An Effective Teaching Method for Problem Solving in Engineering

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Abstract

This paper presents a tandem method for teaching procedural problem solving concepts to students. This method improves the quality of students' learning by allowing instructors to apply and relate course concepts to solving problems. An example of a procedural approach in problem solving is the design of sequential circuits in the Digital Systems course taught to engineering students where a procedural algorithm consisting of many steps is introduced. Typically the teaching process includes solving a numerical example. Traditionally, the example is taught after the procedural algorithm is described. By this time, students have already become distant from the steps explained for the procedure and their rational. Thus, it is difficult to show the importance of each step in the procedure while describing it. It is also hard to relate the example to the procedure when the example is being solved. As a result, students become bored and inattentive during the lecture and cannot follow the relation between the procedure and the example. An alternative is to introduce the example side by side, in tandem, with the procedure. Along with the start of the procedure, an example is also introduced. Then, as each step of the procedure is being discussed, the corresponding step is applied to the example. The tandem method is more effective since it facilitates *(a)* the explanation of the procedure and *(b)* the students' realization of the conceptual topics and therefore saves time. Two procedural algorithms are considered. The first one is from a Linear Algebra course explaining a procedure for solving first order differential equations and the second is from a Digital Systems course that provides steps in designing Sequential circuits.

I. Introduction

In teaching students, a variety of ways can be explored to draw the students' attention. Typically students learn by means of visualization, hearing, intuition, rationalization, memorization, and drawing analogies in understanding abstract mathematical subjects [1]. There are many different teaching methods such as using the old school blackboard and chalk or using PowerPoint. In addition, some instructors attempt to demonstrate and discuss some of the concepts in the course, while others place an emphasis on rote learning [2]. In all of these cases, the amount that the students learn depends upon factors such as the students' prior preparation and/or learning style abilities [3]. More importantly, it relies on how effectively the instructor can present the material such that students learn most of the new concepts during the lecture. Therefore, the way instructor organizes the material and presents them to the class becomes paramount. A well-organized and well-presented lecture can effectively improve a deep realization of the concepts for students.

Instructors often have to teach a procedure for solving problems. In particular, engineering instructors have to teach and provide students with steps on how to solve engineering problems. These kinds of problems are structured in a manner that students can easily follow a few steps and apply their own creativity to solve the problems. Frequently, instructors teach these procedural problems in such a way that first they introduce the steps by explaining them one after the other and then follow thereafter with an example. As a result the connection between the procedure and the example can be easily lost in the process. Furthermore, the procedure itself appears to be very abstract to the students at the time the procedure is introduced. Therefore, students become more distant from the material, bored, and inattentive during the lecture. In turn, this can create a chain reaction and as a result students may perform poorly on exams and, more importantly, lose their enthusiasm for the subject. In addition, the nature of these problems is often based on mathematical concepts and thus increasing realization of concepts which may develop “I hate math” attitude. In some cases, students may start talking among themselves and this in turn can have an additional negative impact on the learning process.

Over the past few years of teaching at the Electrical and Computer Engineering, and Computer Science Departments of the University of Toronto, I have come across topics involving procedural problem solving and have noticed that the aforementioned problem can be alleviated, for the most part, by introducing the procedure along with an example. This is a tandem process that introduces the example and associates some numerical values to the abstract concepts along with the procedure. This paper explains this method of teaching. Moreover, it is demonstrated that this method improves the learning process for students.

Sections II and III describe two procedural methods where an example is introduced in tandem with each method. Section IV presents cases where the proposed tandem method does not prove to be beneficial. Other courses that can benefit from the tandem method are listed in Section V. Finally, Section VI presents the concluding remarks.

II. Procedural Example One: Sequential Circuits

This example considers the design of sequential circuits that involves a set of steps. These steps, when followed, results in a digital logic circuit known as a sequential circuit. Sequential circuits are an integral element in most courses dealing with digital logic concepts. At the University of Toronto, sequential circuits are taught in courses such as:

- Digital Systems (ECE241) in the Electrical and Computer Engineering Department, and
- Computer Organization (CSC258) in the Computer Science Department.

This section begins with a description of the terminology used followed by a design of sequential circuits in parallel with a design example. The design example introduces a procedure that points out the steps involved in the design.

A. Terminology

The definitions of some of the technical terms referred to in the following parallel example are provided in this section.

Gate: Block of electronics hardware that takes one or more logic inputs and produces one logic output.

Flip-Flop: is a logic cell that can store one bit of logic information.

K-Map or *Karnaugh-Map*: provides a map or table that facilitates the minimization of the number of terms needed to express a function algebraically.

Combinational Circuit: is a circuit where the binary value of an output is a function of the binary value(s) at the inputs. Typically, the combinational circuit is built from a combination of different logic gates. For instance, in Figure 1, AND and OR gates are combined to make the outputs ***S*** and ***C*** that depend on the input binary values of ***a*** and ***b*** [4].

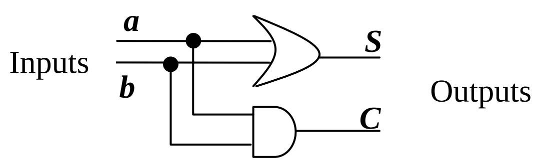


Figure 1: An example of a combinational circuit known as a half-adder.

B. Sequential Circuits

The sequential circuits are logic circuits where the output binary values are determined by the previous state(s) of the system that is the binary values at the output of the flip-flop(s) in addition to any binary values at the input(s). In fact, output states are fed back into the circuits in addition to the circuit inputs. Figure 2 illustrates a block diagram representation of a sequential circuit [4].

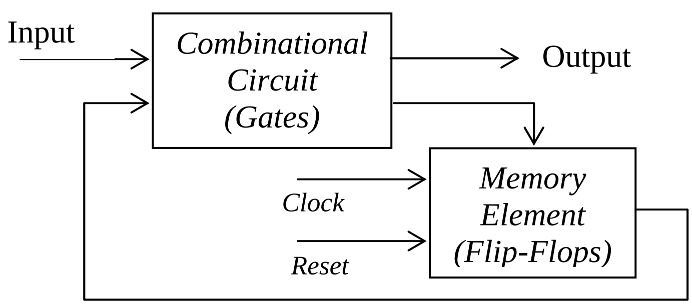


Figure 2: A block diagram representation of a sequential circuit.

C. Procedural Design Steps

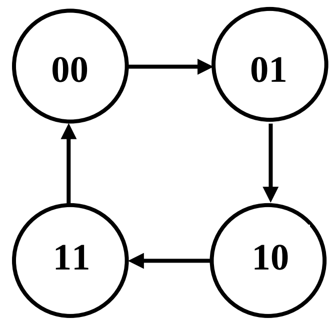
This section details the steps involved in designing a sequential circuit. An example is also worked out along side the procedure. This is best performed if two blackboards placed side by side are employed. After introducing one step from the procedure on one blackboard, the instructor can move to the other blackboard and illustrate that step with an example. The following two column table in Table 1 represents two blackboards side by side where after reading the left hand side column on blackboard one, the reader should follow through on the right hand side blackboard with the example.

Blackboard 1: Procedure	***Blackboard 2: Example***
Step 1 Provide a formulation of the design criteria.	This example considers the design of an up-counter that continuously loops through the sequence of numbers *0* to *3*, i.e. *0*, *1*, *2*, *3*, 0…

Step 2

Illustrate the design criteria from the previous step in a diagram referred to as a state diagram. Then the number of the flip-flops required for this design is equal to the number of circles in the state diagram. Identify each circle with a binary number and write it inside the circle. Flip-flops are required since they keep track of this number.

Remark: It is much easier and makes more sense to explain this step while solving the problem and pointing to the circles while writing down the binary values in the diagram. Otherwise, how can this step make sense and not be lost among all other steps.



Step 3

Assign variable names, i.e. letters and develop a table that records all the possible binary values that the variables can take. Then identify what the desired next state (NS) is going to be. This is performed by following the directions of the arrows in the state diagram. The previous state (PS) is the binary number shown inside a circle while the next state is the circle pointed to by an arrow from the existing state.

Remark: Similar to the previous step, Step 3 could also be easily demonstrated if presented side by side with the example by jumping back and forth to the example while introducing each sub-step.

PS		***NS***		***Excitation Table***			
A	***B***	***A***	***B***	S_A	R_A	S_B	R_B
0	0	0	1	0	X	1	0
0	1	1	0	1	0	0	1
1	0	1	1	X	0	1	0
1	1	0	0	0	1	0	1

This part is filled during Step3.

Step 4

Select a certain type of flip-flop (the different types are: *RS*, *JK*, *D*) Then build and populate a table denoted as an excitation table based on the values from the previous states and next states. The excitation table is typically organized as part of a state table.

Remark: This step is part of a state diagram. This step becomes confusing to explain if combined with step 3 since it makes step 3 very

Choosing *SR* flip-flop and accordingly filling up the Excitation Table in here.

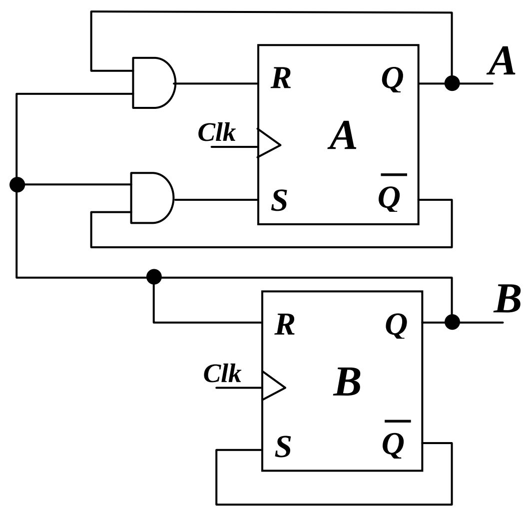
lengthy. In contrast, if it is presented as a separate step then it is difficult to connect it to the state table. On the other hand, if it is described as two separate steps and in parallel with an example then it is easy to convey the idea behind the steps.	
Step 5 Develop algebraic equations and if necessary draw k-map to simplify the equations.	$S_A = \overline{A}\,B$ $R_A = A\,B$ $S_B = \overline{B}$ $R_B = B$
Step 6 Draw the gate level circuit.	

Table 1: Illustration of a procedure for designing a sequential circuit in tandem with an example placed side by side on two separate blackboards.

III. Procedural Example Two: Solving Differential Equations

In this section, a parallel process for solving first order linear differential equations that is taught in Linear Algebra course is considered. Initially, differential equations are defined and then a procedural solution method based on the proposed tandem method is presented.

A. Differential Equation

Many laws of science involve energy storage components and can be formulated in terms of differential equations [5]. A differential equation has a solution whenever a deterministic relationship between some quantities and their rates of change is known. Therefore, a differential equation is a relationship between an independent variable (e.g. time) and a dependent variable (e.g. temperature) and another term that shows the rate of change of a dependent variable with respect to an independent variable (e.g. change of temperature with respect to time) are present. An example of a differential equation is shown below:

$$\frac{dy}{dt} + y = t^2 . \qquad (1)$$

B. First Order Linear Differential Equations

This is an important form of differential equation since it is present in nature and physics and can be solved using a conventional approach [5]. This differential equation is in the form of:

$$\frac{dy}{dt} + P(t)\cdot y = Q(t) \quad (2)$$

A step by step procedure is presented in this section in parallel with an example. During the actual presentation of this procedure to the class, the procedure will be on one blackboard, i.e. on the left hand side while the example is described on another blackboard, i.e. on the right hand side.

Consider solving the initial value problem where *y(1) = -1* and the differential equation is given as:

$$\frac{dy}{dt} + \frac{1}{t} = t \quad (3)$$

Blackboard 1: Procedure	***Blackboard 2: Example***
Step 1 Calculate an integrating factor that is in the form of: $$e^{\int P(t)\,dt} \quad (4)$$ and then drop the constant of the integration.	***Solution:*** *Step 1*: Find integrating factor: $$e^{\int P(t)\,dt} = e^{\int \frac{1}{t}\,dt} = e^{ln(t)+c} = t \quad (5)$$ where the constant of integration, *c*, has been dropped resulting in only *t*.
Step 2 Multiply the given differential equation which is in the form of (2) by the integrating factor obtained in (4). This results in the following equation. $$\frac{dy}{dt}\cdot e^{\int P(t)\,dt} + P(t)\cdot y\cdot e^{\int P(t)\,dt} = Q(t)\cdot e^{\int P(t)\,dt} \quad (6)$$	*Step 2:* Multiply (3) by *t*. This results in: $$t\cdot\frac{dy}{dt} + \frac{t}{t}\cdot y = t^2 \quad (7)$$
Step 3 Recognize that the left hand side in (6) is the derivative of the product of an integrating factor and *y* (this is the chain rule), and hence, $$\frac{d}{dt}e^{\int P(t)\,dt}\cdot y = Q(t)\cdot e^{\int P(t)\,dt} \quad (8)$$	*Step 3:* Recognize that left hand side is the derivative of *t.y* as follows: $$\frac{d}{dt}t\cdot y = t^2 \quad (9)$$

Step 4 Integrate both sides in (8) with respect to *t*. This results in: $$y\cdot e^{\int P(t)\,dt} = \int Q(t)\cdot e^{\int P(t)\,dt}\,dt \quad (10)$$	Integrate (9) with respect to *t*, hence, $$\int \left(\frac{d}{dt}t\cdot y\right)dt = \int t^2\,dt \quad , \quad (11)$$ and $$t\cdot y = \frac{1}{3}t^3 + C \quad . \quad (12)$$
Step 5 Solve the result of (10) for the final value of *y(t)* with any initial value specified.	Solving (12) for *y(t)* gives: $$y(t) = \frac{1}{3}t^2 + \frac{C}{t} \quad (13)$$ and considering the initial value given by *y(1) = -1* results in particular solution of: $$y(t) = \frac{1}{3}\left(t^2 - \frac{4}{t}\right) \quad . \quad (14)$$

Table 2: Depicts a procedural solution to linear first order differential equation along with an example placed side by side on two separate blackboards.

IV. Remarks

The tandem method can be very effective in teaching procedural problem solving. Nevertheless, in some cases where there are few steps in the procedure and where the example has many steps due to its mechanics then the tandem method might not be very useful. This occurs since the lengthy nature of some examples causes a loss of connection with the procedure. Therefore, the tandem method loses its effectiveness.

In cases where the procedure tends to be short and consists of only few steps, it is better to introduce the procedure first and then follow this with and example. In general, if the procedure is about 3 steps then provide the procedure first and then the example or vise versa.

V. Application to Other Subjects

There are many subjects taught at universities where the proposed method may be useful. This section provides the names of courses followed by the potential topics covered in these courses where the tandem method can be applied. These examples are as follows:

- In the subject of Linear Algebra:
    - Gaussian Elimination.
    - Guass-Jordan Elimination.
    - Solving First Order Linear Equations.
- In the subject of Electric and Magnetic Fields:
    - Magnetic Circuits.
- Circuit Theory

- Thevenin and Norton Equivalent Circuits.
- Superposition Concept.

VI. Conclusions

A tandem method for presenting the course material to engineering students is demonstrated. This tandem method facilitates the explanation of procedural problem solving topics. The details of two examples are described; one for a procedure in solving sequential circuits and the other for solving linear first order differential equations. Both cases demonstrate that the introduction of an example in parallel with the procedure can be used as an effective teaching tool.

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