An Electronics Lab Project—Tutorial and Design of Printed Circuit Board ”big blinky”

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Abstract - Laboratory projects can be strategically used to improve the Electrical and Computer Engineering (ECE) curriculum across all four years, according to National Science Foundation (NSF) research in which we participated. In this "spiral model" approach, lab component themes are introduced in the freshman year and revisited with increased sophistication and interconnection in the following years. Labs are thus used as a "cohesive framework" that connects and integrates individual courses. Three themes were used in the research: video (and image), sound, and touch sensors. In this paper, we present a new lab project within the video/image theme—a 10-component printed circuit board (PCB) design, based on a 555 timer chip, that alternately flashes two light emitting diodes (LEDs). Based on prior experience, and for ease of soldering, this project uses only through-hole (and not surface mount) components—hence the name "big" *blinky*. The main contribution of this paper is to integrate together the spiral model concept (by providing a flashing LEDs lab project) with a useful, how-to PCB tutorial that should help students (and professors) to make future circuits for labs and research. Specifically, we provide a two-part, detailed, easy-to-follow tutorial which teaches the student how to use the popular industry PCB software, Altium Designer 2018 (AD18), and then to submit the project to a PCB maker's website to manufacture *big_blinky*. A three-day introductory AD18 course taken by one of the faculty authors did not show how to do a simple design from start-to-finish. In contrast, the *big_blinky* tutorial provides a simple, interesting, start-to-finish, guaranteed-to-work ECE project for professors and students who want to learn PCB design using world-class software. At the same time, this paper provides a relatively simple circuit design that fits nicely within the video/image theme of the spiral model for ECE curriculum improvement—the control of LEDs. Proposed upgrades of the project, which show "increased sophistication and interconnection" for later years of the curriculum, are also provided. This project has been successfully used in our first year "Introduction to Engineering" course, but has also been used effectively as an IEEE club project that included freshmen through seniors (and graduate students). Student feedback through formal surveys has been very positive. The project was also successfully converted to CircuitMaker (the free version of Altium Designer). The tutorial documents (PDFs) and AD18 (plus CircuitMaker) project code (and bill of materials for ordering components) will be available for downloading online, via the *Wixsite* web-hosting service: https://cbuece.wixsite.com/repositories.

Introduction—Educational Research Using Labs

Laboratory projects can be strategically used to improve the Electrical and Computer Engineering (ECE) curriculum across all four years, according to National Science Foundation (NSF) research done by Chu [1]. The aim is to enhance student learning and better prepare graduates for new challenges. Chu's viewpoint is that a good engineer must not only become knowledgeable in certain content areas (*components*, learned in individual courses), but also be able to apply and *integrate* that content to solve complex, real-world problems.

Motivation for Chu's work came from an earlier 5-year study of engineering education [2]. That study found a deficiency in the curricula—subjects were taught in isolation, did not have proper context, and did not adequately prepare students to integrate knowledge across courses.

Furthermore, labs were not used effectively. The study recommended a so-called "spiral model" and effective use of labs (by basing them on design projects):
"… the ideal learning trajectory is a spiral, with all components revisited at increasing levels of sophistication and interconnection. Learning in one area supports learning in another." [1]-[2]
A digest version of the study is available online. It compares a "linear components" model (of a curriculum) to their proposed "spiral model"—using two helpful diagrams [3].

Chu's approach applies the spiral model by introducing certain lab component *themes* (for freshman labs) and then maps out a plan to revisit them with increased sophistication and interconnection in the following years. In addition, he emphasizes design-oriented projects—because they can effectively "approximate professional practice", enhance knowledge synthesis, build teamwork, and even encourage student persistence. Thus, within a spiral model approach, labs are used as a "cohesive framework" that connects and integrates individual courses. The three themes employed in Chu's research are focused on video (and image), sound, and touch sensors. It is interesting to note that these are the main interface subsystems used in contemporary hand-held devices (like smart phones).

One of the faculty authors (of this current paper), and a colleague, participated in Chu's work as external collaborators. Some new lab projects were implemented and tested within three existing courses over a two-year period—a second-year digital logic design course, a third-year microcontrollers course, and a senior course in advanced digital design. In addition, some of this work has been used in our Institute of Electrical and Electronic Engineers (IEEE) student club. Students were surveyed at the end of the courses to assess the impact of the labs on their learning. Results seemed quite positive. Consequently, we were inspired by seeing the benefits of creating lab projects which can be useful across the ECE curriculum to provide a cohesive framework (for our courses) and thereby enhance learning. For example, our students are exposed to lab projects using visual feedback (LEDs and LCDs) in all four years—but with more "sophistication and interconnection" introduced in each year. This inspiration led to the development of two lab projects as contributions within the spiral model, in previous work [4], [5].

This paper's contribution

In this paper, we present our own design of a new (first-year) lab project within the video/image theme—a 10-component PCB design, based on a 555 timer chip, that alternately flashes two LEDs. Based on prior experience, and for ease of soldering, this project uses only through-hole (and not surface mount) components. Hence the name "big" *blinky*.

The main contribution of this paper is to integrate together the spiral model concept (by providing a flashing LEDs lab project) with a useful, how-to PCB tutorial that should help students (and professors) to make many more circuits for labs and research. Specifically, we provide a two-part, detailed, easy-to-follow tutorial which teaches the student how to use the popular industry PCB software, Altium Designer 2018 (AD18), and then to submit the project to a PCB maker's website to manufacture *big_blinky*. A three-day introductory AD18 course taken by one of the faculty authors did not show how to do a simple design from start-to-finish. In contrast, the *big_blinky* tutorial provides a simple, interesting, start-to-finish, guaranteed-to-work

ECE project for professors and students who want to learn PCB design using world-class software. Recently, we were able to convert the entire design into CircuitMaker (the "free" version of Altium Designer), and also create versions of our tutorial documents based on that software.

At the same time, this paper provides a relatively simple circuit design that fits nicely within the video/image theme of the spiral model for ECE curriculum improvement—the control of LEDs. Proposed upgrades of the project, which show "increased sophistication and interconnection" for later years of the curriculum, are also provided later. For assessment, we adapted surveys from Chu's NSF work and applied them to the current work. Results are presented below. Overall, (and consistent with our previous work [4], [5]), we found that students really enjoyed creating hands-on lab projects that implement real-world electronic circuits, and learning something of how the (PCB) design software works to create the desired functionality (a simplified timer flashing LEDs, in this case). In addition, we consistently find that students have a lot of interest in learning and practicing soldering skills—as they assemble the finished circuit.

A final point of introduction is that the spiral model approach, more broadly, is also consistent with the growing interest in hands-on (or project-based) learning that is becoming widespread in engineering education. As an example, *The STEM Lab Report* stated [6]:
"Throughout higher education in engineering, colleges are requiring students to pull their gaze from a text-book to perform real-world, hands-on, team-based project learning. In short, they are teaching students to become engineers by having them work as engineers."

And in a previous work [7], we concluded:
"…the key benefits of hands-on approaches for students are better outcomes, seeing the relevance of math (and engineering) with real-world examples, deeper understanding, more enjoyment, and persistence in engineering."

The 555 Timer Circuit (to be implemented in the PCB)

At the heart of the *big_blinky* design is an integrated circuit (IC) chip known as a 555 Timer, which provides the timing at which the LEDs flash. 555 timers have been popular for decades in electronics, are known as "the classic timer chip", and are discussed in detail in the well-known electronics textbook by Horowitz and Hill [8]. A good online tutorial for doing 555 Timer designs—showing how to choose component values to create the timing you want—is found here [9].

The *big_blinky* PCB Project

I. Learning Objectives

The key learning objectives for this learn-by-doing project are:

- To understand and implement control of LEDs using analog circuitry (as opposed to digital control)
- To understand the function of a basic 555 timer circuit—and see it in action, controlling the flashing of two LEDs.
- To understand basic printed circuit board concepts: design, manufacture, and build.

- To gain preliminary experience in using the PCB design software (Altium Designer or CircuitMaker) which is used to create the board.
- To gain basic experience in building/connecting the finished *big_blinky* board and circuit components.
- To learn/practice soldering (of *big_blinky*).

II. Description

Figure 1 is a photograph of the completed and working project presented in this paper. The *big_blinky* tutorial is based on Jeremy Blum's "blinky" PCB design done in *Eagle* software, and using only surface-mount components [10]. His tutorial consisted of 3 videos (over 1 million views to-date). For the benefit of our students and our ECE department, we wanted to provide more PCB learning opportunities. Inspired by Blum's work, we recreated "blinky", and then offered a tutorial in our IEEE Club. However, we found that it was not so effective to base the tutorial on his videos (watching them step by step as the class was being conducted). Also, it was somewhat difficult for students to do the tedious hand soldering of very small surface mount components once we had the blank boards back from the manufacturer.

Figure 1—The completed, assembled, and working PCB design project: *big_blinky*

Therefore, we decided to improve our approach by changing to world-class software Altium Designer (which looks good on student resumes) and to redesign Blum's project using larger, easy-to-solder, through-hole components (hence *big_blinky*). However, a three-day introductory AD18 course taken by one of the faculty authors did not show how to do a simple design from start-to-finish. This motivated us to learn how to design and create *big_blinky* in AD18 from start-to-finish, and capture the details (with lots of screen-captured images) in our own user-friendly tutorial documents. The result is that the *big_blinky* tutorial provides a simple, interesting, start-to-finish, guaranteed-to-work ECE project for professors and students who want to learn PCB design using world-class software.

III. Lab Steps

Overall, the tutorial consists of six steps:
1. Introduction.
2. Explanation of the design and function of the 555 timer circuit.
3. Schematic design of *big_blinky*—using AD18 (or CircuitMaker)
4. PCB layout of *big_blinky* using AD18 (or CircuitMaker)
5. Guidance for having the (blank) PCBs ordered and manufactured
6. Soldering of the components to the PCB to create the working design (Fig. 1)

Figure 2 shows an AD18 screen image of the finished *big_blinky* design. The tutorial is arranged in two portable data format (PDF) documents. Part 1 (58 pages) contains the first three steps and focuses on teaching/illustrating how to create the schematic diagram in AD18 (Fig. 2 right side). Part 2 (36 pages) contains the last two steps and focuses on creating the physical layout of the PCB circuit in AD18 (Fig. 2 left side).

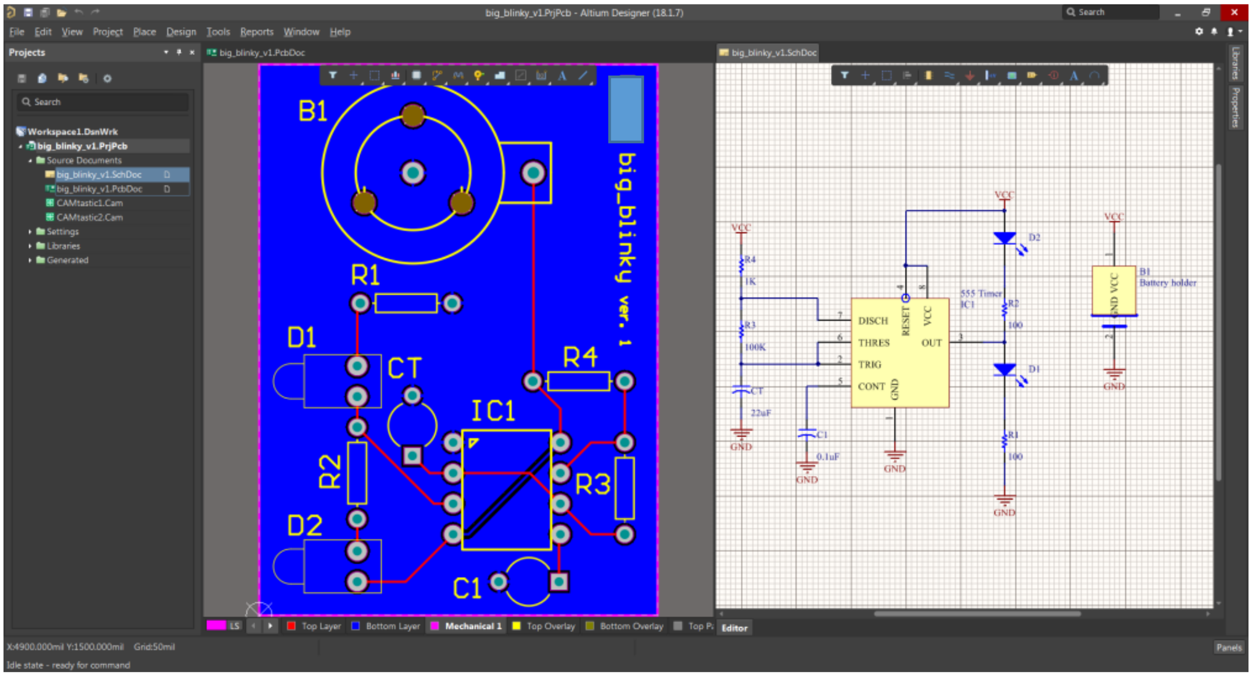

Figure 2—Altium Designer screen image of the completed PCB design project: *big_blinky*

IV. Revisiting the Project in Second to Fourth Year Courses

As a freshman-year lab, this project is mostly just the building of a "kit"—with no real design work required. Even the physical layout of the board was provided. However, each year, course work (and labs) should give students increased opportunity and responsibility to design additional functionality onto the original implementation—so as to train-by-doing into "professional practice". Here are some potentially more sophisticated versions of the project:

• **Sophomore year**—add an additional 555 timer chip and associated components so as to control 4 LEDs in total, plus add a switch to turn battery power on/off; students must design the timing, and work out the new layout on their own; converting to surface mount LED (and other) components would be an additional option.

• **Junior year**—Design and implement an LED dimmer PCB circuit using a 555 timer to create pulse width modulation (PWM) signals, as in example here [11].

• **Senior year**—implement an Arduino-clone microcontroller on PCB and write a small software program to control LEDs in either on/off mode or PWM mode; a good example of a do-it-yourself PCB project is found here [12].

big_blinky as an IEEE Club Tutorial

The *big_blinky* design project was initially developed and offered as a tutorial for our IEEE club—in four two-hour sessions on Wednesday nights, in one of our ECE laboratories. It was offered to all of our College of Engineering and attracted both ECE and some non-ECE students. The AD18 software was available on the lab computers, and after a short introduction students followed the PDF documents, with an instructor and IEEE club officers available to provide guidance. Happily, we found that within a few minutes, students were able to follow the tutorial documents on their own and seldom asked for any guidance.

The tutorial was offered in the spring 2019 semester and 15-20 students participated. However, we did not ask them to take the assessment survey (mentioned below) until late in the following semester. Unfortunately, only 4 students replied in time for this report.

big_blinky as a lab project in EGR 101 (Introduction to Engineering)

EGR 101 is a 3-unit course. It is divided into two portions each week: two 90-minute lectures, which act as an introduction to engineering through readings and projects, and one 90-minute lecture, which focuses on purpose, integrity, discernment and service as they relate to the vocation of engineering. The introduction to engineering portion of the course is divided into three parts. First, the students read two books to prepare for their time as students in the engineering field. The primary textbook for this course is *Studying Engineering: A Roadmap to a Rewarding Career* by Raymond Landis, Steffen Peuker, and Jennifer Mott. This book serves as an introduction to engineering and gives the students the necessary tools to be successful in their time as students.

The second and third parts of the course are divided between two projects, simply named Project #1 and Project #2. Project #1 introduces students to working in groups and the different engineering majors offered at our college; it will be discussed in detail below. For Project #2, the students are given a LEGO® Mindstorm kit and an Arduino (microcontroller) kit with sensors. They are then tasked with creating a novel robot with the Mindstorm kit that interacts in some way with the Arduino and sensor kit. The purpose of this project is to further cultivate each student's ability to work in groups and to introduce them to the Internet-of-Things (IoT).

The *big_blinky* project was offered as part of the introduction-to-engineering portion of the course, in the fall 2019 semester, as one of the options for students to pick for their first project in the course. For Project #1, students are given a choice between 30-40 different projects all relating to the various majors that are offered in our college of engineering. Students are asked to rank their top choices and then professors create groups based upon these rankings. Once the students are given their group/project assignments, they then have a little less than a month to complete the project. Besides just working on the project, students are required to create a project, a poster, and give an in-class presentation. They are also required to present their project at an out-of-class exhibition in order to gain experience in presenting their work to the public. In the fall 2019 semester, there was one group of 3 students that was assigned the *big_blinky* project.

Survey Results and Student Feedback

As mentioned above, one of the faculty authors acted as an external collaborator in Chu's NSF work. Surveys, adapted from that work, were given to students in EGR 101 and the IEEE club who worked on the *big_blinky* lab/tutorial. Four pairs of selected questions are analyzed here. The questions given to the IEEE club are given below. Note that the "a" questions (1a, 2a, etc.) are "generic" to courses (and associated labs), while the corresponding "b" questions (1b, 2b, etc.) are specific to the *big_blinky* lab/tutorial. Very similar "a" questions were used for the EGR 101 students, except modified to refer to "this course" instead of "my courses", and using "engineering" instead of "ECE". But the "b" questions were identical.

1a. The lab work I do for my courses is relevant to my learning.
1b. The *big_blinky* lab/tutorial was relevant to my learning.

2a. Doing the labs from my engineering courses is interesting to me.
2b. Doing the *big_blinky* lab/tutorial was interesting to me.

3a. The labs for my courses show me how to problem-solve in Engineering.
3b. The *big_blinky* lab/tutorial showed me something about how to problem-solve in ECE.

4a. Doing engineering labs shows me real life applications of the information.
4b. Doing the *big_blinky* lab/tutorial showed me a real life application of ECE.

Possible responses (with numerical values) were: Strongly Agree (5), Agree (4), Undecided (3), Disagree (2), Strongly Disagree (1). Tables 1 and 2 summarize the data.

Table 1
Student Survey Results: Selected Questions—Average Score
(From **IEEE Club** Using the "Spiral Approach")—**4** students surveyed

Question-pair	Generic ("a")	*big_blinky*-specific ("b")
1	5	4.8
2	4.5	5
3	4.5	4.5
4	4.8	4.5

Table 2
Student Survey Results: Selected Questions—Average Score
(From **EGR 101** Using the "Spiral Approach")—**3** students surveyed

Question-pair	Generic ("a")	*big_blinky*-specific ("b")
1	4.3	3.7
2	5	5
3	4.7	3.3
4	4.7	4.3

Overall, the table shows that students generally agree or strongly agree with each of the four pairs of questions about course labs (and the *big_blinky* lab). For example, question 1a-Generic (The lab work I do [in this course or courses] is relevant to my learning) got an average response/score of 5 (out of 5.0 maximum) for IEEE (Table 1) and 4.3 for EGR 101 (Table 2)—calculated by adding student response values (5 to 1) and dividing by the number of students. Thus, per the questions, on the whole, students find ECE/Engineering labs to be relevant, interesting, helpful, and realistic in their learning.

Similarly, the *big_blinky* lab responses were high for the IEEE club participants (all 4 students indicated ECE as their major) for the same questions. For *big_blinky* in EGR 101, the interest response was high, but the other three questions lower (two students indicated ECE majors, and the third student a Chemical engineering major). And again, overall, the *big_blinky* lab was also perceived as relevant, interesting, helpful, and realistic in their learning.

Discussion and Conclusion

This paper presents a fully-working, relatively easy-to-use, first-year lab project within the video/image theme of the spiral model approach to improving the ECE curriculum. The project demonstrates a 555-timer-based circuit that alternately flashes LEDs, and shows how to implement the design on a custom PCB, using Altium Designer (or CircuitMaker) software. This work also provides detailed, easy-to-follow tutorial documents. Project design code (for both software packages) and the tutorial documents (PDFs) will be provided on the *Wixsite* web-hosting website: https://cbuece.wixsite.com/repositories.

Despite being a relatively simple design project, its content addresses important material within the ECE curriculum—control of LEDs, use of 555 Timers, implementation of a circuit into a custom PCB, and initial experience with industry standard PCB design software.

Since we (the faculty authors) use control of LEDs in other lab-based courses with both freshmen and senior students, we believe that this project makes a useful connection between first-year introduction of "LED control" to more sophisticated versions of this design in second to fourth years of study. And examples were provided above as a guideline for such developments.

Thus, based on written student surveys and the interest shown by students when doing and building the project, we believe this approach (spiral model plus themed labs across the four years), and this specific lab project, will be effective in improving student learning and preparing graduates for new challenges.

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