Journal of
INDUSTRIAL TECHNOLOGY

Volume 17, Number 2 - February 2001 to April 2001

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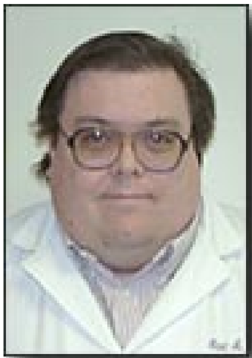
KEYWORD SEARCH

Curriculum
Electricity
Electronics
Teaching Methods

Reviewed Article



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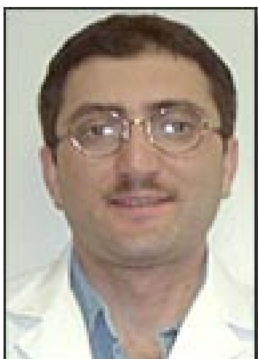

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A Paradigm for Breadboard use in Electronics Laboratory Instruction

By Dr. Marc A. Timmerman & Dr. Recayi Pecen

Introduction

Most courses in analog, digital, or microprocessor electronics involve the activity of breadboarding. A breadboard is a plastic device equipped with metal connectors for the purpose of constructing electronic circuits without the need for soldering the components. Sample breadboards are depicted in Figure 1. The components can be removed from the breadboard after use and reused in future activities. Most current texts in electronics have accompanying laboratory manuals that prominently feature elaborate breadboard activities. Although breadboarding is near universal in its usage in Industrial Technology education, not much has been written about it in the pedagogical literature. This paper presents a paradigm for implementing and improving breadboard-based laboratories based on general pedagogical principals used in culinary instruction at the Culinary Institute of America, Hyde Park, New York, as described in the educational literature. Both culinary instruction and breadboarding require the students to integrate manual skills and cognitive skills in a goal oriented fashion. These similarities in pedagogical processes have the potential to greatly improve the breadboarding experiences of Industrial Technology students.

Purpose

Why should breadboarding be discussed in pedagogical literature? An average three-hour semester-long Industrial Technology class in analog or digital electronics or microprocessors will include 28 hours of lecture and perhaps 20 hours of breadboarding labs. Any changes that will help make the students' breadboarding experience more valuable, especially if these changes are at little or no cost, would be an enhancement to this type of instruction.

Common student remarks on breadboarding include the following:

- The overall purpose of the activity gets lost in the blizzard of details of pin-out diagrams, and spaghetti-like mazes of wiring.
- The lab activities manuals accompanying most textbooks do not indicate what the expected result should be. Students often will not realize an early error in a multi-part lab. This causes the students to waste a lot of time taking useless data.
- Due to the device-specific nature of electronic components, the illustrations and pin-outs in the lab manuals often do not match what is actually used in the lab.
- Many published labs *simply do not work* or are very dependent on having specific electronic parts or on very fine types of adjusting or "tweaking" of circuits.
- Students often fail to estimate correctly how much space will be needed to wire a device. They invest a lot of time wiring devices only to have to tear their work-up later on.
- The finished circuit is presented only in schematic form in most lab manuals. This makes it difficult for the students to understand what the physical end product of the lab is supposed to look like.

For these reasons and many others, breadboarding frequently becomes a rote, mechanical activity devoid of real comprehension. The students frequently cannot finish the activity in the time allowed or get lab data that is so hopelessly corrupted that they cannot write a valid report. Of course, this negatively impacts both the learning process and student morale.

Literature Review

In the educational literature on breadboarding Bergquist (1995) has contributed an extensive summary of the development and use of breadboarding in laboratory activities. Melton (1999) and Weis (1993) have described specific breadboard-based products aimed at the academic market. In the technical literature devoted to industrial circuit prototyping tools, Moran, Fernandez and Dixon (1997) have described the use of breadboards for the development of prototype high-voltage circuits. Kimura (1996) has described the use of breadboarding prototypes for low-voltage analog circuits. Mann (1995) has contributed an article on a proprietary breadboard system intended for high frequency circuit development.

A number of articles have appeared predicting the end of breadboard usage in electronics instruction. Berardinis (1989) and Dion (1994) have contributed articles stating that software packages like Electronics Workbench and Micro-cap would lead to the abandonment of breadboarding in electronics curricula. History has shown that these student friendly software packages have complemented rather than replaced breadboarding activities as nothing can replace true hands-on experiences.

Likewise, in industrial circuit prototyping, the introduction of field-programmable circuit products like digital Programmable Logic Devices (PLDs) and similar analog products, has been heralded as the end of breadboarding in the professional workplace. Anderson (1991) has contributed an article on the use of Programmable Logic Devices in this context. Again, breadboarding has been complemented rather than replaced by such developments and breadboarding continues to be a subject of current industrial interest.

The instructional curriculum of the Culinary Institute of America has been described in detail by Biemiller (2000), Sabo (1999), Zemke (1997), and Ingalls (1983). Donovan (1995) has edited a popular textbook that prominently features the Culinary Institute of America's clinical instructional style.

Methodology

In culinary instruction at the Culinary Institute of America, students study hands-on food preparation skills in a highly systematic manner:

- The students first review the recipe and come to an understanding of the *various steps* involved in the exercise. The students need to understand the precise sequence of steps involved in the preparation and the relationships between these steps.
- The students view, taste, and smell, an *example* of the finished product that is the goal of the lesson. In complex, multi-part preparations, examples of *intermediate products* are also studied.
- The students gather the needed components and order them in a precise fashion in a special presentation known as the "mis en place." This is a French language term that means "*put into place*." The students carefully study the relationships between the components as to quantity and quality.
- Finally, the students rigorously *compare and contrast* their finished product with the initial example. If something went wrong in the lesson, the students are encouraged to identify what went wrong and how to remedy the mistake.

The paradigm for successful breadboarding is as follows:

- PRE-LAB INSTRUCTOR: The instructor must do the experiment himself or herself. The instructor writes an addendum sheet with any corrections or clarifications to the lab manual's instructions. As electronic components vary from maker to maker, any changes caused by differences in the types and pinouts of the electronic components should be included in the addendum sheet. Often there will be differences between the figures shown in the lab manual and the actual components used. This addendum should be given to the students before the lab. *It is important that the instructor uses exactly the same components and instruments that will be used by the students in the lab.* If the lab is sensitive to the components used, it may work with some components and not others. The best time to find this out is BEFORE the lab!
- PRE-LAB STUDENTS: The students must read the lab manual and the addendum sheet prior to the activity. The students may be required to use web or library resources to obtain data sheets on components. If there is doubt as to the students' sincerity in the pre-lab assignment, a brief quiz or homework assignment due at the start of the lab based on the lab manual and the pre-lab addendum sheet may be helpful. Often, the possibility of a "pop quiz" is sufficient to insure good effort on the students' part.
- THE EXAMPLE SET-UP: The instructor should prepare and present a completed version of the lab circuit for the students at the start of the lab period. The circuit should (1) be fully powered and functional, (2) be connected to the instruments to be used in the exercise, and (3) be fully demonstrated by the instructor to the students at the start of the lab. The instructor must take care to present the circuit as a *neatly and carefully* assembled construction. The instructor may label parts of the circuit to aid in identification. This is also a good time for the instructor to give special instrument instructions, for example demonstrating unusual oscilloscope triggering modes.

- THE STUDENT "PUT INTO PLACE": The students may be presented with the parts for the lab pre-sorted in a container or may be allowed to select the parts themselves from storage bins. In large classes, pre-sorting seems to save a lot of time and confusion. The lab handout may include a sheet with labels for arranging the components or the students can create this sheet themselves. The students are required to identify and place by the correct label each individual part prior to starting the construction of their circuit. The students should reconcile any changes in pin-outs in the pre-lab addendum to the actual appearance of the components used.
- THE COMPARISON: Throughout a multi-part lab the students should compare and contrast their actual results with the desired results. A good technique to use is an "initial sheet." This sheet contains places for the students to write the intermediate and final results for the lab with places for the instructor to initial each result as the lab progresses. This prevents the students from proceeding with later stages of the lab with erroneous data. Alternatively, the students can be presented with a "range sheet" which gives acceptable ranges for intermediate and final results. The students can then check their intermediate results as they proceed through the lab and make sure their final results are OK prior to leaving the room. The "range sheet" seems to work better in large classes. Table 1 depicts these two styles of comparisons.

As can be seen, the tasks in this paradigm require some advanced preparation on the part of the instructor, but the added cost is small. An added benefit of this paradigm is in the situation where graduate students or others with little formal teaching experience are used as lab instructors. In this situation, the structured nature of the instructor's duties is helpful in guiding the neophyte instructor through the steps of the lab preparation and supervision.

Findings

As an example of this paradigm, the classic 555 Timer Chip lab is presented. The purpose of this lab is to construct a "clock" or "square wave" generating circuit. This lab is commonly found in both Analog and Digital Electronics classes. The circuit as shown produces a pulse with a period (T) of 1.35 milliseconds and a duty cycle (DC) of 74.7% with an input voltage (V_s) of 4.93 VDC. Figure 2 presents a basic schema of the lab. Figure 3 presents an example set-up as it would be demonstrated to the students by the instructor. The students often have trouble in identifying the connections between their breadboard and the power supply, oscilloscope, and other instruments. Labeling these connections is helpful. An added benefit of presenting the example is that it helps build the students' confidence. The students are often presented with complex schemas in breadboarding lab manuals that seem impossible to construct. By presenting the students with a successful circuit, it encourages the students to know that the lab CAN be done. By helping the students to visualize a completed circuit, the students are better able to integrate their knowledge of the schema with the physical reality of the circuit components. Figure 4 shows a "put into place" sheet with the components properly arranged. In this case, the instructor prepared the sheet and gave it to the students prior to the lab. The students are required to place their components on this sheet prior to the breadboarding the circuit. This requires the students to carefully consider the labeling of the parts, such as the resistor color code, and to identify the polarity of polarized parts such as chips, electrolytic capacitors, and diodes. This step of completing the "put into place" BEFORE breadboarding the circuit greatly cuts down on errors in circuit construction. Table 2 presents a "range sheet" for the lab indicating the typical experimental values recorded by the students and their acceptable ranges.

Figure 1. Sample breadboards.

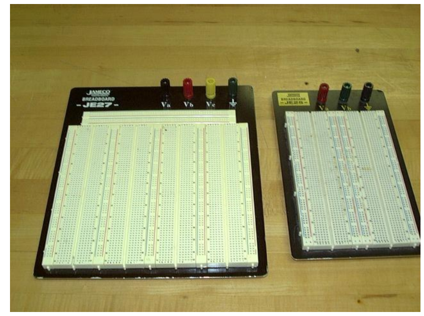


Figure 2. Timer lab schematic.

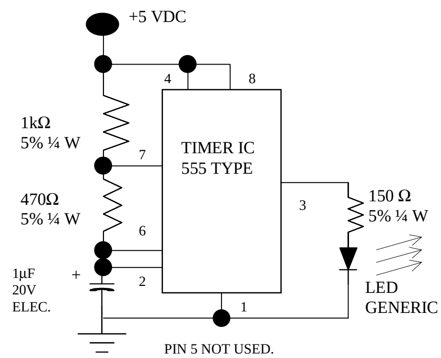


Figure 3. The example set-up.

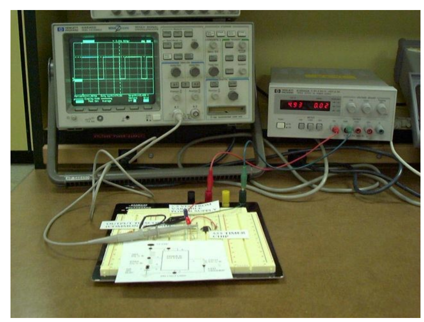
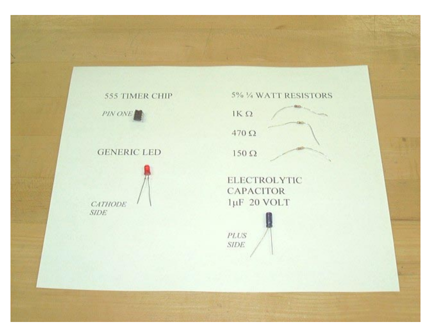


Figure 4. The "put into place" exercise.



This sheet is very useful in helping the students debug their labs. For example, if the students' measurement of the power supply voltage is outside of the acceptable ranges, the students know that they should check their power supply settings and connections. If the period of the output signal is outside of the acceptable range, the students should check the values of the resistors and capacitors used and the signal connections of the chip and so forth.

A further value of the example set-up is in debugging the students' circuits. If the students are unable to find their error or errors and their circuit does not work, they can measure the voltages at various points in their set-up and compare these values to the voltages at various points in the example set-up. This technique of comparison is especially useful when the students have complex multi-stage circuits to debug.

Implications in the Research

The paradigm presented in this paper is an adaptation of pedagogical techniques using in culinary arts instruction to the Industrial Technology curriculum in electronics. The basic elements of the paradigm are a thorough pre-lab preparation by both the students and the instructor including an addendum sheet with device-specific information, an example set-up demonstrated at the start of the lab by the instructor and made available to the students during the lab as a debugging aid, the use of a "put into place" exercise to require the students to formally identify each component used in the lab and its polarity before assembling their circuits, and a "range sheet" or "initial sheet" used during the lab to assess the validity of intermediate and final results during the lab session. This paradigm does not add anything to the cost of breadboarding exercises. It does however, require some advanced preparation by both the instructor and the students. It is hoped that this paradigm will prove as useful to other instructors as it has to the authors. It is also hoped that other will be inspired to consider the pedagogical aspects of breadboarding and contribute their own improvements to the educational literature.

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Table 1. Generic examples of a "range sheet" and an "initial sheet." The boldface text is written in by the students and the instructor during the lab exercise.

Initial sheet.

result	initials
V1 = **11.5 Volts**	**MT**
V2 = **-4.75 Volts**	**MT**
V3 = **1.05 Volts**	**MT**

Please obtain the instructor's initials before proceeding to the next step in the lab.

Range sheet.

result	acceptable range
V1 =	10 VDC to 11 VDC
V2 =	-5 VDC to -4.5 VDC
V3 =	1 to 1.5 VAC

Please make sure that your data is within the indicated ranges before proceeding to the next step in the lab.

Table 2. A "range sheet" for the timer lab example.

Range sheet for timer lab.

result	acceptable range
Supply Voltage V_s =	4.9 to 5.1 VDC
Period of Output T =	1.3 to 1.4 milliseconds
Duty Cycle DC =	73% to 77%

Please make sure that your data is within the indicated ranges before proceeding to the next step in the lab.