Work in Progress: Inquiry-Based Lessons for Introduction to Engineering Instruction

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Abstract

This Work in Progress describes efforts to introduce Inquiry-Based Learning (IBL) instruction to an introduction to engineering course. Inquiry-based approaches uses inductive teaching strategies. The class is Introduction to Engineering and Computer Science for Mechanical Engineers. It is a required class for incoming freshman students that is held in the fall semester. The motivation behind this Work in Progress is to address the problem that even though education research has proven inductive learning promotes deeper and longer retention of information; most university engineering classes are still primarily lecture based. Therefore, students are oblivious to the benefits of the methods and thus are resistant to the learning approaches. The method employed to aid this problem was developing a series of worksheets that use IBL strategies to introduce introductory engineering material. Preliminary assessment of the effectiveness of this approach was conducted by comparing summative exams and real-time feedback of student thoughts using a daily in-class reflection. Preliminary analysis of the exam comparison and student reflections is promising. From reflections, the majority of the students filled out the statement sections of the reflection sheet. Fewer students filled out the question portion, indicating that they comprehended the IBL lessons. Initial exam comparisons indicated that the IBL approaches support increased student learning of the conceptual aspects of technical concepts.

Introduction

Many educational experts recommend that a fundamental paradigm shift needs to occur in engineering education [1]. Both students and teachers need to acquire and implement pedagogical skills that currently are not prevalently found in college teaching of engineering. This work aims to address the following problems; first, the majority of university engineering classes are still taught in an archaic presentation lecture style [2]. Second, most students are unaware of the benefits of inductive learning and think that they prefer deductive, passive presentation of material [3, 4].

This work in progress aims to address these problems by exposing students to IBL instruction at the earliest possible point in engineering curriculum. By using IBL instruction in Introduction to Engineering courses, students will learn the skills necessary to move beyond passive, transmission-based learning, and will engage in inductive learning opportunities from their first semester in college.

Background

Inquiry-based approaches are a form of inductive teaching that emphasize the student's role in the learning process [5]. During class time, students are empowered to explore concepts, ask questions, and share ideas. Instead of the instructor lecturing to passive listeners about the material. A primary aim of IBL strategies is student involvement, which leads to increased understanding and retention of material. All IBL strategies use common elements including active small-group discussion [6].

Inquiry-based learning models are well established in education. Originating in the 1960s, the inductive pedagogies have been used in primary and secondary school education [7-9]. There are several different inquiry-based instruction levels [10, 11]. Level 1 is where students follow the lead of a teacher as the entire class engages to confirm a principle or concept through an activity, where the results may or may not be known in advance. An example of this would be the whole class working on an experiment with professor working through the steps with the students. Level 2 is when students investigate a teacher presented question using teacher prescribe procedures. An example of this is students working on a teacher made worksheet while the teacher walks around the class to answer questions. Level 3 is where students investigate a teacher-chosen topic/question using student designed or selected procedures. For example, students designing an experiment to solve a specific problem a professor gives them. Level 4 is where students choose their own open topics or questions to investigate, and they use procedures that are student formulated. An example is students choose and design their own product to solve a worldwide need.

In primary education, teachers are encouraged to scaffold the levels into their curriculum; beginning with Level 1 and working up to Level 4. Beginning instruction at the lower levels help to develop student’s inquiry skills and their motivation and excitement for the learning methods [12]. However, in secondary education, the levels are implemented more discretely and the format of class is highly dependent on the subject matter. Particularly, STEM disciplines (science, technology, math, and engineering) trend toward the use of Levels 1 thru 3 for their required undergraduate classes, with maybe the exception of a senior capstone class, while other disciplines (social science, language arts, and education) are suited to more prevalently utilize Level 4 [13].

The effectiveness of IBL has been assessed at a range of institutions and for a variety of courses. At the college level, IBL methods have been used for teaching general chemistry [14], foreign language [15], information technology [16], computer science [17], and materials science [18]. For the science and math courses, mostly Level 1 and 2 methods are implemented with proven success. One example in chemistry showed that over a four year period, the attrition rate (scores of D, F or withdraw from course) of students taught with a Level 2 IBL strategy decreased to 9.6% from 21.9% versus traditional teaching methods [14]. However, as with all learning approaches, the gains the students achieve is impacted by the differences of instructors and the conditions of the classroom [19-21].

Using IBL methods is not yet prevalent in engineering curriculum. Currently textbooks are only on the market for freshman level math and science courses [22, 23], and sophomore or junior level engineering science courses [24, 25]. It is anticipated that implementing IBL practices early in the curriculum will lead to increased success of student learning with IBL at any level of engineering education.

Implementation

IBL Worksheets were developed that introduce engineering material to first-year undergraduate students. The worksheets draw on different IBL instruction levels. The topic chosen was *Dimensions and Units*. This area fell under the first Course Level Outcome and was associated with ABET Outcome 1, namely to "Develop an ability to identify, formulate, and solve complex engineering problems by applying principles of engineering, science, and mathematics" [26]. For each topic within Dimensions and Units, there are Daily-Level Student Outcomes. A summary of the activities developed along with their outcomes and the class period where they were taught is given in Table 1.

Table 1: Summary of IBL worksheet activities created.

Activity	Title	Daily-Level Student Outcome	When it was taught
1	Fundamental Dimensions and Units	Students learned to identify physical quantities in terms of dimensions and units.	Lecture 2
2	Primary and Secondary Units	Students learned to (1) Differentiate between fundamental and derived units, (2) Recognize the different unit systems, and (3) Recognize the different primary, secondary and derived units in each system.	Lecture 2
3	Dimensional Analysis and Homogeneity	Students learned (1) What Dimensional Homogeneity is and (2) How to apply it to engineering problems to understand the meaning of outcomes even before numerical solutions are calculated.	Lecture 3
4	Unit Conversion	Students learned to (1) Systematically convert units from one system to another and (2) Use knowledge of dimensions and units, along with conversion rules in the solution of engineering problems.	Lecture 4
5	Significant Figures	Students learned how to (1) correctly display units when solving engineering problems and (2) write numerical answers with correct significant digits.	Lecture 4

In fall 2019, the classes on Units and Dimensions using were taught using IBL. Typically, a class period was organized and executed as follows:

1. When a new topic was introduced, a brief introduction was given. Alternatively, a review of the previous classes' material was given, if it were a continuation of topic.
2. Students were released to work in groups of 3-4 (studies recommend no more than four in a group [27]). Student roles were not prescribed within a group. There are several reasons for not prescribing roles. Key among them is by letting students invest in all rolls, the instructor attempted to mitigate the typical typecasting of female group members becoming note takers [28]. Everyone wrote her or his own notes. In addition, this helped to address the engagement of introverts within a group, but did not place pressure on them to present [29].
3. The groups worked on the activity for a designated amount of time. The amount of time varied depending on the level of the IBL activity and the components of the worksheet. Typically, the minimum time given for a worksheet was 7 minutes and the maximum was 20 minutes.
4. While the students were working, the instructor walked around and observed each group. When students asked questions, the instructor tried not to directly answer the worksheet questions, but rather guided the students to discover the answer themselves. This was accomplished by responding to a student's inquiries with leading questions, or rephrasing the topic in a different manner.

5. If the instructor observed that the majority of the class was struggling with a particular section or question, they stopped the group work briefly and addressed the entire classes' confusion.
6. Once the allotted work time was up, the instructor actively engaged the class in reviewing the answers to the worksheet. Keep in mind that the instructor did not give the answers. The class was responsible for explaining the answers along with the instructor.
7. Steps 1 thru 6 were repeated for each worksheet. For a 50 minute class period, typically 1-2 worksheets could be covered and for an 80 minute period 2-3 worksheets were completed.
8. Students kept the worksheets as notes for studying and reference for homework.
9. The last five to seven minutes of class time was always reserved for reflection. The reflection was in the form of "Wow…Duh…Hmm" [30]. In the reflection, students were asked to fill in three boxes: (1) Wow: I did not know that! (2) Duh: everyone knows that and (3) Hmm: I'd like to review/lean more about that. The instructor reviewed the reflections prior to the next lecture. This served to gage student feelings about the worksheets and helped the instructor adjust the next class as necessary.

Worksheet Examples and Explanations

The five activities created were mostly IBL Level 2, because the students answered teacher developed questions using prescribe procedures. Examples of selected worksheets can be found in Appendix A. Each activity was structured such that it met the daily-level student outcomes. In addition, each question set nominally can be broken up into three categories.

The first category were questions that build on student's prior knowledge in order to help them ultimately develop a definition or explain a concept. An example of this is Activity 1 shown in Appendix A.1. Most students are familiar with units by the time they enter college, but they are not familiar with the concept of dimensions. They lack fundamental understanding of the relationship between dimensions and units or why they are both important. Activity 1 is intended to help them define and compare dimensions and units before they even use numbers. Another example is the first set of questions for Activity 3 (questions 3.1 thru 3.13) shown in Appendix A.3. This activity began by using student's prior knowledge of the definition of homogeneity, which they learned most likely from beginning chemistry. The students were given a simple object, a nail file, with a list of quantities that define the product and how it works. Student worked through a series of questions where they developed equations that define the nail file, namely "how heavy the file would be?" and "how much nail particles would be removed when you run the file over a nail once?" Students compared these two equations in terms of fundamental dimensions and units. For the first equation about weight, the students deduced that the equation that would define "heavy" is not valid because the base dimensions of each relevant parameter are all different. For the second equation about filing effectiveness, the equation is valid because all of the terms have dimensions of length. Working through this activity ultimately led to the students defining mathematical homogeneity in their own words.

The second category were questions that direct students to recognize and recall specific information. For these, students were asked to work with and read a graph or a table. An example of this is Activity 2 shown in Appendix A.2. This activity focuses on students learning to differentiate between fundamental and derived units, recognize the different unit systems, and identify the different primary, secondary and derived units in each system. In this activity, students read from the different tables and fill in the missing cells with unit names and/or symbols.

The third category was application questions that help students practice solving problems using the introduced concepts. An example of this is in Activity 3 the second set of questions (questions 3.14 thru 3.20). This IBL activity gives students practice using dimensional analysis to check whether an equation is valid or invalid and determine the dimensions of a physical quantity or engineering constant if they are unknown.

Also included at the end of most of the activities were higher-order thinking questions or straightforward exercises that have the students apply the content they just learned. An example is the final pair of questions in Activity 3 (questions 3.21 and 3.22). Here, students were asked to use dimensional analysis to determine an unknown constant (Modulus of Elasticity). Another example of exercises with the concepts occurs again in Activity 4 question 4.6 shown in Appendix A.4. Students use unit conversion to calculate "How many times does a honeybee flap its wings in one week."

Assessment

In fall 2019, approximately 15% of the classroom lectures were switched to an IBL format, which was presented to the entire class. Preliminary assessment of the impact of the worksheets utilized two markers. Early summative assessment used the exam where the Unit and Dimensions topics were covered. Specifically, exam questions from the Fall 2018 course offering (where all the classroom lectures were deductive based) was compared to exam questions from the Fall 2019 offering. Specifically the True/False, and multiple-choice questions that assessed the units and dimensions topics. Examples of representative questions from the sections of both exams can been seen in Figure 1. For the True/False and multiple-choice sections the average in Fall 2018 was an 81%, with the average being an 93% in Fall 2019. This is promising, showing that the students seem to better understand the conceptual material being taught with the inquiry worksheets.

For real-time feedback, students were asked to write an in-class reflection after each lesson. The reflection was in the form of "Wow…Duh…Hmm" [28]. Activities 1&2 were performed on the same day and Activities 4&5 were performed together, so students reflected on those activities in the same form. Figure 2 displays the quantity of responses received in each category. The results show that the students mostly filled out the statement sections of the reflection sheet. Specifically, an average of 38 ± 7% of students filled out the "Wow" category, 39 ± 7% filled out the "Duh" section. Fewer students (average 23 ± 0.6%) filled out the question "Hmm" portion, indicating that overall they comprehended the worksheet topics after the inquiry lessons.

True/False Section

1. There is no difference between "dimensions" and "units"
   a. True b. False
2. Units are scales or division used to quantify dimensions.
   a. True b. False
3. Velocity is a primary dimension.
   a. True b. False

Multiple Choice Section

1. Which of the following is the British Gravitation unit for mass?
   a. kilograms c. grams
   b. pound mass d. slugs
2. Which of the following are fundamental SI units?
   a. seconds, meters, liters c. Newton, seconds, kilograms
   b. seconds, meters, grams d. seconds, kilograms, Kelvins
3. The principle of dimensional homogeneity serves the following useful concepts
   (i) It helps to check whether an equation of any physical phenomenon is dimensionally homogenous or not
   (ii) It helps to determine the dimensions of a physical quantity
   (iii) It helps to convert the units from one system to another
   Identify the correct statements:
   a. 1 and 2 c. 1, 2 and 3
   b. 2 and 3 d. 2 only

Figure 1: Examples of representative questions from the True/False and Multiple Choice sections of both exams that assessed concept understanding from the IBL worksheets.

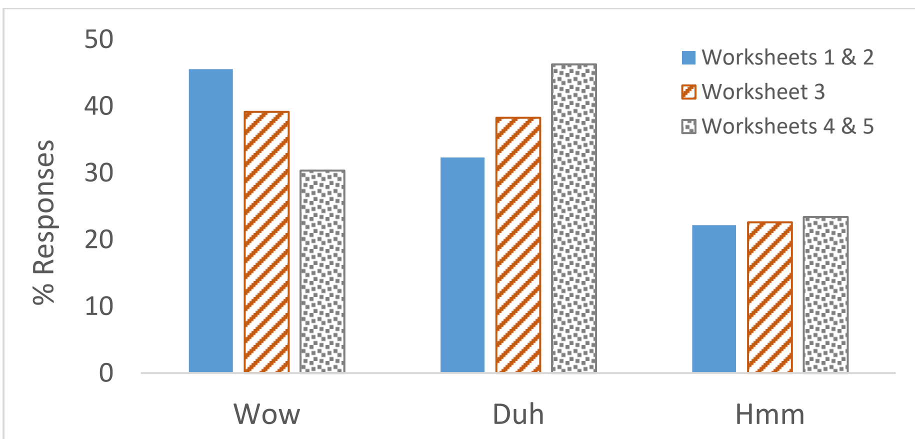

Figure 2: Quantity of Responses for each inquiry reflection worksheet sheet.

To qualitatively investigate student feedback, the responses were categorized based on worksheet learning goals and the concepts being taught. From reading the responses, some distinct learning trends appeared.

Activities 1&2 responses are shown in Figure 3. With Activity 1, most students were aware of, and could list examples of either the S.I. units, U.S. units or both systems, but they struggled to explain or define the concept of a dimension (code B). In addition, they could not explain the relationship between dimensions and units (code C). The students felt the first activity really taught them to define the terms, compare the terms and explain their importance. For Activity 2, the majority of students could list some fundamental units (Code E). Student's main mistakes were calling "weight" a fundamental dimension instead of "mass." Also, they did not know the fundamental dimensions of "light" and "amount of matter," so they were very interested in learning more about those quantities (code E). Finally, students knew most of the primary units in either the U.S. or S.I. unit system. However, they were unfamiliar with most of the secondary units (such as force), so they wanted to learn more (code F). Examples of student responses for Activities1&2 can be seen in Appendix B.1.

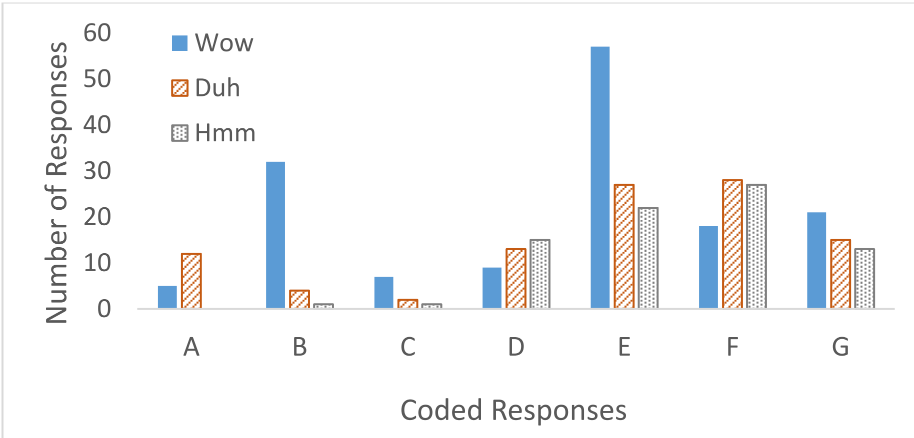

Figure 3: Responses based on themes from Worksheets 1&2. Responses are coded based on the following themes: (A) What is a unit?, (B) What is a dimension?, (C) Relationship between units and dimensions, (D) Primary and Secondary Units, (E) Unit quantities and symbols from the charts, (F) Unit systems (SI/US), (G) Other.

Activity 3 responses are in Figure 4. For Activity 3, many students already had a preconceived definition of homogenous (code A) with regard to substances. They were able to leverage this past knowledge into learning to define "dimensional homogeneity" (code B). However, students struggled with the engineering applications of the concept. Specifically, they wanted to learn more about how to check whether an equation of any physical phenomenon is valid or invalid and determining the dimensions of a physical quantity or material constant that they are unfamiliar with (code C & D). Examples of student responses for Activity 3 are in Appendix B.2.

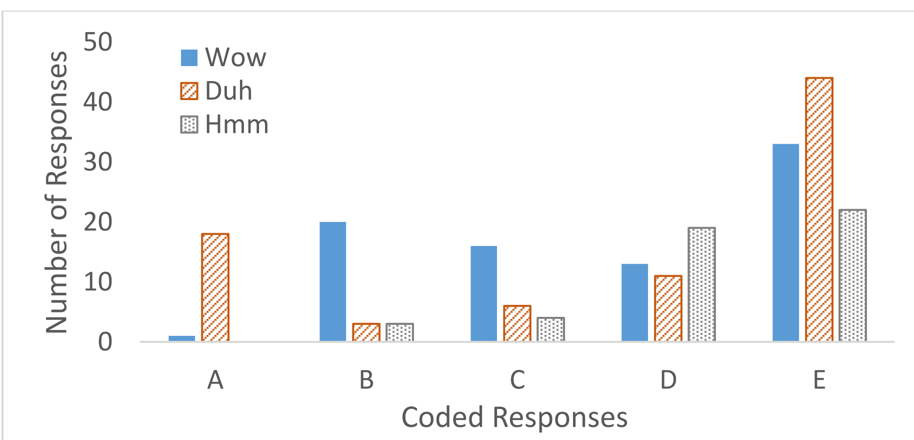

Figure 4: Responses based on themes from Worksheet 3. Responses are coded based on the following themes: (A) What is homogeneity?, (B) What is a dimensional homogeneity?, (C) Valid versus un-valid equations, (D) Applying dimensional homogeneity, (E) Other.

Activities 4&5 responses are shown in Figure 5. The majority of students were familiar with all the topics from worksheets 4&5. Specifically unit conversions, significant figures and rounding (Codes A, B and C). However, students still indicated that they would like to learn more about application and practice of the topics. Finally, there was a fatigue with the "Wow…Duh…Hmm" reflections. Total relevant comments decreased from 329 responses for Activities 1&2, to 213 responses about Activity 3, down to 195 responses for Activities 4&5. Examples of student's reflection forms for Activities 4&5 are in Appendix B.3.

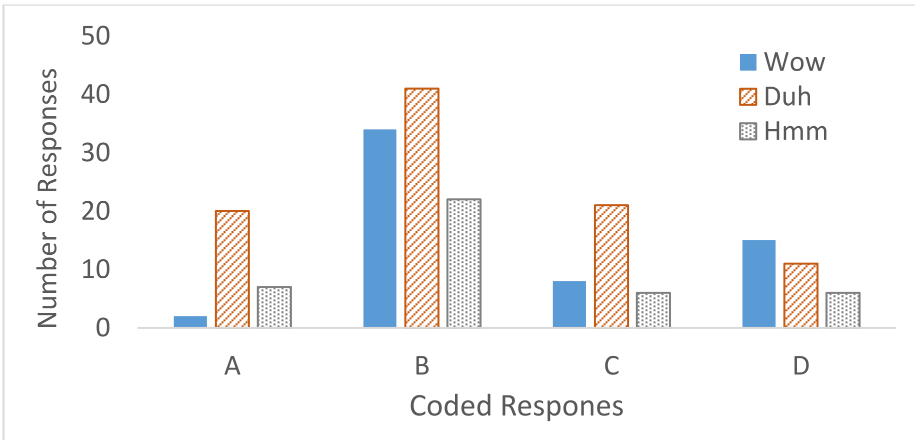

Figure 5: Responses based on themes from Worksheets 4&5. Responses are coded based on the following themes: (A) Unit conversions, (B) Significant figures, (C) Rounding numbers, (D) Other.

Conclusions and Future Work

While this method shows promise, there are several limitations to this Work in Progress. Specifically, work samples were not collected, because students used the worksheets as notes. They referred to them for homework and for studying. In the future, a process will be developed so that work samples can be collected, copied to be used for assessment, and then returned to students for reference and study purposes. Also, IBL approaches have not been fully implemented in the class, and thus comprehensive assessment data comparing standard lecture format with inquiry format is not yet available. Assessment of student learning using the inductive approach vs. the control deductive approach needs to be addressed in a long-term longitudinal study. Also, for this initial work in progress the class size is relatively stable (around 60 students). Therefore, in the future, a more comprehensive study will address the suitability of the current approach for large versus for small classes. One technique that will be implemented next class offering is direct comparison of short answer questions. A short answer question from when the class was deductive based in 2018 can be given in future exams and compared.

Overall, the use of IBL methods has the potential to greatly improve the teaching and learning of first year engineers. It will educate students early in their college career to the benefits and skills essential to inductive learning. Over time, students will see improved retention and satisfaction in their learning. While a number of issues remain unaddressed, this work is progress is a very promising step in the development of improved first year engineering curricula.

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Appendix A: Examples of selective IBL Worksheets.

A.1: Example of IBL Worksheet for Activity 1.

ECS 101 (ME) – Intro to Engineering & Computer Science

IN-CLASS ACTIVITY: Dimensions and Units

Activity 1 – Fundamental Dimensions and Units

In this section, students will learn to:

- Identify physical quantities in terms of dimensions and units

Throughout history, humans have learned from interacting with their environment and each other. Through observations, they realized they needed some way to describe surroundings and events to each other, so that they could communicate in a consistent manner. Once common communication was established, people began to design, develop, test, and fabricate societal improvements such as tools, shelter, weapons, water transportation, and resources to grow food. In this first guided inquiry, you will explore the need for dimensions and units and label the categories for each physical quantity.

Guided Inquiry:

1.1 Back in the day, when answering the question "how old are you?" or "how long does it take to get from here to there?" a person might answer, "I am many moons old." or "it takes many moons to go from my village to your village." Based on the examples given, explain why we need physical variables.

1.2 See how many physical quantities you can name that we use in everyday life.

1.3 When baking, if we say, "bake the brownies for a long time," what physical quantity are we trying to describe?

1.4 Based on the two sentences, which sentence define in your own words what the term *dimension* means.

1.5 Based on your definition to the previous question, name the seven *fundamental dimensions*. (It is from these base dimensions that all other physical quantities are defined)

1.6 When baking, we actually say, "Bake the brownies for *28 minutes*." We do not say, "Bake the brownies for *a long time*." Based on the two sentences, define in your own words what the term *unit* means.

1.7 Based on your definition to the previous question, list three examples of *units*.

1.8 Explain how Dimensions and Units are different from each other.

1.9 Explain how Dimensions and Units are related to each other.

A.2: Example of IBL Worksheet for Activity 2.

ECS 101 (ME) – Intro to Engineering & Computer Science

IN-CLASS ACTIVITY: Dimensions and Units

Activity 2 – Primary and Secondary Units

In this section, students will learn to:

- Differentiate between fundamental and derived units
- Recognize the different unit systems
- Recognize the different primary, supplementary and derived units in each system

Primary Units

Units can be likened to colors. The three primary colors (blue, yellow, red) are mixed in different combinations to make other colors (for example, mixing blue and yellow together makes the color green). The Primary Units (also known as Base Units) are used to measure each of the fundamental dimensions. Currently, two primary unit systems are predominantly used in engineering applications throughout the world:

International System of Units (SI units): The SI unit system is the most commonly used system of measurement, with only three countries around the world not adopting its usage; the United States, Liberia and Myanmar [1]. Essentially, it is the modern form of the metric system, built on seven base units, which correspond to the seven fundamental dimensions. The units are derived from invariant constants of nature, which are measured with extreme precision. For example, natural quantities such as the speed of light in vacuum and the triple point of water are used [2]. In addition, to specify fractions and multiples of the units, there is a set of twenty prefixes that can be applied. These prefixes are based upon multiples of ten. The SI system is the standard units used in medicine, science, engineering, and the military [3].

United States customary system (USCS or US System): The USCS is the system of measurements commonly used in the United States (U.S.). The system evolved from the British Imperial unit system, established by the British Empire, and used during U.S. colonial times [4]. The units derived over thousands of years from Roman, Celtic, Anglo-Saxon, and customary local units employed in the Middle Ages and were standardized by Great Britain in 1824 [5]. The US System is commonly used for measurement in commercial activities, consumer products, construction and manufacturing, because builders and manufacturers argue that measurements are easier to remember in the form of an integer number plus a fraction [6].

In order to scale numbers to primary dimensions, primary units must be assigned. The next activity provides an opportunity to determine which dimension a given unit indicates, and allows us to provide an appropriate unit given the quantity in the SI and English unit systems.

2.1 Looking at Table 2.1, what is the difference between the *m* in row 1 and the *M* in row 2? (Note: one letter can represent different quantities in various engineering problems)

2.2 What does the *K* symbol stand for in Row 4?

2.3 Which rows have the same Base Units in both the SI system and the US system? (hint: there are three of them)

2.4 Fill in the empty cells in Table 2.1.

Table 2.1: Table of fundamental dimensions and base units for each of the common unit systems.

Row Number	Primary Dimension	Dimensional Symbol	Base unit (SI)	Symbol (SI)	Base unit (US System)	Symbol (US System)
1	Length	L		m		
2	Mass	M		kg		lb_m
3	Time	t				
4	Temperature			K		R
5	Amount of Matter (Count)	N			pound-mole	
6	Electric Current			A		A
7	Amount of Light (luminous intensity)	C		c		c

Secondary Units

Just like with colors, as the quantities we measure become more complex, so must our units. Secondary units, also known as derived units, are combinations of two or more of the primary dimensions, and thus units. Most engineering measurements are of derived dimensions in secondary units. The SI system has 22 secondary units, but there are some common ones that engineers should be familiar with. When expressing derived dimensions, it is helpful to be able to report the dimension in (1) dimensional symbols – using only the based dimensions (for example, Length = "L") and (2) the SI and English base units. The common secondary quantities can be grouped based on Interaction Quantities, Geometric Quantities and Rate Quantities. The next activity provides an opportunity to explore expressing derived dimensions in this way.

2.5 Looking at Table 2.2, explain the reason for the three groups of quantities (Interaction versus Geometric versus Rate).

2.6 Explain the difference between Mass Flowrate and Volume Flowrate in rows 9 and 10.

2.7 **In Table 2.2 row 1, what is the engineering symbol for the quantity force?**

2.8 **In Table 2.2 row 1, what is the derived SI units of the quantity force?**

2.9 **In Table 2.2 row 1, what is the derived US unit of the quantity force?**

2.10 **In Table 2.2 row 1, explain the difference between the SI units of force and the US units of force.**

2.11 **In Table 2.2 row 2, based on the dimensional symbols and the US units, define the quantity *Work* in your own words.**

2.12 **Fill in the empty cells in Table 2.2. (Refer back to Table 2.1 for symbols and base units.)**

Table 2.2: Table of Secondary Units and their derived dimensions for some common engineering quantities.

Row Number	Quantity	Engineering Symbol	Dimensional Symbols	Derived Units (SI)	Derived Units (USCS)
Group 1: Interaction Quantities					
1	Force		$\frac{M \cdot L}{t^2}$		lb_f
2	Work (Energy)	E or W	$\frac{M \cdot L^2}{t^2}$		$ft \cdot lb_f$
3	Pressure			$\frac{kg}{m \cdot s^2}$	$\frac{lb_f}{in^2}$
Group 2: Geometric Quantities					
4	Area	A	L^2		ft^2
5	Volume				
6	Density	ρ			lb_m/ft^3
Group 3: Rate Quantities					
7	Velocity	v			
8	Acceleration			$\frac{m}{s^2}$	
9	Mass Flowrate	$\dot{m}$		$\frac{kg}{s}$	
10	Volume Flowrate	$\dot{V}$			$\frac{ft^3}{s}$

A.3: Example of IBL Worksheet for Activity 3.

ECS 101 (ME) – Intro to Engineering & Computer Science

IN-CLASS ACTIVITY: Dimensions and Units

Activity 3 – Dimensional Analysis and Homogeneity

In this section, students will learn:

- What Dimensional Homogeneity is
- How to apply it to engineering problems to understand the meaning of final outcomes even before numerical solutions are calculated

To describe a physical phenomenon, engineers created mathematical formulas, which can be likened to sentences. Where the terms of the formula ($4x$, $5y^2$, etc.) equate to the words in a sentence, and the operational symbols ($+$, $\times$, $-$, $\div$) are the punctuation marks. Just like there are rules to writing sentences, there are laws that govern equations. Dimensional Homogeneity is a concept that aids engineers in observing those laws because it helps to check whether an equation of any physical phenomenon is valid and dimensionally correct or invalid. It is important to understand that all formulas in engineering must be dimensionally homogeneous, and that certain *formula laws* need to be followed, namely,

1. Every term in a formula must have the same units so that arithmetic operations (such as addition multiplication, subtraction and division) can be carried correctly out.
2. When formula parameters are multiplied or divided, the dimensions and units are treated with the same operation rules as the numerical values they are describing.

The first inquiry allows us to discover what dimensional homogeneity means.

3.1 Give three examples of substances that are homogenous.

3.2 Define what homogenous means.

3.3 Suppose we are interested in manufacturing a nail file shown in Figure 3.A. important quantities that define the product and how it works are listed in Table 3.1. Use the symbols in the table to develop an equation to calculate how heavy the file would be (H =).

3.4 Use the answer to 3.3 to develop an equation to calculate how heavy the file would in term of it dimensions.

3.5 **Use the answer to 3.4 to develop an equation to calculate how heavy the file would in term of its units.**

3.6 **Is the equation that was developed in 3.3 thru 3.5 valid to use to calculate how heavy the file would be? Why or why not?**

3.7 **Would you have to make any changes to the equation in 3.5 to actually calculate the heaviness of the nail file?**

3.8 **Now suppose we are interested in assessing the functionality of the nail file. Use the symbols in Table 3.1 to develop an equation to calculate how much nail particles would be removed when you ran the file over a nail once (N =).**

3.9 **Use the answer to 3.8 to develop an equation to calculate how much nail particles would be removed in term of its dimensions.**

3.10 **Use the answer to 3.9 to develop an equation to calculate how much nail particles would be removed in term of its units.**

3.11 **Is the equation that was developed in 3.8 thru 3.10 valid to use to calculate how heavy the file would be? Why or why not?**

3.12 **Would you have to make any changes to the equation in 3.8 to actually calculate the heaviness of the nail file?**

3.13 Using the definition you gave in 3.2 and the answer to 3.3 thru 3.12, what does it mean to have a mathematical equation be homogeneous?

Figure 3.A: Drawing of a nail file. Shown together (below), and then broken down into components that are labeled in Table 3.1.

Table 3.1 List of quantities that affect the final product of a nail file (like the one shown in Figure 3.A.

Symbol	What it represents	Unit	Dimension
H	How heavy the file is	Newton	ML/t^2
D	Density of file grains	Kg/m^3	M/L^3
G	Thickness of glue to stick sand grains to the file	mm	L
R	Roughness of sand grains	mm	L
N	Amount of nail removed	in	L
L	Length of one stroke of the nail file	cm	L
S	Thickness of the base stick	mm	L

The principle of dimensional homogeneity serves engineers because

1. It helps to check whether an equation of any physical phenomenon is valid or invalid.
2. It helps to determine the dimensions of a physical quantity or engineering constant.

This inquiry gives us practice using dimensional analysis.

IN-CLASS ACTIVITY: Dimensions and Units

3.14 **Is the equation $F = mv$ valid? Explain why it is, or is not? Recall that F = force, m = mass and v = velocity, (you can check back to Worksheet 2 Table 2.1 and Table 2.2 for help)**

3.15 **Is the equation $F = ma$ valid? Explain why it is, or is not? Recall that F = force, m = mass and a = acceleration, (you can check back to Worksheet 2 Table 2.1 and Table 2.2 for help)**

3.16 **Write an expression for force in primary dimensions?**

3.17 **The surface tension of a liquid is defined as the force per unit length. Write an expression for the equation for surface tension in terms of primary dimensions only.**

3.18 **When a constant load is applied to a bar of constant cross sectional area, as shown in Figure 3.B, the amount by which the end of the bar will deflect can be determined from the following relationship:**

$$d = \frac{PL}{AE} \text{ where } \begin{aligned} d &= \text{ end deflection of the bar} \\ P &= \text{applied load} \\ A &= \text{cross sectional area of the bar} \\ E &= \text{ modulus of elasticity of the material} \end{aligned}$$

What is the primary dimension symbol(s) and SI unit for the end deflection of the bar?

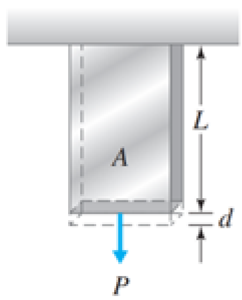
3.19 **What is the primary dimension symbol(s) and SI unit for the cross sectional area of the bar?**

3.20 **What is the primary dimension symbol(s) and SI unit for the applied load?**

3.21 **Based on the answers to questions 3.16 and 3.18 thru 3.20, use Dimensional Analysis to determine the modulus of elasticity in terms of primary dimensions.**

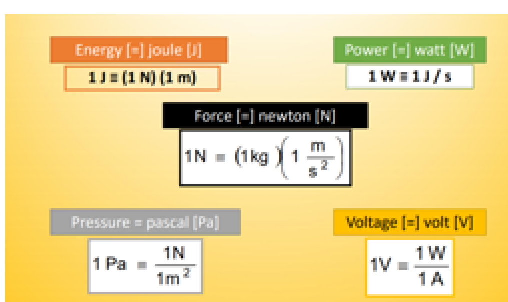
3.22 **Based on the answers to questions 3.16 and 3.18 thru 3.20, Use Dimensional Analysis to determine the units for modulus of elasticity in SI units.**

Figure 3.B: Representative example of bar being pulled by a force for use in Guided Inquiry 3.3.



By understanding these specially named units, and using dimensional analysis, engineers can determine the dimensions of a physical quantity or engineering variable. As we measure and describe more complex phenomenon, the dimensions and units become more complex. In certain cases, some special names have been given to derived units. They are named after a famous scientist or engineer and can be found in Figure 3.C.

Figure 3.C: Special names for certain derived SI units.



A.4: Example of IBL Worksheet for Activity 4.

ECS 101 (ME) – Intro to Engineering & Computer Science

IN-CLASS ACTIVITY: Dimensions and Units

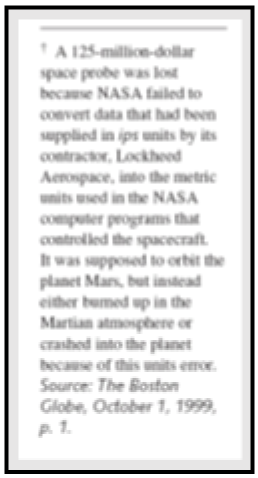
<u>Activity 4 – Unit Conversions</u>

In this section, students will learn to:

- Systematically convert units from one system to another
- Use knowledge of dimensions and units, along with conversion rules in the solution of engineering problems

Units are probably one of the most underappreciated tools in engineering existence, but they are so important. A prime example of unit importance is perfectly summarized in the article sown in Figure 4.

Figure 4: Print Article about Mars Climate Orbiter.



[†] A 125-million-dollar space probe was lost because NASA failed to convert data that had been supplied in *ips* units by its contractor, Lockheed Aerospace, into the metric units used in the NASA computer programs that controlled the spacecraft. It was supposed to orbit the planet Mars, but instead either burned up in the Martian atmosphere or crashed into the planet because of this units error. *Source: The Boston Globe, October 1, 1999, p. 1.*

Unit conversion is a multi-step process that involves multiplication or division by a numerical factor to change the presentation of the unit, but not the value of the measurement [7]. The standard procedure for unit conversion is called the Ratio Method. In this method, we write different unit equivalences as ratios with a clear top and bottom. For example, there is 5,280 feet in 1 mile, so the ratio would be set up as follows: $\frac{5{,}280\ \text{ft}}{1\ \text{mile}}$. The conversions can be between things that are also exchangeable. For example, if a car get 25 mpg, that means the car can drive 25 miles using 1 gallon of gas. The equivalency is $\frac{25\ \text{miles}}{1\ \text{gal}}$.

To do the conversion, choose the ratio that will allow the undesired unit or units to cancel out. Units will cancel when they appear once on top and once on bottom in a multiplication string. Note that it may be necessary to multiply by more than one conversion ratio in more difficult problems. In that case, you set up multiple ratios of the units and cancel them out until only the desired unit remains. In addition, it helps to remember that any number can be thought of as the ratio of that number over one. As practicing engineers, when performing analysis, you will typically use unit conversion for two purposes:

(1) converting within a given unit system and (2) from one system of units to another. This inquiry gives us practice doing both.

4.1 Write a ratio to show how many kilometers are there in a meter?

4.2 Using the ratio method, calculate how many kilometers are in 32.4 meters?

4.3 If your car gets the mileage described in the above paragraph, how far can you drive on a full tank of gas, if your car has an 18 gal tank?

4.4 If you can run a mile in 8.5 minutes, how long does it take you to run 26,400 ft?

4.5 Using the answer from 4.4, how many miles have you ran?

4.6 A honeybee's wing flap is said to take about 5 milliseconds. How many times does a honeybee flap its wings in 1 week?

Appendix B: Examples of In-class student responses to "Wow…Duh…Hmmm"

B.1: Student reflections for Activities 1 and 2.

WOW...DUH...HMM

Use the chart below to record your thoughts about today's lesson.

WOW: I did not know that!	*DUH: I already knew that!*	*HMMM: I'm a little confused about or I would like to learn more about that!*
the difference between dimensions and units	what a unit is	Derived Units (USCS)
Physical quantities can be many different things	Primary dimensions	lb_{mass} v lb_{mol}
Rankine is Temperature	base units	
Candela is amount of light	Engineering symbols and Derived Units	

Any other comments you would like to privately express to Dr. Blum? (write below)

WOW...DUH...HMM

Use the chart below to record your thoughts about today's lesson.

WOW: I did not know that!	*DUH: I already knew that!*	*HMMM: I'm a little confused about or I would like to learn more about that!*
Definition and understanding of dimension	Units	The three groups of quantities
Dimensional symbols such as matter, electric current, and light	US system / SI system Conversions	Mass Flowrate Volume Flowrate
7 primary dimensions		

Any other comments you would like to privately express to Dr. Blum? (write below)

B.2: Student reflections for Activity 3.

WOW…DUH…HMM

Use the chart below to record your thoughts about today's lesson.

WOW: I did not know that!	*DUH: I already knew that!*	*HMMM: I'm a little confused about or I would like to learn more about that!*
seeing if an equasion is "valid" by using primary dimensions	homogenus means same throughout	dimensional homography
	if dimensions aren't the same on both sides of the equation then the equation isn't valid.	naming specific units for dimensions

Any other comments you would like to privately express to Dr. Blum? (write below)

WOW…DUH…HMM

Use the chart below to record your thoughts about today's lesson.

WOW: I did not know that!	*DUH: I already knew that!*	*HMMM: I'm a little confused about or I would like to learn more about that!*
what it meant to have an equation that is homogeneous	Examples of homogeneous substances / definition of homogenous	Modulus of elasticity equation
SI units	Dimensions need to be equal on both sides of the equation.	

Any other comments you would like to privately express to Dr. Blum? (write below)

Thank you for letting me come into your class!
I really enjoyed learning about engineering!

B.3: Student reflections for Activity 4 and 5.

WOW…DUH…HMM

Use the chart below to record your thoughts about today's lesson.

WOW: I did not know that!	*DUH: I already knew that!*	*HMMM: I'm a little confused about or I would like to learn more about that!*
equivalent/infinite sigfigs	Counting sigfigs	how to determine what's measured vs. what's definition
	unit conversion	

Any other comments you would like to privately express to Dr. Blum? (write below)

Thank you!

WOW…DUH…HMM

Use the chart below to record your thoughts about today's lesson.

WOW: I did not know that!	*DUH: I already knew that!*	*HMMM: I'm a little confused about or I would like to learn more about that!*
Exact #s have ∞ sig figs	Ratio method	converting units between SI and English system

Any other comments you would like to privately express to Dr. Blum? (write below)