others	8,483	48,842
	Totals	48,656	427,264

TABLE 3
Top ten most frequently converted unit categories by count of events during the period March 1, 2014 to February 28, 2019.

Rank	Unit Category	Dimensions	Events
1	Length	length	299,603
2	Pressure	mass length^{-1} time^{-2}	114,805
3	Temperature	N/A	102,848
4	Mass	mass	83,095
5	Volume	length^3	80,440
6	Area	length^2	45,956
7	Flowrate (Volumetric)	length^3 time^{-1}	21,446
8	Power	energy time^{-1}	20,149
9	Velocity	length time^{-1}	14,667
10	Force	mass length time^{-2}	14,649
11-53	All other categories		72,065
	Total Unit Conversions		869,723

greatest value to the reader. However, measurement of digital activity provides a clear picture of what actions are actually being performed. The following tables and discussion are focused on specific conversions within length, pressure, temperature, mass, and volume, which are respectively ranked #1-5 in Table 3.

Table 4 summarizes the conversion of units of length.

Converting from inch and millimeter to other units of length accounts for more than 50% of all length conversions performed, and inclusion of actions converting from meter, foot, and centimeter accounts for 90% of all length conversion events. This suggests that users are most concerned with measures that are comparable in magnitude to features of the human body, and these quantities are readily and accurately measured by humans with common rulers/calipers. This is in contrast to the much larger kilometer and mile (5.8% of events) and much smaller micrometer and mils (1.7% of events). As previously mentioned, although the app only captures the "from" unit and not the "to" unit, the frequencies at which inch (27.8%) and millimeter (25.6%) conversions are performed may indicate that the inch/millimeter pair is of greatest interest. From the data, it might be inferred that conversions of inches to millimeters would also necessitate a roughly equal amount of conversions of millimeters to inches. A similar observation can be made for the meter/foot pair, which occur at 14.6% and 13.6%, respectively. Table 4 also shows that conversions from yards, which are very similar in size to meters, account for only 1% of actions.

Table 5 shows the unit conversion events for pressure.

The top six units of pressure are all related to measures of force/area, and these six units along with mbar (#8 in Table 5) accounted for 82% of all pressure conversion events. Fluid "head" (or manometric) pressures (e.g. in. H_2O, mm Hg, etc.) are respectively ranked #7, #9, and #10 in Table 5 and together only account for ~10% of pressure conversion events, suggesting that converting "from" manometric measurements is much less frequent than the use of force/area units of pressure.

Table 6 shows the frequency of temperature conversions in the various scales.

Table 6 clearly shows that more than 94.1% of temperature conversion events involve converting from °C or °F. Conversions from °C are slightly greater than those from °F. Conversions from K account for 4.9%. There is < 1% conversion from °R, indicating that there is very little interest/utility in the use of a temperature scale that is just a single constant adjustment of °F to account for absolute zero. The historic temperature scales (ranked #5-8 in Table 6) account for just 0.2% of all conversions events, and perhaps these records are simply artifacts of users' curiosity. Of these four, only the Réaumur scale is known to be currently in use in the production of cheeses in Italy and Switzerland.[12, 13]

TABLE 4
Frequency of length conversion events by specific unit.

Rank	Unit	Symbol	Conversion Factor (1 in =)	Count
1	inch	in	1	83,151
2	millimeter	mm	25.4	76,785
3	meter	m	0.0254	43,837
4	foot	ft	1/12 = 0.083333	40,650
5	centimeter	cm	2.54	25,439
6	kilometer	km	2.54×10^{-5}	8,768
7	mile	mi	$1/63360 = 1.578 \times 10^{-5}$	8,678
8	micrometer	μm	254,000	4,151
9	yard	yd	1/36 = 0.027778	2,911
10	mils	mil	1000	1,041
11-36	All others			2,356
	Total Unit Conversions			299,603

TABLE 5
Frequency of pressure conversion events by specific unit.

Rank	Unit	Symbol	Conversion Factor (1 psi =)	Count
1	pounds per square inch	psi	1	30,026
2	bar	bar	0.06895	23,468
3	kilopascal	kPa	6.895	14,882
4	megapascal	MPa	0.006895	10,740
5	atmosphere	atm	0.068046	5,677
6	pascal	Pa	6894.757	5,194
7	inches of water	in H_2O	27.681	4,718
8	millibar	mbar	68.9476	4,176
9	inches of mercury	in Hg	2.03602	3,492
10	millimeters of mercury	mm Hg	51.7149	3,239
11-16	All others			9,193
	Total Pressure Conversions			114,805

TABLE 6 Frequency of temperature conversion events by specific scale.				
Rank	**Scale**	**Symbol**	**Conversion from °C**	**Count**
1	Celsius	°C	°C	50,680
2	Fahrenheit	°F	°F = (°C x 1.8) + 32	46,067
3	Kelvin	K	K = °C – 273.15	5,025
4	Rankine	°R	°R = (°C + 273.15) x 1.8	699
5	Delisle	°D	°D = (100 - °C) x 1.5	128
6	Newton	°N	°N = °C x 0.33	121
7	Rømer	°Rø	°Rø = (°C x 21/40) + 7.5	81
8	Réaumur	°Ré	°Ré = °C x 0.8	47
	Total Temperature Conversions			102,848

Table 7 presents data for unit conversions of mass.

Just three units (kg, lb, g) make up nearly 80% of unit conversions involving mass, with oz also contributing 7.5%. The similar amount of activity in kilograms and pounds, which is also ~3x greater than that in grams, may suggest that conversions between the kg/lb pair are of most interest. Similar to the observations associated with length conversions (Table 4), the prevalence of these units is likely due to their occurrence in common tasks and their association to quantities encountered in everyday life. Furthermore, measurements in these units of mass are also readily performed with common laboratory balances or household scales.

Table 8 presents data for conversions of volume by specific unit.

Although L is the most frequently converted unit of volume (22.9% of events), conversions from liters are not nearly as dominant in this category as the top unit in other categories (Tables 4-7), where the top unit accounted for between one-quarter to one-half of all conversion actions. Gallon is ranked #2, which again, like the mass and length categories, suggests that conversions involving more tangible quantities associated with common tasks and everyday life (e.g. liters of petrol, gallons of milk) are likely to be the most frequently converted quantities. Interestingly, despite inch being the most frequently converted unit of length (27.8% of activity in that category), interest in converting from cubic inches accounts for only 7.0% of volume conversions. However, the frequencies at which conversions of feet and meters (Table 4, 14.6% and 13.6%) and cubic meters and cubic feet (Table 8, 16.5% and 12.8%) are performed are highly comparable. Table 8 suggests that when volume is the subject of the conversion, users are more likely to work from units that are several orders of magnitude larger than the most used length units cubed (i.e. 1 gal = 231 in^3, 1 L = 10^6 mm^3).

While Tables 3-8 summarize the total activity in the *Engineering Unit Converter & Calculator*, it is also of great interest to determine if and how the app is used differently in the United States compared to the rest of the world. Table 9 presents unit conversion activity in the ten countries with the most sessions (Table 2) in the five most frequently accessed unit categories (Table 3).

Table 9 shows that for all countries presented, length was the most utilized category of units, often several times more

TABLE 7 Frequency of mass conversions by specific unit.				
Rank	**Unit**	**Symbol**	**Conversion Factor (1 kg =)**	**Count**
1	kilogram	kg	1	29,528
2	pound	lb	2.205	27,109
3	gram	g	1000	9,625
4	ounce	oz	35.274	6,229
5	metric ton	tonne	0.001	2,775
6	stone	stone	0.158	2,312
7	short ton	ton (short)	0.001102	1,513
8	milligram	mg	1,000,000	1,050
9	troy ounce	oz (troy)	32.151	632
10	troy pound	ib (troy)	2.679	622
11-21	All others			1,700
	Total Mass Events			83,095

TABLE 8 Frequency of volume conversions by specific unit.				
Rank	**Unit**	**Symbol**	**Conversion Factor (1 L =)**	**Count**
1	liter	L	1	18,455
2	gallon	gal	0.2642	15,242
3	cubic meter	m^3	0.001	13,309
4	cubic foot	ft^3	0.0353	10,304
5	cubic inch	in^3	61.024	5,591
6	fluid ounce	oz	33.814	5,425
7	cubic centimeter	cm^3	1000	3,786
8	oil barrel	bbl	0.00629	3,005
9	quart	qt	1.057	1,932
10	gallon (UK)	gal (UK)	0.220	1,819
11-13	All others			1,756
	Total Volume Events			80,440

frequently than the next unit category. Pressure unit conversions were the second most frequent action in each of the countries shown, except for the United States and Canada, where temperature ranked second; the United Kingdom, where "mass" ranked second; and India, where "area" ranked second. The occurrence of "area" in the top five most frequently converted units for Canada, Malaysia, India, and United Arab Emirates is surprising; although it is at position #6 in Table 3, the number of area conversion actions is only about 55% of the number of volume conversions.

TABLE 9
Total number of unit conversion events in each category for ten countries logging the most sessions. Rank of each category in the respective country in parentheses.

Country	Length	Pressure	Temperature	Mass	Volume
United States	145,699 (1)	51,988 (3)	57,655 (2)	43,614 (4)	40,459 (5)
Canada[a]	20,555 (1)	8,670 (3)	8,913 (2)	5,118 (6)	7,274 (4)
United Kingdom	13,981 (1)	4,164 (3)	2,840 (5)	6,917 (2)	2,952 (4)
Malaysia[b]	10,296 (1)	2,888 (2)	1,677 (4)	1,343 (6)	1,621 (5)
India[c]	12,716 (1)	1,627 (3)	1,365 (5)	1,011 (6)	1,598 (4)
Australia	6,801 (1)	4,225 (2)	1,745 (4)	2,351 (3)	1,403 (5)
Thailand	5,068 (1)	4,687 (2)	2,322 (3)	1,193 (5)	1,671 (4)
Saudi Arabia	6,259 (1)	2,696 (2)	2,296 (3)	1,326 (5)	1,800 (4)
Philippines	10,256 (1)	1,772 (2)	1,167 (5)	1,354 (4)	1,666 (3)
United Arab Emirates[d]	4,781 (1)	2,012 (2)	1,905 (3)	1,121 (7)	1,855 (4)

a: area was #5 (5,703 events)
b: area was #3 (2,305 events)
c: area was #2 (4,532 events)
d: area was #5 (1,818 events) and volumetric flowrate was #6 (1,229 events)

While Table 9 illustrates that length clearly dominates the conversion activities in the countries shown, are there differences in the units of length converted, especially given that the United States does not officially use the metric system? Table 10 provides insight into the conversions of the specific length units, which comprised > 90% of all actions in Table 4 in the 7 countries from Table 9 with the most length conversion events.

TABLE 10
Number of length conversion events by "from" unit in selected countries. Rank in each country in parentheses.

Country	mm	in	m	ft	cm
United States	50,218 (1)	39,784 (2)	17,883 (3)	11,857 (4)	10,415 (5)
Canada	4,838 (2)	5,648 (1)	4,199 (3)	3,121 (4)	1,287 (5)
United Kingdom	2,095 (3)	3,492 (1)	1,971 (4)	2,213 (2)	1,539 (5)
Malaysia	2,182 (3)	2,774 (1)	1,283 (4)	2,523 (2)	1,088 (5)
India	2,510 (4)	2,608 (3)	2,643 (2)	3,014 (1)	1,384 (5)
Philippines	1,470 (4)	3,338 (1)	1,786 (2)	1,629 (3)	1,386 (5)
Australia	1,074 (2)	2,642 (1)	764 (4)	1,043 (3)	614 (5)

In Table 10, it is seen that in the United States, conversions from "mm" (a metric unit) are the most frequently occurring length conversion action. In all of the other countries, which are officially on the metric system, conversion from inch (except India) or foot (India) is the most common action. This suggests that the most common length conversion actions in the US are from a metric unit, while the rest of the world is more concerned with converting from American Engineering Units. As can also been seen in Table 10, although the ranking of the relative units of length may differ by country, no country had any other unit of length among its five most frequently converted.

Table 11 presents the data for the seven countries from Table 9 with the most pressure conversion events.

The data for pressure conversion actions in Table 11 show that psi and bar are ranked at either #1 and #2 in each of the seven countries shown, except for Canada (#1 = kPa, #2 = psi) and Australia (#1 = psi, #2 = kPa). This high utilization of psi in countries outside of the United States again suggests that the metricated world is still very much concerned with converting from pressure quantities in the non-metric unit of psi. Canada and Australia show a much stronger preference for kPa relative to MPa, which is likely due to the reporting of atmospheric pressure in kPa in weather reports in those countries. In the United States, Canada, and Australia, conversions from quantities expressed in fluid head (e.g. in H_2O) are performed more frequently than conversions from atm (see Table 11 footnotes). This is not the case in other countries where fluid head pressures were not ranked higher than #6.

Table 12 presents the data for the seven countries from Table 9 with the most temperature conversion events.

Table 12 again confirms that in the United States, conversion from a metric unit (i.e. °C) is the most common action. For the other countries shown, conversions from °F rank as #1, with the exception of the United Kingdom where conversions from °C and °F were nearly 1:1. As was also shown in Table 6, conversions from K account for only a few percent of all actions, likely due to the fact that K is primarily used by scientists and engineers and is not used to report the weather. Furthermore, Table 12 shows that outside of the United States, there is virtually no interest in converting from °R, which accounted for 85.6% of use of °R among these seven countries.

TABLE 11
Number of pressure conversion events by unit in selected countries. Rank in each country in parentheses.

Country	psi	bar	kPa	MPa	atm	Pa
United States[a]	12,888 (1)	9,297 (2)	5,324 (4)	5,538 (3)	2,115 (9)	2,246 (8)
Canada[b]	2,756 (2)	1,038 (3)	2,830 (1)	367 (4)	205 (7)	205 (7)
Thailand	1,219 (2)	1,237 (1)	537 (3)	533 (4)	272 (5)	182 (6)
Australia[c]	1,279 (1)	833 (3)	1,065 (2)	269 (4)	130 (6)	114 (7)
United Kingdom[d]	928 (2)	1,377 (1)	451 (3)	301 (4)	153 (7)	212 (6)
Malaysia	823 (2)	839 (1)	404 (3)	217 (4)	94 (6)	151 (5)
Saudi Arabia	685 (2)	762 (1)	363 (3)	256 (4)	185 (5)	117 (6)

a: in H_2O was #5 (3,189 events), in Hg was #6 (2,531 events), mbar was #7 (2,316 events)
b: in H_2O was #5 (368 events), ft H_2O was #6 (225 events)
c: cm H_2O was #5 (251 events)
d: mbar was #5 (216 events)

Table 13 presents the data for the seven countries from Table 9 with the most mass conversion events.

Table 13 further confirms that mass conversions from a metric unit, in this case kg, is the most common action in the United States, albeit by a much smaller margin than in other categories. These data also show that in all countries, pounds and kilograms ranked at either #1 or #2, with ratios near 1:1, except in the United Kingdom where kilograms were converted nearly twice as frequently as pounds. The much smaller relative number of actions involving pounds in the United Kingdom is likely due to the use of stones, which ranked #3 with 1,175 events (see Table 13 footnotes). When combining pounds and stone actions from the United Kingdom, the number of events is roughly equal to the number of kilogram conversions. While Table 7 showed that 2,312 conversions of stones were performed over the 5-year period (ranking it #6), it is now clear that ~50% of these actions originate in the United Kingdom, where personal body weight is often expressed in stones.

Table 14 shows that in the United States, liters are the most frequently converted unit of volume, again showing that metric units

TABLE 12
Number of temperature conversion events by unit in selected countries. Rank in each country in parentheses.

Country	°C	°F	K	°R
United States	31,970 (1)	22,322 (2)	2,716 (3)	456 (4)
Canada	3,915 (2)	4,765 (1)	180 (3)	35 (4)
United Kingdom	1,300 (1)	1,291 (2)	223 (3)	10 (4)
Thailand	700 (2)	1,391 (1)	214 (3)	10 (4)
Saudi Arabia	1,000 (2)	1,154 (1)	119 (3)	18 (4)
United Arab Emirates	795 (2)	1,062 (1)	44 (3)	1 (4)
Australia	578 (2)	1,046 (1)	106 (3)	3 (4)

TABLE 13
Number of mass conversion events by unit in selected countries. Rank in each country in parentheses.

Country	kg	lb	g	oz	tonne
United States	14,487 (1)	14,106 (2)	7,009 (3)	3,329 (4)	1,268 (5)
Canada	1,846 (1)	1,787 (2)	484 (4)	572 (3)	156 (5)
United Kingdom[a]	2,934 (1)	1,640 (2)	427 (4)	366 (5)	140 (6)
Australia[b]	673 (2)	977 (1)	152 (4)	247 (3)	65 (6)
Philippines	493 (1)	435 (2)	140 (3)	85 (4)	80 (5)
Malaysia	470 (2)	537 (1)	52 (5)	80 (3)	80 (3)
Saudi Arabia	556 (1)	435 (2)	76 (4)	100 (3)	68 (5)

a: stone was #3 (1,175 events)
b: stone was #5 (100 events)

are of great interest to convert from. However, the next metric unit, cubic meters, ranks fifth behind gallons, cubic feet, and cubic inches. Except for Thailand, where gallons was the most frequently converted unit of volume, liters or cubic meters were #1. Outside of the United States and Canada, there is generally much less interest in the use of cubic inches in the other countries in Table 14. In fact, the 4,243 conversion events originating in the United States and Canada involving cubic inches account for ~80% of the total conversions for this unit logged in the app (see Table 8), whereas the events originating from the United States and Canada account for only ~60% of conversions involving liters or cubic feet. As seen in the footnotes for Table 14, a number of other units of volume are also prevalent outside of the US and Canada, including UK (imperial) gallons and oil barrels (bbl).

TABLE 14
Number of volume conversion events by unit in selected countries. Rank in each country in parentheses.

Country	L	gal	m^3	ft^3	in^3
United States	9,526 (1)	7,905 (2)	4,027 (5)	5,729 (3)	4,243 (4)
Canada	1,137 (3)	990 (4)	2,018 (1)	1,240 (2)	390 (5)
United Kingdom[a]	887 (1)	385 (3)	517 (2)	160 (5)	101 (8)
United Arab Emirates[b]	391 (3)	506 (2)	507 (1)	83 (5)	8 (9)
Saudi Arabia[c]	450 (1)	417 (2)	387 (3)	144 (4)	45 (9)
Thailand[d]	441 (2)	253 (3)	449 (1)	123 (6)	26 (8)
Philippines[e]	416 (2)	428 (1)	277 (3)	179 (4)	62 (7)

a: gal (UK) was #4 (210 events), oz was #6 (147) events, cm^3 was #7 (139 events)
b: gal (UK) was #4 (171 events), bbl was #5 (83 events), cm^3 was #7 (52 events), oz was #8 (40 events)
c: bbl was #5 (125 events), oz was #6 (99 events), cm^3 was #7 (64 events), gal (UK) was #8 (52 events)
d: bbl was #4 (139 events), cm^3 was #5 (129 events), oz was #7 (65 events)
e: oz was #5 (99 events), cm^3 was #6 (98 events)

Of course, further analyses of additional unit conversion categories can be performed but are not reported here in the interest of length of the manuscript. The authors will make the entire dataset used in this manuscript freely accessible upon request for teaching data analysis and visualization. For additional information, email jbara@eng.ua.edu.

CONCLUSIONS

The proliferation of mobile devices and apps has undoubtedly facilitated and streamlined a variety of professional and personal tasks. When data collection tools and analytics are embedded within apps, vast new insights can be gained into user behavior and activity, and these efforts can be directed toward making measurements that would never been possible if these tasks were performed using traditional methods. Here, for the first time, unit conversions have been studied and data have been continuously collected and analyzed over a five-year period from nearly 50,000 users in over 200 countries. While many might consider unit conversion to be a mundane task, there is no doubt that it is also a critically important activity that nearly all scientists, engineers, students, and even those not in technical fields will encounter. When considered in the "big picture" sense where activity is illuminated through analytics, a number of interesting (and perhaps fascinating) trends for unit conversions are observed. This study may be just the beginning of what can be learned about unit conversions.

REFERENCES

1. Hotz, R.L (1999) Mars Probe Lost Due to Simple Math Error. *Los Angeles Times*, https://www.latimes.com/archives/la-xpm-1999-oct-01-mn-17288-story.html Accessed May 8, 2020.
2. McCormick, D (2012) Columbus's Geographical Miscalculations. *IEEE Spectrum* https://spectrum.ieee.org/tech-talk/at-work/test-and-measurement/columbuss-geographical-miscalculations Accessed May 8, 2020.
3. Cardarelli, F (2003) *Encyclopaedia of Scientific Units, Weights, and Measures : Their SI Equivalences and Origins*. Springer-Verlag, London.
4. Dresner, S (1972) *Units of Measurement; An Encyclopaedic Dictionary of Units, Both Scientific and Popular, and the Quantities They Measure*. Hastings House, New York.
5. Chiu, Y (1975) *A Dictionary for Unit Conversion*. School of Engineering and Applied Science, George Washington University, Washington, DC.
6. Wikipedia System of measurement. https://en.wikipedia.org/wiki/System_of_measurement Accessed May 8,2020
7. Stevin, S, Norton, R (1608) *Disme: the Art of Tenths, Or, Decimall Arithmetike: Teaching how to Performe All Computations Whatsoever, by Whole Numbers Without Fractions*. Imprinted by S.S. for Hugh Astley.
8. Villareal, R (2013) America, Liberia, Myanmar: The Anti-Metric System Holdouts. International Business Times, https://www.ibtimes.com/america-liberia-myanmar-anti-metric-system-holdouts-1109357 Accessed May 8, 2020.
9. UK Metric System Association, Metric Views - Commentary on the Measurement Muddle in the UK. http://metricviews.org.uk/ Accessed May 8, 2020
10. UNIT CONVERTER (1961) *Ind. Eng. Chem Res*. 53:19A.
11. DeviceAtlas (2019) Android v iOS Market Share https://deviceatlas.com/blog/android-v-ios-market-share Accessed May 8, 2020
12. Fabio (2007) Hard to Kill. http://secondversion.blogspot.com/2007/07/hard-to-kill.html Accessed May 8, 2020
13. Wikipedia Réaumur scale. https://en.wikipedia.org/wiki/R%C3%A9aumur_scale Accessed May 8, 2020. ❐