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Scholarship of Teaching and Learning (SoTL) as a complementary outcomes assessment strategy: Case study on unit conversions, including test creation

Juan C. Morales, PhD[1], Wilson J. González-Espada, PhD[2], Albert A. Espinoza, MS[3], Amaury J. Malavé, PhD[3], Brian D. Montejo-Valencia, PhD[3], Eduardo E. Castillo, PhD[3], Luis Miguel Traverso Avilés, PhD[3]
[1,3]Universidad Ana G. Méndez – Recinto de Gurabo, Puerto Rico, USA, jcmorales@uagm.edu
[2]Morehead State University, USA, w.gonzalez-espada@moreheadstate.edu

Abstract– The Scholarship of Teaching and Learning (SoTL) involves faculty undertaking systematic and scholarly inquiry about student learning, using the findings to improve their own students' achievement, and sharing the results with the broader higher education community. This paper proposes that SoTL may be used as a complementary and deeper outcomes assessment strategy compared to the typical strategy of using student coursework (exams, projects, lab reports, etc.) to conduct direct assessment based on a rubric. The case study of this SoTL intervention was conversion of units of measure. The motivation for the inquiry was based on the faculty's consensus that many students lack proficiency with this fundamental engineering skill. The research questions were, (a) How proficient is the school's mechanical engineering (ME) population in converting units of measurement? and (b) What are the differences between 1st year and senior students? The SoTL group consisted of six ME faculty members at an engineering school in Puerto Rico and one invited researcher who performed the statistical analyses and assisted at all levels. The inquiry led to the creation of an objective test of unit conversions. The test was based on eight objectives identified by the researchers as essential in correctly converting units. Two questions were generated for each objective for a total of 16 questions. The ME faculty distributed the test in their courses and offered a 5% bonus incentive for answering the test (regardless of their score). The test results suggest that 1st year students are coming into the program with deficiencies in unit conversions; however, there is a statistically significant gain in half of the skills as the students progress through the curriculum. The worst performance in the test was converting metric prefixes, which is consistent with similar studies with U.S. students. Although an intervention to fix the problem is a future goal of the researchers, they recommend a major change in how unit conversions and metric prefixes are presented in textbooks and the NCEES FE Exam Reference Handbook.

Keywords—SoTL, ABET, accreditation, outcomes assessment, unit conversions.

I. Introduction

A typical outcomes assessment strategy used to satisfy ABET accreditation criteria consists of conducting direct assessment (with a rubric) of student coursework such as exams, projects, lab reports, etc. All the students in a course are assessed and the average score is used as the basis to determine if an improvement strategy is required to enhance performance. At a future date, a new average score is calculated to determine the effectiveness of an improvement strategy, a process known as "closing the loop". The key to this assessment strategy relies on ensuring that each instance of student coursework is aligned with a specific course learning objective which, in turn, is aligned with one of the seven student outcomes specified by ABET [1]. It is a reliable strategy that yields very good results and has been well accepted by ABET, based on four successful accreditation visits in 20 years.

However, there are instances where faculty require a deeper level of assessment. This paper proposes the use of the SoTL approach as a complementary strategy to achieve this deeper level of understanding for teaching/learning issues that intrigue the faculty. In essence, SoTL involves faculty undertaking systematic and scholarly inquiry about student learning, using the findings to improve their own students' achievement, and sharing the results with the broader higher education community [2].

When compared to traditional educational research, the distinguishing feature of the SoTL approach is that it focuses on the classroom, where the teaching of a course is treated as an experiment and the syllabus as a hypothesis that "if I teach a class this way, if I teach this material in this order, and students do these things, then I hypothesize that something will happen, that students will learn and the world will benefit. Therefore, SoTL can help faculty become more reflective and scholarly teachers" [3].

SoTL may be used independently by individual instructors, or by several faculty members who join as a team to study an issue of common interest. In this case, SoTL was used by a team at an engineering school in Puerto Rico to determine the proficiency of the school's ME student population in converting units of measure. The SoTL group consisted of the six ME faculty members of the School of Engineering and one invited researcher who performed the statistical analyses and assisted at all levels.

The motivation for the study arose from the consensus in faculty perception that many students had difficulties with the fundamental and critical skill of unit conversions. This SoTL research study provided the opportunity to determine the overall skill level of a large percentage of the ME student population, compare the skill level of first-year students versus senior students, and identify common misconceptions. This line of inquiry required the creation of an objective test of unit conversions that will be presented in its entirety, including the details of how it was developed. The paper does not cover follow-up interventions to determine the efficacy of proposed classroom interventions to improve student performance.

The results of this study provided a different perspective and a deeper level of understanding of the problem. Based on this added value, the authors argue that SoTL may be declared as a complementary assessment strategy for ABET accreditation purposes in cases where direct assessment of student coursework falls short. The results are used as evidence of a deeper level of assessment of student performance. The concept of using SoTL as a complementary strategy is presented in Fig. 1.

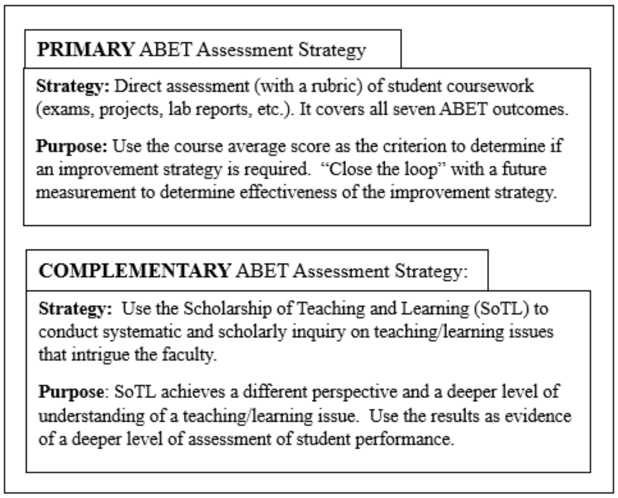

Fig. 1 The SoTL approach is proposed as a complementary ABET outcomes assessment strategy. SoTL achieves a different perspective and a deeper level of understanding regarding teaching/learning issues of interest to faculty. The primary assessment strategy is maintained, i.e, it is not replaced by SoTL.

The rest of the paper considers the case study on unit conversions that motivated the SoTL approach. It is organized as follows: a literature review of students' difficulties with units of measure; methodology, including the development of the test that was used to measure the proficiency of students' skills, and the test itself (in the appendix); results of the test given to the ME student population which were organized in the following three tiers: overall results, results of first year students, and results of senior students; discussion of the results; recommendations; conclusions; and acknowledgments.

II. LITERATURE REVIEW OF STUDENTS' DIFFICULTIES WITH UNITS OF MEASURE

As with traditional educational research, the SoTL research approach places a high value on previous scholarly work. The literature on the nature and extent of students' struggles with units is limited; however, all of it points to a pervasive problem in STEM programs [4]. This same article [4] provides a list of seven references [5,6,7,8,9,10,11]. The four most relevant papers are summarized below to provide context.

Dorko and Speer (2015) [5] investigated unit use in computations of area and volume in a Calculus I course. It sampled N=198 students from a large public northeastern university in the USA. They found that 73% of the students gave incorrect units for at least one task.

Mikula and Heckler (2013) [9] conducted extensive testing and interviews of sophomore, junior, and senior engineering students at The Ohio State University and found that students struggle with many "essential skills" that were prerequisites, and that little to no instruction time was spent on them. Among these skills were dimensional analysis, using metric prefixes for various conversions, and operating equations when given variables in mixed units. They conducted an online training activity that, except for interpreting log plots and log scales, saw "little and insufficient improvement as a result of training, despite the basic nature of the skills".

Dincer and Osmanoglu (2018) [10] administered a 14-question exam to N=73 prospective science teachers to examine their knowledge with unit conversions. The exam covered metric units for length, area, volume, and mass. The findings indicated that "the performance was not satisfying in general". They also reported that the major difficulties were related to the metric prefixes, i.e., converting gram to microgram, dm^3 into mm^3, etc.

Saitta, Gittings, and Geiger (2011) [8] reported on an activity in a first-semester general chemistry course in which dimensional analysis was used as a tool to keep track of units and to guide students through calculations. The activity was motivated by their observations that many students have not mastered unit conversions by the time they enter college.

The other three papers addressed the following issues: not recognizing that the units in all terms in a differential equation must be the same [7]; students' tendency to want to put numbers into equations right away thus losing the possibility of doing unit checks for consistency [6]; and that students have difficulties with units in representations of classical mechanics problems [11].

In summary, although there is limited literature on the nature and extent of students' struggles with units, it is shown that all of it, without exception, points to a pervasive problem in STEM programs.

III. METHODOLOGY

The methodology for conducting the inquiry required the creation of a test of unit conversions. The development of the test was guided by Fig. 2, taken from (Beichner, 1994) [12].

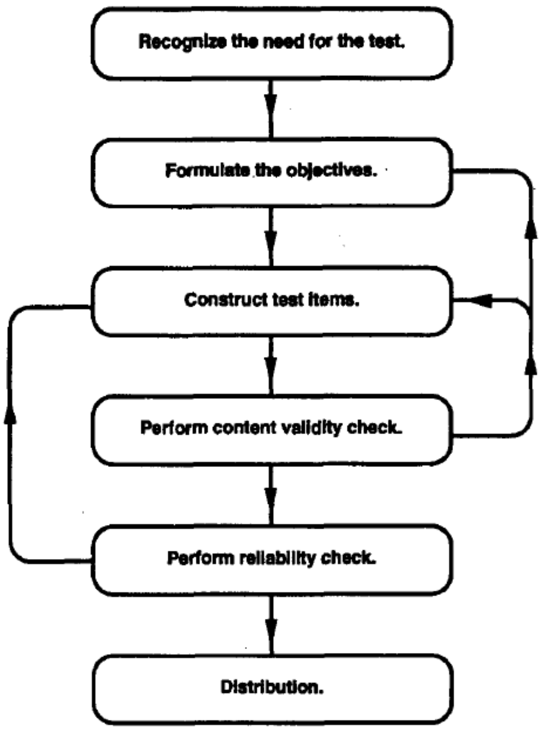

Fig. 2 A flowchart for test development showing feedback loops between steps (source: Beichner (1994) [12])

Step 1 (need). The need for the test was established by the fact that the authors could not find in the literature an objective test of unit conversions that had been checked for validity and reliability.

Step 2 (objectives). Eight objectives (A through H) for the test were defined as follows:

A. Convert linear units. One step. (for ex, feet to inches, or feet to cm).
B. Convert linear units. Multiple steps (for ex, 55 mph to ft/s).
C. Convert area units.
D. Convert volume units. Cubic operation not required (for ex, gallons to cubic feet).
E. Convert volume units. Cubic operation required (for example cubic feet to cubic inches).
F. Convert between scientific notation and decimal numbers (prerequisite check for metric prefixes).
G. Convert between metric prefixes.
H. Select the most appropriate metric prefix given a number.

Step 3 (construct the test). Two questions were generated for each objective, one question required multiplication of the conversion factor while the second question required division of the conversion factor. The total number of questions was 16 questions, all of them multiple choice with five possible answers (A, B, C, D, E). The answers included distractors, i.e., choices that the students were likely to obtain if they converted units incorrectly. The 16 questions are presented as an appendix to this paper.

Step 4 (validity). "Validity is really accuracy - does the test measure what we think it does? Validity is not calculated, it is established" [12]. Fig. 3 shows four cases to assist the reader in differentiating between validity and reliability. Validity refers to how close the measurements are to the center of the target (the center represents what the test is supposed to measure). The validity check was established by an expert panel that consisted of all the authors, except the first author who initially wrote the 16 questions. All the authors took the test, they all achieved perfect scores (100%), and they provided comments to improve the questions. Minor changes were made to the test based on the expert panel's comments. The test was deemed to have validity at this point.

Step 5 (reliability). "Reliability is an indicator of how precisely we made the measurement. Reliability is calculated and there are several different ways to statistically determine whether a test is reliable or not" [12]. Fig. 3 shows that, in a reliable test, the measurements are closely clustered (but not necessarily near the center of the target). The reliability check was performed on the results of the test of N = 138 students, and considered the results of the 16 questions. The calculated Cronback Alpha Index of the test was 0.823 (determined by SPSS software) which is considered very good. Based on this value, the test was deemed reliable.

Step 6 (distribution). At this point, the test was deemed ready for distribution. The authors encourage other SoTL researchers to use this test and report their findings in the literature.

The test is included as an appendix to this paper. The test questions are given in the same order as the objectives listed above.

The order of the test questions was randomized in the actual test. The questions were written in a Microsoft Forms form, and the test was given as a take-home assignment in the ME courses offered during the Fall term of 2022. The faculty provided the hyperlink to the test and coordinated the efforts to maximize the number of ME students that took the test. The students were given a bonus of 5% in the course if they answered the test (regardless of their test score). The first author cleaned up the test results to eliminate repetitions (some students did not follow instructions and took the test more than once). A total of N=138 students took the test which represented 46% of the ME undergraduate student population (300 students). The second author then analyzed the results with SPSS software.

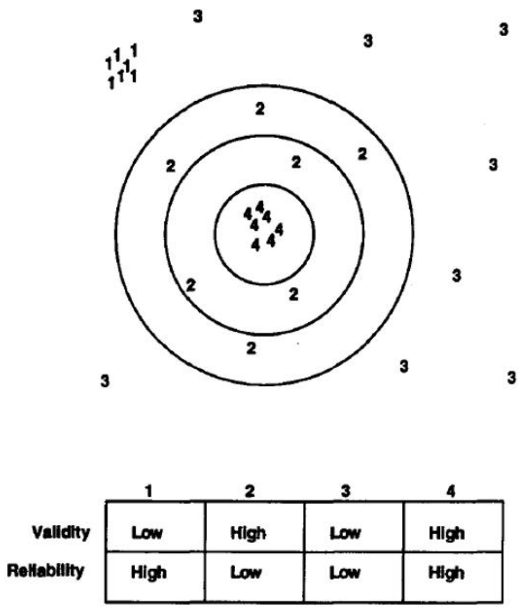

Fig. 3 "A comparison of test validity and reliability. The center of the target represents what the test purports to measure". (Source: Beichner (1994) [12])

IV. Results

Table 1 shows the results of the test. The first three columns provide the objective letter, the question number, and the correct answer. The last three columns provide the percentage of students that answered the question correctly (the overall column includes all the test takers). The bottom row of the table provides the average score in the test.

TABLE I
TEST SCORES

Obj.	Q.	Correct Answer	1st year N=21	Overall N=138	Seniors N=24
A	1	D	95%	95%	96%†
A	2	B	57%	75%	92%*†
B	3	C	67%	86%	92%*
B	4	A	48%	75%	88%*†
C	5	E	52%	69%	88%*
C	6	B	57%	64%	75%
D	7	C	90%	93%	92%†
D	8	A	62%	78%	92%*†
E	9	E	43%	65%	83%*†
E	10	C	43%	64%	75%*
F	11	B	81%	86%	88%†
F	12	D	57%	75%	75%
G	13	A	48%	52%	50%
G	14	C	52%	61%	58%
H	15	E	57%	79%	92%*
H	16	B	67%	62%	75%
A-H	*Avg.*	---	*61%*	*74%*	*82%*

Notes:
(*) An asterisk indicates that there was a statistically significant difference (p-value < 0.05) between the average scores of 1st year students and senior students.
(†) A cross means that SPSS software warned that there was insufficient data to deem the results conclusive. The statistical results provide an idea but are not fully generalizable.

V. Discussion of Results

The bottom row of Table 1 provides the average test scores for the three groups. The first-year students scored an average of 61%, and equivalent to a grade of "D". Also, 90% of the 1st year students made at least one mistake. It tends to indicate that first-year students are coming in from high school with deficiencies in unit conversions. The overall score was 74% which is equivalent to a passing grade of "C". However, 85% of the entire N=138 population made at least one mistake. Senior students scored an average of 82% which is equivalent to a passing grade of "B". However, 79% of the seniors made at least one mistake. These results tend to indicate that students improve their skills at converting units as they progress through the curriculum. In fact, the asterisks in Table 1 indicate that there was a statistically significant gain in skills in seven of the 16 questions. Still, units are such a fundamental part of engineering that faculty expect seniors to score perfectly (100%) or nearly perfectly in the test. There is room to improve student performance.

Objective A (convert linear units in one step). The difference in test scores between questions 1 and 2 shows that students (particularly 1st year students) perform much better when the conversion factor is multiplied (question 1) than when division is required (question 2). Part of the reason may be that many conversion tables are based on multiplying conversion factors. Fig. 4 shows that the National Council of Examiners for Engineering and Surveying (NCEES) uses a table based on multiplying the conversion factor in the FE Exam Reference Handbook [13], which is the sole reference that students have available while taking the Fundamentals of Engineering (FE) licensing exam. The table favors a left-to-right (multiplication) conversion. Students must think further when division is required (right-to-left conversion) which adds a degree of difficulty. It is much more helpful to present conversion factors as equalities, as shown in Fig. 5, as is used by the American Society of Civil Engineers (ASCE) [14].

Multiply	By	To Obtain
joule (J)	9.478×10^{-4}	Btu
J	0.7376	ft-lbf
J	1	newton•m (N•m)
J/s	1	watt (W)

Fig. 4 Part of the conversion table provided in the NCEES FE Reference Handbook [13]. It includes the headings “Multiply”, “By”, and “To Obtain” which favors a left-to-right unit conversion. Students must think further when division is required (right-to-left unit conversion) which adds a degree of difficulty.

Measurement	*S.I. Units*	*Customary Units*
Length	1 m = 3.2808 ft = 1.0936 yd 1 cm = 0.3937 in. 1 km = 0.6214 mile	1 ft = 3 yd = 0.3048 m 1 in. = 2.54 cm 1 mile = 0.869 nautical mile = 1.6093 km
Area	1 m^2 = 10.7643 ft^2 1 km^2 = 0.3861 mi^2 1 ha = 2.4710 acre	1 ft^2 = 0.0929 m^2 1 mi^2 = 2.59 km^2 1 acre = 43,560 ft^2 = 0.4047 ha
Volume	1 L = 0.2642 gal 1 ml = 1 cm^3	1 gal = 4 qt = 3.7854 L 1 ft^3 = 7.481 gal = 28.32 L

Fig. 5 Part of the conversion table used by ASCE [14]. The use of equalities to show unit conversions has a neutral nature because it does not favor either multiplication or division of the conversion factor.

Objective B (convert linear units in multiple steps). Both questions 3 and 4 required multiplication and division of conversion factors. There was a slight dip in performance compared to Objective A which may be due to the more complex chain of conversion factors.

Objective C (convert area units). The scores in questions 5 and 6 dropped significantly with area units. Nearly 25% of the students chose the distractor answer in both questions. The distractor did not square the conversion factor.

Objective D (convert volume units, cubic operation not required). Question 7 required multiplication of the conversion factor and all the scores were at or above 90%. The scores drop in Question 8 (62% for 1st year students) which requires division. The results are very similar to Objective A because the cubic operation was not required, i.e., it was like a case of linear units.

Objective E (convert volume units, cubic operation required). The scores in questions 9 and 10 dropped significantly with volume units. Nearly 20% of the students chose the distractor answer in both questions. The distractor answer did not cube the conversion factor. Nearly 10% of the students in question 9 chose the distractor of dividing the conversion factor when multiplication was the correct path.

Objective F (scientific notation). Students found it easier to convert a decimal number to scientific notation (question 11) than converting scientific notation to a decimal number (question 12). In question 11, nearly 7% of the students chose the distractor answer of reversing the sign of the exponent. In question 12, nearly 10% of the students chose the distractor answer of using a negative sign in front of the decimal for a negative exponent.

Objective G (convert between metric prefixes). Questions 13 and 14 yielded the worst results in the test, even for senior students. This same difficulty was reported in the literature review [9, 10]. The use of metric prefixes is an area that must be prioritized as the faculty discuss improvement strategies. The difficulty may lie in not being able to conceptualize metric prefixes as conversion factors. The table given to students, which is the same one used in the NCEES FE Reference Handbook (see Fig.7 in the appendix), only provides the exponent for each prefix. Students seem uncapable of expressing the exponent as a conversion factor. A simple fix may be to present a conversion example at the bottom of the table (see Fig. 7).

Objective H (select the most appropriate metric prefix given a number). The scores were better than for converting between metric prefixes but still lower than expected. There is room for improvement with this objective.

VI. Conclusions

Although the number of students was relatively low (particularly for 1st year students (21%), and senior students (24%)), the following conclusions may be made.

1st year students are coming into the ME program with deficiencies in unit conversions.

Students improved their unit conversion skills as they progress through the curriculum (statistical significance in half of the questions).

The worst performance was observed when converting between metric prefixes.

Part of the reason that may explain why students have difficulties with unit conversions may lie in the way that tables of unit conversions and tables of metric prefixes are presented. These could be improved by (a) preparing a conversion table that is based on equalities of the conversion factors rather than showing conversion factors as multiplication, and (b) providing one conversion example below the table of metric prefixes.

SoTL provided an interesting and different perspective on outcomes assessment. In this case it provided an approach to reach a deeper level of understanding of the difficulties that students have with unit conversions.

Acknowledgment

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APPENDIX: TEST

The test consists of 16 questions. Questions 1-10 included the conversion table shown in Fig. 6. Note that Fig. 6 includes conversions as equalities rather than a multiplication.

Questions 13-16 included the table of metric prefixes shown in Fig. 7. The note under Fig. 7 is a recommendation of the authors. It consists of one example of a metric prefix conversion to assist readers and thus minimize the high degree of confusion that exists with metric prefixes (see section V. Discussion of Results).

Following the tables, the 16 questions are presented in the order established in Table 1 (the table includes the correct answers to the test and the average scores). Readers are welcome to copy the questions verbatim to ensure that the test is the same for all the exam takers. However, the test questions should be randomized before giving the test to students.

Conversion factors

1 day (day) = 24 hours (hr)
1 hour (hr) = 60 minutes (min)
1 minute (min) = 60 seconds (s)
1 inch (in) = 2.54 centimeters (cm)
1 foot (ft) = 12 inches (in)
1 yard (yard) = 3 feet (ft)
1 mile (mile) = 5,280 feet (ft)
1 gallon (gal) = 3.785 liters (L)
1 cubic foot (ft^3) = 7.481 gallons (gal)

Fig. 6 Table of conversion factors given to students in questions 1 through 10. The list is short because it only includes relevant conversion factors.

METRIC PREFIXES		
Multiple	Prefix	Symbol
10^{-18}	atto	a
10^{-15}	femto	f
10^{-12}	pico	p
10^{-9}	nano	n
10^{-6}	micro	μ
10^{-3}	milli	m
10^{-2}	centi	c
10^{-1}	deci	d
10^{1}	deka	da
10^{2}	hecto	h
10^{3}	kilo	k
10^{6}	mega	M
10^{9}	giga	G
10^{12}	tera	T
10^{15}	peta	P
10^{18}	exa	E

(The authors recommend the inclusion of the following note)
Note: Example of a metric prefix conversion:1 Gm = 1 x 10^9 m

Fig. 7. Table of metric prefixes given to students in questions 13-16. The recommended note provides guidance to table users, thus minimizing the high degree of confusion with metric prefixes. (Source: NCEES FE Exam Handbook [13])

1. Convert 17 inches (in) to centimeters (cm).
The answer is most nearly:
   A. 0.15 cm
   B. 6.68 cm
   C. 27.09 cm
   D. 43.18 cm
   E. 54.75 cm

2. Convert 1,500 feet (ft) to miles (mile).
The answer is most nearly:
   A. 0.03 mile
   B. 0.3 mile
   C. 3 mile
   D. 30 mile
   E. 7,920,000 mile

3. Convert 55 miles per hour (mile/hr) to feet per second (ft/s).
The answer is most nearly:
   A. 37.5 ft/s
   B. 62.5 ft/s
   C. 80.7 ft/s
   D. 104.3 ft/s
   E. 484.1 ft/s

4. Convert 123 inches per second (in/s) to miles per hour (mile/hr).
The answer is most nearly:

A. 7 mile/hr
B. 23 mile/hr
C. 84 mile/hr
D. 120 mile/hr
E. 246 mile/hr

5. Convert 2 square feet (ft^2) to square inches (in^2).
The answer is most nearly:

A. 0.014 in^2
B. 0.14 in^2
C. 24 in^2
D. 186 in^2
E. 288 in^2

6. Convert 30,000,000 square feet (ft^2) to square miles ($mile^2$).
The answer is most nearly:

A. 0.3 $mile^2$
B. 1.1 $mile^2$
C. 5.68 $mile^2$
D. 568 $mile^2$
E. 5681 $mile^2$

7. Convert 18 gallons (gal) to liters (L).
The answer is most nearly:

A. 4.75 L
B. 34.52 L
C. 68.13 L
D. 93.29 L
E. 125.11 L

8. Convert 18 gallons (gal) to cubic feet (ft^3).
The answer is most nearly:

A. 2.4 ft^3
B. 4.8 ft^3
C. 48.0 ft^3
D. 84.5 ft^3
E. 134.7 ft^3

9. Convert 2 cubic feet (ft^3) to cubic inches (in^3).
The answer is most nearly:

A. 0.0012 in^3
B. 0.14 in^3
C. 24 in^3
D. 288 in^3
E. 3,456 in^3

10. Convert 270 cubic feet (ft^3) to cubic yards ($yard^3$).
The answer is most nearly:

A. 0.1 $yard^3$
B. 1 $yard^3$
C. 10 $yard^3$
D. 30 $yard^3$
E. 90 $yard^3$

11. Convert the decimal number 234,500,000 to scientific notation.
The answer is:

A. 2.345×10^{8}
B. 2.345×10^{-8}
C. 2.345×10^{9}
D. 2.345×10^{-9}
E. 2.345×10^{10}

12. Convert 7.654×10^{-5} to a decimal number.
The answer is:

A. – 0.000007654
B. – 0.00007654
C. 0.0007654
D. 0.00007654
E. 0.000007654

13. Convert 10 nanometers (nm) to kilometers (km).
The answer is:

A. 1×10^{-11} km
B. 1×10^{11} km
C. 1×10^{-12} km
D. 1×10^{12} km
E. 1×10^{-13} km

14. Convert 3.8 gigameter (Gm) to decimeters (dm).
The answer is:

A. 3.8×10^{9} dm
B. 3.8×10^{-9} dm
C. 3.8×10^{10} dm
D. 3.8×10^{-10} dm
E. 3.8×10^{11} dm

15. If you wish to express 29,000,000 m with a metric prefix, which prefix would be the most appropriate?

A. Nano
B. Micro
C. Deca
D. Kilo
E. Mega

16. If you wish to express 0.00003 m with a metric prefix, which prefix would be the most appropriate?

A. Nano
B. Micro
C. Milli
D. Centi
E. Deci