HS Digital Electronics
Pre-Engineering

Course Description
This course covers fundamentals of analog and digital electronics. Students learn about the different number systems used in the design of digital circuitry. They design circuits to solve open-ended problems, assemble their solutions and trouble-shoot them as necessary. Students then use combined logic, integrated circuits and microprocessors to solve open-ended problems.

Scope And Sequence

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Course Rationale
The Park Hill School District offers Project Lead the Way (PLTW) at both of the high schools. PLTW is a four year sequence of courses which, when combined with traditional mathematics and science courses in high school, introduces students to the scope, rigor and discipline of engineering prior to entering college.

Enduring Understandings
Engineers and technicians use Circuit Design Software as a tool to verify functionality of their analog and digital designs.

An understanding of the binary number system and its relationship to the decimal number system is essential in the combinational logic design process.

Asynchronous counters, also called ripple counters, are characterized by an external signal clocking the first flip-flop. All subsequent flip-flops are clocked by the output of the previous flip-flop.

Microcontrollers can be programmed to sense and respond to outside stimuli.

Key Resources
PLTW curriculum and resources downloaded from the PLTW Virtual Academy.

Board Approval Date
Board Approved 5-24-2012

Course Details

Unit: Fundamentals of Analog and Digital Electronics
Duration: 16 Day(s)
HS Digital Electronics
Pre-Engineering

Unit Overview
This unit begins with the students creating the Board Game Counter including the basics of circuit theory, circuit simulation and Breadboarding, and an overview of analog and digital signal characteristics.

Enduring Understandings
Proper safety guidelines and soldering techniques must be followed when constructing, testing, and diagnosing circuits.
Basic electric theories can be utilized in all circuits.
Combinational and sequential logic have special applications

Essential Questions
Why is it important to understanding electrical current?
Why is it important to express very large and very small numbers in proper scientific, engineering and Systems International (SI) notation?
What is the process for doing so?
Why is AOI logic utilized?

Example Assessment Items
Given the General Safety Quiz the students' will identify proper soldering safety guidelines.
Upon completion of the Electrion Theory Hand Calculations using scientific notation the students' will demonstrate the Engineering Systems International notation.
Given the Board Game Activity the students' will demonstrate combination and sequential logic.

Academic Vocabulary
Soldering
Parallel Circuits
Logic Gate

Topic: Foundations and the Board Game Counter
Duration: 4 Day(s)

Description
This is the first of three lessons in Unit One. Unit One provides the students with an overview of digital electronics and what they will be learning throughout the course. The students will be introduced to basic circuit concepts and the fundamentals of combinational and sequential logic. These concepts will be introduced as the students assemble and analyze an electronic kit called the Board Game Counter. The Board Game Counter is an electronic game that emulates the rolling of a game cube used to play a board game (see below). When the ROLL button is pressed, the light emitting diodes will rapidly cycle through the count from (1) to (6). Once the ROLL button is released, the count rate will slow and then stop to display the results.

In this lesson students will assemble their own Board Game Counter. Students will learn classroom/laboratory safety guidelines, scientific and engineering notations, component identification, and proper soldering techniques.

At the completion of this lesson, the students are expected to have a level of understanding at the knowledge, or lowest level, of Bloom's Taxonomy. For comparison purposes, this is the same level of understanding that is expected of someone who works on an electronics manufacturing assembly line. They should know what the Board Game Counter does and how to assemble it, but they will not be able to describe in detail how it works or design one.

Learning Targets
The student will be able to determine a resistor's actual value by reading its resistance with a Digital Multimeter (DMM).
The student will be able to properly tin the tip of a soldering iron.
The student will use proper soldering/de-soldering techniques to solder and de-solder components on a printed circuit boards.

Topic: Introduction to Analog
Duration: 6 Day(s)

Description
This is the second of three lessons in unit one. As with the other lessons in this unit, the Board Game Counter will be utilized to introduce the students to analog electronics.

In this lesson students will receive instruction on the basics of circuit theory, circuit simulation and Breadboarding, and an overview of analog and digital signal characteristics. This introduction will be limited to the components utilized in the Board Game Counter design. Using this knowledge as a foundation, the students will analyze, through simulation, the analog portion of the Board Game Counter.

At the completion of this lesson, the students are expected to have a level of understanding at the comprehension, or second lowest level, of Bloom's Taxonomy. For comparison purposes, this is the same level of understanding that would be expected of someone who works as a tester on an electronics-manufacturing assembly line. Students should know what the Board Game Counter does, how to assemble the device, and they should be able to describe how it works. At this point students do not have the knowledge necessary to design anything this complex, as these skills will be developed in units three and four of this course.

Learning Targets
The student will be able to analyze and design simple digital oscillators using the 555 Timer chip.
The student will be able to identify the parts of an atom and determine if an element would make a good conductor, insulator, or semiconductor.
The student will use Ohm's Law, Kirchhoff's Voltage Law, and Kirchhoff's Current Law to solve for simple series and parallel circuit.

**Topic:** Introduction to Digital Electronics

**Duration:** 6 Day(s)

**Description**
This is the third and final lesson in unit one. As with the other lessons in this unit, the Board Game Counter will be utilized to introduce the students to combinational and sequential electronics.

In this lesson students will receive instruction on the basics of combinational and sequential logic. This introduction will be limited to the components utilized in the Board Game Counter design. Using this knowledge as a foundation, the students will analyze, through simulation, the digital electronics portion of the Board Game Counter.

At the completion of this lesson, the students are expected to have a level of understanding at the comprehension, or second lowest level, of Bloom's Taxonomy. For comparison purposes, this is the same level of understanding that would be expected of someone who works as a tester on an electronics-manufacturing assembly line. They should know what the Board Game Counter does, how to assemble it, and should be able to describe how it works. At this point students will not have the knowledge necessary to design anything this complex, as these skills will be developed in units three and four of this course.

**Learning Targets**
The student will be able to identify various integrated circuit (IC) package styles.

The student will identify and describe the function of AND, OR, & Inverter gates.

The student will know how to identify commonly used electronic components given their part number or schematic symbol.

The student will know the fundamental differences between combinational and sequential logic.

**Unit:** Combinational Logic

**Duration:** 15 Day(s)
HS Digital Electronics
Pre-Engineering

Grade(s) 10th - 12th, 1 Credit
Elective Course

Unit Overview
This unit begins with the construction a device that can count votes in order to introduce students to binary number systems, truth tables, Boolean expression with simplification, AOI logic analysis, and implementation.

Enduring Understandings
Understanding the binary number system and its relationship to the decimal number system is essential in the combinational logic design process.

NAND gate is considered a universal gate because it can be used to implement an AND gate, OR gate, and an inverter gate. Any combinational logic expression can be implemented using only NAND gates.

Formal design process exists for translating a set of design specifications into a functional combinational logic circuit.

Understanding the hexadecimal and octal number systems and their relationship to the decimal number system is necessary for comprehension of digital electronics.

Programmable logic devices can be used to implement any combinational logic circuits but are best suited for larger, more complex designs.

Essential Questions
What are the processes for converting numbers between the binary and decimal number systems, and why is the understanding of these two numbers systems essential to your ability to design combinational logic circuits?

How do you use the process for using the K-Mapping technique to simplify a logic expression? Why are there advantages of using this process over Boolean algebra?

How can you describe the relationship between the resistor value used, the amount of current flowing, and the brightness of a segment of seven-segment display?

What are the processes for converting numbers between the hexadecimal or octal and decimal number systems, and why is the understanding of these two numbers systems important to your comprehension of digital electronics?

Why are programmable logic devices best suited for larger, more complex designs?

Example Assessment Items
Given Activity 2.1.5 AOI Logic Implementation the students' will convert numbers between the binary and decimal number system.

Upon completion of the Activity 2.2.1 K-Mapping the students' will be able to explain the advantages and disadvantages of K-Mapping verse Boolean algebra.

Through the completion of Activity 2.3.1 Seven-Segment Displays the students' will understand the relationship between the resistor value used, the amount of current flowing, and the brightness of a segment of seven-segment display.

Given Activity 2.4.1 Octal & Hexadecimal Number Systems the students' will be able to convert numbers between the hexadecimal or octal and decimal number systems and explain the differences.

Using the Project 2.5.2 Date of Birth with a PLD the students' will demonstrate why programmable logic devices are best suited for larger, more complex designs.

Academic Vocabulary
Binary Number System
NAND Gate
Seven-Segment Display
Hexadecimal Number System
Integrated Circuit (IC)

Topic: Introduction to AOI Logic

Duration: 5 Day(s)
Description
When a contractor builds a new house, the contractor does not just buy a load of bricks and lumber and start throwing it together hoping to end up with a nice product. The work begins with a plan. The plan is followed step-by-step. The plan allows the contractor to know exactly what supplies are needed and how they all come together to create a nice home. In engineering we call this a plan a process. In this lesson we will use such a process to transform a set of written design specifications into an AND/OR/Invert logic circuit. In later lessons we will expand on this process to include NAND gates, NOR gates, and Programmable Logic Devices.

Unlike most lessons developed in the standard APP (Activity/Project/Problem) format, the organization of the activities and projects in this lesson is somewhat different. Rather than completing a series of guided activities followed by a culminating culminating capstone project, this lesson is structured around completing a single project in stages, with each stage being assigned only after the student has completed one or more supporting activities.

Specifically, the project will have the students apply the Combinational Logic Design Process (version 1) to the development of a Majority Vote - Voting Machine. This process will walk the students through the steps required to transform a set of written design specifications into a functional logic circuit. Along the way students will complete supporting activities on Binary Number Systems, Truth Tables, Boolean Expression and Simplification, AOI Logic Analysis, and Implementation.

Learning Targets
The student will convert numbers between the binary and decimal number systems.

The student will extract un-simplified logic expressions from truth tables.

The student will use Circuit Design Software (CDS) and a Digital Logic Board (DLB) to simulate and prototype AOI logic circuits.

Topic: Intro to NAND and NOR Logic  Duration: 2 Day(s)

Description
In the first lesson of this unit, we 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. Second, as we will see in this lesson, AOI circuit implementations are rarely the most cost-effective solutions for combinational logic designs.

This lesson follows the standard APP (Activity/Project/Problem) format. After completing a series of guided foundational activities on Karnaugh Mappings, NAND only logic design, NOR only logic design, and MultSim's Logic Converter, the students will apply the Combinational Logic Design Process (version 2) 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.

Learning Targets
The student will be able to compare and contrast the quality of combinational logic designs implemented with AOI, NAND, and NOR logic gates.

The student will design combinational logic circuit using NAND and NOR logic gates.

The student will use Circuit Design Software (CDS) and a Digital Logic Board (DLB) to simulate and prototype NAND and NOR logic circuits.

Topic: Date of Birth Design  Duration: 3 Day(s)

Description
Engineering is not about completing step-by-step activities or even mid-size projects where the outcome is predefined. Engineering is about solving problems and engaging in a distinct process in order to do so.

Though this lesson includes few new concepts and is relatively short in duration, completion of this lesson requires an understanding of knowledge and concepts learned earlier in this unit. Student will gain first-hand design experience by transferring their prior knowledge as they transform a design from written specifications to circuit implementation.

In this lesson students will learn how to utilize a seven-segment display to show alpha/numeric values. Students will design a large combinational logic circuit, with multiple outputs, that will display their individual date of birth. The implementation of this logic circuit will require the use of NAND, NOR, and AOI logic.

Learning Targets
The student will design AOI, NAND, & NOR solutions for a logic expression and select the solution that uses the least number of ICs to implement.

The student will follow a formal design process to translate a set of design specifications for a design containing multiple outputs into a functional combinational logic circuit.
The student will use a seven-segment display in a combinational logic design to display alpha/numeric values.

**Topic:** Specific Combinational Logic Circuits and Miscellaneous Topics  

**Description**
In the first three lessons of this unit, students learned how to use a design process to transform design specifications into functional combinational logic. At this point the students may think they know everything there is to know about combinational logic design and number systems. While they have learned a lot, this is truly just a glimpse of the many devices that they could design and build with combinational logic. Though they could literally spend the remainder of the school year completing increasingly complex combinational logic designs, additional digital electronic topics must be covered as well.

This lesson will address a few classic 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.

**Learning Targets**
The student will convert numbers between the hexadecimal or octal number systems and the decimal number system.
The student will use Circuit Design Software (CDS) and a Digital Logic Board (DLB) to simulate and prototype specific combinational logic circuits.
The student will use XOR and XNOR gates to design binary half-adders and full-adders.

**Topic:** Programmable Logic: Combinational  

**Description**
In the first three lessons of this unit, we learned how to use a design process to transform design specifications into functional AOI, NAND, and NOR combinational logic circuits. In this lesson we will take the circuit implementation to the next level and utilize a programmable logic device. Specifically, we will use a Field Programmable Gate Array (FPGA). FPGA is a state-of-the-art programmable device capable of implementing large, sophisticated designs. Admittedly, using such a device to implement our relatively simple circuits is a bit like duck hunting with a cannon: effective, but a bit more than needed.

The first activity in this lesson will be a tutorial on the programmable logic design tool and the FPGA programming process. For this tutorial the Fireplace Control Circuit that was the basis of a NAND/NOR design project in lesson 2.2 will be programmed into the FPGA. This reimplementation will permit the students to see the ease of designing with programmable logic over discrete logic gates.

Following the activity, the students will implement their Date of Birth design (lesson 2.3) with programmable logic. Along with giving the students another opportunity to practice using the programmable logic design tools, this project will demonstrate one of the significant advantages of programmable logic, less wiring.

Finally, this lesson will conclude with a design problem. This problem requires the students to design a combinational logic circuit that will detect a jam in an office copier. The solution to the problem will be implemented in programmable logic.

**Learning Targets**
The student will be able to cite the advantages and disadvantages of programmable logic devices over discrete logic gates.
The student will design combinational logic circuits using a programmable logic device.
The student will use Circuit Design Software (CDS) and a Digital Logic Board (DLB) to simulate and prototype combinational logic designs implemented with programmable logic.
Unit Overview
In this unit students learn that sequential logic is needed in order for electronic systems to utilize signals to control the sequence of events, and also have the ability to remember past events. Students also learn to distinguish between asynchronous and synchronous counters and the role flip-flops play in each. Students first create a 60 second counter, and then a device to count cars entering a parking lot. In the last unit students design a state machine to simulate the operation of an elevator door.

Enduring Understandings
Flip-flops can be used to design single event detection circuits, data synchronizers, shift registers, and frequency dividers.

Asynchronous counters, also called ripple counters, are characterized by an external signal clocking the first flip-flop. All subsequent flip-flips are clocked by the output of the previous flip-flop.

Synchronous counters can be implemented using small scale integrated (SSI) and medium scale integrated (MSI) logic gates.

State machines can be implemented using small and medium scale integrated gates and programmable logic devices.

Essential Questions
How do the synchronous and asynchronous input function serve on flip-flops and transparent latches?

How is the process for designing asynchronous counters implemented using discrete D and J/K flip-flops and medium scale integrated (MSI) circuit counters?

How do you use the process for designing up, down, and modulus synchronous counters?

How do you use the two variations of the state machine design?

Example Assessment Items
Given the Activity 3.1.1 Introduction to Flip-Flops the students' will understand the function that synchronous and asynchronous inputs serve on flip-flops and transparent latches.

Upon completing Activity 3.2.2 SSI Asynchronous Modulus Counters the students' will comprehend the process for designing asynchronous counters implemented using discrete D and J/K flip-flops and medium scale integrated (MSI) circuit counters.

Given the Project 3.3.4 Now Serving Display Design Project the students' will utilize the process for designing up, down, and modulus synchronous counters.

Given the Problem 3.4.2FT State Machine the students’ will be able to identify the advantages of the various designs of state machines.

Academic Vocabulary
Sequential Logic
Modulus
Up/Down Counter
State Machines

Topic: Flip-Flops and Latches Duration: 3 Day(s)

Description
Sequential logic, the topic of study for this unit, has two characteristic 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 pass-code in a specific order necessitates memory of past events.

Learning Targets
The student will describe the function of, and differences between, a flip-flop's synchronous and asynchronous inputs.

The student will draw detailed timing diagrams for the D or J/K flip-flop's Q output in response to a variety of synchronous and asynchronous input conditions.

The student will use Circuit Design Software (CDS) and a Digital Logic Board (DLB) to simulate and prototype introductory flip-flop applications.

Topic: Asynchronous Counters Duration: 7 Day(s)
Description
Digital design applications that necessitate the ability to count are numerous. 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.

Asynchronous counters will be the topic of study of this lesson. 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 SSI and MSI asynchronous counters, this lesson will conclude with a design problem that requires the students to design and simulate a sixty-second timer. The specifications for this timer are such that the students are required to utilize both the SSI and the MSI design techniques in their solution.

Learning Targets
The student will be able to analyze and design up, down and modulus asynchronous counters using medium scale integrated (MSI) circuit counters.

The student will know the advantages and disadvantage of counters designed using the asynchronous counter method.

The student will use Circuit Design Software (CDS) and Digital Logic Board (DLB) to simulate and prototype SSI and MSI asynchronous counters.

Topic: Synchronous Counters Duration: 7 Day(s)

Description
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 all 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 circuit that counts the number of cars entering and leaving a parking garage.

Learning Targets
Students will be able to analyze and design up, down and modulus synchronous counters using medium scale integrated (MSI) circuit counters.

The student will be able to analyze and design up, down and modulus synchronous counters using discrete D and J/K flip-flops.

The student will use Circuit Design Software (CDS) and Digital Logic Board (DLB) to simulate and prototype SSI and MSI synchronous counters.

Topic: State Machine Design Duration: 11 Day(s)

Description
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 both discrete logic gates and programmable logic.

After completing two foundational activities on state machine design, the lesson will conclude with a design problem where the students will be assigned the task of designing and implementing a state machine that controls the operation of an elevator door. This state machine will be implemented using programmable logic.

Learning Targets
The student will be able to implement Boolean equations into a functional state machine.

The student will describe the two variations of state machines and list the advantages of each.

The student will use Circuit Design Software (CDS) and a Digital Logic Board (DLB) to simulate and prototype state machines designs implemented with discrete and programmable logic.

Unit: Microcontrollers Duration: 29 Day(s)
HS Digital Electronics
Pre-Engineering

Unit Overview
Microcontrollers are the brains behind most of today's modern electronic devices. Students in this unit program microcontrollers to do a variety of tasks. Students will program a BOE-bot to be a fully autonomous unit. For the last challenge students program the BOE-bot to navigate a maze as quick as possible.

Enduring Understandings
Programming languages have their own grammar, called syntax.

Microcontrollers are used to control many everyday products like robots, garage door openers, traffic lights, and home thermostats.

Digital devices are only relevant if they can interact with the real world.

Essential Questions
Why is it important to know about syntax?

What is a servo motor and what parameters does it use in programming code?

How does a microcontroller enable users to interface the analog world with the digital world?

Example Assessment Items
Given Activity 4.1.1 Microcontrollers and the BOE the students' will understand syntax and why it is important.

Upon completion of Activity 4.2.3 Boe-Bot Tactile Whiskers the students' understand how parameters are used in the programming code for servo motors.

Given the Project 4.3.1 Boe-Bot Design Projects (P4_3_1A, P4_3_1B, and P4_3_1C) the students' will demonstrate how a microprocessor intertwines the analog and digital world.

Academic Vocabulary
Microcontroller
Servo Motor
Interface

Topic: Introduction to Microcontrollers
Duration: 9 Day(s)

Description
How is it that your cell phone today can hold more data than the computers used twenty years ago? The answer is a tiny little device called a microcontroller. A microcontroller is a miniature computer that is used in many common devices. In this lesson students will learn about a specific microcontroller, the BASIC stamp. They will learn how to communicate with it and program it to perform a variety of tasks.

Learning Targets
The student will create programs that use variables.

The student will create a program that utilizes the Debug screen.

The student will create programs that use inputs and outputs.

Topic: Microcontrollers and The Boe-Bot
Duration: 9 Day(s)

Description
While a microcontroller is a powerful little device, it would be nothing without its hardware. Think of the microcontroller as the brain that operates a body.

Learning Targets
The student will program a servo motor.

The student will program and test an autonomous robot.

The student will use mathematics to calculate programming values.

Topic: Boe-Bot Design Projects
Duration: 11 Day(s)
Description
In this lesson, students will be given the opportunity to draw together all of the concepts and skills that they have developed in this unit to programming a microcontroller to maneuver a robot through a design course.

They will be given the choice of three projects. These projects are:

- Light Sensitive Navigation with Photo Resistors
- Navigating with Infrared Headlights
- Robot Control with Distance Detection

Learning Targets
The student will draw a flowchart for a microcontroller program that will be used to maneuver a robot.

The student will program a microcontroller to maneuver a robot through a design course.