DELAWARE VALLEY SCHOOL DISTRICT

PLANNED INSTRUCTION

A PLANNED COURSE FOR:

Engineering 3: Digital Electronics

Grade: 11 &12

Date of Board Approval: 2011

DELAWARE VALLEY SCHOOL DISTRICT

PLANNED INSTRUCTION

Title of Planned Instruction: **Engineering 3: Digital Electronics**

Subject Area: Engineering **Grade Level:** 11 &12

Course Description: Students use computer simulations to learn about the logic of electronics as they design, test, and actually construct circuits and devices.

Time/Credit for the Course: 2 semesters, 1Credit

Curriculum Writing Committee: Steve Rhule

PROJECT LEAD THE WAY

PLTW

Digital Electronics

2010

Project Lead The Way, Inc.
Clifton Park, NY

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Introduction – Digital Electronics Course

This file is intended to be a complete teaching curriculum, not just a guide or an outline. The curriculum is composed of units, which contain lessons and activities. The teacher guidelines and resource materials are integrated, via links, into the curriculum to make it easier for teachers to have access to the teaching tools needed to implement the course.

Each Unit begins with a Purpose, a listing of Concepts, Essential Questions, and Lessons for the Unit with a recommendation for Unit Evaluations. The Concepts are the broad learning objectives for the unit. The intent of the Essential Questions, in combination with the Purpose of each lesson that is an anticipatory set, is to create a framework for teachers and students to focus student learning. Course specific projects can be developed by the students to solve problems posed by the questions. The Concepts and Essential Questions along with the anticipatory set should be communicated to the students at the beginning of every Unit to establish the focus of the unit's learning objectives.

Each Unit is composed of lessons. Included in the Lessons are the Concepts specific to each Lesson; a listing of technology, science, mathematics, and English language arts national standards; Performance Objectives aligned with the national standards; Assessment suggestions; Essential questions aligned with the Concepts; Key Terms; a Day-by-Day Lesson plan; and a listing of instructional resources to aid instruction. Each of these components is clearly discussed and described in the **Lesson Template** and **Activities, Projects, Problems Template** found in the Course Implementation Suggestions section. Each Lesson is to begin with the instructor presenting the Lesson's Purpose and Essential Questions to the students for them to think about and to develop solutions to, by the end of the Lesson. These questions are repeated for students at the end of an activity that is designed to help students focus their thoughts, learn skills, and apply those skills to solve problems, a key tenet of project-based learning.

This curriculum is designed to be taught to high school students within a *typical* high school schedule. This means that a class which meets each day for 45 minutes, 175 days a year should be able to cover the content of this course. Some minor adjustments will need to be made by those schools that teach under a *double block* system. For the most part, this will simply entail combining two *days* worth of activities into one.

Teacher Resources

The Teacher Resources provide links to several useful documents in the Digital Electronics™ course.

Course Overview – contains documents with instructions for teachers for the implementation of the course.

Course Description	htm	doc
Detailed Outline	htm	doc
Topical Outline	htm	doc
Key Terms Glossary	htm	doc

Teacher Resources – contains documents with instructions for teachers for the implementation of the Digital Electronics™ course.

Lesson 1.1 Teacher Notes	htm	doc
Lesson 1.2 Teacher Notes	htm	doc
Lesson 1.3 Teacher Notes	htm	doc
Lesson 2.1 Teacher Notes	htm	doc
Lesson 2.2 Teacher Notes	htm	doc
Lesson 2.3 Teacher Notes	htm	doc
Lesson 2.4 Teacher Notes	htm	doc
Lesson 2.5 Teacher Notes	htm	doc
Lesson 3.1 Teacher Notes	htm	doc
Lesson 3.2 Teacher Notes	htm	doc
Lesson 3.3 Teacher Notes	htm	doc
Lesson 3.4 Teacher Notes	htm	doc
Lesson 4.1 Teacher Notes	htm	doc
Lesson 4.2 Teacher Notes	htm	doc
Lesson 4.3 Teacher Notes	htm	doc
Circuit Design Software Files		zip
Reading Across the Curriculum	htm	doc
Writing Across the Curriculum	htm	doc

Student Resources – contains documents students use throughout the course.

Engineering Abbreviations and Symbols	htm	doc

Citations APA Styles	**htm**	**doc**
DE Equations and Theorems	**htm**	**doc**
Example Design Process	**htm**	**doc**
Presentation Rationale	**htm**	**doc**
Sample Engineers Notebook Entry	**htm**	**doc**
Written Report Format	**htm**	**doc**
Isometric Paper Graph		**pdf**
Orthographic Paper Graph		**pdf**

Assessment - contains documents to provide helpful information for implementing authentic assessment and clarity on expectations for the course.

Assessment Methods	**htm**	**doc**
Assessment Overview	**htm**	**doc**
How to Create a Rubric	**htm**	**doc**
Generic Rubric Presentation	**htm**	**doc**
Project Assessment	**htm**	**doc**
Written Report Rubric	**htm**	**doc**

PLTW® Curriculum Support Materials – contains documents that explain project-based learning, how to read and use the lessons, activities, projects, problems and rubrics for use in the course.

Project Lead The Way® APPB-Learning	**htm**	**doc**
Major Concepts and ABET	**htm**	**doc**
Lesson Template Instructions	**htm**	**doc**
Activities, Projects, and Problems Template Instructions	**htm**	**doc**

National Standards – contains complete listings of Standards for Technological Literacy, National Science Education Standards, Principles and Standards for School Mathematics, and Standards for the English Language Arts. In addition, a matrix of each of the national standards is provided to show how each standard is addressed in the course.

National Science Education Standards Listing	**htm**	**doc**
Principles and Standards for School Mathematics Listing	**htm**	**doc**
Standards for the English Language Arts Listing	**htm**	**doc**
Standards for Technological Literacy Listing	**htm**	**doc**
National Science Education Standards Matrix		**doc**
Principles and Standards for School Mathematics Matrix		**doc**
Standards for the English Language Arts Matrix		**doc**

Standards for Technological Literacy Matrix		**doc**

Unit 1 – Fundamentals of Analog and Digital Electronics

Preface

This unit begins with the students creating the Board Game Counter. In the first lesson students learn classroom/laboratory safety guidelines, scientific and engineering notations, component identification, and proper soldering techniques. In the second lesson students use the Board Game Counter to expand their understanding of digital electronics, including the basics of circuit theory, circuit simulation and Breadboarding, and an overview of analog and digital signal characteristics. In the final lesson students use the Board Game Counter to learn basic combinational and sequential logic.

Lesson Documents

Lesson 1.1: Foundations and the Board Game Counter
Lesson 1.2: Introduction to Analog
Lesson 1.3: Introduction to Digital Electronics

Concepts

1. Safety is an important concept that must be considered for the safety of the individual, class, and overall environment of the classroom/laboratory.
2. Electricity, even at the nominal levels used in this curriculum, can cause bodily harm or even death.
3. Engineers and technicians use scientific notation, engineering notation, and Systems International (SI) notation to conveniently write very large or very small numbers frequently encountered when working with electronics.
4. Manufacturers of resistors and capacitors use an accepted industry standard to label the nominal value of resistors and capacitors.
5. Soldering is the process of joining two metal surfaces together to form an electrical connection. Soldering is used extensively in the assembly of electronic components.
6. The ability to properly solder electronic components and recognition of improper solder connections is an important skill for engineers and technicians.
7. Analog and digital signals have different waveforms with distinctive characteristics.
8. Digital signals have two well-defined voltage levels, one for a logic high and one for a logic low.
9. Analog signals have an infinite number of voltage levels that vary continuously over the voltage range for that particular system.
10. The atomic structure of a material determines whether it is a conductor, an insulator, or a semiconductor.
11. An understanding of the basics of electricity requires the understanding of three fundamental

concepts of voltage, current, and resistance

12. Engineers and technicians use Circuit Design Software as a tool to verify functionality of their analog and digital designs.
13. The manufacturer datasheet contains a logic gate's general description, connection diagram, and function table.
14. Integrated circuits are categorized by their underlying circuitry, scale of integration, and packaging style.
15. Transistor-Transistor Logic (TTL) gates are available in a series of sub-families, each having their own advantages and disadvantages related to speed and power.
16. Logic gates are depicted by their schematic symbol, logic expression, and truth table.
17. The output of combinational logic is a function solely of the present input values.
18. The output of sequential logic is a function of the current input values as well as previous output values.
19. Combinational logic designs implemented with AND gates, OR gates, and INVERTER gates are referred to as AOI designs.
20. The flip-flop is the fundamental building block of sequential logic.
21. The ability to troubleshoot electronic circuits is an important skill for engineers and technicians.

Essential Questions

Lesson 1.1: Foundations and the Board Game Counter

1. Why is safety of the utmost importance when working with electricity or electronics?
2. What level of electrical current is safe for the human body? What level of electrical current can kill a human? What are the factors that affect the level of harm (i.e., slight pain to death) that electrical current can cause the human body?
3. 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?
4. What is the resistor color code, and how is it used to identify and select resistors?
5. What is the labeling nomenclature for capacitors, and how is it used to identify and select capacitors?
6. What is the process for properly soldering and de-soldering electronic components from a printed circuit board?
7. What are the characteristics of a good solder connection? What are the most common soldering mistakes and how are they identified?

Lesson 1.2: Introduction to Analog

1. What are the characteristics of analog and digital signals?
2. What are the voltage levels associated with digital signals?
3. What is the voltage range of an analog signal?
4. What determines whether a material is a conductor, an insulator, or a semiconductor?
5. An understanding of basic electricity requires the understanding of what three fundamental concepts?

6. What is the relationship between voltage, current, and resistance in an electrical circuit?
7. What is true about the sum of all voltages around a closed path in an electrical circuit?
8. What is a breadboard, and what is it used for?
9. What function does a Circuit Design Software serve when designing analog and digital circuit?

Lesson 1.3: Introduction to Digital Electronics

1. What information is contained in a manufacturer datasheet for logic gates?
2. What are the three characteristics that categorize integrated circuits?
3. What are the available Transistor-Transistor Logic sub-families?
4. What are the three ways to depict any logic gate?
5. What are the outputs of combinational logic a function of?
6. What is AOI logic?
7. What are the outputs of sequential logic a function of?
8. What is the fundamental building block of sequential logic?
9. What are the steps for troubleshooting digital electronics circuits?

Unit Evaluation

The Essential Questions and Conclusion questions at the end of each activity may be used along with the Assessment suggestions provided in each lesson to develop summative assessment tools, such as tests or end of unit projects.

Lesson 1.1 Foundations and the Board Game Counter

Preface

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.

Board Game Counter

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.

Concepts

1. Safety is an important concept that must be considered for the safety of the individual, class, and overall environment of the classroom/laboratory.

2. Electricity, even at the nominal levels used in this curriculum, can cause bodily harm or even death.

3. Engineers and technicians use scientific notation, engineering notation, and Systems International (SI) notation to conveniently write very large or very small numbers frequently encountered when working with electronics.

4. Manufacturers of resistors and capacitors use an accepted industry standard to label the nominal value of resistors and capacitors.

5. Soldering is the process of joining two metal surfaces together to form an electrical connection. Soldering is used extensively in the assembly of electronic components.

6. The ability to properly solder electronic components and recognition of improper solder connections is an important skill for engineers and technicians.

Standards and Benchmarks Addressed

Standards for Technological Literacy

Standard 1: Students will develop an understanding of the characteristics and scope of technology.

BM K: The rate of technological development and diffusion is increasing rapidly.

BM L: Inventions and innovations are the results of specific, goal-directed research.

Standard 2: Students will develop an understanding of the core concepts of technology.

BM Y: The stability of a technological system is influenced by all of the components in the system especially those in the feedback loop.

Standard 3: Students will develop an understanding of the relationships among technologies and the connections between technology and other fields of study.

BM G: Technology transfer occurs when a new user applies an existing innovation developed for one purpose in a different function

BM H: Technological innovation often results when ideas, knowledge, or skills are shared within a technology, among technologies, or across other fields.

BM J: Technological progress promotes the advancement of science and mathematics. Likewise, progress in science and mathematics leads to advances in technology.

Standard 5: Students will develop an understanding of the effects of technology on the environment.

BM H: When new technologies are developed to reduce the use of resources, considerations of trade-offs are important.

BM K: Humans devise technologies to reduce the negative consequences of other technologies.

Standard 9: Students will develop an understanding of engineering design.

BM K: A prototype is a working model used to test a design concept by making actual observations and necessary adjustments.

Standard 12: Students will develop the abilities to use and maintain technological products and systems.

BM L: Document processes and procedures and communicate them to different audiences using appropriate oral and written techniques.

BM M: Diagnose a system that is malfunctioning and use tools, materials, machines, and knowledge to repair it.

BM N: Troubleshoot, analyze, and maintain systems to ensure safe and proper function and precision.

BM O: Operate systems so that they function in the way they were designed.

Standard 17: Students will develop an understanding of and be able to select and use information and communication technologies.

BM O: Communication systems are made up of source, encoder, transmitter, receiver, decoder, storage, retrieval, and destination.

National Science Education Standards

Standard K-12: Unifying Concepts and Processes: As a result of activities in grades K-12, all students should develop understanding and abilities aligned with the following concepts and processes;

- Form and function
- Evidence, models, and explanation

Principles and Standards for School Mathematics

Number and Operations: Instructional programs from pre-kindergarten through grade 12 should enable all students to; understand numbers, ways of representing numbers, relationships among numbers, and number systems; understand meanings of operations and how they relate to one another; compute fluently and make reasonable estimates.

Algebra: Instructional programs from pre-kindergarten through grade 12 should enable all students to; understand patterns, relations, and functions; represent and analyze mathematical situations and structures using algebraic symbols;
use mathematical models to represent and understand quantitative relationships; analyze change in various contexts.

Data Analysis and Probability: Instructional programs from pre-kindergarten through grade 12 should enable all students to; formulate questions that can be addressed with data and collect, organize, and display relevant data to answer them; select and use appropriate statistical methods to analyze data; develop and evaluate inferences and predictions that are based on data; understand and apply basic concepts of probability.

Standards for English Language Arts

Standard 4: Students adjust their use of spoken, written, and visual language (e.g. conventions, style, vocabulary) to communicate effectively with a variety of audiences and for different purposes.

Standard 12: Students use spoken, written and visual language to accomplish their own purposes (e.g. for learning, enjoyment, persuasion, and the exchange of information).

Performance Objectives

It is expected that students will:

- Know and practice proper safety while working with electronics.
- Be able to express numbers in scientific notation, engineering notation, and System International (SI) notation.
- Identify many of the common components used in electronics.
- Be able to determine a resistor's nominal value by reading its color code.
- Be able to determine a resistor's actual value by reading its resistance with a Digital Multimeter (DMM).
- Be able to determine a capacitor's nominal value by reading its labeled nomenclature.
- Be able to properly tin the tip of a soldering iron.
- Use proper soldering/de-soldering techniques to solder and de-solder components on a printed circuit boards.

Assessment

Explanation

- How will the knowledge about soldering aid you in designing a circuit?

Interpretation

- Using the Key Terms of the lesson, students will write an essay explaining their understanding of how a digital circuit works.
- Students will explain to a third grader the importance of following safety protocols when working with electricity.

Application

- Demonstrate to an adult an alternative method of remembering the color code on a resistor.

Essential Questions

1. Why is safety of the utmost importance when working with electricity or electronics?
2. What level of electrical current is safe for the human body? What level of electrical current can kill a human? What are the factors that affect the level of harm (i.e., slight pain to death) that electrical current can cause the human body?
3. 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?
4. What is the resistor color code, and how is it used to identify and select resistors?
5. What is the labeling nomenclature for capacitors, and how is it used to identify and select capacitors?
6. What is the process for properly soldering and de-soldering electronic components from a printed circuit board?
7. What are the characteristics of a good solder connection? What are the most common soldering mistakes and how are they identified?

Key Terms

Capacitor	An electrical device used to store electrical charge.
Cold Solder Joint	A solder connection that exhibits poor wetting and is characterized by a grayish, porous appearance due to excessive impurities in the solder, inadequate cleaning prior to soldering, and/or the insufficient application of heat during the soldering process.
Digital Multimeter	Electronic test equipment that can perform multiple tasks. Typically one capable of measuring voltage, current, and resistance. More sophisticated modern digital multimeters also measure capacitance, inductance, current gain of transistors, and/or anything else that can be measured electronically.
Diode	A two terminal device that conducts in only one direction.
Dual In-Line Package (DIP)	A very common IC package with two parallel rows of pins intended to be inserted into a socket of through holes drilled in a printed circuit board.
Engineering Notation	A floating point system in which numbers are expressed as products consisting of a number greater than one multiplied by an appropriate power of ten that is some multiple of three.
Fuse	A protective device in the current path that melts or breaks when current exceeds a predetermined maximum value.
LED	Light-emitting diode. An electronic device that conducts current in one direction only and illuminates when it is conducting.
Plastic Leaded Chip Carrier (PLCC)	A square IC package with leads on all four sides designed for surface mounting on a circuit board.
Printed Circuit Board	Insulating board containing conductive tracks for circuit connections.
Resistor	Component made of material that opposes flow of current and therefore has some value of resistance.

Resistor Color Code	Coding system of colored stripes on a resistor to indicate the resistor's value and tolerance.
Scientific Notation	Numbers entered as a number from one to ten multiplied by a power of ten.
SI Notation	Abbreviation of System International, a system of practical units based on the meter, kilogram, second, ampere, Kelvin, mole, and candela.
Seven-Segment Display	An array of seven independently controlled light-emitting diodes (LED) or liquid crystal display (LCD) elements, shaped like a figure-8, which can be used to display decimal digits and other characters by turning on the appropriate elements.
Small Outline IC (SOIC)	An IC package similar to a DIP, but smaller, which is designed for automatic placement and soldering on the surface of a circuit board.
Solder	Metallic alloy of tin and lead that is used to join two metal surfaces.
Solder Bridge	The unwanted formation of a conductive path of solder between conductors.
Soldering	Process of joining two metallic surfaces to make an electrical contact by melting solder (usually tin and lead) across them.
Soldering Iron	Tool with an internal heating element used to heat surfaces being soldered to the point where the solder becomes molten.
Tinning	The process of applying a thin coat of solder to materials prior to their being soldered; for example, application of a light coat of solder to the filaments of a conductor to hold the filaments in place prior to soldering the conductor.
Transistor	Term derived from "transfer resistor." Semiconductor device that can be used as an amplifier or as an electronic switch.

Day-by-Day Plans

Time: 9 days

NOTE: In preparation for teaching, it is strongly recommended that the teacher read the **Lesson 1.1 Teacher Notes.**

Day 1: Course Overview

- Students will participate in a teacher-led discussion on electronic products that they use daily and what their lives would be like without such products. As part of this discussion, have each student mentally walk through their day and list all of the electronics products that they use regularly.

- The teacher will present an overview of the PLTW™ Digital Electronics™ course, the make-up of its four units, and what skills they will possess after they have completed the course. To help facilitate this overview, it is imperative that completed examples of each of the units' major projects and/or problems are available for the students to examine.

- The teacher will distribute an engineer's notebook to each student.

- **Note:** The teacher will determine whether students will record their notes in a daily journal, portfolio, or their engineer's notebook. For purposes of written directions in the day-by-day plans for each lesson, it will be assumed that students will record their notes in a journal. The journal may be a three-ring binder, spiral bound notebook, or electronic.

Day 2: Lesson Overview and General Safety

- The teacher will present **Concepts**, **Essential Questions**, and **Key Terms** in order to provide a lesson overview.

- The teacher will present **General Safety.ppt**

- Students will take notes in their engineering journals.

- The teacher will distribute and introduce **Activity 1.1.1 General Safety Quiz**.

- Students will work on Activity 1.1.1 General Safety Quiz.

- Using **Activity 1.1.1 General Safety Quiz Answer Key** as a guide, the teacher will review the answers to the General Safety Quiz with the class.

- **Optional:** After the key terms have been introduced, the teacher may choose to distribute **Lesson 1.1 Key Term Crossword** for homework.

Day 3: Scientific & Engineering Notation

- The teacher will present **Scientific & Engineering Notation.ppt**

- Students will take notes in their engineering journals.

- The teacher will distribute and introduce **Activity 1.1.2 Scientific & Engineering Notation.**
- Students will work on Activity 1.1.2 Scientific & Engineering Notation.
- The teacher will assess student work using **Activity 1.1.2 Scientific & Engineering Notation Quiz Answer Key.**

Day 4: Component Identifications

- The teacher will present **Component Identification.ppt**
- Students will take notes in their engineering journals.
- The teacher will distribute and introduce **Activity 1.1.3 Component Identification.**
- Students will work on Activity 1.1.3 Component Identification.
- The teacher will assess student work using **Activity 1.1.3 Component Identification Quiz Answer Key.**

Day 5 – 7: Solder and De-Soldering

- The teacher will present **Soldering & De-Soldering.ppt**
- Students will take notes in their engineering journals.
- The teacher will distribute and introduce **Activity 1.1.4 Solder & De-Soldering Practice** as well as the *Solder Practice Board Kits*.
- Students will work on Activity 1.1.4 Solder & De-Soldering Practice.
- The teacher will assist students as needed.

Day 8 – 9: Board Game Counter & Lesson Review

- The teacher will present **Board Game Counter.ppt**
- Students will take notes in their engineering journals.
- The teacher will distribute and introduce **Project 1.1.5 Board Game Counter** as well as the *Board Game Counter Kits*.
- Students will work on Project 1.1.5 Board Game Counter.
- The teacher will assist students as needed.
- The teacher will review the lesson's **Essential Questions**.
- Students will work in small groups (2-4) to answer the lesson's essential questions. Each group will be assigned one essential question that they must discuss, formulate a response for, and present to the class. The

intent of this activity is to give closure to the lesson's topics and to have the students reflect back on the underlying concepts covered in the lesson's activities, projects, and problems.

- Students will take notes in their engineering journals.

Instructional Resources

Presentations

General Safety

Scientific & Engineering Notation

Component Identification

Soldering & De-Soldering

Board Game Counter

Word Documents

Lesson 1.1 Key Term Crossword

Activity 1.1.1 General Safety Quiz

Activity 1.1.2 Scientific & Engineering Notation

Activity 1.1.3 Component Identification

Activity 1.1.4 Solder & De-Soldering Practice

Project 1.1.5 Board Game Counter

Answer Keys and Rubrics

Lesson 1.1 Key Term Crossword Answer Key

Activity 1.1.1 General Safety Quiz Answer Key

Activity 1.1.2 Scientific & Engineering Notation Quiz Answer Key

Activity 1.1.3 Component Identification Quiz Answer Key

Teacher Guidelines

Lesson 1.1 Teacher Notes

Reference Sources

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Lesson 1.2 Introduction to Analog

Preface

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.

Concepts

1. Analog and digital signals have different waveforms with distinctive characteristics.
2. Digital signals have two well-defined voltage levels, one for a logic high and one for a logic low.
3. Analog signals have an infinite number of voltage levels that vary continuously over the voltage range for that particular system.
4. The atomic structure of a material determines whether it is a conductor, an insulator, or a semiconductor.
5. An understanding of the basics of electricity requires the understanding of three fundamental concepts of voltage, current, and resistance
6. Engineers and technicians use Circuit Design Software as a tool to verify functionality of their analog and digital designs.

Standards and Benchmarks Addressed

Standards for Technological Literacy

Standard 1: Students will develop an understanding of the characteristics and scope of technology.

BM J: The nature and development of technological knowledge and processes are functions of the setting.

BM K: The rate of technological development and diffusion is increasing rapidly.

Standard 2: Students will develop an understanding of the core concepts of technology.

- **BM X:** Systems, which are the building blocks of technology, are embedded within larger technological, social, and environmental systems.
- **BM Y:** The stability of a technological system is influenced by all of the components in the system especially those in the feedback loop.
- **BM CC:** New technologies create new processes.

Standard 3: Students will develop an understanding of the relationships among technologies and the connections between technology and other fields of study.

- **BM H:** Technological innovation often results when ideas, knowledge, or skills are shared within a technology, among technologies, or across other fields.
- **BM J:** Technological progress promotes the advancement of science and mathematics. Likewise, progress in science and mathematics leads to advances in technology.

Standard 4: Students will develop an understanding of the cultural, social, economic, and political effects of technology.

- **BM H:** Changes caused by the use of technology can range from gradual to rapid and from subtle to obvious.
- **BM I:** Making decisions about the use of technology involves weighing the trade-offs between the positive and negative effects.
- **BM J:** Ethical considerations are important in the development, selection, and use of technologies.

Standard 7: Students will develop an understanding of the influence of technology on history.

- **BM G:** Most technological development has been evolutionary, the result of a series of refinements to a basic invention.
- **BM H:** The evolution of civilization has been directly affected by, and has in turn affected, the development and use of tools and materials.
- **BM I:** Throughout history, technology has been a powerful force in reshaping the social, cultural, political, and economic landscape.
- **BM J:** Early in the history of technology, the development of many tools and machines was based not on scientific knowledge but on technological know-how.

Standard 12: Students will develop the abilities to use and maintain technological products and systems.

- **BM L:** Document processes and procedures and communicate them to different audiences using appropriate oral and written techniques.
- **BM O:** Operate systems so that they function in the way they were designed.
- **BM P:** Use computers and calculators to access, retrieve, organize and process, maintain, interpret, and evaluate data and information in order to communicate.

Standard 16: Students will develop an understanding of and be able to select and use energy and power technologies.

- **BM J:** Energy cannot be created or destroyed; however, it can be converted from one form to another.
- **BM K:** Energy can be grouped into major forms: thermal, radiant, electrical, mechanical, chemical, nuclear, and others.
- **BM M:** Energy resources can be renewable or nonrenewable.
- **BM N:** Power systems must have a source of energy, a process, and loads.

Standard 17: Students will develop an understanding of and be able to select and use information and communication technologies.

BM L:	Information and communication technologies include the inputs, processes, and outputs associated with sending and receiving information.
BM M:	Information and communication systems allow information to be transferred from human to human, human to machine, machine to human, and machine to machine.
BM N:	Information and communication systems can be used to inform, persuade, entertain, control, manage, and educate.
BM O:	Communication systems are made up of source, encoder, transmitter, receiver, decoder, storage, retrieval, and destination.
BM P:	There are many ways to communicate information, such as graphic and electronic means.
BM Q:	Technological knowledge and processes are communicated using symbols, measurement, conventions, icons, graphic images, and languages that incorporate a variety of visual, auditory, and tactile stimuli.

National Science Education Standards

Standard K-12: Unifying Concepts and Processes: As a result of activities in grades K-12, all students should develop understanding and abilities aligned with the following concepts and processes;

- Systems, order, and organization
- Form and function

Standard B: Physical Science: As a result of activities in grades 9-12, all students should develop an understanding of;

- Structure of atoms
- Structure and properties of matter
- Chemical reactions
- Motions and forces
- Interactions of energy and matter

Standard E: Science and Technology: As a result of activities in grades 9-12, all students should develop

- Understandings about science and technology

Standard F: Science in Personal and Social Perspectives: As a result of activities in grades 9-12, all students should develop understanding of;

- Natural resources
- Environmental quality
- Natural and human-induced hazards
- Science and technology in local, national, and global challenges

Standard G: History and Nature of Science: As a result of activities in grades 9-12, all students should develop understanding of;

- Historical perspectives

Principles and Standards for School Mathematics

Number and	Instructional programs from pre-kindergarten through

Operations:	grade 12 should enable all students to; understand numbers, ways of representing numbers, relationships among numbers, and number systems; understand meanings of operations and how they relate to one another; compute fluently and make reasonable estimates.
Algebra:	Instructional programs from pre-kindergarten through grade 12 should enable all students to; understand patterns, relations, and functions; represent and analyze mathematical situations and structures using algebraic symbols; use mathematical models to represent and understand quantitative relationships; analyze change in various contexts.
Measurement:	Instructional programs from pre-kindergarten through grade 12 should enable all students to; understand measurable attributes of objects and the units, systems, and processes of measurement; apply appropriate techniques, tools, and formulas to determine measurements.
Data Analysis and Probability:	Instructional programs from pre-kindergarten through grade 12 should enable all students to; formulate questions that can be addressed with data and collect, organize, and display relevant data to answer them; select and use appropriate statistical methods to analyze data; develop and evaluate inferences and predictions that are based on data; understand and apply basic concepts of probability.
Communication:	Instructional programs from pre-kindergarten through grade 12 should enable all students to; organize and consolidate their mathematical thinking through communication; communicate their mathematical thinking coherently and clearly to peers, teachers, and others; analyze and evaluate the mathematical thinking and strategies of others; use the language of mathematics to express mathematical ideas precisely.
Connections:	Instructional programs from pre-kindergarten through grade 12 should enable all students to; recognize and use connections among mathematical ideas; understand how mathematical ideas interconnect and build on one another to produce a coherent whole; recognize and apply mathematics in contexts outside of mathematics.
Representation:	Instructional programs from pre-kindergarten through grade 12 should enable all students to; create and use representations to organize, record, and communicate mathematical ideas; select, apply, and translate among mathematical representations to solve problems; use representations to model and interpret physical, social, and mathematical phenomena.

Standards for English Language Arts

Standard 2:	Students read a wide range of literature from many periods in many genres to build an understanding of the many dimensions (e.g. philosophical, ethical, aesthetic) of human experience
Standard 4:	Students adjust their use of spoken, written, and visual language (e.g. conventions, style, vocabulary) to communicate

effectively with a variety of audiences and for different purposes.

Performance Objectives

It is expected that students will:

- Be able to identify the parts of an atom and determine if an element would make a good conductor, insulator, or semiconductor.
- Use Ohm's Law, Kirchhoff's Voltage Law, and Kirchhoff's Current Law to solve for simple series and parallel circuit.
- Be able to use a Circuit Design Software to analyze simple analog circuits.
- Be able to use a breadboard and digital multimeter to analyze simple analog circuits.
- Be able to determine the amplitude, period, frequency, and duty cycle analog and digital signals.
- Be able to analyze and design simple digital oscillators using the 555 Timer chip.
- Utilize the Circuit Design Software (CDS) to simulate and test a complete analog design.

Assessment

Explanation

- Students will demonstrate and explain to another student the parts of an atom and how it works.

Application

- Assess a student's engineering notebook for evidence of effective communication of ideas such as,

    a. Do students' sketches and drawings clearly communicate their ideas?
    b. Have students used a variety of methods to communicate their ideas?
    c. Have students integrated information from a variety of sources into their work?

Perspective

- Students will select a common household product they use everyday and prepare a one page essay that expresses two points of view about what role electronics has on the operating of the product.

Essential Questions

1. What are the characteristics of analog and digital signals?
2. What are the voltage levels associated with digital signals?
3. What is the voltage range of an analog signal?
4. What determines whether a material is a conductor, an insulator, or a semiconductor?
5. An understanding of basic electricity requires the understanding of what three fundamental concepts?

6. What is the relationship between voltage, current, and resistance in an electrical circuit?
7. What is true about the sum of all voltages around a closed path in an electrical circuit?
8. What is a breadboard, and what is it used for?
9. What function does a Circuit Design Software serve when designing analog and digital circuit?

Key Terms

Analog	A way of representing some physical quantity, such as temperature or velocity, by a proportional continuous voltage or current. An analog voltage or current can have any value within a defined range.
Amplitude	The instantaneous voltage of a waveform. Often used to mean maximum amplitude, or peak voltage, or a pulse.
Atom	The smallest particle of an element that still has the same characteristics as the element.
Breadboard	A circuit board for wiring temporary circuits, usually used for prototypes or laboratory work.
Conductor	Any material that allows the free movement of electric changes, such as electrons, to provide an electric current.
Conventional Current	The direction of current flow associated with positive charge in motion. The current flow direction is from a positive to negative potential, which is in the opposite direction of electron flow.
Clock	Digital signal in the form of a rectangular pulse train or a square wave.
Current	A movement of electrical charges around a closed path or circuit.
Digital	A way of representing a physical quantity by a series of binary numbers. A digital representation can have only specific discrete values.
Digital Waveform	A series of logic 1s and 0s plotted as a function of time.
Digital Multi-Meter (DMM)	A piece of test equipment used to measure voltage, current, and resistance in an electronic circuit.
Duty Cycle (DC)	Fraction of the total period that a digital waveform is in the HIGH state. $DC = t_h/T$ (often expressed as a percentage: $\% DC = t_h/T \times 100\%$).
Electron	Basic particle of negative charge in orbit; around the nucleus in an atom.
Electron Flow	Current of negative charges in motion. Direction is from the negative terminal of the voltage source, through the external, circuit, and returning to the positive side of the source. Opposite to the direction of conventional current.
Falling Edge	The part of a pulse where the logic level is in transition from a HIGH to a LOW.
Frequency	The number of cycles per unit time of a periodic waveform.
Hertz (Hz)	Unit of frequency. One hertz equals one cycle per second.
Insulator	A material that does not allow current to flow when voltage is applied because of its high resistance.

Kirchhoff's Current Law (KCL)	The algebraic sum of all currents into and out of any branch point in a circuit must equal zero.
Kirchhoff's Voltage Law (KVL)	The algebraic sum of all voltages around any closed path must equal zero.
Logic HIGH	The higher of two voltages in a digital system with two logic levels.
Logic LOW	The lower of two voltages in a digital system with two logic levels.
Nucleus	The massive, stable part of the atom that contains both protons and neutrons.
Ohms	Unit of resistance. Value of one ohm allow current of one ampere with potential difference of one volt.
Ohm's Law	In electric circuits, I=V/R.
Oscilloscope	A piece of test equipment used to view and measure a variety of different waveforms.
Parallel Circuit	One that has two or more branches for separate current from one voltage source.
Period	The amount of time required for one complete cycle of a periodic event or waveform.
Proton	Particle with positive charge in the nucleus of an atom.
Simulation	Testing design function by specifying a set of inputs and observing the resultant outputs. Simulation is generally shown as a series of input and output waveforms.
Resistance	Opposition to current. Unit is the ohm.
Series Circuit	One that has only one path current.
Sine Wave	One in which amplitude varies in proportion to the sine function of an angle.
Square Wave	An almost instantaneous rise and decay of voltage or current in a periodic pattern with time and with a constant peak value.
555 Timer	TTL-compatible IC that can be wired to operate in several different modes, such as a one-shot and an astable multivibrator.

Day-by-Day Plans

Time: 11 days

NOTE: In preparation for teaching, it is strongly recommended that the teacher read the **Lesson 1.2 Teacher Notes.** All Circuit Design Software (CDS) files for this lesson can be found in the **CDS Files** folder.

Day 1: Lesson Overview and Electron Theory

- The teacher will present **Concepts**, **Essential Questions**, and **Key Terms** in order to provide a lesson overview.
- The teacher will present **Basic Electron Theory.ppt**
- Students will take notes in their engineering journals.
- The teacher will distribute and introduce **Activity 1.2.1 Electron Theory**.

- Students will work on Activity 1.2.1 Electron Theory.
- The teacher will assess student work using **Activity 1.2.1 Electron Theory Answer Key.**
- Optional: After the key terms have been introduced, the teacher may choose to distribute **Lesson 1.2 Key Term Crossword** for homework.

Day 2 – 3: Circuit Theory Laws

- The teacher will present **Circuit Theory Laws.ppt**
- Students will take notes in their engineering journals.
- The teacher will distribute and introduce **Activity 1.2.2 Circuit Theory – Hand Calculations.**
- Students will work on Activity 1.2.2 Circuit Theory – Hand Calculations.
- The teacher will assist the students as needed.
- The teacher will assess student work using **Activity 1.2.2 Circuit Theory – Hand Calculations Answer Key.**

Day 4 – 5: Introduction to the Circuit Design Software (CDS)

- The teacher will introduce the Circuit Design Software and will demonstrate how to use the feature tools needed to complete this activity.
- Students will take notes in their engineering journals.
- The teacher will distribute and introduce **Activity 1.2.3 Circuit Theory – Simulation.**
- Students will work on Activity 1.2.3 Circuit Theory – Simulation.
- The teacher will assist the students as needed.
- The teacher will assess student work using **Activity 1.2.3 Circuit Theory – Simulation Answer Key.**

Day 6 – 7: Breadboarding

- The teacher will present **Breadboard.ppt**
- The teacher will introduce the digital multimeter (DMM) and will demonstrate how to use the meter to make voltage and current measurements.
- Students will take notes in their engineering journals.
- The teacher will distribute and introduce **Activity 1.2.4 Circuit Theory – Breadboarding.**
- Students will work on Activity 1.2.4 Circuit Theory – Breadboarding.

- The teacher will assist the students as needed.

Day 8: Analog and Digital Signals

- The teacher will present **Analog and Digital Signals.ppt**
- Students will take notes in their engineering journals.
- The teacher will distribute and introduce **Activity 1.2.5 Analog and Digital Signals.**
- Students will work on Activity 1.2.5 Analog and Digital Signals.
- The teacher will assist the students as needed.
- The teacher will assess student work using **Activity 1.2.5 Analog and Digital Signals Answer Key.**

Day 9: 555 Timer

- The teacher will present **555 TImer.ppt**
- Students will take notes in their engineering journals.
- The teacher will distribute and introduce **Activity 1.2.6 555 Timer**.
- Students will work on Activity 1.2.6 555 Timer.
- The teacher will assist the students as needed.
- The teacher will assess student work using **Activity 1.2.6 555 Timer Answer Key.**

Day 10 – 11: Board Game Counter - Analog & Lesson Review

- The teacher will present **Board Game Counter - Analog.ppt**
- Students will take notes in their engineering journals.
- The teacher will distribute and introduce **Project 1.2.7 Board Game Counter - Analog.**
- Students will work on Project 1.2.7 Board Game Counter - Analog.
- The teacher will assist the students as needed.
- The teacher will assess student work using **Project 1.2.7 Board Game Counter - Analog Answer Key.**
- The teacher will review the lesson's **Essential Questions**.
- Students will work in small groups (2-4) to answer the lesson's essential questions. Each group will be assigned one essential question that they must discuss, formulate a response for, and present to the class. The

intent of this activity is to give closure to the lesson's topics and to have the students reflect back on the underlying concepts covered in the lesson's activities, projects, and problems.

- Students will take notes in their engineering journals.

Instructional Resources

Presentations

Electron Theory

Circuit Theory Laws

Breadboard

Analog and Digital Signals

555 Timer

Board Game Counter - Analog

Word Documents

Lesson 1.2 Key Term Crossword

Activity 1.2.1 Electron Theory

Activity 1.2.2 Circuit Theory – Hand Calculations

Activity 1.2.3 Circuit Theory – Simulation

Activity 1.2.4 Circuit Theory – Breadboarding

Activity 1.2.5 Analog and Digital Signals

Activity 1.2.6 555 Timer

Project 1.2.7 Board Game Counter - Analog

Answer Keys and Rubrics

Lesson 1.2 Key Term Crossword Answer Key

Activity 1.2.1 Electron Theory Answer Key

Activity 1.2.2 Circuit Theory – Hand Calculations Answer Key

Activity 1.2.3 Circuit Theory – Simulation Answer Key.

Activity 1.2.5 Analog and Digital Signals Answer Key.

Activity 1.2.6 555 Timer Answer Key.

Project 1.2.7 Board Game Counter - Analog Answer Key.

Teacher Guidelines

Lesson 1.2 Teacher Notes

Reference Sources

Dueck, R., & Reid, K. (2008). Introduction to digital electronics. Clifton Park , NY: Thompson Delmar Learning.

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Lesson 1.3 Introduction to Digital Electronics

Preface

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.

Concepts

1. The manufacturer datasheet contains a logic gate's general description, connection diagram, and function table.
2. Integrated circuits are categorized by their underlying circuitry, scale of integration, and packaging style.
3. Transistor-Transistor Logic (TTL) gates are available in a series of sub-families, each having their own advantages and disadvantages related to speed and power.
4. Logic gates are depicted by their schematic symbol, logic expression, and truth table.
5. The input and output values of combinational and sequential logic function differently.
6. Combinational logic designs implemented with AND gates, OR gates, and INVERTER gates are referred to as AOI designs.
7. The flip-flop is the fundamental building block of sequential logic.

Standards and Benchmarks Addressed

Standards for Technological Literacy

Standard 2: Students will develop an understanding of the core concepts of technology.

BM Y: The stability of a technological system is influenced by all of the components in the system especially those in the feedback loop.

BM AA: Requirements involve the identification of the criteria and constraints of a product or system and the determination of how they affect the final design and development.

BM FF: Complex systems have many layers of controls and feedback loops to provide information.

Standard 8: Students will develop an understanding of the attributes of design.

BM H: The design process includes defining a problem, brainstorming, researching and generating ideas, identifying criteria and specifying constraints, exploring possibilities, selecting an approach, developing a design proposal, making a model or prototype, testing and evaluating the design using specifications, refining the design, creating or making it, and communicating processes and results.

BM I: Design problems are seldom presented in a clearly defined form.

BM J: The design needs to be continually checked and critiqued, and the ideas of the design must be redefined and improved.

BM K: Requirements of a design, such as criteria, constraints, and efficiency, sometimes compete with each other.

Standard 10: Students will develop an understanding of the role of troubleshooting, research and development, invention and innovation, and experimentation in problem solving.

BM J: Technological problems must be researched before they can be solved.

BM L: Many technological problems require a multidisciplinary approach.

Standard 12: Students will develop the abilities to use and maintain technological products and systems.

BM L:	Document processes and procedures and communicate them to different audiences using appropriate oral and written techniques.
BM M:	Diagnose a system that is malfunctioning and use tools, materials, machines, and knowledge to repair it.
BM N:	Troubleshoot, analyze, and maintain systems to ensure safe and proper function and precision.
BM O:	Operate systems so that they function in the way they were designed.
BM P:	Use computers and calculators to access, retrieve, organize and process, maintain, interpret, and evaluate data and information in order to communicate.

Standard 17: Students will develop an understanding of and be able to select and use information and communication technologies.

BM L:	Information and communication technologies include the inputs, processes, and outputs associated with sending and receiving information.
BM M:	Information and communication systems allow information to be transferred from human to human, human to machine, machine to human, and machine to machine.
BM N:	Information and communication systems can be used to inform, persuade, entertain, control, manage, and educate.
BM O:	Communication systems are made up of source, encoder, transmitter, receiver, decoder, storage, retrieval, and destination.
BM P:	There are many ways to communicate information, such as graphic and electronic means.
BM Q:	Technological knowledge and processes are communicated using symbols, measurement, conventions, icons, graphic images, and languages that incorporate a variety of visual, auditory, and tactile stimuli.

National Science Education Standards

Standard K-12: Unifying Concepts and Processes: As a result of activities in grades K-12, all students should develop understanding and abilities aligned with the following concepts and processes;

- Systems, order, and organization
- Evidence, models, and explanation
- Change, constancy, and measurement

Principles and Standards for School Mathematics

Number and Operations:	Instructional programs from pre-kindergarten through grade 12 should enable all students to; understand numbers, ways of representing numbers, relationships among numbers, and number systems; understand meanings of operations and how they relate to one another; compute fluently and make reasonable estimates.
Algebra:	Instructional programs from pre-kindergarten through grade 12 should enable all students to; understand patterns, relations, and functions; represent and analyze mathematical situations and structures using algebraic symbols; use mathematical models to represent and understand

	quantitative relationships; analyze change in various contexts.
Problem Solving:	Instructional programs from pre-kindergarten through grade 12 should enable all students to; build new mathematical knowledge through problem solving; solve problems that arise in mathematics and in other contexts; apply and adapt a variety of appropriate strategies to solve problems; monitor and reflect on the process of mathematical problem solving.
Reasoning and Proof:	Instructional programs from pre-kindergarten through grade 12 should enable all students to; recognize reasoning and proof as fundamental aspects of mathematics; make and investigate mathematical conjectures; develop and evaluate mathematical arguments and proofs; select and use various types of reasoning and methods of proof.
Connections:	Instructional programs from pre-kindergarten through grade 12 should enable all students to; recognize and use connections among mathematical ideas; understand how mathematical ideas interconnect and build on one another to produce a coherent whole; recognize and apply mathematics in contexts outside of mathematics.
Representation:	Instructional programs from pre-kindergarten through grade 12 should enable all students to; create and use representations to organize, record, and communicate mathematical ideas; select, apply, and translate among mathematical representations to solve problems; use representations to model and interpret physical, social, and mathematical phenomena.

Standards for English Language Arts

Standard 12:	Students use spoken, written and visual language to accomplish their own purposes (e.g. for learning, enjoyment, persuasion, and the exchange of information).

Performance Objectives

It is expected that students will:

- Be able to obtain and extract information from the manufacturer datasheets for components commonly used in digital electronics.
- Know how to identify commonly used electronic components given their part number or schematic symbol.
- Be able to identify various integrated circuit (IC) package styles.
- Know the fundamental differences between combinational and sequential logic.
- Identify and describe the function of AND, OR, & Inverter gates.
- Be able to use Circuit Design Software (CDS) to simulate and test a simple combinational logic circuit designed with AND, OR, & Inverter gates.
- Identify and describe the function of a D flip-flop.

- Be able to use Circuit Design Software (CDS) to simulate and test a simple sequential logic circuit design with D flip-flops.

- Utilize the Circuit Design Software (CDS) to simulate and test a complete design containing both combinational and sequential logic.

Assessment

Application

- Students will analyze and interpret ways in which political, cultural, social, and psychological concepts are explored in the world of electronics.

Interpretation

- Students will explain the role of geometric shapes to the design of their puzzle cube.

Self-Knowledge

- Students will be required to reflect on their work in their journals by recording their thoughts and ideas. They may use their self-assessments as a basis for improvement. Ideas and questions students may pose and answer in their journals are:

- Today, the hardest part for me to understand was…
- When I work in a group, I find that…
- When I work by myself, I find that…
- What did I accomplish today?
- Now that I have done this, what is next?

Essential Questions

1. What information is contained in a manufacturer datasheet for logic gates?
2. What are the three characteristics that categorize integrated circuits?
3. What are the available Transistor-Transistor Logic sub-families?
4. What are the three ways to depict any logic gate?
5. What are the outputs of combinational logic a function of?
6. What is AOI logic?
7. What are the outputs of sequential logic a function of?
8. What is the fundamental building block of sequential logic?
9. What are the steps for troubleshooting digital electronics circuits?

Key Terms

AND Gate	Digital circuit that implements the AND operation. The output of this circuit is HIGH only if all of its inputs are HIGH.
Boolean Expression	An algebraic expression made up of Boolean variables and operators, such as AND (-), OR (+), or NOT (-). Also referred to as Boolean function or a logic function.
Clocked D Flip-Flop	Type of flip-flop in which the D (data) input is the synchronous input.
Combinational Logic	Digital circuitry in which an output is derived from the combination of inputs, independent of the order in which they are applied.
Datasheet	A printed specification giving details of the pin configuration, electrical properties, and mechanical profile of an electronic device.
Digital Waveform	A series of logic 1s and 0s plotted as a function of time.
Dual In-Line Package (DIP)	One style of integrated circuit package which has two rows of lead.
Flip-Flop	A sequential circuit based on a latch whose output changes when its CLOCK input receives a pulse.
Frequency	The number of cycles per unit time of a periodic waveform.
Integrated Circuit (IC)	An electronic circuit having many components, such as transistors, diodes, resistors, and capacitors, in a single package.
Inverter	Also called a NOT gate or an inverting buffer. A logic gate that changes its input logic level to the opposite state.
Large Scale Integration (LSI)	An IC that contains circuitry equivalent to 100 gates or more.
Logic Diagram	A diagram, similar to a schematic, showing the connection of logic gates.
Logic Gate	An electronic circuit that performs a Boolean algebraic function.
Medium Scale Integration (MSI)	An IC that contains circuitry equivalent to more than 11 and less than 100 gates.
NOT Circuit	Also called an INVERTER gate or an inverting buffer. A logic gate that changes its input logic level to the opposite state.
OR Gate	Digital circuit that implements the OR operation. The output of this circuit is HIGH (logic level 1) if any or all of its inputs are HIGH.
Period	The amount of time required for one complete cycle of a periodic event or waveform.
Plastic Leaded Chip Carrier (PLCC)	Surface-mount integrated circuit package with leads that bend back under the package.
Propagation Delays (tPLH/tPHL)	Delay from the time a signal is applied to the time when the output makes its change.
Schematic Entry	A technique of entering CPLD design information by using a CAD (computer aided design) tool to draw a logic circuit as a schematic. The schematic can then be interpreted by design software to generate programming information for the CPLD.
Schottky TTL	TTL subfamily that uses the basic TTL standard circuit except

	that it uses a Schottky barrier code (SBD) connected between the base and the collector of each transistor for faster switching.
Sequential Logic	Digital circuitry in which the output state of the circuit depends not only on the states of the inputs, but also on the sequence in which they reached their present states.
Simulation	Testing design function by specifying a set of inputs and observing the resultant outputs. Simulation is generally shown as a series of input and output waveforms.
Small-Scale Integration (SSI)	An integrated circuit having 12 or fewer gates in one package.
Small Outline Integrated Circuit (SOIC)	Dual-inline style surface-mount IC package.
Transistor-Transistor (TTL)	A family of digital logic devices whose basic element is the bipolar junction transistor.
Truth Table	A list of all possible input values to a digital circuit, listed in ascending binary order, and the output response for each input combination.
555 Timer	TTL-compatible IC that can be wired to operate in several different modes, such as a one-shot and an astable multivibrator.

Day-by-Day Plans

Time: 12 days

NOTE: In preparation for teaching, it is strongly recommended that the teacher read the **Lesson 1.3 Teacher Notes**. All Circuit Design Software (CDS) files for this lesson can be found in the **CDS Files** folder.

Day 1 – 4: Combinational Logic – An Overview

- The teacher will present **Concepts**, **Essential Questions**, and **Key Terms** in order to provide a lesson overview.
- The teacher will present **Combinational Logic – An Overview.ppt**
- Students will take notes in their engineering journals.
- The teacher will distribute and introduce **Activity 1.3.1 Combinational Logic.**
- Students will work on Activity 1.3.1 Combinational Logic.
- The teacher will assist the students as needed.
- The teacher will assess student work using **Activity 1.3.1 Combinational Logic Answer Key.**
- Optional: After the key terms have been introduced, the teacher may choose to distribute **Lesson 1.3 Key Term Crossword** for homework.

Day 5 – 7: Sequential Logic – An Overview

- The teacher will present **Sequential Logic – An Overview.ppt**
- Students will take notes in their engineering journals.
- The teacher will distribute and introduce **Activity 1.3.2 Sequential Logic.**
- Students will work on Activity 1.3.2 Sequential Logic.
- The teacher will assist the students as needed.
- The teacher will assess student work using **Activity 1.3.2 Sequential Logic Answer Key.**

Day 8 – 10: Board Game Counter - Digital

- The teacher will present **Board Game Counter – Digital.ppt**
- Students will take notes in their engineering journals.
- The teacher will distribute and introduce **Project 1.3.3 Board Game Counter - Digital.**
- Students will work on Project 1.3.3 Board Game Counter.
- The teacher will assist the students as needed.

Day 11: Introduction to Logic & Datasheets

- The teacher will present **Introduction to Logic & Datasheets.ppt**
- Students will take notes in their engineering journals.
- The teacher will distribute and introduce **Activity 1.3.4 Introduction to Logic & Datasheets.**
- Students will work on Activity 1.3.4 Introduction to Logic & Datasheets.
- The teacher will assess student work using **Activity 1.3.4 Introduction to Logic & Datasheets Answer Key.**

Day 12: Troubleshooting and Lesson Review

- The teacher will present **Troubleshooting.ppt**
- Students will take notes in their engineering journals.
- The teacher will review the lesson's **Essential Questions.**
- Students will work in small groups (2-4) to answer the lesson's essential questions. Each group will be assigned one essential question that they must discuss, formulate a response for, and present to the class. The intent of this activity is to give closure to the lesson's topics and to have the students reflect back on the underlying concepts covered in the lesson's activities, projects, and problems.

- Students will take notes in their engineering journals.

Instructional Resources

Presentations

Introduction to Logic & Datasheets

Combinational Logic – An Overview

Sequential Logic – An Overview

Board Game Counter – Digital

Troubleshooting

Word Documents

Lesson 1.3 Key Term Crossword

Activity 1.3.1 Combinational Logic

Activity 1.3.2 Sequential Logic

Project 1.3.3 Board Game Counter - Digital

Activity 1.3.4 Introduction to Logic & Datasheets

Answer Keys and Rubrics

Lesson 1.3 Key Term Crossword Answer Key

Activity 1.3.1 Combinational Logic Answer Key

Activity 1.3.2 Sequential Logic Answer Key

Activity 1.3.4 Introduction to Logic & Datasheets Answer Key

Teacher Guidelines

Lesson 1.3 Teacher Notes

Reference Sources

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Floyd, T. (2006). Digital fundamentals. Upper Saddle River, NY: Pearson Education.

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Schultz, M. E. (2007). Grob's basic electronics: Fundamentals of DC and AC circuits. New York, NY: McGraw Hill.

International Technology Education Association, (2000). Standards for technological literacy. Reston, VA:

ITEA.

National Council of Teachers of English (NCTE) and International Reading Association (IRA) (1996). Standards for the English language arts. Newark, DE: IRA; Urbana, IL: NCTE.

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National Research Council (NRC). (1996). National science education standards. Washington, D. C.: National Academy Press.

Unit 2 – Combinational Logic

Preface

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. Building upon the majority vote activity students build fireplace control circuit using combinational logic. The circuit introduces the students to Karnaugh Mapping, NAND only logic design, NOR only logic design, and MultSim's Logic Converter. Students then apply their knowledge to display their birthday using a seven-segment display. Students also delve into hexadecimal and octal number systems, XOR, XNOR, and binary adders, 2's complement arithmetic, and multiplexers/de-multiplexers. In the last lesson students the students will implement their date of birth design 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.

Lesson Documents

Lesson 2.1 Introduction to AOI Logic
Lesson 2.2: Introduction to NAND and NOR Logic
Lesson 2.3: Date of Birth Design
Lesson 2.4: Specific Comb Logic Circuits & Misc. Topics
Lesson 2.5: Programmable Logic – Combinational

Concepts

1. An understanding of the binary number system and its relationship to the decimal number system is essential in the combinational logic design process.
2. The first step in designing a combinational logic circuit is to translate a set of design specifications into a truth table.
3. A truth table describes the behavior of a combinational logic design by listing all possible input combinations and the desired output for each.
4. Logic expressions can be derived from a given truth table; likewise, a truth table can be constructed from a given logic expression.
5. All logic expressions can be expressed in one of two forms: sum-of-products (SOP) or products of sum (POS).
6. All logic expressions, whether simplified or not, can be implemented using AND, OR, & Inverter Gates.
7. There is a formal design process for translating a set of design specifications into a functional combinational logic circuit.
8. Karnaugh Mapping is a graphical technique for simplifying logic expressions containing two, three, and four variables.
9. A don't care condition is a situations where the design specifications "don't care" what the

output is for one or more input conditions. Don't care conditions in K-Maps can lead to significantly simpler logic expressions and circuit implementations.

10. A 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.
11. A NOR 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 NOR gates.
12. There is a formal design process for translating a set of design specifications into a functional combinational logic circuit implement with NAND or NOR gates.
13. Combinational logic designs implemented with NAND gates or NOR gates will typically required fewer Integrated Circuits (IC) than AOI equivalent implementations.
14. Seven-segment displays are used to display the digits 0-9 as well as some alpha characters.
15. The two varieties of seven-segment displays are common cathode and common anode.
16. Any combinational logic expression can be implemented with AOI, NAND, or NOR logic.
17. A formal design process exists for translating a set of design specifications into a functional combinational logic circuit.
18. An understanding of the hexadecimal and octal number systems and their relationship to the decimal number system is necessary for comprehension of digital electronics.
19. XOR and XNOR gates can be used to implement combinational logic circuits, but their primary intended purpose is for implementing binary adder circuits.
20. The addition of two binary numbers of any bit length can be accomplished by cascading one half-adder with one or more full adders.
21. Multiplexer/de-multiplexer pairs are most frequently used when a single connection must be shared between multiple inputs and multiple outputs.
22. Electronics displays that use multiple seven-segment display utilize de-multiplexers to significantly reduce the amount of power required to operate the display.
23. Two's complement arithmetic is the most commonly used method for handling negative numbers in digital electronics.
24. Engineers and technicians use Circuit Design Software to enter and synthesize digital designs into programmable logic devices.
25. Programmable logic devices can be used to implement combinational logic circuits.
26. Circuits implemented with programmable logic devices require significantly less wiring than discrete logic, but they typically require a dedicated printed circuit board to hold the device.
27. Programmable logic devices can be used to implement any combinational logic circuits but are best suited for larger, more complex designs.

Essential Questions

Lesson 2.1 Introduction to AOI Logic

1. 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?
2. What is the relationship between a combinational logic design's truth table, logic expression,

and circuit implementation? Describe the process of obtaining any of the first two given the third.

3. When you simplify a logic expression using Boolean algebra, how do you know that you have the simplest solution and that the solution is correct?
4. In terms of circuit implementation, what is the advantage of representing all logic expression in either the SOP or POS form?
5. Defend the following statement: *"All logic expression, regardless of complexity, can be implemented with AND, OR, & Inverter Gates."*
6. What are the steps in the design process of converting a set of design specifications into a functional combinational logic circuit?

Lesson 2.2: Introduction to NAND and NOR Logic

1. What is the process for using the K-Mapping technique to simplify a logic expression? What are the advantages of using this process over Boolean algebra?
2. What is a *don't care* condition, and how can it be used in a K-Map to reduce the complexity of the combinational logic design?
3. What does the term universal gate mean? Why are NAND gates and NOR gates considered universal gates?
4. What is the advantage of implementing a combinational logic design with only NAND gates (or NOR gates)?
5. What are the steps in the design process for converting an AOI combinational logic design into a NAND only or NOR only design?
6. Typically, what is the advantage of NAND only design (or NOR only design) over an AOI design? Why is it important to it compare both the NAND only and NOR only designs?

Lesson 2.3: Date of Birth Design

1. What is the relationship between the resistor value used, the amount of current flowing, and the brightness of a segment of seven-segment display.
2. Why is it more difficult to design logic circuits with NAND logic or NOR logic than it is with straightforward AOI logic, in terms of circuit implementation.
3. Why does a logic expression require fewer ICs to implement if NAND logic or NOR logic is used than would be required if AOI logic were used.
4. What are the steps in the design process of converting a set of design specifications, containing multiple outputs, into a functional combinational logic circuit?
5. When compared to a design with a single output, is the process different for multiple outputs? Explain.

Lesson 2.4: Specific Comb Logic Circuits & Misc. Topics

1. 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?
2. In terms of circuit complexity, what is the advantage of implementing binary half and full adders with XOR gates over other logic gates?
3. Describe how the addition of two binary numbers of any bit length can be accomplished by cascading one half-adder with one or more full adders.
4. What is the basic operation of digital multiplexers and de-multiplexers?

5. Explain how digital de-multiplexers are used to significantly reduce the amount of power required to operate the electronics displays that use multiple seven-segment display.
6. What are the steps in the two's complement process for adding or subtracting two binary numbers?

Lesson 2.5: Programmable Logic – Combinational

1. What is the design process for using a Circuit Design Software to enter and synthesize combinational logic into a programmable logic device?
2. Describe how programmable logic devices can be used to implement combinational logic circuits.
3. List the advantages and disadvantages of using a programmable logic device over discrete logic gates.
4. Why are programmable logic devices best suited for larger, more complex designs?

Unit Evaluation

The Essential Questions and Conclusion questions at the end of each activity may be used along with the Assessment suggestions provided in each lesson to develop summative assessment tools, such as tests or end of unit projects.

Lesson 2.1 Introduction to AOI Logic

Preface

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 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 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.

Concepts

1. An understanding of the binary number system and its relationship to the decimal number system is essential in the combinational logic design process.
2. The first step in designing a combinational logic circuit is to translate a set of design specifications into a truth table.
3. A truth table describes the behavior of a combinational logic design by listing all possible input combinations and the desired output for each.
4. Logic expressions can be derived from a given truth table; likewise, a truth table can be constructed from a given logic expression.
5. All logic expressions can be expressed in one of two forms: sum-of-products (SOP) or products of sum (POS).
6. All logic expressions, whether simplified or not, can be implemented using AND, OR, & Inverter Gates.
7. There is a formal design process for translating a set of design specifications into a functional combinational logic circuit.

Standards and Benchmarks Addressed

Standards for Technological Literacy

Standard 2: Students will develop an understanding of the core concepts of technology.

BM W: Systems' thinking applies logic and creativity with appropriate compromises in complex real-life problems.

BM Y: The stability of a technological system is influenced by all of the components in the system especially those in the feedback loop.

BM Z: Selecting resources involves trade-offs between competing values, such as availability, cost, desirability, and waste.

BM AA: Requirements involve the identification of the criteria and constraints of a product or system and the determination of how they affect the final design and development.

BM BB: Optimization is an on going process or methodology of designing or making a product and is dependent on criteria and constraints.

BM FF: Complex systems have many layers of controls and feedback loops to provide information.

Standard 9: Students will develop an understanding of engineering design.

BM I: Established design principles are used to evaluate existing designs, to collect data, and to guide the design process.

BM J: Engineering design is influenced by personal characteristics, such as creativity, resourcefulness, and the ability to visualize and think abstractly.

BM K: A prototype is a working model used to test a design concept by making actual observations and necessary adjustments.

BM L: The process of engineering design takes into account a number of factors.

Standard 10: Students will develop an understanding of the role of troubleshooting, research and development, invention and innovation, and experimentation in problem solving.

BM I: Research and development is a specific problem-solving approach that is used intensively in business and industry to prepare devices and systems for the marketplace.

BM J: Technological problems must be researched before they can be solved.

BM K: Not all problems are technological, and not every problem can be solved using technology.

BM L: Many technological problems require a multidisciplinary approach.

Standard 11: Students will develop abilities to apply the design process.

BM N: Identify criteria and constraints and determine how these will affect the design process.

BM O: Refine a design by using prototypes and modeling to ensure quality, efficiency, and productivity of the final product.

BM P: Evaluate the design solution using conceptual, physical, and mathematical models at various intervals of the design process in order to check for proper design and to note areas where improvements are needed.

BM Q: Develop and produce a product or system using a design process.

BM R: Evaluate final solutions and communicate observation, processes, and results of the entire design process, using verbal, graphic, quantitative, virtual, and written means, in addition to three-dimensional models.

Standard 12: Students will develop the abilities to use and maintain technological products and systems.

BM L: Document processes and procedures and communicate them to different audiences using appropriate oral and written techniques.

BM M: Diagnose a system that is malfunctioning and use tools, materials, machines, and knowledge to repair it.

BM N: Troubleshoot, analyze, and maintain systems to ensure safe and proper function and precision.

BM O: Operate systems so that they function in the way they were designed.

BM P: Use computers and calculators to access, retrieve, organize and process, maintain, interpret, and evaluate data and information in order to communicate.

Standard 13: Students will develop the abilities to assess the impacts of products and systems.

BM J: Collect information and evaluate its quality.

Standard 17: Students will develop an understanding of and be able to select and use information and communication technologies.

BM L: Information and communication technologies include the inputs, processes, and outputs associated with sending and receiving information.

BM M: Information and communication systems allow information to be transferred from human to human, human to machine, machine to human, and machine to machine.

BM N: Information and communication systems can be used to inform, persuade, entertain, control, manage, and educate.

BM O: Communication systems are made up of source, encoder, transmitter, receiver, decoder, storage, retrieval, and destination.

BM P: There are many ways to communicate information, such as graphic and electronic means.

BM Q: Technological knowledge and processes are communicated using symbols, measurement, conventions, icons, graphic images, and languages that incorporate a variety of visual, auditory, and tactile stimuli.

National Science Education Standards

Standard K-12: Unifying Concepts and Processes: As a result of activities in grades K-12, all students should develop understanding and abilities aligned with the following concepts and processes;

- Systems, order, and organization
- Evidence, models, and explanation
- Change, constancy, and measurement
- Form and function

Content Standard A: Science As Inquiry: As a result of activities in grades 9-12, all students should develop;

- Abilities necessary to do scientific inquiry
- Understandings about scientific inquiry

Standard E: Science and Technology: As a result of activities in grades 9-12, all students should develop

- Abilities of technological design
- Understandings about science and technology

Principles and Standards for School Mathematics

Number and Operations:	Instructional programs from pre-kindergarten through grade 12 should enable all students to; understand numbers, ways of representing numbers, relationships among numbers, and number systems; understand meanings of operations and how they relate to one another; compute fluently and make reasonable estimates.
Algebra:	Instructional programs from pre-kindergarten through grade 12 should enable all students to; understand patterns, relations, and functions; represent and analyze mathematical situations and structures using algebraic symbols; use mathematical models to represent and understand quantitative relationships; analyze change in various contexts.
Problem Solving:	Instructional programs from pre-kindergarten through grade 12 should enable all students to; build new mathematical knowledge through problem solving; solve problems that arise in mathematics and in other contexts; apply and adapt a variety of appropriate strategies to solve problems; monitor and reflect on the process of mathematical problem solving.
Reasoning and Proof:	Instructional programs from pre-kindergarten through grade 12 should enable all students to; recognize reasoning and proof as fundamental aspects of mathematics; make and investigate mathematical conjectures; develop and evaluate mathematical arguments and proofs; select and use various types of reasoning and methods of proof.
Communication:	Instructional programs from pre-kindergarten through grade 12 should enable all students to; organize and consolidate their mathematical thinking through communication; communicate their mathematical thinking coherently and clearly to peers, teachers, and others; analyze and evaluate the mathematical thinking and strategies of others; use the language of mathematics to express mathematical ideas precisely.

Connections: Instructional programs from pre-kindergarten through grade 12 should enable all students to; recognize and use connections among mathematical ideas; understand how mathematical ideas interconnect and build on one another to produce a coherent whole; recognize and apply mathematics in contexts outside of mathematics.

Representation: Instructional programs from pre-kindergarten through grade 12 should enable all students to; create and use representations to organize, record, and communicate mathematical ideas; select, apply, and translate among mathematical representations to solve problems; use representations to model and interpret physical, social, and mathematical phenomena.

Standards for English Language Arts

Standard 1: Students read a wide range of print and non-print texts to build an understanding of texts of themselves, and of the cultures of the United States and the world; to acquire new information; to respond to the needs and demands of society and the workplace; and for personal fulfillment. Among these texts are fiction and nonfiction, classical and contemporary works.

Standard 4: Students adjust their use of spoken, written, and visual language (e.g. conventions, style, vocabulary) to communicate effectively with a variety of audiences and for different purposes.

Standard 12: Students use spoken, written and visual language to accomplish their own purposes (e.g. for learning, enjoyment, persuasion, and the exchange of information).

Performance Objectives

It is expected that students will:

- Convert numbers between the binary and decimal number systems.
- Translate design specifications into truth tables.
- Extract un-simplified logic expressions from truth tables.
- Construct truth tables from logic expressions.
- Use the rules and laws of Boolean algebra, including DeMorgan's, to simplify logic expressions.
- Analyze AOI (AND/OR/Invert) combinational logic circuits to determine their equivalent logic expressions and truth tables.
- Design combinational logic circuits using AOI logic gates.
- Translate a set of design specifications into a functional AOI combinational logic circuit following a formal design process.
- Use Circuit Design Software (CDS) and a Digital Logic Board (DLB) to simulate and prototype AOI logic circuits.

Assessment

Explanation

- How will the knowledge about AOI Logic aid you in designing, building, and testing of a circuit?

Interpretation

- Students will define and explain the difference between a AND gate, OR gate, and an inverter gate.

Self-knowledge

- Explain to a fifth grader the difference between a binary and decimal number system.

Essential Questions

1. 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?
2. What is the relationship between a combinational logic design's truth table, logic expression, and circuit implementation? Describe the process of obtaining any of the first two given the third.
3. When you simplify a logic expression using Boolean algebra, how do you know that you have the simplest solution and that the solution is correct?
4. In terms of circuit implementation, what is the advantage of representing all logic expression in either the SOP or POS form?
5. Defend the following statement: *"All logic expression, regardless of complexity, can be implemented with AND, OR, & Inverter Gates."*
6. What are the steps in the design process of converting a set of design specifications into a functional combinational logic circuit?

Key Terms

Associative Property	A mathematical function is associative if its operands can be grouped in any order without affecting the result. For example, addition is associative ((a+b) + c = a + (b+c)), but subtraction is not ((a-b) –c ≠ a-(b-c)).
Binary Number System	A number system used extensively in digital systems, based on the number 2. It uses two digits to write any number.
Boolean Algebra	Algebraic process used as a tool in the design and analysis of digital systems. In Boolean algebra only two values are possible, 0 and 1.
Boolean Expression	An algebraic expression made up of Boolean variables and operators, such as AND (•), OR (+), or NOT (-). Also referred to as Boolean function or a logic function.
Boolean Theorems	Rules that can be applied to Boolean algebra to simplify logic expressions.
Boolean Variable	A variable having only two possible values, such as HIGH/LOW, 1/0, On/Off, or True/False.
Combinational Logic	Digital circuitry in which an output is derived from the combination of inputs, independent of the order in which they are applied.
Commutative Property	A mathematical operation is commutative if it can be applied to its operands in any order without affecting the result. For example, addition is commutative (a+b=b+a), but subtraction is not (a-b≠b-a).

Decimal System	Number system that uses 10 different digits or symbols to represent a quantity.
DeMorgan's Theorems	1) Theorem stating that the complement of a sum (OR operation) equals the product (AND operation) of the complements, and 2) theorem stating that the complement of a product (AND operation) equals the sum (OR operation) of the complements.
Distributive Property	Full name: distributive property of multiplication over addition. The property that allows us to distribute ("multiply through") an AND across several OR functions. For example, a(b+c)=ab+ac.
Least Significant Bit (LSB)	The rightmost bit of a binary num ber. This bit has the number's smallest positional multiplier.
Logic Circuit	Any circuit that behaves according to a set of logic rules.
Logic Diagram	A diagram, similar to a schematic, showing the connection of logic gates.
Maxterm	A sum term in a Boolean expression where all possible variables appear once in true or complement form.
Minterm	A product term in a Boolean expression where all possible variables appear once in true or complement form.
Most Significant Bit (MSB)	The leftmost bit in a binary number. This bit has the number's loargest positional multiplier.
Product-of-Sums (POS)	A type of Boolean expression where several sum terms are multiplied (ANDed) together.
Product Term	A term in a Boolean expression where one or more true or complement variables are ANDed.
Sum-of-Products (SOP)	A type of Boolean expression where several product terms are summed (ORed) together.
Sum Term	A term in a Boolean expression where one or more true or complement variables are ORed.
Truth Table	A list of all possible input values to a digital circuit, listed in ascending binary order, and the output response for each input combination.

Day-by-Day Plans

Time: 20 days

NOTE: In preparation for teaching, it is strongly recommended that the teacher read the **Lesson 2.1 Teacher Notes** for this lesson. All Circuit Design Software (CDS) files for this lesson can be found in the **CDS Files** folder.

Day 1: Lesson Overview & Introduction to the Majority Vote Problem

- The teacher will present **Concepts**, **Essential Questions**, and **Key Terms** in order to provide a lesson overview.
- Students will participate in a teacher-led discussion on common everyday devices that contain combinational logic circuits. The intent is to create connectivity between devices that a student may use every day and how they, at the completion of this unit, will be able to analyze and design such a device.
- The teacher will distribute and introduce **Project 2.1.1 Majority Vote**.

- The teacher will present **Comb Logic Design Process (v1).ppt.**
- Students will take notes in their engineering notebooks/portfolios.
- **Optional:** After the key terms have been introduced, the teacher may choose to distribute **Lesson 2.1 Key Term Crossword** for homework.

Day 2: Binary Number Systems

- The teacher will present **Binary Number System & Conversion.ppt.**
- Students will take notes in their engineering notebooks/portfolios.
- The teacher will distribute and introduce **Activity 2.1.2 Binary Numbers & Conversion.**
- Students will work on Activity 2.1.2 Binary Numbers & Conversion.
- After the class has completed the first few problems in the activity, the teacher will review these problems with the class to clarify any misconceptions. The students will have the remainder of the class to complete the activity. Any unfinished work will be completed as homework.
- The teacher will assess student work using **Activity 2.1.2 Binary Numbers and Conversion Answer Key.**

Day 3 – 4: Truth Tables and Boolean Expressions

- The teacher will present **Truth Tables & Logic Expressions.ppt.**
- Students will take notes in their engineering notebooks/portfolios.
- The teacher will distribute and introduce **Activity 2.1.3 Truth Tables & Logic Expressions.**
- Students will work on Activity 2.1.3 Truth Table & Logic Expressions.
- The teacher will assess student work using **Activity 2.1.3 Truth Tables & Logic Expressions Answer Key.**

Day 5: Truth Tables and Boolean Expressions – Majority Vote

- The teacher will review the Word Problem - Create Truth Table - Write Boolean Expression steps of the Combinational Logic Design Process (v1) flow chart (see day 1).
- Students will complete procedure steps 1 and 2 for the Majority Vote Project, documenting their work in their engineering notebooks/portfolios.
- The teacher will assist the students as needed.
- Using the **Project 2.1.1 Majority Vote – Voting Machine Answer Key** as a guide, the teacher will review the results with the class to ensure that each student understands the process and has obtained the correct results.

Day 6: AOI Logic Analysis

- The teacher will present **AOI Logic Analysis.ppt.**
- Students will take notes in their engineering notebooks/portfolios.
- The teacher will distribute and introduce **Activity 2.1.4 AOI Logic Analysis.**
- Students will work on Activity 2.1.4 AOI Logic Analysis.
- The teacher will assess student work using **Activity 2.1.4 AOI Logic Analysis Answer Key.**

Day 7 – 8: AOI Logic Implementation

- The teacher will present **AOI Logic Implementation.ppt.**

- Students will take notes in their engineering notebooks/portfolios.
- The teacher will distribute and introduce **Activity 2.1.5 AOI Logic Implementation.**
- Students will work on Activity 2.1.5 AOI Logic Analysis.
- The teacher will assess student work using **Activity 2.1.5 AOI Logic Analysis Answer Key.**

Day 9 – 10: AOI Logic Implementation – Majority Vote

- The teacher will review the Write Logic Expression – No Simplification – AOI Logic Implementation steps of the Combinational Logic Design Process (v1) flow chart (see day 1).
- Students will complete procedure steps 3 and 4 for the Majority Vote Project, documenting their work in their engineering notebooks/portfolios.
- The teacher will assist the students as needed.
- Using the **Project 2.1.1 Majority Vote – Voting Machine Answer Key** as a guide, the teacher will review the results with the class to ensure that each student understands the process and has obtained the correct results.

Day 11 – 13: Boolean Algebra

- The teacher will present **Boolean Algebra.ppt.**
- Students will take notes in their engineering notebooks/portfolios.
- The teacher will distribute and introduce **Activity 2.1.6 Boolean Algebra** and **Activity 2.1.6a Boolean Algebra and DeMorgan's Theorems**
- Students will work on Activity 2.1.6 Boolean Algebra.
- After the class has completed the first few problems in the activity, the teacher will review these problems with the class to clarify any misconceptions. The students will have the remainder of the class to complete the activity. Any unfinished work will be completed as homework.
- The teacher will assess student work using **Activity 2.1.6 Boolean Algebra Answer Key.**

Day 14 – 15: DeMorgan's Theorems

- The teacher will present **DeMorgan's Theorems.ppt.**
- Students will take notes in their engineering notebooks/portfolios.
- The teacher will distribute and introduce **Activity 2.1.7 DeMorgan's Theorems.**
- Students will work on Activity 2.1.7 DeMorgan's Theorems.
- After the class has completed the first few problems in the activity, the teacher will review these problems with the class to clarify any misconceptions. The students will have the remainder of the class to complete the activity. Any unfinished work will be completed as homework.
- The teacher will assess student work using **Activity 2.1.7 DeMorgan's Theorems Answer Key.**

Day 16: Boolean Algebra – Majority Vote

- The teacher will review the Write Logic Expression – Boolean Simplification – AOI Logic Implementation steps of the Combinational Logic Design Process (v1) flow chart (see day 1).
- Students will complete procedure step 5 for the Majority Vote Project, documenting their

work in their engineering notebooks/portfolios.

- The teacher will assist the students as needed.
- Using the Project 2.1.1 Majority Vote – Voting Machine Answer Key as a guide, the teacher will review the results with the class to ensure that each student understands the process and has obtained the correct results.

Day 17 – 19: Majority Vote Simulation and Protoboarding

- The teacher will review the Write Logic Expression – Boolean Simplification – AOI Logic Implementation steps of the Combinational Logic Design Process (v1) flow chart (see day 1).
- Students will complete procedure steps 6, 7, and 8 for the Majority Vote Project, documenting their work in their engineering notebooks/portfolios.
- The teacher will assist the students as needed.
- Using the Project 2.1.1 Majority Vote – Voting Machine Answer Key as a guide, the teacher will review the results with the class to ensure that each student understands the process and has obtained the correct results.

Day 20: Lesson Review

- The teacher will collect the student's report on their Majority Vote – Voting Machine.
- The teacher will review the lesson's **Essential Questions**.
- Students will work in small groups (2-4) to answer the lesson's essential questions. Each group will be assigned one essential question that they must discuss, formulate a response for, and present to the class. The intent of this activity is to give closure to the lesson's topics and to encourage students to reflect back on the underlying concepts covered in the lesson's activities, projects, and problems.
- Students will take notes in their engineering notebooks/portfolios.

Instructional Resources

Presentations

Combo Logic Design Process

Binary Number Systems & Conversion

Truth Tables & Logic Expressions

AOI Logic Analysis

AOI Logic Implementation

Boolean Algebra

DeMorgan's Theorems

Word Documents

Lesson 2.1 Key Term Crossword

Project 2.1.1 Majority Vote

Activity 2.1.2 Binary Numbers & Conversion

Activity 2.1.3 Truth Tables & Logic Expressions

Activity 2.1.4 AOI Logic Analysis

Activity 2.1.5 AOI Logic Implementation

Activity 2.1.6 Boolean Algebra

Activity 2.1.6a Boolean Algebra and DeMorgan's Theorems

Activity 2.1.7 DeMorgan's Theorems

Answer Keys and Rubrics

Lesson 2.1 Key Term Crossword Answer Key

Project 2.1.1 Majority Vote – Voting Machine Answer Key

Activity 2.1.2 Binary Numbers & Conversion Answer Key

Activity 2.1.3 Truth Tables & Logic Expressions Answer Key

Activity 2.1.4 AOI Logic Analysis Answer Key

Activity 2.1.5 AOI Logic Implementation Answer Key

Activity 2.1.6 Boolean Algebra Answer Key

Activity 2.1.7 DeMorgan's Theorems Answer Key

Teacher Guidelines

Lesson 2.1 Teacher Notes

Reference Sources

Dueck, R. & Reid, K. (2008). Introduction to digital electronics. Clifton Park , NY: Thompson Delmar Learning.

Tocci, R., Widmer, N., & Moss, G. (2007). Digital systems: Principles and applications. Upper Saddle River, NJ: Pearson Education.

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Lesson 2.2 Intro to NAND & NOR Logic

Preface

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.

Concepts

1. Karnaugh Mapping is a graphical technique for simplifying logic expressions containing two, three, and four variables.
2. A don't care condition is a situations where the design specifications "don't care" what the output is for one or more input conditions. Don't care conditions in K-Maps can lead to significantly simpler logic expressions and circuit implementations.
3. A 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.
4. A NOR 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 NOR gates.
5. There is a formal design process for translating a set of design specifications into a functional combinational logic circuit implement with NAND or NOR gates.
6. Combinational logic designs implemented with NAND gates or NOR gates will typically required fewer Integrated Circuits (IC) than AOI equivalent implementations.

Standards and Benchmarks Addressed

Standards for Technological Literacy

Standard 1: Students will develop an understanding of the characteristics and scope of technology.

BM J:	The nature and development of technological knowledge and processes are functions of the setting.
BM L:	Inventions and innovations are the results of specific, goal-directed research.
BM M:	Most development of technologies these days is driven by the profit motive and the market.

Standard 2: Students will develop an understanding of the core concepts of technology.

BM W:	Systems' thinking applies logic and creativity with appropriate compromises in complex real-life problems.
BM X:	Systems, which are the building blocks of technology, are embedded within larger technological, social, and environmental systems.
BM Y:	The stability of a technological system is influenced by all of the components in the system especially those in the feedback loop.
BM Z:	Selecting resources involves trade-offs between competing values, such as availability, cost, desirability, and waste.
BM AA:	Requirements involve the identification of the criteria and constraints of a product or system and the determination of how they affect the final design and development.
BM BB:	Optimization is an on going process or methodology of designing or making a product and is dependent on criteria and constraints.
BM CC:	New technologies create new processes.
BM DD:	Quality control is a planned process to ensure that a product, service, or system meets established criteria.
BM FF:	Complex systems have many layers of controls and feedback loops to provide information.

Standard 3: Students will develop an understanding of the relationships among technologies and the connections between technology and other fields of study.

BM G:	Technology transfer occurs when a new user applies an existing innovation developed for one purpose in a different function
BM H:	Technological innovation often results when ideas, knowledge, or skills are shared within a technology, among technologies, or across other fields.
BM J:	Technological progress promotes the advancement of science and mathematics. Likewise, progress in science and mathematics leads to advances in technology.

Standard 9: Students will develop an understanding of engineering design.

BM I:	Established design principles are used to evaluate existing designs, to collect data, and to guide the design process.
BM J:	Engineering design is influenced by personal characteristics, such as creativity, resourcefulness, and the ability to visualize and think abstractly.
BM K:	A prototype is a working model used to test a design concept by making actual observations and necessary adjustments.
BM L:	The process of engineering design takes into account a number of factors.

Standard 10: Students will develop an understanding of the role of troubleshooting, research and development, invention and innovation, and experimentation in problem solving.

BM I:	Research and development is a specific problem-solving approach that is used intensively in business and industry to prepare devices and systems for the marketplace.
BM J:	Technological problems must be researched before they can be solved.
BM K:	Not all problems are technological, and not every problem can be solved using technology.
BM L:	Many technological problems require a multidisciplinary approach.

Standard 11: Students will develop abilities to apply the design process.

BM M:	Identify the design problem to solve and decide whether or not to

address it.

BM N: Identify criteria and constraints and determine how these will affect the design process.

BM O: Refine a design by using prototypes and modeling to ensure quality, efficiency, and productivity of the final product.

BM P: Evaluate the design solution using conceptual, physical, and mathematical models at various intervals of the design process in order to check for proper design and to note areas where improvements are needed.

BM Q: Develop and produce a product or system using a design process.

BM R: Evaluate final solutions and communicate observation, processes, and results of the entire design process, using verbal, graphic, quantitative, virtual, and written means, in addition to three-dimensional models.

Standard 12: Students will develop the abilities to use and maintain technological products and systems.

BM L: Document processes and procedures and communicate them to different audiences using appropriate oral and written techniques.

BM M: Diagnose a system that is malfunctioning and use tools, materials, machines, and knowledge to repair it.

BM N: Troubleshoot, analyze, and maintain systems to ensure safe and proper function and precision.

BM O: Operate systems so that they function in the way they were designed.

BM P: Use computers and calculators to access, retrieve, organize and process, maintain, interpret, and evaluate data and information in order to communicate.

Standard 13: Students will develop the abilities to assess the impacts of products and systems.

BM J: Collect information and evaluate its quality.

Standard 17: Students will develop an understanding of and be able to select and use information and communication technologies.

BM L: Information and communication technologies include the inputs, processes, and outputs associated with sending and receiving information.

BM M: Information and communication systems allow information to be transferred from human to human, human to machine, machine to human, and machine to machine.

BM N: Information and communication systems can be used to inform, persuade, entertain, control, manage, and educate.

BM O: Communication systems are made up of source, encoder, transmitter, receiver, decoder, storage, retrieval, and destination.

BM P: There are many ways to communicate information, such as graphic and electronic means.

BM Q: Technological knowledge and processes are communicated using symbols, measurement, conventions, icons, graphic images, and languages that incorporate a variety of visual, auditory, and tactile stimuli.

National Science Education Standards

Standard K-12: Unifying Concepts and Processes: As a result of activities in grades K-12, all students should develop understanding and abilities aligned with the following concepts and processes;

- Systems, order, and organization

- Evidence, models, and explanation
- Form and function

Standard A: Science As Inquiry: As a result of activities in grades 9-12, all students should develop;

- Abilities necessary to do scientific inquiry
- Understandings about scientific inquiry

Standard E: Science and Technology: As a result of activities in grades 9-12, all students should develop

- Abilities of technological design

Principles and Standards for School Mathematics

Number and Operations:	Instructional programs from pre-kindergarten through grade 12 should enable all students to; understand numbers, ways of representing numbers, relationships among numbers, and number systems; understand meanings of operations and how they relate to one another; compute fluently and make reasonable estimates.
Algebra:	Instructional programs from pre-kindergarten through grade 12 should enable all students to; understand patterns, relations, and functions; represent and analyze mathematical situations and structures using algebraic symbols; use mathematical models to represent and understand quantitative relationships; analyze change in various contexts.
Measurement:	Instructional programs from pre-kindergarten through grade 12 should enable all students to; understand measurable attributes of objects and the units, systems, and processes of measurement; apply appropriate techniques, tools, and formulas to determine measurements.
Data Analysis and Probability:	Instructional programs from pre-kindergarten through grade 12 should enable all students to; formulate questions that can be addressed with data and collect, organize, and display relevant data to answer them; select and use appropriate statistical methods to analyze data; develop and evaluate inferences and predictions that are based on data; understand and apply basic concepts of probability.
Problem Solving:	Instructional programs from pre-kindergarten through grade 12 should enable all students to; build new mathematical knowledge through problem solving; solve problems that arise in mathematics and in other contexts; apply and adapt a variety of appropriate strategies to solve problems; monitor and reflect on the process of mathematical problem solving.
Reasoning and Proof:	Instructional programs from pre-kindergarten through grade 12 should enable all students to; recognize reasoning and proof as fundamental aspects of mathematics; make and investigate mathematical conjectures; develop and evaluate mathematical arguments and proofs; select and use various types of reasoning and methods of proof.
Communication:	Instructional programs from pre-kindergarten through grade 12 should enable all students to; organize and consolidate their

	mathematical thinking through communication; communicate their mathematical thinking coherently and clearly to peers, teachers, and others; analyze and evaluate the mathematical thinking and strategies of others; use the language of mathematics to express mathematical ideas precisely.
Connections:	Instructional programs from pre-kindergarten through grade 12 should enable all students to; recognize and use connections among mathematical ideas; understand how mathematical ideas interconnect and build on one another to produce a coherent whole; recognize and apply mathematics in contexts outside of mathematics.
Representation:	Instructional programs from pre-kindergarten through grade 12 should enable all students to; create and use representations to organize, record, and communicate mathematical ideas; select, apply, and translate among mathematical representations to solve problems; use representations to model and interpret physical, social, and mathematical phenomena.

Standards for English Language Arts

Standard 4:	Students adjust their use of spoken, written, and visual language (e.g. conventions, style, vocabulary) to communicate effectively with a variety of audiences and for different purposes.
Standard 12:	Students use spoken, written and visual language to accomplish their own purposes (e.g. for learning, enjoyment, persuasion, and the exchange of information).

Performance Objectives

It is expected that students will:

- Use the K-Mapping technique to simplify combinational logic problems containing two, three, and four variables.
- Be able to solve K-Maps that contain one or more *don't care* conditions.
- Design combinational logic circuit using NAND and NOR logic gates.
- Translate a set of design specifications into a functional NAND or NOR combinational logic circuit following a formal design process.
- Be able to compare and contrast the quality of combinational logic designs implemented with AOI, NAND, and NOR logic gates.
- Use Circuit Design Software (CDS) and a Digital Logic Board (DLB) to simulate and prototype NAND and NOR logic circuits.

Assessment

Explanation

- Students will explain the differences between NAND andNOR logic.

Application

- Students will demonstrate to an adminstrator how to K-Map a combinational logic problem

Self-knowledge

- Students will create a brainstorming list of improvements that could be made to the CDS software and justify why these changes would make the learning curve easier for students.

Essential Questions

1. What is the process for using the K-Mapping technique to simplify a logic expression? What are the advantages of using this process over Boolean algebra?
2. What is a *don't care* condition, and how can it be used in a K-Map to reduce the complexity of the combinational logic design?
3. What does the term universal gate mean? Why are NAND gates and NOR gates considered universal gates?
4. What is the advantage of implementing a combinational logic design with only NAND gates (or NOR gates)?
5. What are the steps in the design process for converting an AOI combinational logic design into a NAND only or NOR only design?
6. Typically, what is the advantage of NAND only design (or NOR only design) over an AOI design? Why is it important to it compare both the NAND only and NOR only designs?

Key Terms

Adjacent Cell	Two cells in a K-map are adjacent if there is only one variable that is different between the coordinates of the two cells.
Cell	The smallest unit of Karnaugh map, corresponding to one line of a truth table. The input variables are the cell's coordinates and the output variable is the cell's contents.
Don't Care Condition	Situation when a circuit's output level for a given set of input conditions can be assigned as either a 1 or 0.
Karnaugh Map	A graphical tool for finding the maximum SOP or POS simplification of a Boolean expression. A Karnaugh map works by arranging the terms of an expression so that variable scans are cancelled by grouping minterms or maxterms.
NAND Gate	Logic circuit that operates like an AND gate followed by an INVERTER. The output of a NAND gate is LOW (logic level 0) only if all inputs are HIGH (logic level 1).
NOR Gate	Logic circuit that operates like an OR gate followed by an INVERTER. The output of a NOR gate is LOW (logic level 0) when any or all inputs are HIGH (logic level 1).

Day-by-Day Plans

Time: 14 days

- **NOTE:** In preparation for teaching, it is strongly recommended that the teacher read the **Lesson 2.2 Teacher Notes.** All Circuit Design Software (CDS) files for this lesson can be found in the **CDS Files** folder.

Day 1 – 2: Lesson Overview and Karnaugh Mapping

- The teacher will present **Concepts**, **Essential Questions**, and **Key Terms** in order to provide a lesson overview.

- The teacher will present **Karnaugh Mapping.ppt.**

- Students will take notes in their engineering journals.

- The teacher will distribute and introduce **Activity 2.2.1 K-Mapping**.

- Students will work on Activity 2.2.1 K-Mapping.

- After the class has completed the first few problems in the activity, the teacher will review these problems with the class to clarify any misconceptions. The students will have the remainder of the class to complete the activity. Any unfinished work will be completed as homework.

- The teacher will assess student work using **Activity 2.2.1 K-Mapping Answer Key.**

- Optional: After the key terms have been introduced, the teacher may choose to distribute **Lesson 2.2 Key Term Crossword** for homework.

Day 3 – 5: NAND Logic Implementation

- The teacher will present **Universal Gate – NAND.ppt.**

- Students will take notes in their engineering journals.

- The teacher will distribute and introduce **Activity 2.2.2 NAND Logic Design**.

- Students will work on Activity 2.2.2 NAND Logic Design.

- The teacher will assess student work using **Activity 2.2.2 NAND Logic Design Answer Key.**

Day 6 – 8: NOR Logic Implementation

- The teacher will present **Universal Gate – NOR.ppt.**

- Students will take notes in their engineering journals.

- The teacher will distribute and introduce **Activity 2.2.3 NOR Logic Design**.

- Students will work on Activity 2.2.3 NOR Logic Design.

- The teacher will assess student work using **Activity 2.2.3 NOR Logic Design Answer Key.**

Day 9: Logic Converter

- The teacher will give a brief demonstration on the MultiSim Logic Converter.
- Students will take notes in their engineering journals.
- The teacher will distribute and introduce **Activity 2.2.4 Logic Converter**.
- Students will work on Activity 2.2.4 Logic Converter.
- The teacher will assess student work using **Activity 2.2.4 Logic Converter Answer Key.**

Day 10 – 13 Fireplace Control Circuit Design, Simulation and Prototyping

- The teacher will present **Comb Logic Design Process (v2).ppt.**
- The teacher will distribute and introduce **Project 2.2.5 Fireplace Control Circuit.**
- Students will take notes in their engineering journals.
- Students will work on Project 2.2.5 Fireplace Control Circuit.
- The teacher will assist the students as needed.

Day 14: Lesson Review

- The teacher will collect student reports on the Fireplace Control Circuit design.
- Using the **Project 2.2.5 Fireplace Control Circuit Answer Key** as a guide, the teacher will review the results with the class to ensure that each student understands the process and has obtained the correct results.
- The teacher will review the lesson's **Essential Questions**.
- Students will work in small groups (2-4) to answer the lesson's essential questions. Each group will be assigned one essential question that they must discuss, formulate a response for, and present to the class. The intent of this activity is to give closure to the lesson's topics and to have the students reflect back on the underlying concepts covered in the lesson's activities, projects, and problems.
- Students will take notes in their engineering journals.

Instructional Resources

Presentations

Karnaugh Mapping

Universal Gate – NAND

Universal Gate - NOR

Comb Logic Design Process

Word Documents

Lesson 2.2 Key Term Crossword
Activity 2.2.1 K-Mapping
Activity 2.2.2 NAND Logic Design
Activity 2.2.3 NOR Logic Design
Activity 2.2.4 Logic Converter
Project 2.2.5 Fireplace Control Circuit

Answer Keys and Rubrics

Lesson 2.2 Key Term Crossword Answer Key
Activity 2.2.1 K-Mapping Answer Key
Activity 2.2.2 NAND Logic Design Answer Key
Activity 2.2.3 NOR Logic Design Answer Key
Activity 2.2.4 Logic Converter Answer Key
Project 2.2.5 Fireplace Control Circuit Answer Key

Teacher Guidelines

Lesson 2.2 Teacher Notes

Reference Sources

Dueck, R. & Reid, K. (2008). Introduction to digital electronics. Clifton Park , NY: Thompson Delmar Learning.

Tocci, R., Widmer, N., & Moss, G. (2007). Digital systems: Principles and applications. Upper Saddle River, NJ: Pearson Education.

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National Research Council (NRC). (1996). National science education standards. Washington, D. C.: National Academy Press.

Lesson 2.3 Date of Birth Design

Preface

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.

Concepts

1. Seven-segment displays are used to display the digits 0-9 as well as some alpha characters.
2. The two varieties of seven-segment displays are common cathode and common anode.
3. Any combinational logic expression can be implemented with AOI, NAND, or NOR logic.
4. A formal design process exists for translating a set of design specifications into a functional combinational logic circuit.

Standards and Benchmarks Addressed

Standards for Technological Literacy

Standard 2: Students will develop an understanding of the core concepts of technology.

BM Z: Selecting resources involves trade-offs between competing values, such as availability, cost, desirability, and waste.

BM AA: Requirements involve the identification of the criteria and constraints of a product or system and the determination of how they affect the final design and development.

BM BB: Optimization is an on going process or methodology of designing or making a product and is dependent on criteria and constraints.

BM DD: Quality control is a planned process to ensure that a product, service, or system meets established criteria.

Standard 8: Students will develop an understanding of the attributes of design.

BM I: Design problems are seldom presented in a clearly defined form.

BM J: The design needs to be continually checked and critiqued, and the ideas of the design must be redefined and improved.

BM K: Requirements of a design, such as criteria, constraints, and efficiency, sometimes compete with each other.

Standard 9: Students will develop an understanding of engineering design.

BM J: Engineering design is influenced by personal characteristics, such as creativity, resourcefulness, and the ability to visualize and think abstractly.

BM L: The process of engineering design takes into account a number of factors.

Standard 11: Students will develop abilities to apply the design process.

BM N: Identify criteria and constraints and determine how these will affect the design process.

BM O: Refine a design by using prototypes and modeling to ensure quality, efficiency, and productivity of the final product.

BM P: Evaluate the design solution using conceptual, physical, and mathematical models at various intervals of the design process in order to check for proper design and to note areas where improvements are needed.

BM Q: Develop and produce a product or system using a design process.

BM R: Evaluate final solutions and communicate observation, processes, and results of the entire design process, using verbal, graphic, quantitative, virtual, and written means, in addition to three-dimensional models.

Standard 12: Students will develop the abilities to use and maintain technological products and systems.

BM M: Diagnose a system that is malfunctioning and use tools, materials, machines, and knowledge to repair it.

BM N: Troubleshoot, analyze, and maintain systems to ensure safe and proper function and precision.

BM O: Operate systems so that they function in the way they were designed.

Standard 17: Students will develop an understanding of and be able to select and use information and communication technologies.

BM L: Information and communication technologies include the inputs, processes, and outputs associated with sending and receiving information.

BM M: Information and communication systems allow information to be transferred from human to human, human to machine, machine to human, and machine to machine.

BM N: Information and communication systems can be used to inform, persuade, entertain, control, manage, and educate.

BM O: Communication systems are made up of source, encoder, transmitter, receiver, decoder, storage, retrieval, and destination.

BM P: There are many ways to communicate information, such as graphic and electronic means.

BM Q: Technological knowledge and processes are communicated using symbols, measurement, conventions, icons, graphic images, and languages that incorporate a variety of visual, auditory, and tactile stimuli.

National Science Education Standards

Science as Inquiry Standard A: As a result of activities in grades 9-12, all students should develop

- Abilities necessary to do scientific inquiry

- Understandings about scientific inquiry

Science and Technology Standard E: As a result of activities in grades 9-12, all students should develop

- Abilities of technological design
- Understandings about science and technology

Principle and Standards for School Mathematics

Number and Operations:	Instructional programs from pre-kindergarten through grade 12 should enable all students to compute fluently and make reasonable estimates.
Algebra:	Instructional programs from pre-kindergarten through grade 12 should enable all students to understand patterns, relations, and functions, represent and analyze mathematical situations and structures using algebraic symbols, use mathematical models to represent and understand quantitative relationships, and analyze change in various contexts.
Problem Solving:	Instructional programs from pre-kindergarten through grade 12 should enable all students to build new mathematical knowledge through problem solving, solve problems that arise in mathematics and in other contexts, apply and adapt a variety of appropriate strategies to solve problems, and monitor and reflect on the process of mathematical problem solving
Reasoning and Proof:	Instructional programs from pre-kindergarten through grade 12 should enable all students to recognize reasoning and proof as fundamental aspects of mathematics, make and investigate mathematical conjectures, and select and use various types of reasoning and methods of proof.
Connections:	Instructional programs from pre-kindergarten through grade 12 should enable all students to recognize and apply mathematics in contexts outside of mathematics.
Number and Operations:	Instructional programs from pre-kindergarten through grade 12 should enable all students to compute fluently and make reasonable estimates.
Communication:	Instructional programs from pre-kindergarten through grade 12 should enable all students to communicate their mathematical thinking coherently and clearly to peers, teachers, and others.

Standards for the English Language Arts

Standard 4:	Students adjust their use of spoken, written, and visual language (e.g. conventions, style, vocabulary) to communicate effectively with a variety of audiences and for different purposes.

Performance Objectives

It is expected that students will:

- Use a seven-segment display in a combinational logic design to display alpha/numeric values.
- Select the correct current limiting resistor and properly wire both common cathode and common anode seven-segment displays.

- Follow a formal design process to translate a set of design specifications for a design containing multiple outputs into a functional combinational logic circuit.

- Design AOI, NAND, & NOR solutions for a logic expression and select the solution that uses the least number of ICs to implement.

- Use Circuit Design Software (CDS) and Digital Logic Board (DLB) to simulate and prototype AOI, NAND, & NOR logic circuits.

Assessment

Explanation

- Students will explain why design options of a project are determined by criteria and constraints.

Application

- Students will demonstrate and explain to another student how their date of birth problem works.

Empathy

- Students will discuss in their engineering notebook concerns they may have for the environment regarding electronic components.

Essential Questions

1. What is the relationship between the resistor value used, the amount of current flowing, and the brightness of a segment of seven-segment display.
2. Why is it more difficult to design logic circuits with NAND logic or NOR logic than it is with straightforward AOI logic, in terms of circuit implementation.
3. Why does a logic expression require fewer ICs to implement if NAND logic or NOR logic is used than would be required if AOI logic were used.
4. What are the steps in the design process of converting a set of design specifications, containing multiple outputs, into a functional combinational logic circuit?
5. When compared to a design with a single output, is the process different for multiple outputs? Explain.

Key Terms

Common Anode Display	A seven-segment LED display where the anodes of all the LEDs are connected to the circuit supply voltage. Each segment is illuminated by a logic LOW at its cathode.
Common Cathode Display	A seven-segment display in which the cathodes of all the LEDs are connected together and grounded. A logic HIGH illuminates a segment when applied to its anode.
Datasheet	A printed specification giving details of the pin configuration, electrical properties, and mechanical profile of an electronic device.
Design Specifications	A detailed description, especially one providing information needed to make, build, or produce something.
Seven-Segment	An array of seven independently controlled light-emitting

Display	diodes (LED) or liquid crystal display (LCD) elements, shaped like a figure 8, which can be used to display decimal digits and other characters by turning on the appropriate elements.

Day-by-Day Plans

Time: 9 days

NOTE: In preparation for teaching, it is strongly recommended that the teacher read the **Lesson 2.3 Teacher Notes** for this lesson. All Circuit Design Software (CDS) files for this lesson can be found in the **CDS Files** folder.

Day 1: Lesson Overview and Introduction to Seven-Segment Displays

- The teacher will present **Concepts**, **Essential Questions**, and **Key Terms** in order to provide a lesson overview.
- The teacher will present **Seven-Segment Displays.ppt**.
- Students will take notes in their engineering journals.
- The teacher will distribute and introduce **Activity 2.3.1 Seven-Segment Displays.**
- Students will work on Activity 2.3.1 Seven-Segment Displays.
- The teacher will assess student work using **Activity 2.3.1 Seven-Segment Displays Answer Key.**
- Optional: After the key terms have been introduced, the teacher may choose to distribute **Lesson 2.3 Key Term Crossword** for homework.

6. Day 3 – 8: Date of Birth Design Problem

- The teacher will review the *Combinational Logic Design Process (v1)* flow chart.
- The teacher will present **Date of Birth Design Problem.ppt**.
- Students will take notes in their engineering journals.
- The teacher will distribute and introduce **Problem 2.3.2 Date of Birth.**
- Assessed by completion of working date of birth
- Students will work on Problem 2.3.2 Date of Birth.
- The teacher will assist the students as needed.

7. Day 9: Lesson Review

- The teacher will collect the students' *Date of Birth* reports.
- Using the **Project 2.3.2 Date of Birth Answer Key** as a guide, the teacher will review the results

with the class to ensure that each student understands the process and has obtained the correct results.

- The teacher will review the lesson's **Essential Questions.**

- Students will work in small groups (2-4) to answer the lesson's essential questions. Each group will be assigned one essential question to discuss, formulate a response for, and present to the class. Note: The intent of this activity is to give closure to the lesson's topics and to have the students reflect back on the underlying concepts covered in the lesson's activities, projects, and problems.

- Students will take notes in their journal.

Instructional Resources

Presentations

Seven-Segment Displays

Date of Birth Design Problem

Word Documents

Lesson 2.3 Key Term Crossword

Activity 2.3.1 Seven-Segment Displays

Problem 2.3.2 Date of Birth

Answer Keys and Rubrics

Lesson 2.3 Key Term Crossword Answer Key

Activity 2.3.1 Seven-Segment Displays Answer Key

Problem 2.3.2 Date of Birth Answer Key

Teacher Guidelines

Lesson 2.3 Teacher Notes

Reference Sources

Dueck, R. & Reid, K. (2008). Introduction to digital electronics. Clifton Park, NY: Thompson Delmar Learning.

Floyd, Thomas (2006). Digital Fundamentals. Upper Saddle River, NY Pearson Education.

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Tokeim, R. L. (2003). Digital electronics principles and applications. Columbus, OH: Glencoe/McGraw-Hill.

MSN Encarta (March 2008). *Dictionary*. Retrieved March 19. 2008 from http://encarta.msn.com/dictionary_1861711433/specification.html

Lesson 2.4 Specific Combinational Logic Curcuits & Miscellaneous Topics

Preface

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.

Concepts

1. An understanding of the hexadecimal and octal number systems and their relationship to the decimal number system is necessary for comprehension of digital electronics.
2. XOR and XNOR gates can be used to implement combinational logic circuits, but their primary intended purpose is for implementing binary adder circuits.
3. The addition of two binary numbers of any bit length can be accomplished by cascading one half-adder with one or more full adders.
4. Multiplexer/de-multiplexer pairs are most frequently used when a single connection must be shared between multiple inputs and multiple outputs.
5. Electronics displays that use multiple seven-segment display utilize de-multiplexers to significantly reduce the amount of power required to operate the display.
6. Two's complement arithmetic is the most commonly used method for handling negative numbers in digital electronics.

Standards and Benchmarks Addressed

Standards for Technological Literacy

Standard 1: Students will develop an understanding of the characteristics and scope of technology.

BM J:	The nature and development of technological knowledge and processes are functions of the setting.
BM K:	The rate of technological development and diffusion is increasing rapidly.
BM L:	Inventions and innovations are the results of specific, goal-directed research.
BM M:	Most development of technologies these days is driven by the profit motive and the market.

Standard 2: Students will develop an understanding of the core concepts of technology.

BM W:	Systems' thinking applies logic and creativity with appropriate compromises in complex real-life problems.
BM X:	Systems, which are the building blocks of technology, are embedded within larger technological, social, and environmental systems.
BM Y:	The stability of a technological system is influenced by all of the components in the system especially those in the feedback loop.
BM Z:	Selecting resources involves trade-offs between competing values, such as availability, cost, desirability, and waste.
BM AA:	Requirements involve the identification of the criteria and constraints of a product or system and the determination of how they affect the final design and development.
BM BB:	Optimization is an on going process or methodology of designing or making a product and is dependent on criteria and constraints.
BM CC:	New technologies create new processes.
BM DD:	Quality control is a planned process to ensure that a product, service, or system meets established criteria.
BM EE:	Management is the process of planning, organizing, and controlling work.
BM FF:	Complex systems have many layers of controls and feedback loops to provide information.

Standard 10: Students will develop an understanding of the role of troubleshooting, research and development, invention and innovation, and experimentation in problem solving.

BM I:	Research and development is a specific problem-solving approach that is used intensively in business and industry to prepare devices and systems for the marketplace.
BM J:	Technological problems must be researched before they can be solved.
BM K:	Not all problems are technological, and not every problem can be solved using technology.
BM L:	Many technological problems require a multidisciplinary approach.

Standard 12: Students will develop the abilities to use and maintain technological products and systems.

BM L:	Document processes and procedures and communicate them to different audiences using appropriate oral and written techniques.
BM M:	Diagnose a system that is malfunctioning and use tools, materials, machines, and knowledge to repair it.
BM N:	Troubleshoot, analyze, and maintain systems to ensure safe and

	proper function and precision.
BM O:	Operate systems so that they function in the way they were designed.
BM P:	Use computers and calculators to access, retrieve, organize and process, maintain, interpret, and evaluate data and information in order to communicate.

Standard 16: Students will develop an understanding of and be able to select and use energy and power technologies.

BM J:	Energy cannot be created or destroyed; however, it can be converted from one form to another.
BM K:	Energy can be grouped into major forms: thermal, radiant, electrical, mechanical, chemical, nuclear, and others.
BM M:	Energy resources can be renewable or nonrenewable.
BM N:	Power systems must have a source of energy, a process, and loads.

Standard 17: Students will develop an understanding of and be able to select and use information and communication technologies.

BM L:	Information and communication technologies include the inputs, processes, and outputs associated with sending and receiving information.
BM M:	Information and communication systems allow information to be transferred from human to human, human to machine, machine to human, and machine to machine.
BM N:	Information and communication systems can be used to inform, persuade, entertain, control, manage, and educate.
BM O:	Communication systems are made up of source, encoder, transmitter, receiver, decoder, storage, retrieval, and destination.
BM P:	There are many ways to communicate information, such as graphic and electronic means.
BM Q:	Technological knowledge and processes are communicated using symbols, measurement, conventions, icons, graphic images, and languages that incorporate a variety of visual, auditory, and tactile stimuli.

National Science Education Standards

Standard K-12: Unifying Concepts and Processes: As a result of activities in grades K-12, all students should develop understanding and abilities aligned with the following concepts and processes;

- Systems, order, and organization
- Evidence, models, and explanation
- Form and function

Standard E: Science and Technology: As a result of activities in grades 9-12, all students should develop

- Understandings about science and technology

Principles and Standards for School Mathematics

Number and Operations:	Instructional programs from pre-kindergarten through grade 12 should enable all students to; understand numbers, ways of representing numbers, relationships among numbers, and number systems; understand meanings of operations and how they relate to one another; compute fluently and make

	reasonable estimates.
Algebra:	Instructional programs from pre-kindergarten through grade 12 should enable all students to; understand patterns, relations, and functions; represent and analyze mathematical situations and structures using algebraic symbols; use mathematical models to represent and understand quantitative relationships; analyze change in various contexts.
Measurement:	Instructional programs from pre-kindergarten through grade 12 should enable all students to; understand measurable attributes of objects and the units, systems, and processes of measurement; apply appropriate techniques, tools, and formulas to determine measurements.
Data Analysis and Probability:	Instructional programs from pre-kindergarten through grade 12 should enable all students to; formulate questions that can be addressed with data and collect, organize, and display relevant data to answer them; select and use appropriate statistical methods to analyze data; develop and evaluate inferences and predictions that are based on data; understand and apply basic concepts of probability.
Problem Solving:	Instructional programs from pre-kindergarten through grade 12 should enable all students to; build new mathematical knowledge through problem solving; solve problems that arise in mathematics and in other contexts; apply and adapt a variety of appropriate strategies to solve problems; monitor and reflect on the process of mathematical problem solving.
Reasoning and Proof:	Instructional programs from pre-kindergarten through grade 12 should enable all students to; recognize reasoning and proof as fundamental aspects of mathematics; make and investigate mathematical conjectures; develop and evaluate mathematical arguments and proofs; select and use various types of reasoning and methods of proof.
Communication:	Instructional programs from pre-kindergarten through grade 12 should enable all students to; organize and consolidate their mathematical thinking through communication; communicate their mathematical thinking coherently and clearly to peers, teachers, and others; analyze and evaluate the mathematical thinking and strategies of others; use the language of mathematics to express mathematical ideas precisely.
Connections:	Instructional programs from pre-kindergarten through grade 12 should enable all students to; recognize and use connections among mathematical ideas; understand how mathematical ideas interconnect and build on one another to produce a coherent whole; recognize and apply mathematics in contexts outside of mathematics.
Representation:	Instructional programs from pre-kindergarten through grade 12 should enable all students to; create and use representations to organize, record, and communicate mathematical ideas; select, apply, and translate among mathematical representations to solve problems; use representations to model and interpret physical, social, and mathematical phenomena.

Standards for English Language Arts

Standard 4: Students adjust their use of spoken, written, and visual language (e.g. conventions, style, vocabulary) to communicate effectively with a variety of audiences and for different purposes.

Standard 12: Students use spoken, written and visual language to accomplish their own purposes (e.g. for learning, enjoyment, persuasion, and the exchange of information).

Performance Objectives

It is expected that students will:

- Convert numbers between the hexadecimal or octal number systems and the decimal number system.
- Use XOR and XNOR gates to design binary half-adders and full-adders.
- Use SSI and MSI gates to design and implement binary adders.
- Design electronics displays using seven-segment displays that utilize de-multiplexers.
- Use the two's complement process to add and subtract binary numbers.
- Use Circuit Design Software (CDS) and a Digital Logic Board (DLB) to simulate and prototype specific combinational logic circuits.

Assessment

Explanation

- Students will explain the advantages and disadvantages of combinational logic circuits.

Interpretation

- Students observe a fellow classmate and hypothesize its intended function of the logic circuit.

Perspective

- Having the advantage of hind-sight, at the conclusion of the design experience students will reflect on what they would have done differently if the project were to be repeated.

Essential Questions

1. 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?
2. In terms of circuit complexity, what is the advantage of implementing binary half and full adders with XOR gates over other logic gates?
3. Describe how the addition of two binary numbers of any bit length can be accomplished by cascading one half-adder with one or more full adders.
4. What is the basic operation of digital multiplexers and de-multiplexers?

5. Explain how digital de-multiplexers are used to significantly reduce the amount of power required to operate the electronics displays that use multiple seven-segment display.

6. What are the steps in the two's complement process for adding or subtracting two binary numbers?

Key Terms

De-multiplexer	A circuit that uses a binary decoder to direct a digital signal from a single source to one of several destinations.
Encoder	A digital circuit that produces an output code depending on which of its inputs is activated.
Exclusive-NOR (XNOR) Circuit	Two-input logic circuit that produces a high output only when the inputs are equal.
Exclusive-OR (XOR) Circuit	Two-input logic circuit that produces a high output only when the inputs are different.
Full Adder	Logic circuit with three inputs and two outputs. The inputs are a carry bit (C_{IN}) from a previous stage, a bit from the augend, and a bit from the addend, respectively. The outputs are the sum bit and the carry-out bit (C_{OUT}) produced by the addition of the bit from the addend with the bit from the augend and C_{IN}.
Half Adder	Logic circuit with two inputs and two outputs. The inputs are a bit from the augend and a bit from the addend. The outputs are the sum bit produced by the addition of the bit from the addend with the bit from the augend and the resulting carry (C_{OUT}) bit, which will be added to the next stage.
Hexadecimal Number System	Base-16 number system. Hexadecimal numbers are written with sixteen digits, 0-9 and A-F, with power-of-16 positional multipliers.
Multiplexer	A circuit that directs one of several digital signals to a single output, depending on the states of several select inputs.
Octal Number System	A number system that has a base of 8; digits from 0 to 7 are used to express an octal number.
Seven-Segment Display	An array of seven independently controlled light-emitting diodes (LED) or liquid crystal display (LCD) elements, shaped like a figure-8, which can be used to display decimal digits and other characters by turning on the appropriate elements.
Signed Binary Number	A binary number of fixed length whose sign is represented by one bit, usually the most significant bit, and whose magnitude is represented by the remaining bits.
Sign Bit	A binary bit that is added to the leftmost position of a binary number to indicate whether that number represents a positive or a negative quantity.
1's Complement	A form of signed binary notation in which negative numbers are created by complementing all bits of a number, including the sign bit.

2's Complement	A form of signed binary notation in which negative numbers are created by adding 1 to the 1's complement form of the number.

Day-by-Day Plans

Time: 8 days

NOTE: In preparation for teaching, it is strongly recommended that the teacher read **Lesson 2.4 Teacher Notes**. All Circuit Design Software (CDS) files for this lesson can be found in the **CDS Files** folder.

Day 1: Lesson Overview and Octal & Hexadecimal Number Systems

- The teacher will present **Concepts**, **Essential Questions**, and **Key Terms** in order to provide a lesson overview.
- The teacher will present **Octal & Hexadecimal Number Systems.ppt.**
- The teacher will distribute and introduce **Activity 2.4.1 Octal & Hexadecimal Number Systems.**
- Students will take notes in their engineering journals.
- Students will work on Activity 2.4.1 Octal & Hexadecimal Number Systems.
- The teacher will assist the students as needed.
- The teacher will assess student work using **Activity 2.4.1 Octal & Hexadecimal Number Systems Answer Key.**
- Optional: After the key terms have been introduced, the teacher may choose to distribute **Lesson 2.4 Key Term Crossword** for homework.

Day 2-3: XOR, XNOR & Binary Adders

- The teacher will present **XOR, XNOR, & Binary Adders.ppt.**
- The teacher will distribute and introduce **Activity 2.4.2 XOR, XNOR, & Binary Adders.**
- Students will take notes in their engineering journals.
- Students will work on Activity 2.4.2 XOR, XNOR & Binary Adders.
- The teacher will assist the students as needed.
- The teacher will assess student work using **Activity 2.4.2 XOR, XNOR, & Binary Adders Answer Key.**

Day 4-5: 2's Complement Arithmetic

- The teacher will present **Two's Complement Arithmetic.ppt.**

- The teacher will distribute and introduce **Activity 2.4.3 Two's Complement Arithmetic.**
- Students will take notes in their engineering journals.
- Students will work on Activity 2.4.3 Two's Complement Arithmetic.
- The teacher will assist the students as needed.
- The teacher will assess student work using **Activity 2.4.3 Two's Complement Arithmetic Answer Key.**

Day 6-7: Multiplexers & De-multiplexers

- The teacher will present **Multiplexers & De-multiplexers.ppt.**
- NOTE: The following video should accompany the above presentation in slide 16. **CIAO video**
- The teacher will distribute and introduce **Activity 2.4.4 Multiplexers & De-multiplexers.**
- Students will take notes in their engineering journals.
- Students will work on Activity 2.4.4 Multiplexers & De-multiplexers.
- The teacher will assist the students as needed.
- The teacher will assess student work using **Activity 2.4.4 Multiplexers & De-multiplexers Answer Key**

Day 8: Lesson Review

- The teacher will review the lesson's essential questions.
- Students will work in small groups (2-4) to answer the lesson's essential questions. Each group will be assigned one essential question to discuss, formulate a response for, and present to the class. The intent of this activity is to give closure to the lesson's topics and to have the students reflect back on the underlying concepts addressed in the lesson's activities, projects, and problems.
- Students will take notes in their engineering journals.

Instructional Resources

Presentations

Octal & Hexadecimal Number Systems

XOR, XNOR, & Binary Adders

Two's Complement Arithmetic

Multiplexers & De-multiplexers

Word Documents

Lesson 2.4 Key Term Crossword
Activity 2.4.1 Octal & Hexadecimal Number Systems
Activity 2.4.2 XOR, XNOR, & Binary Adders
Activity 2.4.3 Two's Complement Arithmetic
Activity 2.4.4 Multiplexers & De-multiplexers

Answer Keys and Rubrics

Lesson 2.4 Key Term Crossword Answer Key
Activity 2.4.1 Octal & Hexadecimal Number Systems Answer Key
Activity 2.4.2 XOR, XNOR, & Binary Adders Answer Key
Activity 2.4.3 Two's Complement Arithmetic Answer Key
Activity 2.4.4 Multiplexers & De-multiplexers Answer Key

Teacher Guidelines

Lesson 2.4 Teacher Notes

Reference Sources

Dueck, R., & Reid, K. (2008). Introduction to digital electronics. Clifton Park, NY: Thompson Delmar Learning.

Tocci, R., Widmer, N., & Moss, G. (2007). Digital systems: Principles and applications. Upper Saddle River, NJ: Pearson Education.

Tokeim, R. L. (2003). Digital electronics principles and applications. Columbus, OH: Glencoe/McGraw-Hill.

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National Research Council (NRC). (1996). National science education standards. Washington, D. C.: National Academy Press.

Lesson 2.5 Programmable Logic: Combinational

Preface

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.

Concepts

1. Engineers and technicians use Circuit Design Software to enter and synthesize digital designs into programmable logic devices.
2. Programmable logic devices can be used to implement combinational logic circuits.
3. Circuits implemented with programmable logic devices require significantly less wiring than discrete logic, but they typically require a dedicated printed circuit board to hold the device.
4. Programmable logic devices can be used to implement any combinational logic circuits but are best suited for larger, more complex designs.

Standards and Benchmarks Addressed

Standards for Technological Literacy

Standard 1: Students will develop an understanding of the characteristics and scope of technology.

BM J: The nature and development of technological knowledge and processes are functions of the setting.

BM K: The rate of technological development and diffusion is increasing rapidly.

BM M: Most development of technologies these days is driven by the profit motive and the market.

Standard 2: Students will develop an understanding of the core concepts of technology.

BM W: Systems' thinking applies logic and creativity with appropriate compromises in complex real-life problems.

BM X: Systems, which are the building blocks of technology, are embedded within larger technological, social, and environmental systems.

BM Y: The stability of a technological system is influenced by all of the components in the system especially those in the feedback loop.

BM Z: Selecting resources involves trade-offs between competing values, such as availability, cost, desirability, and waste.

BM AA: Requirements involve the identification of the criteria and constraints of a product or system and the determination of how they affect the final design and development.

BM BB: Optimization is an on going process or methodology of designing or making a product and is dependent on criteria and constraints.

BM CC: New technologies create new processes.

BM DD: Quality control is a planned process to ensure that a product, service, or system meets established criteria.

BM EE: Management is the process of planning, organizing, and controlling work.

BM FF: Complex systems have many layers of controls and feedback loops to provide information.

Standard 3: Students will develop an understanding of the relationships among technologies and the connections between technology and other fields of study.

BM G: Technology transfer occurs when a new user applies an existing innovation developed for one purpose in a different function

BM H: Technological innovation often results when ideas, knowledge, or skills are shared within a technology, among technologies, or across other fields.

BM J: Technological progress promotes the advancement of science and mathematics. Likewise, progress in science and mathematics leads to advances in technology.

Standard 4: Students will develop an understanding of the cultural, social, economic, and political effects of technology.

BM H: Changes caused by the use of technology can range from gradual to rapid and from subtle to obvious.

BM I: Making decisions about the use of technology involves weighing the trade-offs between the positive and negative effects.

BM J: Ethical considerations are important in the development, selection, and use of technologies.

BM K: The transfer of a technology from one society to another can cause cultural, social, economic, and political changes affecting both societies to varying degrees.

Standard 12: Students will develop the abilities to use and maintain technological products and systems.

BM L: Document processes and procedures and communicate them to different audiences using appropriate oral and written techniques.

BM O: Operate systems so that they function in the way they were designed.

Standard 17: Students will develop an understanding of and be able to select and use information and communication technologies.

BM L: Information and communication technologies include the inputs,

	processes, and outputs associated with sending and receiving information.
BM M:	Information and communication systems allow information to be transferred from human to human, human to machine, machine to human, and machine to machine.
BM N:	Information and communication systems can be used to inform, persuade, entertain, control, manage, and educate.
BM O:	Communication systems are made up of source, encoder, transmitter, receiver, decoder, storage, retrieval, and destination.
BM P:	There are many ways to communicate information, such as graphic and electronic means.
BM Q:	Technological knowledge and processes are communicated using symbols, measurement, conventions, icons, graphic images, and languages that incorporate a variety of visual, auditory, and tactile stimuli.

National Science Education Standards

Standard K-12: Unifying Concepts and Processes: As a result of activities in grades K-12, all students should develop understanding and abilities aligned with the following concepts and processes;

- Systems, order, and organization
- Evidence, models, and explanation
- Form and function

Standard E: Science and Technology: As a result of activities in grades 9-12, all students should develop

- Understandings about science and technology

Principles and Standards for School Mathematics

Number and Operations:	Instructional programs from pre-kindergarten through grade 12 should enable all students to; understand numbers, ways of representing numbers, relationships among numbers, and number systems; understand meanings of operations and how they relate to one another; compute fluently and make reasonable estimates.
Algebra:	Instructional programs from pre-kindergarten through grade 12 should enable all students to; understand patterns, relations, and functions; represent and analyze mathematical situations and structures using algebraic symbols; use mathematical models to represent and understand quantitative relationships; analyze change in various contexts.
Measurement:	Instructional programs from pre-kindergarten through grade 12 should enable all students to; understand measurable attributes of objects and the units, systems, and processes of measurement; apply appropriate techniques, tools, and formulas to determine measurements.
Data Analysis and Probability:	Instructional programs from pre-kindergarten through grade 12 should enable all students to; formulate questions that can be addressed with data and collect, organize, and display relevant data to answer them; select and use appropriate statistical

	methods to analyze data; develop and evaluate inferences and predictions that are based on data; understand and apply basic concepts of probability.
Problem Solving:	Instructional programs from pre-kindergarten through grade 12 should enable all students to; build new mathematical knowledge through problem solving; solve problems that arise in mathematics and in other contexts; apply and adapt a variety of appropriate strategies to solve problems; monitor and reflect on the process of mathematical problem solving.
Reasoning and Proof:	Instructional programs from pre-kindergarten through grade 12 should enable all students to; recognize reasoning and proof as fundamental aspects of mathematics; make and investigate mathematical conjectures; develop and evaluate mathematical arguments and proofs; select and use various types of reasoning and methods of proof.
Communication:	Instructional programs from pre-kindergarten through grade 12 should enable all students to; organize and consolidate their mathematical thinking through communication; communicate their mathematical thinking coherently and clearly to peers, teachers, and others; analyze and evaluate the mathematical thinking and strategies of others; use the language of mathematics to express mathematical ideas precisely.
Connections:	Instructional programs from pre-kindergarten through grade 12 should enable all students to; recognize and use connections among mathematical ideas; understand how mathematical ideas interconnect and build on one another to produce a coherent whole; recognize and apply mathematics in contexts outside of mathematics.
Representation:	Instructional programs from pre-kindergarten through grade 12 should enable all students to; create and use representations to organize, record, and communicate mathematical ideas; select, apply, and translate among mathematical representations to solve problems; use representations to model and interpret physical, social, and mathematical phenomena.

Standards for English Language Arts

Standard 3:	Students apply a wide range of strategies to comprehend, interpret, evaluate, and appreciate texts. They draw on their prior experience, their interactions with other readers and writers, their knowledge of word meaning and other texts, their word identification strategies, and their understanding of textual features (e.g. sound-letter correspondence, sentence structure, context, graphics).
Standard 4:	Students adjust their use of spoken, written, and visual language (e.g. conventions, style, vocabulary) to communicate effectively with a variety of audiences and for different purposes.
Standard 5:	Students employ a wide range of strategies as they write and use different writing process elements appropriately to communicate with different audiences and for a variety of purposes.
Standard 12:	Students use spoken, written and visual language to accomplish their own purposes (e.g. for learning, enjoyment, persuasion,

and the exchange of information).

Performance Objectives

It is expected that students will:

- Design combinational logic circuits using a programmable logic device.
- Be able to cite the advantages and disadvantages of programmable logic devices over discrete logic gates.
- Use Circuit Design Software (CDS) and a Digital Logic Board (DLB) to simulate and prototype combinational logic designs implemented with programmable logic.

Assessment

Explanation

- Explain to your teacher how a programmable logic device works.

Application

- What are the types of daily used products that have benefited from the programmable technology used in this lesson?
- Students will verbally present, to their teacher, the stages of the design process that was covered during the Date of Birth problem.

Essential Questions

1. What is the design process for using a Circuit Design Software to enter and synthesize combinational logic into a programmable logic device?
2. Describe how programmable logic devices can be used to implement combinational logic circuits.
3. List the advantages and disadvantages of using a programmable logic device over discrete logic gates.
4. Why are programmable logic devices best suited for larger, more complex designs?

Key Terms

Complex PLD (CPLD)	A digital device consisting of several programmable sections with internal interconnections between the sections.
Compiler	The process used by CPLD design software to interpret design information (such as a schematic or text file) and create required programming information for a CPLD.
Design Entry	The process of using software tools to describe the design requirements of a PLD. Design entry can be done by entering a schematic or a text file that describes the required digital function.

Field Programmable Gate Array (FPGA)	Class of PLDs that contain an array of more complex logic cells that can be very flexibly interconnected to implement high-level logic circuits.
Fitting	Assigning internal PLD circuitry, and input and output pins, to a PLD design.
Integrated Circuit (IC)	An electronic circuit having many components, such as transistors, diodes, resistors, and capacitors, in a single package.
JTAG Port	A four-wire interface specified by the Joint Test Action Group (JTAG) used for loading test data or programming data into a PLD installed in a circuit.
JEDEC	Joint Electron Device Engineering Council.
JEDEC File	An industry standard form of text file indicating which fuses are blown and which are intact in a programmable logic device.
JTAG	Joint Test Action Group. A standards body that developed the format for testing and programming devices while they are installed in a system.
Programmable Logic Device (PLD)	Digital integrated circuit that can be programmed by the user to implement any digital logic function.
Programming	Transferring design information from the computer running PLD design software to the actual PLD chip.
Schematic Entry	A technique of entering CPLD design information by using a CAD (computer aided design) tool to draw a logic circuit as a schematic. The schematic can then be interpreted by design software to generate programming information for the CPLD.
Simple PLD (SPLD)	A PLD with a few hundred logic gates and possibly a few programmable macrocells available.
Target Device	The specific PLD for which a digital design is intended.
TCK	Test Clock. The JTAG signal that drives the JTAG downloading process from one state to the next.
TDI	Test Data In. In a JTAG port, the serial input data to a device.
TDO	Test Data Out. In a JTAG port, the serial output data from a device.
TMS	Test Mode Select. The JTAG signal that controls the downloading of test or programming data.

Day-by-Day Plans

Time: 9 days

NOTE: In preparation for teaching, it is strongly recommended that the teacher read the **Teacher Notes** for this lesson. All Circuit Design Software (CDS) files for this lesson can be found in the **CDS Files** folder.

Day 1 – 3: Lesson Overview & Combinational Logic Design Process

- The teacher will present **Concepts**, **Essential Questions**, and **Key Terms** in order to provide a lesson overview.

- The teacher will present **Comb Logic Design Process (v3)** presentation.

- The teacher will distribute and introduce **Activity 2.5.1 Programming Tutorial**
- Students will take notes in their engineering notebooks/portfolios.
- Students will work on Activity 2.5.1 Design Tool Tutorial.
- The teacher will assist the students as needed.
- Optional: After the key terms have been introduced, the teacher may choose to distribute **Lesson 2.5 Key Term Crossword** for homework.

Day 4 – 5: Date of Birth (DOB) PLD Project

- The teacher will distribute and introduce **Project 2.5.2 Date of Birth with a PLD.**
- Students will take notes in their engineering notebooks/portfolios.
- Students will work on Project 2.5.2 DOB PLD Implementation.
- The teacher will assist the students as needed.
- The teacher will assess student work using **Project 2.5.2 DOB PLD Implementation Answer Key**.

Day 6 – 8: PLD Design Problem: Copier Paper Jam

- The teacher will present **Copier Jam Detector** presentation.
- Students will take notes in their engineering notebooks/portfolios.
- The teacher will distribute and introduce **Problem 2.5.3 Copier Jam Detector.**
- Students will work on Problem 2.5.3 Copier Paper Jam.
- The teacher will assist the students as needed.

Day 9: Lesson Review

- The teacher will collect the student reports on the **Copier Paper Jam design.**
- Using the **Problem 2.5.3 Copier Paper Jam Answer Key** as a guide, the teacher will review the results with the class to ensure that each student understands the process and has obtained the correct results.
- The teacher will review the lesson's **Essential Questions**.
- Students will work in small groups (2-4) to answer the lesson's essential questions. Each group will be assigned one essential question that they must discuss, formulate a response for, and present to the class. The intent of this activity is to give closure to the lesson's topics and to encourage students to reflect back on the underlying concepts covered in the lesson's activities, projects, and problems.
- Students will take notes in their engineering notebooks/portfolios.

Instructional Resources

Presentations

Comb Logic Design Process (v3)

Copier Jam Detector

Word Documents

Lesson 2.5 Key Term Crossword

Activity 2.5.1 Programming Tutorial

Project 2.5.2 Date of Birth with PLD

Problem 2.5.3 Copier Jam Detector

Answer Keys and Rubrics

Lesson 2.5 Key Term Crossword Answer Key

Project 2.5.2 DOB PLD Implementation Answer Key

Problem 2.5.3 Copier Paper Jam Answer Key

Teacher Guidelines

Lesson 2.5 Teacher Notes

Reference Sources

Dueck, R., & Reid, K. (2008). *Introduction to digital electronics*. Clifton Park, NY: Thompson Delmar Learning.

Tocci, R., Widmer, N., & Moss, G. (2007). *Digital systems: Principles and applications.* Upper Saddle River, NJ: Pearson Education.

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Unit 3 – Sequential Logic

Preface

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.

Lesson Documents

Lesson 3.1: Latches & Flip-Flops
Lesson 3.2: Asynchronous Counter
Lesson 3.3: Synchronous Counters
Lesson 3.4: Introduction to State-Machine Design

Concepts

1. The flip-flop and transparent latch are logic devices that have the capability to store data and can act as a memory device.
2. Flip-flops and transparent latches have both synchronous and asynchronous inputs.
3. Flip-flops can be used to design single event detection circuits, data synchronizers, shift registers, and frequency dividers.
4. 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.
5. Asynchronous counters can be implemented using small scale integrated (SSI) and medium scale integrated (MSI) logic gates.
6. Asynchronous counters can be implemented with either D or J/K flip-flops.
7. Up counters, down counters, and modulus counters all can be implemented using the asynchronous counter method.
8. Synchronous counters, also called parallel counters, are characterized by an external signal clocking all flip-flops simultaneously.
9. Synchronous counters can be implemented using small scale integrated (SSI) and medium scale integrated (MSI) logic gates.
10. Synchronous counters can be implemented with either D or J/K flip-flops.
11. Up counters, down counters, and modulus counters all can be implemented using the synchronous counter method.
12. A state machine is a circuit design that sequences through a set of predetermined states controlled by a clock and other input signals.

13. State machines are used to control common everyday devices such as elevator doors, traffic lights, and combinational (electronics) locks.
14. State machines can be implemented in one of two variations: Mealy or Moore.
15. State machines can be implemented using small and medium scale integrated gates and programmable logic devices.

Essential Questions

Lesson 3.1: Latches & Flip-Flops

1. What is the basic function of a flip-flop and transparent latch?
2. What functions do the synchronous and asynchronous inputs serve on flip-flops and transparent latches? Provide an example of each.
3. What are some of the typical applications of flip-flops? Describe how each of these applications work.

Lesson 3.2: Asynchronous Counter

1. 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.
2. Asynchronous counters can be implemented using small scale integrated (SSI) and medium scale integrated (MSI) logic gates.
3. Asynchronous counters can be implemented with either D or J/K flip-flops.
4. Up counters, down counters, and modulus counters all can be implemented using the asynchronous counter method.

Lesson 3.3: Synchronous Counters

1. What is another name for synchronous counters?
2. How are the clock inputs of a synchronous counter's flip-flops connected?
3. What is the process for designing synchronous counters implemented using discrete D and J/K flip-flops and medium scale integrated (MSI) circuit counters?
4. What are the differences between a synchronous counter and a synchronous modulus counter?
5. What is the process for designing up, down, and modulus synchronous counters?

Lesson 3.4: Introduction to State-Machine Design

1. What is the basic function of a state machine?
2. What are some common everyday devices that are controlled by state machines?
3. What are the two variations of state machine design, and what are the advantages of each.
4. What type of logic gates are used to implement state machines?

Unit Evaluation

The Essential Questions and Conclusion questions at the end of each activity may be used along with the Assessment suggestions provided in each lesson to develop summative assessment tools, such as tests or end of unit projects.

Lesson 3.1 Flip-Flops and Latches

Preface

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.

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.

In this lesson we will 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, we 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.

Concepts

1. The flip-flop and transparent latch are logic devices that have the capability to store data and can act as a memory device.
2. Flip-flops and transparent latches have both synchronous and asynchronous inputs.
3. Flip-flops can be used to design single event detection circuits, data synchronizers, shift registers, and frequency dividers.

Standards and Benchmarks Addressed

Standards for Technological Literacy

Standard 2: Students will develop an understanding of the core concepts of technology.

BM W: Systems' thinking applies logic and creativity with appropriate compromises in complex real-life problems.

BM X: Systems, which are the building blocks of technology, are embedded within larger technological, social, and environmental systems.

BM Y: The stability of a technological system is influenced by all of the components in the system especially those in the feedback loop.

BM FF: Complex systems have many layers of controls and feedback loops to provide information.

Standard 9: Students will develop an understanding of engineering design.

BM K: A prototype is a working model used to test a design concept by making actual observations and necessary adjustments.

Standard 10: Students will develop an understanding of the role of troubleshooting, research and development, invention and innovation, and experimentation in problem solving.

BM I: Research and development is a specific problem-solving approach that is used intensively in business and industry to prepare devices and systems for the marketplace.

BM J: Technological problems must be researched before they can be solved.

Standard 12: Students will develop the abilities to use and maintain technological products and systems.

BM L: Document processes and procedures and communicate them to different audiences using appropriate oral and written techniques.

BM M: Diagnose a system that is malfunctioning and use tools, materials, machines, and knowledge to repair it.

BM N: Troubleshoot, analyze, and maintain systems to ensure safe and proper function and precision.

BM O: Operate systems so that they function in the way they were designed.

BM P: Use computers and calculators to access, retrieve, organize and process, maintain, interpret, and evaluate data and information in order to communicate.

Standard 17: Students will develop an understanding of and be able to select and use information and communication technologies.

BM L: Information and communication technologies include the inputs, processes, and outputs associated with sending and receiving information.

BM M: Information and communication systems allow information to be transferred from human to human, human to machine, machine to human, and machine to machine.

BM N: Information and communication systems can be used to inform, persuade, entertain, control, manage, and educate.

BM O: Communication systems are made up of source, encoder, transmitter, receiver, decoder, storage, retrieval, and destination.

BM P: There are many ways to communicate information, such as graphic and electronic means.

BM Q: Technological knowledge and processes are communicated using symbols, measurement, conventions, icons, graphic images, and languages that incorporate a variety of visual, auditory, and tactile stimuli.

National Science Education Standards

Standard K-12: Unifying Concepts and Processes: As a result of activities in grades K-12, all students should develop understanding and abilities aligned with the following concepts and processes;

- Systems, order, and organization
- Form and function

Standard E: Science and Technology: As a result of activities in grades 9-12, all students should develop

- Understandings about science and technology

Principles and Standards for School Mathematics

Number and Operations:	Instructional programs from pre-kindergarten through grade 12 should enable all students to; understand numbers, ways of representing numbers, relationships among numbers, and number systems; understand meanings of operations and how they relate to one another; compute fluently and make reasonable estimates.
Algebra:	Instructional programs from pre-kindergarten through grade 12 should enable all students to; understand patterns, relations, and functions; represent and analyze mathematical situations and structures using algebraic symbols; use mathematical models to represent and understand quantitative relationships; analyze change in various contexts.
Problem Solving:	Instructional programs from pre-kindergarten through grade 12 should enable all students to; build new mathematical knowledge through problem solving; solve problems that arise in mathematics and in other contexts; apply and adapt a variety of appropriate strategies to solve problems; monitor and reflect on the process of mathematical problem solving.
Connections:	Instructional programs from pre-kindergarten through grade 12 should enable all students to; recognize and use connections among mathematical ideas; understand how mathematical ideas interconnect and build on one another to produce a coherent whole; recognize and apply mathematics in contexts outside of mathematics.
Representation:	Instructional programs from pre-kindergarten through grade 12 should enable all students to; create and use representations to organize, record, and communicate mathematical ideas; select, apply, and translate among mathematical representations to solve problems; use representations to model and interpret physical, social, and mathematical phenomena.

Standards for English Language Arts

Standard 4:	Students adjust their use of spoken, written, and visual language (e.g. conventions, style, vocabulary) to communicate effectively with a variety of audiences and for different purposes.
Standard 12:	Students use spoken, written and visual language to accomplish their own purposes (e.g. for learning, enjoyment, persuasion, and the exchange of information).

Performance Objectives

It is expected that students will:

- Know the schematic symbols and excitation tables for the D and J/K flip-flops.
- Describe the function of the D and J/K flip-flops.
- Describe the function of, and differences between, level sensitive and edge sensitive triggers.

- Describe the function of, and differences between, active high and active low signals.
- Describe the function of, and differences between, a flip-flop's synchronous and asynchronous inputs.
- 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.
- Analyze and design introductory flip-flop applications such as event detection circuits, data synchronizers, shift registers, and frequency dividers.
- Use Circuit Design Software (CDS) and a Digital Logic Board (DLB) to simulate and prototype introductory flip-flop applications.

Assessment

Interpretation

- Students will make journal entries reflecting on their learning and experiences. Example of prompts for the general entries: Write about what you learned in class today. What is something you learned today that you did not understand or know before?

Application

- Students will demonstrate and explain to another student the difference between and active high and active low signals.

Essential Questions

1. What is the basic function of a flip-flop and transparent latch?
2. What functions do the synchronous and asynchronous inputs serve on flip-flops and transparent latches? Provide an example of each.
3. What are some of the typical applications of flip-flops? Describe how each of these applications work.

Key Terms

Asynchronous Counter	Type of counter in which each flip-flop output serves as the clock input signal for the next flip-flop in the chain.
Asynchronous Inputs	Flip-flop inputs that can affect the operation of the flip-flop independent of the synchronous and clock inputs.
Clock	Digital signal in the form of a rectangular pulse train or a square wave.
Clocked D Flip-Flop	Type of flip-flop in which the D (data) input is the synchronous input.
Clocked J-K Flip-Flop	Type of flip-flop in which inputs J and K are the synchronous inputs.
D Latch	Circuit that contains a NAND gate latch and two steering NAND gates.
Duty Cycle (DC)	Fraction of the total period that a digital waveform is in the

	HIGH state. DC = th/T (often expressed as a percentage: % DC = th/Tx100%).
Edge-Sensitive	Manner in which a flip-flop is activated by a signal transition. A flip-flop may be either a positive- or a negative-edge-triggered flip-flop.
Falling Edge	The part of a pulse where the logic level is in transition from a HIGH to a LOW.
Flip-Flop	A sequential circuit based on a latch whose output changes when its CLOCK input receives a pulse.
Frequency	The number of cycles per unit time of a periodic waveform.
Level-Sensitive	Enabled by a logic HIGH or LOW level.
Period	The amount of time required for one complete cycle of a periodic event or waveform.
PRESET	Asynchronous input used to set Q=1 immediately.
Propagation Delays (tPLH/tPHL)	Delay from the time a signal is applied to the time when the output makes its change.
RESET / CLEAR	Asynchronous input used to set Q=0 immediately.
Rising Edge	The part of a pulse where the logic level is in transition from a LOW to a HIGH.
Sequential Logic	Digital circuitry in which the output state of the circuit depends not only on the states of the inputs, but also on the sequence in which they reached their present states.
Shift Register	Digital circuit that accepts binary data from some input source and then shifts these data through a chain of flip-flops one bit at a time.
State Machines	A sequential circuit that advances through several defined states.
Synchronous Counter	Counter in which all of the flip-flops are clocked simultaneously.
Trigger	Input signal to a flip-flop or one-shot that causes the output to change states depending on the conditions of the control signals.

Day-by-Day Plans

Time: 6 days

NOTE: In preparation for teaching, it is strongly recommended that the teacher read the **Lesson 3.1 Teacher Notes.** All Circuit Design Software (CDS) files for this lesson can be found in the **CDS Files** folder.

Day 1 – 2: Lesson Overview and Introduction to Flip-Flops and Latches

- Students will participate in a teacher-led discussion on sequential logic. The discussion will center on common everyday devices that are based on the design principal of sequential logic (the ability to hold or remember data). This will lead directly into the introduction of flip-flops and latches.

- The teacher will present **Concepts**, **Essential Questions**, and **Key Terms** in order to provide a lesson overview.

- The teacher will present **Introduction to Flip-Flops and Latches.ppt.**

- Students will take notes in their engineering journals.
- The teacher will distribute and introduce **Activity 3.1.1 Introduction to Flip-Flops.**
- Students will work on Activity 3.1.1 Introduction to Flip-Flops.
- The teacher will assist students as needed.
- The teacher will assess student work using **Activity 3.1.1 Introduction to Flip-Flops Answer Key.**
- **Optional:** After the key terms have been introduced, the teacher may choose to distribute **Lesson 3.1 Key Term Crossword** for homework.

Day 3 – 5: Flip-Flop Applications

- The teacher will present **Flip-Flop Applications.ppt.**
- Students will take notes in their engineering journals.
- The teacher will distribute and introduce **Activity 3.1.2 Flip-Flop Application.**
- Students will work on Activity 3.1.2 Flip-Flop Application
- The teacher will assist students as needed.
- The teacher will assess student work using **Activity 3.1.2 Flip-Flop Application Answer Key**.

Day 6: Lesson Review

- The teacher will review the lesson's **Essential Questions**.
- Students will work in small groups (2-4) to answer the lesson's essential questions. Each group will be assigned one essential question that they must discuss, formulate a response for, and present to the class. The intent of this activity is to give closure to the lesson's topics and to have the students reflect back on the underlying concepts covered in the lesson's activities, projects, and problems.
- Students will take notes in their engineering journals.

Instructional Resources

Presentations

Introduction to Flip-Flops and Latches

Flip-Flop Applications

Word Documents

Lesson 3.1 Key Term Crossword

Activity 3.1.1 Introduction to Flip-Flops

Activity 3.1.2 Flip-Flop Application

Answer Keys and Rubrics

Lesson 3.1 Key Term Crossword Answer Key

Activity 3.1.1 Introduction to Flip-Flops Answer Key

Activity 3.1.2 Flip-Flop Application Answer Key

Teacher Guidelines

Lesson 3.1 Teacher Notes

Reference Sources

Dueck, R., & Reid, K. (2008). *Introduction to digital electronics*. Clifton Park, NY: Thompson Delmar Learning.

Tocci, R., Widmer, N., & Moss, G. (2007). *Digital systems*: *Principles and applications*. Upper Saddle River, NJ: Pearson Education.

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Lesson 3.2 Asynchronous Counters

Preface

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.

Concepts

1. 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.
2. Asynchronous counters can be implemented using small scale integrated (SSI) and medium scale integrated (MSI) logic gates.
3. Asynchronous counters can be implemented with either D or J/K flip-flops.
4. Up counters, down counters, and modulus counters all can be implemented using the asynchronous counter method.

Standards and Benchmarks Addressed

Standards for Technological Literacy

Standard 3:	Students will develop an understanding of the relationships among technologies and the connections between technology and other fields of study.
BM E:	A product, system, or environment developed for one setting may be applied to another setting.
BM F:	Knowledge gained from other fields of study has a direct effect on the development of technological products and systems.
BM G:	Technology transfer occurs when a new user applies an existing innovation developed for one purpose in a different function
BM H:	Technological innovation often results when ideas, knowledge, or skills are shared within a technology, among technologies, or across other fields.
BM J:	Technological progress promotes the advancement of science and mathematics. Likewise, progress in science and mathematics leads to advances in technology.
Standard 6:	Students will develop an understanding of the role of society in the development and use of technology.
BM F:	Social and cultural priorities and values are reflected in technological devices.
BM G:	Meeting societal expectations is the driving force behind the acceptance and use of products and systems.
BM H:	Different cultures develop their own technologies to satisfy their individual and shared needs, wants, and values.

BM I:	The decision whether to develop a technology is influenced by societal opinions and demands, in addition to corporate cultures.
BM J:	A number of different factors, such as advertising, the strength of the economy, the goals of a company and the latest fads contribute to shaping the design of and demand for various technologies.
Standard 7:	Students will develop an understanding of the influence of technology on history.
BM H:	The evolution of civilization has been directly affected by, and has in turn affected, the development and use of tools and materials.
BM I:	Throughout history, technology has been a powerful force in reshaping the social, cultural, political, and economic landscape.
BM J:	Early in the history of technology, the development of many tools and machines was based not on scientific knowledge but on technological know-how.
Standard 9:	Students will develop an understanding of engineering design.
BM H:	Modeling, testing, evaluating, and modifying are used to transform ideas into practical solutions.
BM I:	Established design principles are used to evaluate existing designs, to collect data, and to guide the design process.
BM J:	Engineering design is influenced by personal characteristics, such as creativity, resourcefulness, and the ability to visualize and think abstractly.
Standard 10:	Students will develop an understanding of the role of troubleshooting, research and development, invention and innovation, and experimentation in problem solving.
BM F:	Troubleshooting is a problem-solving method used to identify the cause of a malfunction in a technological system.
BM H:	Some technological problems are best solved through experimentation.
BM L:	Many technological problems require a multidisciplinary approach.
Standard 12:	Students will develop the abilities to use and maintain technological products and systems.
BM H:	Use information provided in manuals, protocols, or by experienced people to see and understand how things work.
BM I:	Use tools, materials, and machines safely to diagnose, adjust, and repair systems.
BM K:	Operate and maintain systems in order to achieve a given purpose.
BM L:	Document processes and procedures and communicate them to different audiences using appropriate oral and written techniques.
BM M:	Diagnose a system that is malfunctioning and use tools, materials, machines, and knowledge to repair it.
BM N:	Troubleshoot, analyze, and maintain systems to ensure safe and proper function and precision.
BM O:	Operate systems so that they function in the way they were designed.
BM P:	Use computers and calculators to access, retrieve, organize and process, maintain, interpret, and evaluate data and information

in order to communicate.

National Science Education Standards

Standard K-12: Unifying Concepts and Processes: As a result of activities in grades K-12, all students should develop understanding and abilities aligned with the following concepts and processes;

- Systems, order, and organization
- Evidence, models, and explanation
- Change, constancy, and measurement
- Form and function

Standard A: Science As Inquiry: As a result of activities in grades 9-12, all students should develop;

- Abilities necessary to do scientific inquiry
- Understandings about scientific inquiry

Standard E: Science and Technology: As a result of activities in grades 9-12, all students should develop

- Abilities of technological design
- Understandings about science and technology

Standard F: Science in Personal and Social Perspectives: As a result of activities in grades 9-12, all students should develop understanding of;

- Science and technology in local, national, and global challenges

Standard G: History and Nature of Science: As a result of activities in grades 9-12, all students should develop understanding of;

- Science as a human endeavor
- Nature of scientific knowledge
- Historical perspectives

Principles and Standards for School Mathematics

Number and Operations:	Instructional programs from pre-kindergarten through grade 12 should enable all students to; understand numbers, ways of representing numbers, relationships among numbers, and number systems; understand meanings of operations and how they relate to one another; compute fluently and make reasonable estimates.
Algebra:	Instructional programs from pre-kindergarten through grade 12 should enable all students to; understand patterns, relations, and functions; represent and analyze mathematical situations and structures using algebraic symbols; use mathematical models to represent and understand quantitative relationships; analyze change in various contexts.
Measurement:	Instructional programs from pre-kindergarten through grade 12 should enable all students to; understand measurable attributes of objects and the units, systems, and processes of measurement; apply appropriate techniques, tools, and formulas to determine measurements.

Problem Solving:	Instructional programs from pre-kindergarten through grade 12 should enable all students to; build new mathematical knowledge through problem solving; solve problems that arise in mathematics and in other contexts; apply and adapt a variety of appropriate strategies to solve problems; monitor and reflect on the process of mathematical problem solving.
Communication:	Instructional programs from pre-kindergarten through grade 12 should enable all students to; organize and consolidate their mathematical thinking through communication; communicate their mathematical thinking coherently and clearly to peers, teachers, and others; analyze and evaluate the mathematical thinking and strategies of others; use the language of mathematics to express mathematical ideas precisely.
Connections:	Instructional programs from pre-kindergarten through grade 12 should enable all students to; recognize and use connections among mathematical ideas; understand how mathematical ideas interconnect and build on one another to produce a coherent whole; recognize and apply mathematics in contexts outside of mathematics.
Representation:	Instructional programs from pre-kindergarten through grade 12 should enable all students to; create and use representations to organize, record, and communicate mathematical ideas; select, apply, and translate among mathematical representations to solve problems; use representations to model and interpret physical, social, and mathematical phenomena.

Standards for English Language Arts

Standard 3:	Students apply a wide range of strategies to comprehend, interpret, evaluate, and appreciate texts. They draw on their prior experience, their interactions with other readers and writers, their knowledge of word meaning and other texts, their word identification strategies, and their understanding of textual features (e.g. sound-letter correspondence, sentence structure, context, graphics).
Standard 4:	Students adjust their use of spoken, written, and visual language (e.g. conventions, style, vocabulary) to communicate effectively with a variety of audiences and for different purposes.
Standard 12:	Students use spoken, written and visual language to accomplish their own purposes (e.g. for learning, enjoyment, persuasion, and the exchange of information).

Performance Objectives

It is expected that students will:

- Know the advantages and disadvantage of counters designed using the asynchronous counter method.
- Be able to describe the ripple effect of an asynchronous counter.
- Be able to analyze and design up, down and modulus asynchronous counters using discrete D and J/K flip-flops.

- Be able to analyze and design up, down and modulus asynchronous counters using medium scale integrated (MSI) circuit counters.

- Use Circuit Design Software (CDS) and Digital Logic Board (DLB) to simulate and prototype SSI and MSI asynchronous counters.

Assessment

Explanation

- Students will explain in their engineering notebook why a clock signal is important when using asynchronous counters.

Interpretation

- What common household products use clock inputs and outputs to relay data?

Empathy

- Students will discuss in their engineering notebook concerns they may have for the environment regarding the creation of electronic products. They will determine how they may be able to dispose or recycle the product once the lifecycle has expired.

Essential Questions

1. What is another name for an Asynchronous counters?
2. How are clock inputs of an asynchronous counter's flip-flops connected?
3. What is the process for designing asynchronous counters implemented using discrete D and J/K flip-flops and medium scale integrated (MSI) circuit counters?
4. What are the differences between an asynchronous counter and an asynchronous modulus counter?
5. What is the process for designing up, down and modulus asynchronous counters?

Key Terms

Asynchronous Counter	Type of counter in which each flip-flop output serves as the clock input signal for the next flip-flop in the chain.
Binary Counter	Group of flip-flops connected in a special arrangement in which the states of the flip-flops represent the binary number equivalent to the number of pulses that have occurred at the input of the counter.
Decade Counter	Any counter capable of going through 10 different logic states.
Down Counter	Counter that counts from a maximum count downward to 0.
Modulus	The number of states through which a counter sequences before repeating.
Modulus N Counter (mod-n counter)	A counter with a modulus of N.

Synchronous Counter	Counter in which all of the flip-flops are clocked simultaneously.
Up Counter	Counter that counts upward from 0 to a maximum count.
Up/Down Counter	Counter that can count up or down depending on how its inputs are activated.

Day-by-Day Plans

Time: 14 days

NOTE: In preparation for teaching, it is strongly recommended that the teacher read the **Teacher Notes** for this lesson. All Circuit Design Software (CDS) files for this lesson can be found in the **CDS Files** folder.

Day 1 – 7: Lesson Overview and Introduction to Asynchronous Counters

- The teacher will present **Concepts**, **Essential Questions**, and **Key Terms** in order to provide a lesson overview.
- Optional: After the key terms have been introduced, the teacher may choose to distribute **Lesson 3.2 Key Term Crossword** for homework.
- The teacher will present **Asynchronous Counters w/SSI Logic.ppt.**
- Students will take notes in their engineering notebooks/portfolios.
- The teacher will distribute and introduce **Activity 3.2.1 SSI Asynchronous Counters.**
- Students will take notes in their engineering notebooks/portfolios.
- Students will work on Activity 3.2.1 SSI Asynchronous Counters.
- The teacher will assist the students as needed.
- The teacher will assess student work using **Activity 3.2.1 SSI Asynchronous Counters Answer Key.**
- The teacher will present **7-segment Display Driver.ppt.**
- Students will take notes in their engineering journals.
- The teacher will distribute and introduce **Activity 3.2.2 SSI Asynchronous Modulus Counters.**
- Students will take notes in their engineering notebooks/portfolios.
- Students will work on Activity 3.2.2 SSI Asynchronous Modulus Counters.
- The teacher will assist the students as needed.
- The teacher will assess student work using **Activity 3.2.2 SSI Asynchronous Modulus Counters**

Answer Key.

Day 8 – 10: PLD Asynchronous Counter Design

- The teacher will present **7-segment Display Driver.ppt.**
- Students will take notes in their engineering journals.
- The teacher will distribute and introduce **Activity 3.2.3 PLD Asynchronous Counter Design.**
- Students will work on Project 3.2.3 PLD Asynchronous Counter Design.
- The teacher will assist students as needed.
- The teacher will assess student work using **Activity 3.2.3 PLD Asynchronous Counter Design Answer Key.**

Day 11 – 13: MSI Asynchronous Counters

- The teacher will present **Asynchronous Counters w/MSI Logic.ppt.**
- Students will take notes in their engineering notebooks/portfolios.
- The teacher will distribute and introduce **Activity 3.2.4 MSI Asynchronous Counters.**
- Students will work on Activity 3.2.4 MSI Asynchronous Counters.
- The teacher will assist the students as needed.
- The teacher will assess student work using **Activity 3.2.4 MSI Asynchronous Counters Answer Key.**
- Optional: The teacher will introduce **Problem 3.2.4 Sixty Second Timer**.
- Optional: Students will complete **Problem 3.2.4 Sixty Second Timer**.
- Optional: The teacher will assess student work using **Problem 3.2.4 Sixty Second Timer Answer Key.**

Day 14: Lesson Review

- The teacher will review the lesson's **Essential Questions**.
- Students will work in small groups (2-4) to answer the lesson's essential questions. Each group will be assigned one essential question that they must discuss, formulate a response for, and present to the class. The intent of this activity is to give closure to the lesson's topics and to encourage students to reflect back on the underlying concepts covered in the lesson's activities, projects, and problems.
- Students will take notes in their engineering notebooks/portfolios.

Instructional Resources

Presentations

Asynchronous Counters w/SSI Logic

Asynchronous Counters w/MSI Logic

7-segment Display Driver

Word Documents

Lesson 3.2 Key Term Crossword

Activity 3.2.1 SSI Asynchronous Counters

Activity 3.2.2 SSI Asynchronous Modulus Counters

Activity 3.2.3 PLD Asynchronous Counter Design

Activity 3.2.4 MSI Asynchronous Counters

Optional : Problem 3.2.4 Sixty Second Timer

Answer Keys and Rubrics

Lesson 3.2 Key Term Crossword Answer Key

Activity 3.2.1 SSI Asynchronous Counters Answer Key

Activity 3.2.2 SSI Asynchronous Modulus Counters Answer Key

Activity 3.2.3 PLD Asynchronous Counter Design Answer Key

Activity 3.2.4 MSI Asynchronous Counters Answer Key

Optional : Problem 3.2.4 Sixty Second Timer Answer Key

Teacher Guidelines

Lesson 3.2 Teacher Notes

Reference Sources

Dueck, R. & Reid, K. (2008). Introduction to digital electronics. Clifton Park , NY: Thompson Delmar Learning.

Tocci, R., Widmer, N., & Moss, G. (2007). Digital systems: Principles and applications. Upper Saddle River, NJ: Pearson Education.

Tokeim, R. L. (2003). Digital electronics principles and applications. Columbus, OH: Glencoe/McGraw-Hill.

Floyd, T. (2006). Digital fundamentals. Upper Saddle River, NY: Pearson Education.

Bignell, J., & Donovan, R. (2007). Digital electronics. Clifton Park, NY: Thompson Delmar Learning.

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National Council of Teachers of Mathematics (NCTM). (2000). Principles and standards for school mathematics. Reston, VA: Author.

National Research Council (NRC). (1996). National science education standards. Washington, D. C.: National Academy Press.

Lesson 3.3 Synchronous Counters

Preface

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.

Concepts

1. Synchronous counters, also called parallel counters, are characterized by an external signal clocking all flip-flops simultaneously.
2. Synchronous counters can be implemented using small scale integrated (SSI) and medium scale integrated (MSI) logic gates.
3. Synchronous counters can be implemented with either D or J/K flip-flops.
4. Up counters, down counters, and modulus counters all can be implemented using the synchronous counter method.

Standards for Technological Literacy

Standard 1: Students will develop an understanding of the characteristics and scope of technology.

BM J: The nature and development of technological knowledge and processes are functions of the setting.

BM K: The rate of technological development and diffusion is increasing rapidly.

BM M: Most development of technologies these days is driven by the profit motive and the market.

Standard 2: Students will develop an understanding of the core concepts of technology.

BM W: Systems' thinking applies logic and creativity with appropriate compromises in complex real-life problems.

BM X: Systems, which are the building blocks of technology, are embedded within larger technological, social, and environmental systems.
BM Y: The stability of a technological system is influenced by all of the components in the system especially those in the feedback loop.
BM Z: Selecting resources involves trade-offs between competing values, such as availability, cost, desirability, and waste.
BM AA: Requirements involve the identification of the criteria and constraints of a product or system and the determination of how they affect the final design and development.
BM FF: Complex systems have many layers of controls and feedback loops to provide information.

Standard 3: Students will develop an understanding of the relationships among technologies and the connections between technology and other fields of study.

BM G: Technology transfer occurs when a new user applies an existing innovation developed for one purpose in a different function
BM H: Technological innovation often results when ideas, knowledge, or skills are shared within a technology, among technologies, or across other fields.
BM I: Technological ideas are sometimes protected through the process of patenting. The protection of a creative idea is central to the sharing of technological knowledge.
BM J: Technological progress promotes the advancement of science and mathematics. Likewise, progress in science and mathematics leads to advances in technology.

Standard 4: Students will develop an understanding of the cultural, social, economic, and political effects of technology.

BM H: Changes caused by the use of technology can range from gradual to rapid and from subtle to obvious.
BM I: Making decisions about the use of technology involves weighing the trade-offs between the positive and negative effects.
BM J: Ethical considerations are important in the development, selection, and use of technologies.
BM K: The transfer of a technology from one society to another can cause cultural, social, economic, and political changes affecting both societies to varying degrees.

Standard 6: Students will develop an understanding of the role of society in the development and use of technology.

BM H: Different cultures develop their own technologies to satisfy their individual and shared needs, wants, and values.
BM I: The decision whether to develop a technology is influenced by societal opinions and demands, in addition to corporate cultures.
BM J: A number of different factors, such as advertising, the strength of the economy, the goals of a company and the latest fads contribute to shaping the design of and demand for various technologies.

Standard 9: Students will develop an understanding of engineering design.

BM I: Established design principles are used to evaluate existing designs, to collect data, and to guide the design process.
BM J: Engineering design is influenced by personal characteristics, such as creativity, resourcefulness, and the ability to visualize and think abstractly.
BM L: The process of engineering design takes into account a number of factors.

Standard 10: Students will develop an understanding of the role of

troubleshooting, research and development, invention and innovation, and experimentation in problem solving.

- **BM J:** Technological problems must be researched before they can be solved.
- **BM L:** Many technological problems require a multidisciplinary approach.

Standard 11: Students will develop abilities to apply the design process.

- **BM N:** Identify criteria and constraints and determine how these will affect the design process.
- **BM P:** Evaluate the design solution using conceptual, physical, and mathematical models at various intervals of the design process in order to check for proper design and to note areas where improvements are needed.
- **BM Q:** Develop and produce a product or system using a design process.
- **BM R:** Evaluate final solutions and communicate observation, processes, and results of the entire design process, using verbal, graphic, quantitative, virtual, and written means, in addition to three-dimensional models.

Standard 12: Students will develop the abilities to use and maintain technological products and systems.

- **BM L:** Document processes and procedures and communicate them to different audiences using appropriate oral and written techniques.
- **BM M:** Diagnose a system that is malfunctioning and use tools, materials, machines, and knowledge to repair it.
- **BM N:** Troubleshoot, analyze, and maintain systems to ensure safe and proper function and precision.
- **BM O:** Operate systems so that they function in the way they were designed.
- **BM P:** Use computers and calculators to access, retrieve, organize and process, maintain, interpret, and evaluate data and information in order to communicate.

Standard 17: Students will develop an understanding of and be able to select and use information and communication technologies.

- **BM L:** Information and communication technologies include the inputs, processes, and outputs associated with sending and receiving information.
- **BM M:** Information and communication systems allow information to be transferred from human to human, human to machine, machine to human, and machine to machine.
- **BM N:** Information and communication systems can be used to inform, persuade, entertain, control, manage, and educate.
- **BM O:** Communication systems are made up of source, encoder, transmitter, receiver, decoder, storage, retrieval, and destination.
- **BM P:** There are many ways to communicate information, such as graphic and electronic means.
- **BM Q:** Technological knowledge and processes are communicated using symbols, measurement, conventions, icons, graphic images, and languages that incorporate a variety of visual, auditory, and tactile stimuli.

National Science Education Standards

Standard K-12: Unifying Concepts and Processes: As a result of activities in grades K-12, all students should develop understanding and abilities aligned with the following concepts and processes;

- Systems, order, and organization

- Evidence, models, and explanation
- Change, constancy, and measurement
- Form and function

Standard A: Science As Inquiry: As a result of activities in grades 9-12, all students should develop;

- Abilities necessary to do scientific inquiry
- Understandings about scientific inquiry

Standard E: Science and Technology: As a result of activities in grades 9-12, all students should develop

- Abilities of technological design
- Understandings about science and technology

Standard F: Science in Personal and Social Perspectives: As a result of activities in grades 9-12, all students should develop understanding of;

- Science and technology in local, national, and global challenges

Principles and Standards for School Mathematics

Number and Operations:	Instructional programs from pre-kindergarten through grade 12 should enable all students to; understand numbers, ways of representing numbers, relationships among numbers, and number systems; understand meanings of operations and how they relate to one another; compute fluently and make reasonable estimates.
Algebra:	Instructional programs from pre-kindergarten through grade 12 should enable all students to; understand patterns, relations, and functions; represent and analyze mathematical situations and structures using algebraic symbols; use mathematical models to represent and understand quantitative relationships; analyze change in various contexts.
Problem Solving:	Instructional programs from pre-kindergarten through grade 12 should enable all students to; build new mathematical knowledge through problem solving; solve problems that arise in mathematics and in other contexts; apply and adapt a variety of appropriate strategies to solve problems; monitor and reflect on the process of mathematical problem solving.
Communication:	Instructional programs from pre-kindergarten through grade 12 should enable all students to; organize and consolidate their mathematical thinking through communication; communicate their mathematical thinking coherently and clearly to peers, teachers, and others; analyze and evaluate the mathematical thinking and strategies of others; use the language of mathematics to express mathematical ideas precisely.
Connections:	Instructional programs from pre-kindergarten through grade 12 should enable all students to; recognize and use connections among mathematical ideas; understand how mathematical ideas interconnect and build on one another to produce a coherent whole; recognize and apply mathematics in contexts outside of mathematics.
Representation:	Instructional programs from pre-kindergarten through grade 12

should enable all students to; create and use representations to organize, record, and communicate mathematical ideas; select, apply, and translate among mathematical representations to solve problems; use representations to model and interpret physical, social, and mathematical phenomena.

Standards for English Language Arts

Standard 3:	Students apply a wide range of strategies to comprehend, interpret, evaluate, and appreciate texts. They draw on their prior experience, their interactions with other readers and writers, their knowledge of word meaning and other texts, their word identification strategies, and their understanding of textual features (e.g. sound-letter correspondence, sentence structure, context, graphics).
Standard 4:	Students adjust their use of spoken, written, and visual language (e.g. conventions, style, vocabulary) to communicate effectively with a variety of audiences and for different purposes.
Standard 12:	Students use spoken, written and visual language to accomplish their own purposes (e.g. for learning, enjoyment, persuasion, and the exchange of information).

Performance Objectives

It is expected that students will:

- Know the advantages and disadvantage of counters designed using the synchronous counter method.
- Be able to analyze and design up, down and modulus synchronous counters using discrete D and J/K flip-flops.
- Be able to analyze and design up, down and modulus synchronous counters using medium scale integrated (MSI) circuit counters.
- Use Circuit Design Software (CDS) and Digital Logic Board (DLB) to simulate and prototype SSI and MSI synchronous counters.

Assessment

Explanation

- Students will explain in their engineering notebook what the common threads are between asynchronous and synchronous counters.

Interpretation

- What common household products use flip-flops in their circuitry?

Essential Questions

1. What is another name for synchronous counters?
2. How are the clock inputs of a synchronous counter's flip-flops connected?
3. What is the process for designing synchronous counters implemented using discrete D and J/K flip-flops and medium scale integrated (MSI) circuit counters?
4. What are the differences between a synchronous counter and a synchronous modulus counter?
5. What is the process for designing up, down, and modulus synchronous counters?

Key Terms

Asynchronous Counter	Type of counter in which each flip-flop output serves as the clock input signal for the next flip-flop in the chain.
Binary Counter	Group of flip-flops connected in a special arrangement in which the states of the flip-flops represent the binary number equivalent to the number of pulses that have occurred at the input of the counter.
Decade Counter	Any counter capable of going through 10 different logic states.
Down Counter	Counter that counts from a maximum count downward to 0.
Modulus	The number of states through which a counter sequences before repeating.
Modulus N Counter **(mod-n counter)**	A counter with a modulus of N.
Synchronous Counter	Counter in which all of the flip-flops are clocked simultaneously.
Up Counter	Counter that counts upward from 0 to a maximum count.
Up/Down Counter	Counter that can count up or down depending on how its inputs are activated.

Day-by-Day Plans

Time: 14 days

NOTE: In preparation for teaching, it is strongly recommended that the teacher read the **Teacher Notes** for this lesson. All Circuit Design Software (CDS) files for this lesson can be found in the **CDS Files** folder.

Day 1 – 3: Lesson Overview and Introduction to Synchronous Counters

- The teacher will present **Concepts**, **Essential Questions**, and **Key Terms** in order to provide a lesson overview.
- The teacher will present **Synchronous Counters w/SSI Logic.ppt.**
- Students will take notes in their engineering notebooks/portfolios.
- The teacher will distribute and introduce **Activity 3.3.1 SSI Synchronous Counters.**
- Students will take notes in their engineering notebooks/portfolios.

- Students will work on Activity 3.3.1 SSI Synchronous Counters.
- The teacher will assist the students as needed.
- The teacher will assess student work using **Activity 3.3.1 SSI Synchronous Counters Answer Key.**

Day 4 – 8: MSI Synchronous Counters

- The teacher will present **Synchronous Counters w/MSI Logic.ppt.**
- Students will take notes in their engineering notebooks/portfolios.
- The teacher will distribute and introduce **Activity 3.3.2 MSI '163 Synchronous Counter.**
- Students will take notes in their engineering notebooks/portfolios.
- Students will work on Activity 3.3.2 MSI 4-Bit Synchronous Counters.
- The teacher will assist the students as needed.
- The teacher will assess student work using **Activity 3.3.2 MSI 4-Bit Binary Synchronous Counters Answer Key.**
- The teacher will distribute and introduce **Activity 3.3.3 MSI '193 Synchronous Counter**.
- Students will take notes in their engineering notebooks/portfolios.
- Students will work on Activity 3.3.3 MSI 4-Bit Binary Synchronous Up/Down Counters.
- The teacher will assist the students as needed.
- The teacher will assess student work using **Activity 3.3.3 MSI 4-Bit Binary Synchronous Up/Down Counters Answer Key.**

Day 9 – 13: Now Serving Display Design Project

- The teacher will distribute and introduce **Project 3.3.4 Now Serving Display Design Project.**
- Students will work on Problem 3.3.4.
- The teacher will assist students as needed.
- Using the **Project 3.3.4 Now Serving Display Design Project Answer Key** as a guide, the teacher will review the results with the class to ensure each student understands the process and has obtained the correct results.

Day 14: Lesson Review

- The teacher will review the lesson's **Essential Questions**.

- Students will work in small groups (2-4) to answer the lesson's essential questions. Each group will be assigned one essential question that they must discuss, formulate a response for, and present to the class. The intent of this activity is to give closure to the lesson's topics and to encourage students to reflect back on the underlying concepts covered in the lesson's activities, projects, and problems.

- Students will take notes in their engineering notebooks/portfolios.

Instructional Resources

Presentations

Synchronous Counters w/SSI Logic

Synchronous Counters w/MSI Logic

Word Documents

Activity 3.3.1 SSI Synchronous Counters

Activity 3.3.2 MSI '163 Synchronous Counter

Activity 3.3.3 MSI '193 Synchronous Counter

Problem 3.3.4 Now Serving Display Design Project

Answer Keys and Rubrics

Activity 3.3.1 SSI Synchronous Counters Answer Key

Activity 3.3.2 MSI 4-Bit Binary Synchronous Counters Answer Key

Activity 3.3.3 MSI 4-Bit Binary Synchronous Up/Down Counters Ans. Key

Project 3.3.4 Now Serving Display Answer Key

Teacher Guidelines

Lesson 3.3 Teacher Notes

Reference Sources

Dueck, R. & Reid, K. (2008). Introduction to digital electronics. Clifton Park , NY: Thompson Delmar Learning.

Tocci, R., Widmer, N., & Moss, G. (2007). Digital systems: Principles and applications. Upper Saddle River, NJ: Pearson Education.

Tokeim, R. L. (2003). Digital electronics principles and applications. Columbus, OH: Glencoe/McGraw-Hill.

Floyd, T. (2006). Digital fundamentals. Upper Saddle River, NY: Pearson Education.

Bignell, J., & Donovan, R. (2007). Digital electronics. Clifton Park, NY: Thompson Delmar Learning.

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National Council of Teachers of English (NCTE) and International Reading Association (IRA) (1996).

Standards for the English language arts. Newark, DE: IRA; Urbana, IL: NCTE.

National Council of Teachers of Mathematics (NCTM). (2000). Principles and standards for school mathematics. Reston, VA: Author.

National Research Council (NRC). (1996). National science education standards. Washington, D. C.: National Academy Press.

Lesson 3.4 State Machine Design

Preface

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.

Concepts

1. A state machine is a circuit design that sequences through a set of predetermined states controlled by a clock and other input signals.
2. State machines are used to control common everyday devices such as elevator doors, traffic lights, and combinational (electronics) locks.
3. State machines can be implemented in one of two variations: Mealy or Moore.
4. State machines can be implemented using small and medium scale integrated gates and programmable logic devices.

Standards and Benchmarks Addressed

Standards for Technological Literacy

Standard 1: Students will develop an understanding of the characteristics and scope of technology.

BM J:	The nature and development of technological knowledge and processes are functions of the setting.
BM K:	The rate of technological development and diffusion is increasing rapidly.
BM L:	Inventions and innovations are the results of specific, goal-directed research.
BM M:	Most development of technologies these days is driven by the profit motive and the market.

Standard 2: Students will develop an understanding of the core concepts of technology.

BM W:	Systems' thinking applies logic and creativity with appropriate compromises in complex real-life problems.
BM X:	Systems, which are the building blocks of technology, are embedded within larger technological, social, and environmental systems.
BM Y:	The stability of a technological system is influenced by all of the components in the system especially those in the feedback loop.
BM Z:	Selecting resources involves trade-offs between competing values, such as availability, cost, desirability, and waste.
BM AA:	Requirements involve the identification of the criteria and constraints of a product or system and the determination of how they affect the final design and development.
BM BB:	Optimization is an on going process or methodology of designing or making a product and is dependent on criteria and constraints.
BM CC:	New technologies create new processes.
BM DD:	Quality control is a planned process to ensure that a product, service, or system meets established criteria.
BM EE:	Management is the process of planning, organizing, and controlling work.
BM FF:	Complex systems have many layers of controls and feedback loops to provide information.

Standard 3: Students will develop an understanding of the relationships among technologies and the connections between technology and other fields of study.

BM G:	Technology transfer occurs when a new user applies an existing innovation developed for one purpose in a different function
BM H:	Technological innovation often results when ideas, knowledge, or skills are shared within a technology, among technologies, or across other fields.
BM I:	Technological ideas are sometimes protected through the process of patenting. The protection of a creative idea is central to the sharing of technological knowledge.
BM J:	Technological progress promotes the advancement of science and mathematics. Likewise, progress in science and mathematics leads to advances in technology.

Standard 4: Students will develop an understanding of the cultural, social, economic, and political effects of technology.

BM J:	Ethical considerations are important in the development, selection, and use of technologies.
BM K:	The transfer of a technology from one society to another can cause cultural, social, economic, and political changes affecting both societies to varying degrees.

Standard 5: Students will develop an understanding of the effects of technology on the environment.

BM G:	Humans can devise technologies to conserve water, soil, and energy through such techniques as reusing, reducing and recycling.
BM H:	When new technologies are developed to reduce the use of resources, considerations of trade-offs are important.

BM I: With the aid of technology, various aspects of the environment can be monitored to provide information for decision-making.
BM J: The alignment of technological processes with natural processes maximizes performance and reduces negative impacts on the environment.
BM K: Humans devise technologies to reduce the negative consequences of other technologies.
BM L: Decisions regarding the implementation of technologies involve the weighing of tradeoffs between predicted positive and negative effects on the environment.

Standard 6: Students will develop an understanding of the role of society in the development and use of technology.

BM H: Different cultures develop their own technologies to satisfy their individual and shared needs, wants, and values.
BM I: The decision whether to develop a technology is influenced by societal opinions and demands, in addition to corporate cultures.
BM J: A number of different factors, such as advertising, the strength of the economy, the goals of a company and the latest fads contribute to shaping the design of and demand for various technologies.

Standard 7: Students will develop an understanding of the influence of technology on history.

BM I: Throughout history, technology has been a powerful force in reshaping the social, cultural, political, and economic landscape.
BM J: Early in the history of technology, the development of many tools and machines was based not on scientific knowledge but on technological know-how.
BM O: The Information Age places emphasis on the processing and exchange of information.

Standard 9: Students will develop an understanding of engineering design.

BM H: Modeling, testing, evaluating, and modifying are used to transform ideas into practical solutions.
BM I: Established design principles are used to evaluate existing designs, to collect data, and to guide the design process.
BM J: Engineering design is influenced by personal characteristics, such as creativity, resourcefulness, and the ability to visualize and think abstractly.
BM K: A prototype is a working model used to test a design concept by making actual observations and necessary adjustments.
BM L: The process of engineering design takes into account a number of factors.

Standard 10: Students will develop an understanding of the role of troubleshooting, research and development, invention and innovation, and experimentation in problem solving.

BM I: Research and development is a specific problem-solving approach that is used intensively in business and industry to prepare devices and systems for the marketplace.
BM J: Technological problems must be researched before they can be solved.
BM K: Not all problems are technological, and not every problem can be solved using technology.
BM L: Many technological problems require a multidisciplinary approach.

Standard 12: Students will develop the abilities to use and maintain technological products and systems.

BM L: Document processes and procedures and communicate them to different audiences using appropriate oral and written techniques.
BM M: Diagnose a system that is malfunctioning and use tools, materials,

machines, and knowledge to repair it.

BM N: Troubleshoot, analyze, and maintain systems to ensure safe and proper function and precision.

BM O: Operate systems so that they function in the way they were designed.

BM P: Use computers and calculators to access, retrieve, organize and process, maintain, interpret, and evaluate data and information in order to communicate.

Standard 16: Students will develop an understanding of and be able to select and use energy and power technologies.

BM G: Power is the rate at which energy is converted from one form to another or transferred from one place to another, or the rate at which work is done.

BM H: Power systems are used to drive and provide propulsion to other technological products and systems.

BM I: Much of the energy used in our environment is not used efficiently.

BM K: Energy can be grouped into major forms: thermal, radiant, electrical, mechanical, chemical, nuclear, and others.

BM M: Energy resources can be renewable or nonrenewable.

BM N: Power systems must have a source of energy, a process, and loads.

Standard 17: Students will develop an understanding of and be able to select and use information and communication technologies.

BM L: Information and communication technologies include the inputs, processes, and outputs associated with sending and receiving information.

BM M: Information and communication systems allow information to be transferred from human to human, human to machine, machine to human, and machine to machine.

BM N: Information and communication systems can be used to inform, persuade, entertain, control, manage, and educate.

BM O: Communication systems are made up of source, encoder, transmitter, receiver, decoder, storage, retrieval, and destination.

BM P: There are many ways to communicate information, such as graphic and electronic means.

BM Q: Technological knowledge and processes are communicated using symbols, measurement, conventions, icons, graphic images, and languages that incorporate a variety of visual, auditory, and tactile stimuli.

National Science Education Standards

Standard K-12: Unifying Concepts and Processes: As a result of activities in grades K-12, all students should develop understanding and abilities aligned with the following concepts and processes;

- Systems, order, and organization
- Evidence, models, and explanation
- Change, constancy, and measurement
- Form and function

Standard A: Science As Inquiry: As a result of activities in grades 9-12, all students should develop;

- Abilities necessary to do scientific inquiry
- Understandings about scientific inquiry

Standard E: Science and Technology: As a result of activities in grades 9-12, all students should develop

- Abilities of technological design

- Understandings about science and technology

Standard F: Science in Personal and Social Perspectives: As a result of activities in grades 9-12, all students should develop understanding of;

- Natural and human-induced hazards
- Science and technology in local, national, and global challenges

Standard G: History and Nature of Science: As a result of activities in grades 9-12, all students should develop understanding of;

- Science as a human endeavor
- Nature of scientific knowledge
- Historical perspectives

Principles and Standards for School Mathematics

Number and Operations:	Instructional programs from pre-kindergarten through grade 12 should enable all students to; understand numbers, ways of representing numbers, relationships among numbers, and number systems; understand meanings of operations and how they relate to one another; compute fluently and make reasonable estimates.
Algebra:	Instructional programs from pre-kindergarten through grade 12 should enable all students to; understand patterns, relations, and functions; represent and analyze mathematical situations and structures using algebraic symbols; use mathematical models to represent and understand quantitative relationships; analyze change in various contexts.
Data Analysis and Probability:	Instructional programs from pre-kindergarten through grade 12 should enable all students to; formulate questions that can be addressed with data and collect, organize, and display relevant data to answer them; select and use appropriate statistical methods to analyze data; develop and evaluate inferences and predictions that are based on data; understand and apply basic concepts of probability.
Problem Solving:	Instructional programs from pre-kindergarten through grade 12 should enable all students to; build new mathematical knowledge through problem solving; solve problems that arise in mathematics and in other contexts; apply and adapt a variety of appropriate strategies to solve problems; monitor and reflect on the process of mathematical problem solving.
Reasoning and Proof:	Instructional programs from pre-kindergarten through grade 12 should enable all students to; recognize reasoning and proof as fundamental aspects of mathematics; make and investigate mathematical conjectures; develop and evaluate mathematical arguments and proofs; select and use various types of reasoning and methods of proof.
Communication:	Instructional programs from pre-kindergarten through grade 12 should enable all students to; organize and consolidate their mathematical thinking through communication; communicate their mathematical thinking coherently and clearly to peers, teachers, and others; analyze and evaluate the mathematical thinking and strategies of others; use the language of

	mathematics to express mathematical ideas precisely.
Connections:	Instructional programs from pre-kindergarten through grade 12 should enable all students to; recognize and use connections among mathematical ideas; understand how mathematical ideas interconnect and build on one another to produce a coherent whole; recognize and apply mathematics in contexts outside of mathematics.
Representation:	Instructional programs from pre-kindergarten through grade 12 should enable all students to; create and use representations to organize, record, and communicate mathematical ideas; select, apply, and translate among mathematical representations to solve problems; use representations to model and interpret physical, social, and mathematical phenomena.

Standards for English Language Arts

Standard 3:	Students apply a wide range of strategies to comprehend, interpret, evaluate, and appreciate texts. They draw on their prior experience, their interactions with other readers and writers, their knowledge of word meaning and other texts, their word identification strategies, and their understanding of textual features (e.g. sound-letter correspondence, sentence structure, context, graphics).
Standard 4:	Students adjust their use of spoken, written, and visual language (e.g. conventions, style, vocabulary) to communicate effectively with a variety of audiences and for different purposes.
Standard 12:	Students use spoken, written and visual language to accomplish their own purposes (e.g. for learning, enjoyment, persuasion, and the exchange of information).

Performance Objectives

It is expected that students will:

- Be able to describe the components of a state machine.
- Be able to draw a state graph and construct a state transition table for a state machine.
- Be able to derive a state machine's Boolean equations from its state transition table.
- Be able to implement Boolean equations into a functional state machine.
- Describe the two variations of state machines and list the advantages of each.
- Use Circuit Design Software (CDS) and a Digital Logic Board (DLB) to simulate and prototype state machines designs implemented with discrete and programmable logic.

Assessment

Explanation

- Students will verbally explain the difference between the two variations of state machines to the instructor.

Interpretation

- Students will research products that use state machine design and present their finding to the class.

Application

- Assess engineering notebook for evidence of effective communication of ideas such as,

o Do students' sketches and schematics clearly communicate their ideas?

o Have students used a variety of methods to communicate their ideas of state machines?

Essential Questions

1. What is the basic function of a state machine
2. What are some common everyday devices that are controlled by state machines?
3. What are the two variations of state machine design, and what are the advantages of each.
4. What type of logic gates are used to implement state machines?

Key Terms

Bubble	A circle in a state diagram containing the state name and values of the state variables.
Conditional Transition	A transition between states of a state machine that occurs only under specific conditions of one or more control inputs.
Control Input	A state machine input that directs the operation of the machine from state to state.
Mealy Machine	A state machine whose output is determined by both the sequential logic and the combinational logic of the machine.
Moore Machine	A state machine whose output is determined only by the sequential logic of the machine.
State Machines	A synchronous sequential circuit, consisting of a sequential logic section and a combinational logic section, whose outputs and internal flip-flops progress through a predictable sequence of states in responds to a clock and other input signals.
State Table	A table whose entries represent the sequence of individual FF states (i.e., 0 or 1) for a sequential binary circuit.
State Transition Diagram	A graphic representation of the operation of a sequential binary circuit, showing the sequence of individual FF states and conditions needed for transitions from one state to the next.
State Variables	The variables held in the flip-flops of a state machine that determine its present state.

Day-by-Day Plans

Time: 20 days

NOTE: In preparation for teaching, it is strongly recommended that the teacher read the **Teacher Notes** for this lesson. All Circuit Design Software (CDS) files for this lesson can be found in the **CDS Files** folder.

Day 1 – 9: State-Machine Design Process & State-Machine Design

- The teacher will present **Concepts**, **Essential Questions**, and **Key Terms** in order to provide a lesson overview.

- Optional: After the key terms have been introduced, the teacher may choose to distribute **Lesson 3.4 Key Term Crossword** for homework.

- The teacher will present **State Machine Design.ppt**.

- Students will take notes in their engineering notebooks/portfolios.

- The teacher will distribute and introduce **Activity 3.4.1State Machine Design.**

- Students will take notes in their engineering notebooks/portfolios.

- Students will work on Activity 3.4.1 SSI State Machine Design

- The teacher will assist the students as needed.

- The teacher will assess student work using **Activity 3.4.1State Machine Design Answer Key.**

Day 10 – 19: Elevator Door State-Machine

- The teacher will distribute and introduce **Problem 3.4.2 Elevator Door State Machine.**

- Students will take notes in their engineering notebooks/portfolios.

- Students will work on Problem 3.4.2 Elevator Door State Machine.

- The teacher will assist the students as needed.

Day 20: Lesson Review

- The teacher will collect the student's report on their Elevator Door State Machine Design.

- Using the **Problem 3.4.2 Elevator Door State Machine Answer Key** as a guide, the teacher will review the results with the class to ensure each student understands the process and has obtained the correct results.

- The teacher will review the lesson's **Essential Questions.**

- Students will work in small groups (2-4) to answer the lesson's essential questions. Each group will be assigned one essential question that they must discuss, formulate a response for, and present to the class. The intent of this activity is to give closure to the lesson's topics and to encourage students to reflect back on the underlying concepts covered in the lesson's activities, projects, and problems.

- Students will take notes in their engineering notebooks/portfolios.

Instructional Resources

Presentations

State Machine Design

Word Documents

Lesson 3.4 Key Term Crossword

Activity 3.4.1State Machine Design

Problem 3.4.2 Elevator Door State Machine

Answer Keys and Rubrics

Lesson 3.4 Key Term Crossword Answer Key

Activity 3.4.1State Machine Design Answer Key

Problem 3.4.2 Elevator Door State Machine Answer Key

Teacher Guidelines

Lesson 3.4 Teacher Notes

Reference Sources

Dueck,R. &Reid,K. (2008). Introduction to digital electronics. Clifton Park, NY: Thompson Delmar Learning.

Tocci, R., Widmer, N., & Moss, G. (2007). Digital systems: Principles and applications. Upper Saddle River, NJ: Pearson Education.

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Unit 4 - Microcontrollers

Preface

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.

Lesson Documents

Lesson 4.1: Introduction to Microcontrollers

Lesson 4.2: Microcontrollers and the Boe-Bot

Lesson 4.3: Boe-Bot Design Projects

Concepts

1. Basic programming skills include variable declaration, loops, and debugging.
2. Programming languages have their own grammar, called syntax.
3. Many everyday products use microcontrollers.
4. Variables used in programming are declared and given a size that is expressed in binary.
5. Microcontrollers are used to control many everyday products like robots, garage door openers, traffic lights, and home thermostats.
6. A servo motor is one that delivers continuous motion at various speeds.
7. Microcontrollers can be programmed to sense and respond to outside stimuli.
8. Digital devices are only relevant if they can interact with the real world.
9. Flowcharting is a powerful graphical organizer used by engineers and professionals in a variety of roles and responsibilities.
10. Realistic problem solving with a control system requires the ability to interface analog inputs and outputs with a digital device.
11. Microcontrollers are a practical tool for controlling a mechanical system.

Essential Questions

Lesson 4.1: Introduction to Microcontrollers

1. What is a microcontroller?
2. What is BASIC?
3. What are the different types of loops and how are they used?
4. What is the purpose of declaring variables?
5. How are variables used in programming?
6. What is syntax and why is it important to know?

Lesson 4.2: Microcontrollers and the Boe-Bot

1. What is a servo motor and what parameters does it use in programming code?
2. What is a tactile switch and how is it used to create an autonomous robot?

Lesson 4.3: Boe-Bot Design Projects

1. How does a microcontroller enable users to interface the analog world with the digital world?
2. How does the design course relate to real-world problems?

Unit Evaluation

The Essential Questions and Conclusion questions at the end of each activity may be used along with the Assessment suggestions provided in each lesson to develop summative assessment tools, such as tests or end of unit projects.

Lesson 4.1 Introduction to Microcontrollers

Preface

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.

Concepts

1. Basic programming skills include variable declaration, loops, and debugging.
2. Programming languages have their own grammar, called syntax.
3. Many everyday products use microcontrollers.
4. Variables used in programming are declared and given a size that is expressed in binary.

Standards and Benchmarks Addressed

Standards for Technological Literacy

Standard 2: Students will develop an understanding of the core concepts of technology.

BM F: A subsystem is a system that operates as a part of another system.
BM G: When parts of a system are missing, it may not work as planned.

BM H: Resources are the things needed to get a job done, such as tools and machines, materials, information, energy, people, capital, and time.
BM I: Tools are used to design, make, use, and assess technology.
BM K: Tools and machines extend human capabilities, such as holding, lifting, carrying, fastening, separating, and computing.
BM M: Technological systems include input, processes, output, and, at times, feedback.
BM N: Systems thinking involves considering how every part relates to others.
BM O: An open-loop system has no feedback path and requires human intervention, while a closed-loop system uses feedback.
BM P: Technological systems can be connected to one another.
BM Q: Malfunctions of any part of a system may affect the function and quality of the system.
BM R: Requirements are the parameters placed on the development of a product or system.
BM S: Trade-off is a decision process recognizing the need for careful compromises among competing factors.
BM T: Different technologies involve different sets of processes.
BM U: Maintenance is the process of inspecting and servicing a product or system on a regular basis in order for it to continue functioning properly, to extend its life, or to upgrade its capability.
BM V: Controls are mechanisms or particular steps that people perform using information about the system that causes systems to change.
BM W: Systems' thinking applies logic and creativity with appropriate compromises in complex real-life problems.
BM X: Systems, which are the building blocks of technology, are embedded within larger technological, social, and environmental systems.
BM Y: The stability of a technological system is influenced by all of the components in the system; especially those in the feedback loop.
BM Z: Selecting resources involves trade-offs between competing values, such as availability, cost, desirability, and waste.
BM AA: Requirements involve the identification of the criteria and constraints of a product or system and the determination of how they affect the final design and development.
BM FF: Complex systems have many layers of controls and feedback loops to provide information.

Standard 3: Students will develop an understanding of the relationships among technologies and the connections between technology and other fields of study.

BM D: Technological systems often interact with one another.
A product, system, or environment developed for one setting may be applied to another setting.
BM F: Knowledge gained from other fields of study has a direct effect on the development of technological products and systems.
BM G: Technology transfer occurs when a new user applies an existing innovation developed for one purpose in a different function
BM H: Technological innovation often results when ideas, knowledge, or skills are shared within a technology, among technologies, or across other fields.

Standard 10: Students will develop an understanding of the role of troubleshooting, research and development, invention and innovation, and experimentation in problem solving.

BM C: Troubleshooting is a way of finding out why something does not work so that it can be fixed.
BM D: Invention and innovation are creative ways to turn ideas into real things.

BM E: The process of experimentation, which is common in science, can also be used to solve technological problems.
BM F: Troubleshooting is a problem-solving method used to identify the cause of a malfunction in a technological system.
BM G: Invention is a process of turning ideas and imagination into devices and systems.
BM H: Some technological problems are best solved through experimentation.
BM I: Research and development is a specific problem-solving approach that is used intensively in business and industry to prepare devices and systems for the marketplace.
BM J: Technological problems must be researched before they can be solved.
BM K: Not all problems are technological, and not every problem can be solved using technology.
BM L: Many technological problems require a multidisciplinary approach.

Standard 12: Students will develop the abilities to use and maintain technological products and systems.

BM D: Follow step-by-step directions to assemble a product.
BM E: Select and safely use tools, products, and systems for specific tasks.
BM F: Use computers to access and organize information.
BM G: Use common symbols, such as numbers and words, to communicate key ideas.
BM H: Use information provided in manuals, protocols, or by experienced people to see and understand how things work.
BM I: Use tools, materials, and machines safely to diagnose, adjust, and repair systems.
BM J: Use computers and calculators in various applications.
BM K: Operate and maintain systems in order to achieve a given purpose.
BM L: Document processes and procedures and communicate them to different audiences using appropriate oral and written techniques.
BM M: Diagnose a system that is malfunctioning and use tools, materials, machines, and knowledge to repair it.
BM N: Troubleshoot, analyze, and maintain systems to ensure safe and proper function and precision.
BM O: Operate systems so that they function in the way they were designed.

National Science Education Standards

Standard K-12: Unifying Concepts and Processes: As a result of activities in grades K-12, all students should develop understanding and abilities aligned with the following concepts and processes;

- Form and function

Content Standard A: Science As Inquiry: As a result of activities in grades 9-12, all students should develop

- Abilities necessary to do scientific inquiry
- Understandings about scientific inquiry

Standard E: Science and Technology: As a result of activities in grades 9-12, all students should develop

- Abilities of technological design
- Understandings about science and technology

Principle and Standards for School Mathematics

Number and Operations:	Instructional programs from pre-kindergarten through grade 12 should enable all students to; understand numbers, ways of representing numbers, relationships among numbers, and number systems; understand meanings of operations and how they relate to one another; compute fluently and make reasonable estimates.
Algebra Standard:	Instructional programs from pre-kindergarten through grade 12 should enable all students to; understand patterns, relations, and functions; represent and analyze mathematical situations and structures using algebraic symbols; use mathematical models to represent and understand quantitative relationships; analyze change in various contexts.
Measurement Standard:	Instructional programs from pre-kindergarten through grade 12 should enable all students to; understand measurable attributes of objects and the units, systems, and processes of measurement; apply appropriate techniques, tools, and formulas to determine measurements.
Data Analysis and Probability Standard:	Instructional programs from pre-kindergarten through grade 12 should enable all students to; formulate questions that can be addressed with data and collect, organize, and display relevant data to answer them; select and use appropriate statistical methods to analyze data; develop and evaluate inferences and predictions that are based on data; understand and apply basic concepts of probability.
Problem Solving Standard:	Instructional programs from pre-kindergarten through grade 12 should enable all students to; build new mathematical knowledge through problem solving; solve problems that arise in mathematics and in other contexts; apply and adapt a variety of appropriate strategies to solve problems; monitor and reflect on the process of mathematical problem solving.
Reasoning and Proof Standard:	Instructional programs from pre-kindergarten through grade 12 should enable all students to; recognize reasoning and proof as fundamental aspects of mathematics; make and investigate mathematical conjectures; develop and evaluate mathematical arguments and proofs; select and use various types of reasoning and methods of proof.
Communication Standard:	Instructional programs from pre-kindergarten through grade 12 should enable all students to; organize and consolidate their mathematical thinking through communication; communicate their mathematical thinking coherently and clearly to peers, teachers, and others; analyze and evaluate the mathematical thinking and strategies of others; use the language of mathematics to express mathematical ideas precisely.
Connections Standard:	Instructional programs from pre-kindergarten through grade 12 should enable all students to; recognize and use connections among mathematical ideas; understand how mathematical ideas interconnect and build on one another to produce a coherent whole; recognize and apply mathematics in contexts outside of mathematics.
Representation Standard:	Instructional programs from pre-kindergarten through grade 12 should enable all students to; create and use representations to

organize, record, and communicate mathematical ideas; select, apply, and translate among mathematical representations to solve problems; use representations to model and interpret physical, social, and mathematical phenomena.

Standards for the English Language Arts

Standard 3: Students apply a wide range of strategies to comprehend, interpret, evaluate, and appreciate texts. They draw on their prior experience, their interactions with other readers and writers, their knowledge of word meaning and other texts, their word identification strategies, and their understanding of textual features (e.g. sound-letter correspondence, sentence structure, context, graphics).

Standard 4: Students adjust their use of spoken, written, and visual language (e.g. conventions, style, vocabulary) to communicate effectively with a variety of audiences and for different purposes.

Standard 6: Students apply knowledge of language structure, language conventions (e.g. spelling and punctuation), media techniques, figurative language, and genre to create, critique, and discuss print and non-print texts.

Performance Objectives

It is expected that students will:

- Use the Board of Education to write programs
- Create a program that utilizes the Debug screen
- Create programs that use variables
- Create programs that use various loops
- Create programs that use inputs and outputs

Assessment

Explanation

- Students will explain what a microcontroller is and how it is used.
- Students will explain the differences in types of loops.
- Students will explain the purpose of the Debug screen.

Application

- Students will apply their knowledge of BASIC to write programs that use the Debug screen, variables, loops, inputs, and outputs.

Essential Questions

1. What is a microcontroller?
2. What is BASIC?
3. What are the different types of loops and how are they used?
4. What is the purpose of declaring variables?
5. How are variables used in programming?
6. What is syntax and why is it important to know?

Key Terms

BASIC	Beginners' All-purpose Symbolic Instruction Code.
BIN	Modifier in PBASIC that designates a variable as being a binary bit.
Bit	Smallest number in binary. Can only have the value of 0 or 1.
Byte	8 bits. Can have values in range from 0 to 255.
CLS	A command in PBASIC that clears the Debug screen.
Code	A set of computer instructions to perform a given operation or solve a given problem.
Comment	A line of text in a computer program that is ignored by the computer. Comments are used to explain programs to humans.
CR	A command in PBASIC that moves the Debug screen down one line or to end the SEROUT command. Also called a carriage return.
Debug	The process of detecting and eliminating a device's malfunctions.
DEBUG	A command in PBASIC that sends text and values to the screen.
DEC	A modifier in PBASIC that designates a variable as being a decimal number.
Declare	The process of informing a program that you plan to use a variable, what you want to call it, and how big it is.
DO Loop	A command in PBASIC that tells a series of commands to loop endlessly.
ESD	Electrostatic discharge. An electronic current that can damage components.
Flowchart	A schematic representation of an algorithm or a process.
FOR…NEXT	A command in PBASIC that is a type of loop that depends on a variable to act as a counter. A series of commands will run until the counter number is reached.
HEX	A modifier in PBASIC that designates a variable as being a hexadecimal number.
Microcontroller	A microcomputer used for precise process control in data handling, communication, or manufacturing.
Nibble	4 bits. Can have values from 0 to 15.
PAUSE	A command in PBASIC that tells a computer to continue the last command for a given number of milliseconds.
SEROUT	A command in PBASIC that is used to transmit asynchronous serial data; an example is that of a servo motor.
Syntax	The rules governing the structure of statements used in a program.
Word	16 bits. Can have values from 0 to 65,535.

Day-by-Day Plans

Time: 9 days

NOTE: In preparation for teaching, it is strongly recommended that the teacher read the **Lesson 4.1 Teacher Notes** for this lesson.

Day 1 – 2 : Lesson Overview and Introduction to Microcontrollers and the BOE

- The teacher will present **Concepts**, **Essential Questions**, and **Key Terms** in order to provide a lesson overview.
- The teacher will present **Introduction to Microcontrollers and the Board-of-Education (BOE).ppt**
- Students will take notes in their engineering journals.
- The teacher will distribute and introduce **Activity 4.1.1 Microcontrollers and the BOE.**
- Students will take notes in their engineering journals.
- Students will work on Activity 4.1.1 Microcontrollers and the BOE.
- The teacher will assist the students as needed.
- Optional: After the key terms have been introduced, the teacher may choose to distribute **Lesson 4.1 Key Term Crossword** for homework.

Day 3 – 5: Microcontroller Output

- The teacher will present **Board-of-Education Output.ppt**
- Students will take notes in their engineering journals.
- The teacher will distribute and introduce **Activity 4.1.2 Microcontroller Output .**
- Students will take notes in their engineering journals.
- Students will work on Activity 4.1.2 Microcontroller Output.
- The teacher will assist the students as needed.

Day 6 – 8: Microcontroller Input

- The teacher will present **Board-of-Education Input.ppt**
- Students will take notes in their engineering journals.
- The teacher will distribute and introduce **Activity 4.1.3 Microcontroller Input.**
- Students will take notes in their engineering journals.
- Students will work on Activity 4.1.3 Microcontroller Input.
- The teacher will assist the students as needed.

Day 9: Lesson Review

- The teacher will review the lesson's essential questions.
- Students will work in small groups (2-4) to answer the lesson's essential questions. Each group will be assigned one essential question to discuss, formulate a response for, and present to the class. The intent of this activity is to give closure to the lesson's topics and to have the students reflect back on the underlying concepts covered in the lesson's activities, projects, and problems.
- Students will take notes in their engineering journals.

Instructional Resources

Presentations

Introduction to Microcontrollers and the Board-of-Education (BOE)

Board-of-Education Output

Board-of-Education Input

Word Documents

Lesson 4.1 Key Term Crossword
Activity 4.1.1 Microcontrollers and the BOE
Activity 4.1.2 Microcontroller Output
Activity 4.1.3 Microcontroller Input

Parallax PDF Documents

Activity 4.1.1
Activity 4.1.2
Activity 4.1.3

Answer Keys and Rubrics

Lesson 4.1 Key Term Crossword Answer Key

Teacher Guidelines

Lesson 4.1 Teacher Notes

Reference Sources

Dueck,R. &Reid,K. (2008). *Introduction to digital electronics.* Clifton Park, NY: Thompson Delmar Learning.

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Tokeim, R. L. (2003). *Digital electronics principles and applications.* Columbus, OH: Glencoe/McGraw-Hill.

Lesson 4.2 Microcontrollers & The Boe-Bot

Preface

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. In our case, the body is made up of many components, including motors, lights, and sensors. The motors provide locomotion, the sensors act as triggers for the motors, and the lights are used primarily as warning devices.

In this lesson students will learn about servo motors and how to program them. They will also program a specific robot, the Boe-Bot. The Boe-Bot uses the Board of Education as its brain. Students will learn how to turn the Boe-Bot into a fully autonomous unit.

Concepts

1. Microcontrollers are used to control many everyday products like robots, garage door openers, traffic lights, and home thermostats.
2. A servo motor is one that delivers continuous motion at various speeds.
3. Microcontrollers can be programmed to sense and respond to outside stimuli.

Standards and Benchmarks Addressed

Standards for Technological Literacy

Standard 2: Students will develop an understanding of the core concepts of technology.

BM Y: The stability of a technological system is influenced by all of the components in the system especially those in the feedback loop.

BM CC: Complex systems have many layers of controls and feedback loops to provide information.

Standard 9: Students will develop an understanding of engineering design.

BM E: Models are used to communicate and test design ideas and processes.

BM J: Engineering design is influenced by personal characteristics, such as creativity, resourcefulness, and the ability to visualize and think abstractly.

Standard 10: Students will develop an understanding of the role of troubleshooting, research and development, invention and innovation, and experimentation in problem solving.

BM F: Troubleshooting is a problem-solving method used to identify the cause of a malfunction in a technological system.

BM H: Some technological problems are best solved through experimentation.

Standard 11: Students will develop abilities to apply the design process.

BM P: Evaluate the design solution using conceptual, physical, and mathematical models at various intervals of the design process in order to check for proper design and to note areas where improvements are needed.

BM Q: Develop and produce a product or system using a design process.

BM R: Evaluate final solutions and communicate observation, processes, and results of the entire design process, using verbal, graphic, quantitative, virtual, and written means, in addition to three-dimensional models.

Standard 12: Students will develop the abilities to use and maintain technological products and systems.

BM D: Follow step-by-step directions to assemble a product.

BM E: Select and safely use tools, products, and systems for specific tasks.
BM G: Use common symbols, such as numbers and words, to communicate key ideas.
BM H: Use information provided in manuals, protocols, or by experienced people to see and understand how things work.
BM I: Use tools, materials, and machines safely to diagnose, adjust, and repair systems.
BM K: Operate and maintain systems in order to achieve a given purpose.
BM L: Document processes and procedures and communicate them to different audiences using appropriate oral and written techniques.
BM M: Diagnose a system that is malfunctioning and use tools, materials, machines, and knowledge to repair it.
BM N: Troubleshoot, analyze, and maintain systems to ensure safe and proper function and precision.
BM O: Operate systems so that they function in the way they were designed.

Standard 17: Students will develop an understanding of and be able to select and use information and communication technologies.

BM K: The use of symbols, measurements, and drawings promotes clear communication by providing a common language to express ideas.
BM L: Information and communication technologies include the inputs, processes, and outputs associated with sending and receiving information.
BM M: Information and communication systems allow information to be transferred from human to human, human to machine, machine to human, and machine to machine.
BM N: Information and communication systems can be used to inform, persuade, entertain, control, manage, and educate.
BM O: Communication systems are made up of source, encoder, transmitter, receiver, decoder, storage, retrieval, and destination.
BM P: There are many ways to communicate information, such as graphic and electronic means.
BM Q: Technological knowledge and processes are communicated using symbols, measurement, conventions, icons, graphic images, and languages that incorporate a variety of visual, auditory, and tactile stimuli.

National Science Education Standards

Standard K-12: Unifying Concepts and Processes: As a result of activities in grades K-12, all students should develop understanding and abilities aligned with the following concepts and processes;

- Systems, order, and organization
- Change, constancy, and measurement

Standard E: Science and Technology: As a result of activities in grades 9-12, all students should develop

- Abilities of technological design

Principles and Standards for School Mathematics

Algebra: Instructional programs from pre-kindergarten through grade 12 should enable all students to; understand patterns, relations,

	and functions; represent and analyze mathematical situations and structures using algebraic symbols; use mathematical models to represent and understand quantitative relationships; analyze change in various contexts.
Geometry:	Instructional programs from pre-kindergarten through grade 12 should enable all students to specify locations and describe spatial relationships using coordinate geometry and other representational systems and use geometric modeling to solve problems.
Measurement:	Instructional programs from pre-kindergarten through grade 12 should enable all students to understand measurable attributes of objects and the units, systems, and processes of measurement; apply appropriate techniques, tools, and formulas to determine measurements.
Data Analysis and Probability:	Instructional programs from pre-kindergarten through grade 12 should enable all students to; formulate questions that can be addressed with data and collect, organize, and display relevant data to answer them; select and use appropriate statistical methods to analyze data; develop and evaluate inferences and predictions that are based on data; understand and apply basic concepts of probability.
Problem Solving:	Instructional programs from pre-kindergarten through grade 12 should enable all students to; build new mathematical knowledge through problem solving; solve problems that arise in mathematics and in other contexts; apply and adapt a variety of appropriate strategies to solve problems; monitor and reflect on the process of mathematical problem solving.

English Standards for English Language Arts

Standard 1:	Students read a wide range of print and non-print texts to build an understanding of texts of themselves, and of the cultures of the United States and the world; to acquire new information; to respond to the needs and demands of society and the workplace; and for personal fulfillment.
Standard 4:	Students adjust their use of spoken, written, and visual language (e.g. conventions, style, vocabulary) to communicate effectively with a variety of audiences and for different purposes.

Performance Objectives

It is expected that students will:

- Program a servo motor.
- Program and test an autonomous robot.
- Use mathematics to calculate programming values.

Assessment

Explanation:

- Students will explain how changes in command are reflected in the operation of a servo motor.

Application:

- Students will apply their knowledge of programming to program a robot to complete given tasks.

Essential Questions

1. What is a servo motor and what parameters does it use in programming code?
2. What is a tactile switch and how is it used to create an autonomous robot?

Key Terms

Servo Motor	A motor that delivers continuous motion at various speeds.
PULSOUT	A command in PBASIC that generates a pulse on *Pin* with a width of *Duration.*
Tactile Switch	A device that changes state based on touch input to its sensors.
Horn	Shaft on the servo motor controlled by PBASIC.
Duration	Modifier on the PULSOUT command in PBASIC; determines the number of 2-μs time spans for the length of the high signal.

Day-by-Day Plans

Time: 9 days

NOTE: In preparation for teaching, it is strongly recommended that the teacher read the **Lesson 4.2 Teacher Notes** for this lesson.

Day 1 – 2 : Lesson Overview and Introduction to the Boe-Bot

- The teacher will present **Concepts**, **Essential Questions**, and **Key Terms** in order to provide a lesson overview.
- The teacher will present **The Boe-Bot and Servo Motors.ppt.**
- Students will take notes in their engineering journals.
- The teacher will distribute and introduce **Activity 4.2.1 Assemble and Test the Boe-Bot.**
- Students will take notes in their engineering journals.
- Students will work on Activity 4.2.1 Assemble and Test The Boe-Bot.
- The teacher will assist the students as needed.
- Optional: After the key terms have been introduced, the teacher may choose to distribute **Lesson 4.2 Key Term Crossword** for homework.

Day 3 – 5: Boe-Bot Navigation

- The teacher will present **Boe-Bot Navigation.ppt.**
- Students will take notes in their engineering journals.
- The teacher will distribute and introduce **Activity 4.2.2 Boe-Bot Navigation**.
- Students will take notes in their engineering journals.
- Students will work on Activity 4.2.2 Boe-Bot Navigation.
- The teacher will assist the students as needed.

Day 6 – 8: Boe-Bot Tactile Whiskers

- The teacher will present **Boe-Bot Tactile Whiskers.ppt.**
- Students will take notes in their engineering journals.

- The teacher will distribute and introduce **Activity 4.2.3 Boe-Bot Tactile Whiskers.**
- Students will take notes in their engineering journals.
- Students will work on Activity 4.2.3 Boe-Bot Tactile Whiskers.
- The teacher will assist the students as needed.

Day 9: Lesson Review

- The teacher will review the lesson's essential questions.
- Students will work in small groups (2-4) to answer the lesson's essential questions. Each group will be assigned one essential question to discuss, formulate a response for, and present to the class. The intent of this activity is to give closure to the lesson's topics and to have the students reflect back on the underlying concepts covered in the lesson's activities, projects, and problems.
- Students will take notes in their engineering journals.

Instructional Resources

Presentations

The Bot-Bot and Servo Motors

Boe-Bot Navigation

Boe-Bot Tactile Whiskers

Word Documents

Lesson 4.2 Key Term Crossword

Activity 4.2.1 Assemble and Test the Boe-Bot

Activity 4.2.2 Boe-Bot Navigation

Activity 4.2.3 Boe-Bot Tactile Whiskers

Parallax PDF Documents

Activity 4.2.1

Activity 4.2.2

Activity 4.2.3

Answer Keys and Rubrics

Lesson 4.2 Key Term Crossword Answer Key

Teacher Guidelines

Lesson 4.2 Teacher Notes

Reference Sources

Dueck, R., & Reid, K. (2008). *Introduction to digital electronics.* Clifton Park, NY: Thompson Delmar Learning.

Floyd, T. (2006). *Digital fundamentals.* Upper Saddle River, NY: Pearson Education.

International Technology Education Association, (2000). Standards for technological literacy. Reston, VA: ITEA.

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Tokeim, R. L. (2003). *Digital electronics principles and applications.* Columbus, OH: Glencoe/McGraw-Hill.

Parallax Inc. (2004). *What's a microcontroller.* Retrieved June 20, 2008, from http://www.parallax.com/tabid/440/Default.aspx

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Lesson 4.3 Boe-Bot Design Projects

Preface

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

Concepts

1. Digital devices are only relevant if they can interact with the real world.
2. Flowcharting is a powerful graphical organizer used by engineers and professionals in a variety of roles and responsibilities.
3. Realistic problem solving with a control system requires the ability to interface analog inputs and outputs with a digital device.
4. Microcontrollers are a practical tool for controlling a mechanical system.

Standards and Benchmarks Addressed

Standards for Technological Literacy

Standard 1: Students will develop an understanding of the characteristics and scope of technology.

BM G: The development of technology is a human activity and is the result of individual or corporate needs and the ability to be creative.

BM H: Technology is closely linked to creativity, which has resulted in innovation.

Standard 2: Students will develop an understanding of the core concepts of technology.

BM F: A subsystem is a system that operates as a part of another system.

BM G: When parts of a system are missing, it may not work as planned.

BM H: Resources are the things needed to get a job done, such as tools and machines, materials, information, energy, people, capital, and time.

BM I: Tools are used to design, make, use, and assess technology.

BM K: Tools and machines extend human capabilities, such as holding, lifting, carrying, fastening, separating, and computing.

BM L: Requirements are the limits to designing or making a product or system.

BM M: Technological systems include input, processes, output, and, at times, feedback.

BM N: Systems thinking involves considering how every part relates to others.

BM O: An open-loop system has no feedback path and requires human intervention, while a closed-loop system uses feedback.

BM P: Technological systems can be connected to one another.

BM Q: Malfunctions of any part of a system may affect the function and quality of the system.

BM R: Requirements are the parameters placed on the development of a product or system.

BM S: Trade-off is a decision process recognizing the need for careful compromises among competing factors.

BM T: Different technologies involve different sets of processes.

BM U: Maintenance is the process of inspecting and servicing a product or system on a regular basis in order for it to continue functioning properly, to extend its life, or to upgrade its capability.

BM V: Controls are mechanisms or particular steps that people perform using information about the system that causes systems to change.

BM W: Systems' thinking applies logic and creativity with appropriate compromises in complex real-life problems.

BM X: Systems, which are the building blocks of technology, are embedded within larger technological, social, and environmental systems.

BM Y: The stability of a technological system is influenced by all of the components in the SYSTEM especially those in the feedback loop.

BM Z: Selecting resources involves trade-offs between competing values, such as availability, cost, desirability, and waste.

BM AA: Requirements involve the identification of the criteria and constraints of a product or system and the determination of how they affect the final design and development.

BM BB: Optimization is an on going process or methodology of designing or making a product and is dependent on criteria and constraints.

BM CC: New technologies create new processes.

BM DD: Quality control is a planned process to ensure that a product, service, or system meets established criteria.

BM EE: Management is the process of planning, organizing, and controlling work.

BM FF: Complex systems have many layers of controls and feedback loops to provide information.

Standard 3: Students will develop an understanding of the relationships among technologies and the connections between technology and other fields of study.

BM D: Technological systems often interact with one another.
A product, system, or environment developed for one setting may be applied to another setting.

BM F: Knowledge gained from other fields of study has a direct effect on the development of technological products and systems.

BM G: Technology transfer occurs when a new user applies an existing innovation developed for one purpose in a different function

BM H: Technological innovation often results when ideas, knowledge, or skills are shared within a technology, among technologies, or across other fields.

Standard 9: Students will develop an understanding of engineering design.

BM C: The engineering design process involves defining a problem, generating ideas, selecting a solution, testing the solution(s), making the item, evaluating it, and presenting the results.

BM D: When designing an object, it is important to be creative and consider all ideas.

BM E: Models are used to communicate and test design ideas and processes.

BM F: Design involves a set of steps, which can be performed in different sequences and repeated as needed.

BM G: Brainstorming is a group problem-solving design process in which each person in the group presents his or her ideas in an open forum.

BM H: Modeling, testing, evaluating, and modifying are used to transform ideas into practical solutions.

BM I: Established design principles are used to evaluate existing designs, to collect data, and to guide the design process.

BM J: Engineering design is influenced by personal characteristics, such as creativity, resourcefulness, and the ability to visualize and think abstractly.

BM K: A prototype is a working model used to test a design concept by making actual observations and necessary adjustments.

BM L: The process of engineering design takes into account a number of factors.

Standard 10: Students will develop an understanding of the role of troubleshooting, research and development, invention and innovation, and experimentation in problem solving.

BM F: Troubleshooting is a problem-solving method used to identify the cause of a malfunction in a technological system.

BM H: Some technological problems are best solved through experimentation.

BM L: Many technological problems require a multidisciplinary approach.

Standard 11: Students will develop abilities to apply the design process.

BM D: Identify and collect information about everyday problems that can be solved by technology, and generate ideas and requirements for solving a problem.

BM E: The process of designing involves presenting some possible solutions in visual form and then selecting the best solution(s) from many.

BM F: Test and evaluate the solutions for the design problem.

BM G: Improve the design solutions.

BM H: Apply a design process to solve problems in and beyond the laboratory-classroom

BM I: Specify criteria and constraints for the design.

BM J: Make two-dimensional and three-dimensional representations of the designed solution.

BM K: Test and evaluate the design in relation to pre-established requirements, such as criteria and constraints, and refine as needed.

BM L: Make a product or system and document the solution.
BM N: Identify criteria and constraints and determine how these will affect the design process.
BM O: Refine a design by using prototypes and modeling to ensure quality, efficiency, and productivity of the final product.
BM P: Evaluate the design solution using conceptual, physical, and mathematical models at various intervals of the design process in order to check for proper design and to note areas where improvements are needed.
BM Q: Develop and produce a product or system using a design process.
BM R: Evaluate final solutions and communicate observation, processes, and results of the entire design process, using verbal, graphic, quantitative, virtual, and written means, in addition to three-dimensional models.

Standard 12: Students will develop the abilities to use and maintain technological products and systems.
BM K: Operate and maintain systems in order to achieve a given purpose.
BM L: Document processes and procedures and communicate them to different audiences using appropriate oral and written techniques.
BM M: Diagnose a system that is malfunctioning and use tools, materials, machines, and knowledge to repair it.
BM N: Troubleshoot, analyze, and maintain systems to ensure safe and proper function and precision.
BM O: Operate systems so that they function in the way they were designed.
BM P: Use computers and calculators to access, retrieve, organize and process, maintain, interpret, and evaluate data and information in order to communicate.

Standard 13: Students will develop the abilities to assess the impacts of products and systems.
BM E: Examine the trade-offs of using a product or system and decide when it could be used.
BM F: Design and use instruments to gather data.

Standard 17: Students will develop an understanding of and be able to select and use information and communication technologies.
BM I: Communication systems are made up of a source, encoder, transmitter, receiver, decoder, and destination.
BM J: The design of a message is influenced by such factors as the intended audience, medium, purpose, and nature of the message.
BM L: Information and communication technologies include the inputs, processes, and outputs associated with sending and receiving information.
BM M: Information and communication systems allow information to be transferred from human to human, human to machine, machine to human, and machine to machine.
BM Q: Technological knowledge and processes are communicated using symbols, measurement, conventions, icons, graphic images, and languages that incorporate a variety of visual, auditory, and tactile stimuli.

Standard 20: Students will develop an understanding of and be able to select and use construction technologies.
BM L: The design of structures includes a number of requirements.

National Science Education Standards

Standard K-12: Unifying Concepts and Processes: As a result of activities in grades K-12, all students should develop understanding and abilities aligned with the following concepts and processes;

- Systems, order, and organization
- Evidence, models, and explanation
- Change, constancy, and measurement
- Form and function

Content Standard A: Science As Inquiry: As a result of activities in grades 9-12, all students should develop;

- Abilities necessary to do scientific inquiry
- Understandings about scientific inquiry

Standard E: Science and Technology: As a result of activities in grades 9-12, all students should develop

- Abilities of technological design
- Understandings about science and technology

Principles and Standards for School Mathematics

Number and Operations:	Instructional programs from pre-kindergarten through grade 12 should enable all students to understand numbers, ways of representing numbers, relationships among numbers, and number systems; understand meanings of operations and how they relate to one another; compute fluently and make reasonable estimates.
Algebra:	Instructional programs from pre-kindergarten through grade 12 should enable all students to understand patterns, relations, and functions; represent and analyze mathematical situations and structures using algebraic symbols; use mathematical models to represent and understand quantitative relationships; analyze change in various contexts.
Measurement:	Instructional programs from pre-kindergarten through grade 12 should enable all students to understand measurable attributes of objects and the units, systems, and processes of measurement; apply appropriate techniques, tools, and formulas to determine measurements.
Data Analysis and Probability:	Instructional programs from pre-kindergarten through grade 12 should enable all students to formulate questions that can be addressed with data and collect, organize, and display relevant data to answer them; select and use appropriate statistical methods to analyze data; develop and evaluate inferences and predictions that are based on data; understand and apply basic concepts of probability.
Problem Solving:	Instructional programs from pre-kindergarten through grade 12 should enable all students to build new mathematical knowledge through problem solving; solve problems that arise in mathematics and in other contexts; apply and adapt a variety of appropriate strategies to solve problems; monitor and reflect on the process of mathematical problem solving.
Reasoning and Proof:	Instructional programs from pre-kindergarten through grade 12 should enable all students to recognize reasoning and proof as fundamental aspects of mathematics; make and investigate mathematical conjectures; develop and evaluate mathematical arguments and proofs; select and use various types of

	reasoning and methods of proof.
Communication:	Instructional programs from pre-kindergarten through grade 12 should enable all students to organize and consolidate their mathematical thinking through communication; communicate their mathematical thinking coherently and clearly to peers, teachers, and others; analyze and evaluate the mathematical thinking and strategies of others; use the language of mathematics to express mathematical ideas precisely.
Connections:	Instructional programs from pre-kindergarten through grade 12 should enable all students to recognize and use connections among mathematical ideas; understand how mathematical ideas interconnect and build on one another to produce a coherent whole; recognize and apply mathematics in contexts outside of mathematics.
Representation:	Instructional programs from pre-kindergarten through grade 12 should enable all students to create and use representations to organize, record, and communicate mathematical ideas; select, apply, and translate among mathematical representations to solve problems; use representations to model and interpret physical, social, and mathematical phenomena.

Standards for English Language Arts

Standard 4:	Students adjust their use of spoken, written, and visual language (e.g. conventions, style, vocabulary) to communicate effectively with a variety of audiences and for different purposes.
Standard 12:	Students use spoken, written and visual language to accomplish their own purposes (e.g. for learning, enjoyment, persuasion, and the exchange of information).

Performance Objectives

It is expected that students will:

- Draw a flowchart for a microcontroller program that will be used to maneuver a robot.
- Program a microcontroller to maneuver a robot through a design course.

Assessment

Explanation:

- Students will explain their choice of design projects.

Application:

- Students will apply their knowledge of programming to program a robot to maneuver through a design course.

Essential Questions

1. How does a microcontroller enable users to interface the analog world with the digital world?
2. How does the design course relate to real-world problems?

Key Terms

Analog	Having a continuous set of values.

Control	A device or mechanism used to regulate or guide the operation of a machine, apparatus, or system.
Digital	Having a series of individual values (discrete).
Discrete	Individual values.
Interface	The place at which independent and often unrelated systems meet and act on or communicate with each other.
Mechanical	Produced or operated by a machine or tool.
Microcontroller	A computer on a chip.

Day-by-Day Plans

Time: 11 days

NOTE: In preparation for teaching, it is strongly recommended that the teacher read the **Lesson 4.3 Teacher Notes** for this lesson.

Day 1 – 2: Project Introduction

- The teacher will present **Concepts**, **Essential Questions**, and **Key Terms** in order to provide a lesson overview.
- The teacher will distribute and introduce **Project 4.3.1 Boe-Bot Design Projects (P4_3_1A, P4_3_1B, and P4_3_1C).**
- Students will take notes in their engineering journals.
- Working in design teams of two or three, students will select which design project that they will complete.
- Optional: After the key terms have been introduced, the teacher may choose to distribute **Lesson 4.3 Key Term Crossword** for homework.

Day 3 – 10: Design Work

- Students will work on their selected design projects.
- The teacher will assist the students as needed.

Day 11: Lesson Review

- The teacher will review the lesson's essential questions.
- Working in their design teams, students will answer the lesson's essential questions. Each group will be assigned one essential question to discuss, formulate a response for, and present to the class. The intent of this activity is to give closure to the lesson's topics and to have the students reflect back on the underlying concepts covered in the lesson's activities, projects, and problems.
- Students will take notes in their engineering journals.

Instructional Resources

Word Documents

Lesson 4.3 Key Term Crossword

Project 4.3.1 Boe-Bot Design Projects

Parallax PDF Documents

Activity 4.3.1A

Reference Sources

International Technology Education Association, (2000). Standards for technological literacy. Reston, VA: ITEA.

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