PLTW
ENGINEERING

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Digital Electronics | Course Outline

> *Open doors to understanding electronics and foundations in circuit design.*
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> *Digital electronics is the foundation of all modern electronic devices such as cellular phones, MP3 players, laptop computers, digital cameras, high definition televisions, etc. Students learn the digital circuit design process to create circuits and present solutions that can improve people's lives.*
>
> *Learn how advancements in foundational electronic components and digital circuit design processes have transformed the world around you.*

Digital electronics is the study of electronic circuits that are used to process and control digital signals. In contrast to analog electronics, where information is represented by a continuously varying voltage, digital signals are represented by two discrete voltages or logic levels. This distinction allows for greater signal speed and storage capabilities and has revolutionized the world of electronics.

The major focus of the DE course is to expose students to the design process of combinational and sequential logic design, teamwork, communication methods, engineering standards, and technical documentation.

Utilizing the activity-project-problem-based (APB) teaching and learning pedagogy, students will analyze, design, and build digital electronic circuits. While implementing these designs, students will continually hone their professional skills, creative abilities, and understanding of the circuit design process.

Digital Electronics (DE) is a high school level course that is appropriate for 10th or 11th grade students interested in exploring electronics. Other than their concurrent enrollment in college preparatory mathematics and science courses, this course assumes no previous knowledge.

The following is a summary of the units of study that are included in the course. Activities, projects, and problems are provided to the teacher in the form of student-ready handouts, teacher notes/lesson planning resources, and supplementary materials, including simulations, instructional videos, and online resources as appropriate.

While many students may have been exposed to basic circuits and electricity in a science course, Digital Electronics is typically a unique experience for students because of its focus on understanding and implementing circuit design skills. The course is planned for a rigorous pace, and it is likely to contain more material than a skilled teacher new to the course will be able to complete in the first iteration. Building enthusiasm for rigorous exploration of electronics and circuit design for students is a primary goal of the course.

DE Unit Summary

Unit 1	Foundations in Electronics
Unit 2	Combinational Logic
Unit 3	Sequential Logic
Unit 4	Controlling Real-World Systems

Unit 1: Foundations in Electronics

In Unit 1 Foundations in Electronics, students will explore the fundamental components, concepts, equipment, and skill sets associated with circuit design. They will learn an engineering design process that can be used to guide the creation of circuits based on a set of design requirements. Throughout the course students will learn about advancements in circuits and circuit design that have shaped the world of digital electronics.

Foundations in Electronics Lesson Summary

Lesson 1.1	Introduction to Electronics
Lesson 1.2	Introduction to Circuit Design

Lesson 1.1 Introduction to Electronics

In Lesson 1.1 Introduction to Electronics, students will learn to distinguish between analog and digital components. They will begin by exploring basic circuits and the measurement tools used to characterize and validate calculations that predict a circuit's behavior. Students will be able to clearly describe electrical circuits, voltage, current, resistance, series and parallel circuits, Ohm's law, and how to use a digital multimeter to measure voltage. Students will be introduced to common components such as resistors, capacitors, light emitting diodes (LEDs), seven-segment displays, combinational logic gates, and sequential logic gates.

Lesson 1.2 Introduction to Circuit Design

In Lesson 1.2 Introduction to Circuit Design, students will explore fundamental circuit designs, manipulate circuits to understand their function, and explore the examples that combine analog, digital combinational logic, and digital sequential logic.

This lesson is meant to serve as a broad overview of circuit design and to expose students to basic designs they will be exploring and incorporating into their own future designs.

Unit 2: Combinational Logic

How do you design a circuit to “do what you want it to do”? The goal of Unit 2 is for students to gain in-depth understanding of the combinational logic circuit design. Student will explore creation of circuits with discrete components and how to simplify these circuits to implement more efficient designs.

Combinational Logic Lesson Summary

Lesson 2.1	AOI Combinational Logic Circuit Design
Lesson 2.2	Alternative Design: Universal Gates and K-Mapping
Lesson 2.3	Specific Combinational Logic Designs
Lesson 2.4	Introduction to Programmable Logic Devices (PLDs)

Lesson 2.1 AOI Combinational Logic Circuit Design

Lesson 2.1 focuses on AND, OR, Inverter (AOI) combinational logic circuit design. Students will reinforce concepts that were introduced in the previous units, including binary number systems, truth tables, and Boolean expressions. They will then expand on these concepts by exploring how mathematics can be used to reduce circuit size, cost, and complexity. Using the systematic approaches of AOI simplification, AOI logic analysis, and AOI implementation, students will learn to take design specifications and translate them into the most efficient circuit possible.

Lesson 2.2 Alternative Design: Universal Gates and K-Mapping

In the first lesson of this unit, students learned how to use a design process to transform design specifications into functional AOI combinational logic. Though the result of this work was a functioning circuit, this process does not address a few issues.

First, Boolean algebra was required to simplify the logic expressions. Though Boolean algebra is an important mathematical process, applying its numerous theorems and laws is not always the easiest task to undertake in simplifying circuits.

Second, AOI circuit implementations are rarely the most cost-effective solutions for combinational logic designs.

After completing a series of guided foundational activities on Karnaugh maps, NAND only logic design, and NOR only logic design, the students will apply the combinational logic design process to develop a Fireplace Control Circuit. This process will walk the students through the steps required to transform a set of written design specifications into a functional combinational logic circuit implemented with either NAND only or NOR only logic.

Lesson 2.3 Specific Combinational Logic Designs

This lesson will address a few fundamental topics related to combinational logic. These topics include hexadecimal and octal number systems, XOR, XNOR, and binary adders, 2's complement arithmetic, and multiplexers/de-multiplexers.

These designs are commonly used in digital circuit designs related to adding/subtracting numbers, the use of seven segment displays in designs, and carrying multiple signals through the same pathway in a circuit.

Lesson 2.4 Introduction to Programmable Logic Devices (PLDs)

In the first three lessons of this unit, students learned how to use a design process to transform design specifications into functional AOI, NAND, and NOR combinational logic circuits. In this lesson students apply all that they have learned to design a circuit in which they define some of the design specifications themselves for the first time.

Students will design, simulate, and breadboard a circuit that displays their unique birthdate. Circuit implementation is then demonstrated at the next level by utilizing a programmable logic device called a Field Programmable Gate Array (FPGA). FPGA is a state-of-the-art programmable device capable of implementing large, sophisticated designs. In this course we have limited our designs to four inputs and circuits that are manageable for breadboarding. The PLD shows us the next evolution of circuit design, allowing us to design more complex circuits in a shorter period of time. Students quickly see the benefit of this new design tool and strategy over designing discrete logic gates.

Unit 3: Sequential Logic

How do you get a circuit to do what you want it to do, when you want it to do it? Sequential logic introduces students to event detection and memory. Sequential logic has two characteristics that distinguish it from combinational logic. First, sequential logic must have a signal that controls the sequencing of events. Second, sequential logic must have the ability to remember past events.

A keypad on a garage door opener is a classic example of an everyday device that utilizes sequential logic. On the keypad, the sequencing signal controls when a key can be pressed. The need to enter the passcode in a specific order necessitates memory of past events.

These characteristics are made possible by a simple device called a flip-flop. The flip-flop is a logic device that is capable of storing a logic level and allowing this stored value to change only at a specific time. For this reason the flip-flop is the fundamental building block for all sequential logic designs.

Sequential Logic Lesson Summary

Lesson 3.1	Sequential Logic Circuit Design
Lesson 3.2	Asynchronous Counters
Lesson 3.3	Synchronous Counters

Lesson 3.1 Sequential Logic Circuit Design

In this lesson students begin the study of sequential logic by examining the basic operation of the two most common flip-flop types, the D and J/K flip-flops. As part of this analysis, they will review the design of four typical flip-flop applications: event detector, data synchronizer, frequency divider, and shift register. In later lessons the application of flip-flops for asynchronous counters, synchronous counters, and state-machines will be studied.

Lesson 3.2 Asynchronous Counters

The ability to count in a digital design application is a fundamental need in most circuits. These counting applications range from the simple Now Serving sign at the neighborhood deli counter to the countdown display used by NASA to launch rockets. A number of techniques are used to design counters, but they all fall into two general categories, each with their own advantages and disadvantages. These two categories are called asynchronous counters and synchronous counters.

The primary design characteristic of asynchronous counters that distinguish them from synchronous counters is that the flip-flop of each stage is clocked by the flip-flop output of the prior stage. Thus, rather than all the flip-flops changing simultaneously, the clock ripples its way from the first flip-flop to the last. This is why asynchronous counters are sometimes referred to as ripple counters.

After completing a series of activities on the process for designing Small Scale Integration (SSI) and Medium Scale Integration (MSI) asynchronous counters, this lesson will conclude with a design problem that requires the students to design, simulate, and create a Now Serving display circuit.

Lesson 3.3 Synchronous Counters

As discussed in the previous lesson of this unit, the two categories of digital counters are asynchronous and synchronous. The analysis and design of synchronous counters is the topic of study of this lesson. The primary design characteristic of synchronous counters is that all of the flip-flops are clocked simultaneously. This simultaneous clocking avoids the rippling effect that is present in asynchronous counters.

After completing a series of activities on the process for designing SSI and MSI synchronous counters, this lesson will conclude with a project that requires the students to design and simulate a Sixty Second Timer circuit.

Unit 4: Controlling Real-World Systems

In Unit 4 students make a final transition to the use of single-board computers used widely today. State machines and computers allow students to integrate sensors and motors. This allows us to create circuits that exist in the world around us.

Controlling Real-World Systems Lesson Summary

Lesson 4.1	Introduction to State Machines
Lesson 4.2	Application of State Machines

Lesson 4.1 Introduction to State Machines

State machines, sometimes called Finite State Machines (FSM), are a form of sequential logic that can be used to electronically control common everyday devices such as traffic lights, electronic keypads, and automatic door openers.

In this lesson students will learn and apply the state machine design process. This design process will be used to implement state machines utilizing the pi-top platform, which is based on the Raspberry Pi.

After completing a foundational activity on state machine design, the lesson introduces students to algorithmic thinking and the use of digital and analog devices to solve a problem. The lesson concludes with a project where students design and build a preemptive traffic light using the pi-top and the Python programming language.

Lesson 4.2 Application of State Machines

This lesson introduces students to more algorithms and programming concepts as they learn to use servo motors and remote communication across pi-top devices. The lesson concludes with a problem in which students use all the knowledge and skills they have learned in the unit to design and implement an escape room using multiple pi-tops.

State machines, the design process, planning, and documentation are threaded throughout the unit as students work in teams and practice transportable skills including communication and collaboration.