An Integrated Analytical, Simulation, and Experimental Approach to the Laboratory Experiments

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An integrated approach of lecture and laboratory through problem analytical solution, simulation, and experimental verification is presented. Typically a laboratory is accomplished by following a set of prescribed instructions, collecting data based on measurements, and processing the data. In this paper we propose a three part approach to the laboratory instruction: analytical, simulation, and experimental followed immediately by comparison of the above results. Typically in industry, based on requirements, a problem is solved either analytically or by simulation or by experimental methods or by a combination of them. It is proposed the integration of all three approaches in a laboratory experiment. A problem is fully studied by first properly formulated and then is analytically solved using traditional mathematical methods. A simulation of the problem follows. It typically provides additional inside either because different mathematical techniques are used or through a parametric study. Finally one or more solution are selected as candidate for experimental verification and, at the end, one of them is selected for experimental investigation. Furthermore, additional insight is achieved, by comparison of the analytical, simulation and experimental results. This approach provides full understanding of the problem and its solution, while helping to develop creative and critical thinking. The approach is applicable to problems in both academia and industry.

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Introduction/Background

Typical organization for the majority of courses includes Lecture, possibly a Recitation, and Laboratory for most courses in the sciences and engineering. Simulation may be included as part of a course, usually part of the homework problem set. The laboratory work consist on an assignment that includes a set of instructions that must be followed in order to collect data. Providing a graph of the data and discussion is the conclusion of a laboratory report. The goal of an experiment is to verify the validity of the phenomenon under investigation. It has been suggested by the Benchmarks for Science Literacy [1] and the National Science Education Standards [2] that students should be engaged in hands-on learning. However, the usual set up of a typical instructional laboratory described above, is of a “cookbook” nature. Due to this approach, the laboratory experiments are not related directly with the lecture. The laboratory course has become disjoint of the corresponding lecture course and far distant with the way scientists and engineers themselves solve and investigate problems. Sometimes lecture and laboratory are parts of the same course and sometimes different.

There are various teaching methods that have been developed [3]. An approach will be to enhance the lectures [4,5]. Attempts have been made to intergrade lecture and laboratory in the sciences and engineering [6,7]. Different methods should be used for the laboratory work to complement the lecture, and is enhanced by computer simulation. Solving a problem requires creative thinking while investigation of the conditions of the validity a solution requires critical thinking. The approach of performing analytical, simulation, and experimental work as well as comparison of the results provided by the previous three methods may be all that is necessary to transform the effectiveness of the laboratory instruction.

Moreover, laboratories should correlate closely with lectures and should not be separate activities. Laboratory experiments must teach students how to develop scientific reasoning, experimental skills, appropriate laboratory methods and techniques, techniques, collaboration, ethical contact, report preparation and report presentation, etc. and thus, prepare the student for professional career.

Data/Formulation/Methodology

In order to transform teaching and learning in the laboratory we have integrated all three: the lecture, the simulation and the laboratory. We have developed and propose an integrated approach of all three approaches. Specifically, we propose: The statement of a problem that will be: 1) analyzed, 2) simulated, and 3) prototyped. The problem can be a typical homework problem of closed or open form solution. Furthermore, the results of the three approaches are compared to develop the critical thinking.

The problem is related to a specific phenomenon or phenomena, which have been discussed in the classroom. At this point the student has the required knowledge to proceed alone or with little guidance into the three proposed components of laboratory work. The three proposed components reflect the way scientists and engineers may approach a problem.

The traditional approach to teaching at the college level involves lectures with or without student interaction, recitations of guided or non-guided problem solving, and cookbook laboratories. Students who are self-motivated independent learners and have strong mathematical background and experimental skills thrive in this environment. But this category represents only a small fraction of students [8].

The proposed approach applies to courses that include a related laboratory component as it is the case in many courses in the sciences and engineering and in nearly all courses in engineering technology. The approach can be used either for the solution of a problem or for investigative inquires. The proposed approach will help students to comprehend the subject matter by approaching in three different ways. Because students work in teams understand the discussed material by building an effective instructional environment. Byproduct of the cooperation is the teamwork, basis in a professional environment. The art of good teaching beneficial to few students becomes a structured science beneficial to all.

The three components of the approach are discussed below:

- Statement of the problem:

The problem is stated. It can be open or closed type. The student must investigate first the existence of solution, before proceeds to the solution.

- Analytical solution:

The problem is solved analytically, if possible, which is the typical case. But some problems do not have analytical solution and require numerical techniques. A symbolic formulation of the solution process will solve the general problem while will clearly present the factors and the way they influence the solution. The textbook of the course can be a resource fat this step.

- Simulated solution:

Simulators have been developed for nearly all aspects of engineering work. Since commercial simulators are commonly used in the practice of engineering, we need to ensure they are part of the engineering education. In Electrical engineering simulators exists for all fields. Examples include elementary science [9] to antenna structures [10]. The problem is simulated and a solution is provided. Simulation is an important part of the design process. In systems engineering an approach can be formulated using an available system modeler [11,12]. Simulators are very helpful in expensive, time consuming, and dangerous experiments. Parametric studies can be done fast, and inexpensively.

- Experimental solution:

The problem is prototyped. A solution is sought by building a prototype and sometimes more in order to investigate an optimum solution. It requires skills, experience, equipment, time, and money. Perhaps the best of all as it shows how a real system will operate under real operating conditions.

- Comparison of results:

The results of the three approaches are compared. It develops critical thinking as examines the meaning of the solution. As part of the design process, it develops creative thinking, the required modification for appropriate operation within specifications.

The approaches presented closely parallel the work done by scientists and engineers in industry, especially in a research and development settings.

Analysis

To illustrate the proposed method, we consider a typical case of an analysis problem selected from general physics, that of a voltage divider.

- Statement of the problem:

The topology of a voltage divider circuit as well as the values of the components are given. Determine an expression for the voltage across the resistor R_2 as function of the components of the circuit. Evaluate the expression of the voltage across the resistor R_2 for the values of the components given.

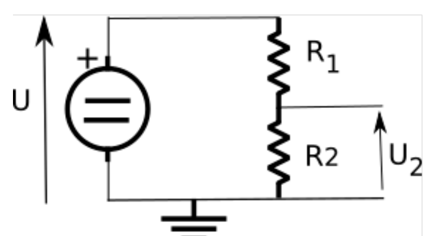

Figure 1.A voltage divider circuit.

- Procedure – Analytical solution – Theory:

The voltage U_2 across the resistor R_2 is equal to the current through the resistor R_2 times the resistance of the resistor R_2 (u-i law or Ohm's law for a dipole). Mathematically we can write,

$$U_2 = IR_2 \tag{1}$$

The current through the resistor R_2 is the common current in the single loop circuit,

$$I = \frac{U}{R_{eq}} \tag{2}$$

The equivalent resistance of the single path circuit is:

$$R_{eq} = R_1 + R_2 \qquad (3)$$

Substituting (3) into (2) and the result into (1) we get,

$$U_2 = U \frac{R_2}{R_1 + R_2} \qquad (4)$$

This equation gives the voltage across the resistor R_2 as function of the values of the other components of the circuit. Every quantity on the right side is known, the unknown be on the left.

In an alternative structural approach of the above operations can be presented as:

$$\left.\begin{aligned} & U_2 = IR_2 \\ & \left.\begin{aligned} & I = \frac{U}{R_{eq}} \\ & R_{eq} = R_1 + R_2 \end{aligned}\right\} I = \frac{U}{R_1 + R_2} \end{aligned}\right\} U_2 = U \frac{R_2}{R_1 + R_2} \qquad (5)$$

The evaluation of equation (4) for the given values can be done in various ways. Here we present the use of a mathematical notepad [13]. This mathematical notepad requires the formation of a template with data and units of measurements, calculations, and results. In addition it can present graphs. The setup of a template and the results are shown in Figure 2.

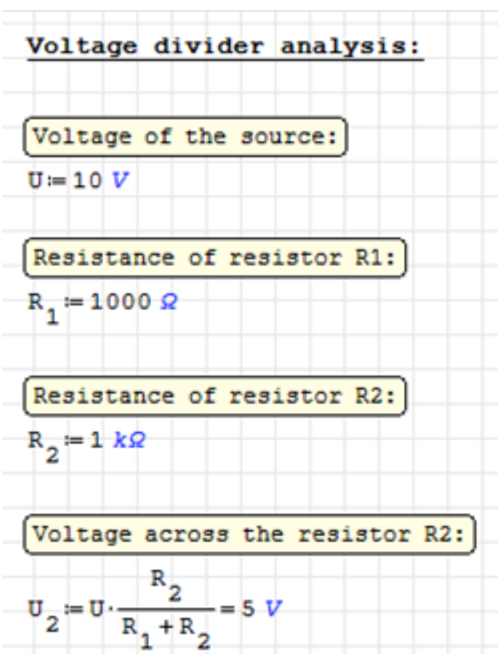

Figure 2. Numerical evaluation of the output voltage.

The above approach of numerical evaluation using a template has the advantage of automatic update of the evaluation of the expression for any value of the input variables by simply changing the input value. Further, the inclusion of units gives the desired physical sense in the calculations.

- Procedure – Simulation:

For the simulation of the circuit we used a free and open source electric circuit simulator, the Quite Universal Circuit Simulator (QUCS) [14].

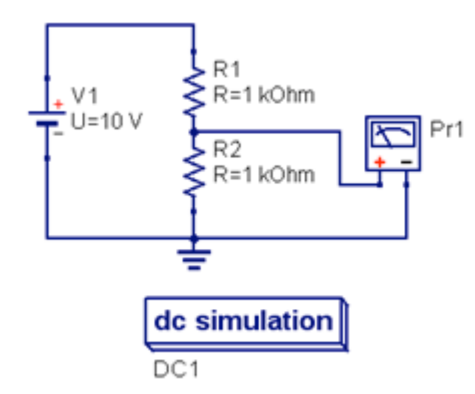

Figure 3. Simulation circuit.

Simulation of the circuit provides the expected result in the form of a Table 1. In addition the current of the source which is the common current of the circuit, is provided.

Table 1. Output results of the simulation.

number	V1.I	Pr1.V
1	-0.005	5

- Procedure – Measurements:

The electric circuit of Figure 1 was build and measurements of the voltage across the resistor R_2 was made. The result U_2=5.037 V is in close approximation with the expected voltage.

- Procedure – Comparison of results:

The analytical, simulation and experimental results are tabulated, Table 1, compared and commended.

- There is difference in the reading among different instruments. The internal voltmeter of the voltage source indicates that the provided voltage of the power supply is 10 V while the external voltmeter indicates 9.81 V. This is due to the various differences between the two voltmeters.
- The analytical and experimental results are in perfect agreement; ideal components have been used.
- The experimental results deviate from both the theoretical and simulation doe to the tolerance of components.

- The electric current is near to the expected value.

The analytical and simulation results are based on ideal components and instruments. The prototyping part is based on real components and instruments. The results verify the differences of the two.

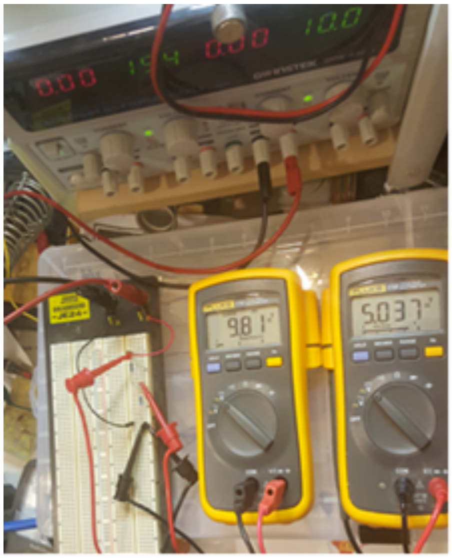

Figure 4. Experimental setup – Measurements.

Table 2. Comparison of results.

Voltage divider			
	Analytical	**Simulation**	**Experimental**
Voltage of the source U, (V)	10	10	9.81
Voltage of resistor R_2 U_2, (V)	5	5	5.037
Common Current I, (mA)	5	5	4.96

Conclusions

A new integrated approach has been presented that integrates Lecture (theory or analytical approach), simulation, and prototyping in conducting laboratory experiments. The method consists of a problem that is posed for solution. The solution is sought using three different approached: analytical or developing the theory, simulation using an appropriate simulator, and finally prototyping to take experimental measurements. The approach bring together three apparently distinct approaches. All three are used in the industry in a professional environment.

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