Development of Virtual laboratories Handout 1

Resource – Guidelines for Virtual labs – Electronics Engineering	**Version 1.0, April 2016** **Version 1.5 March 2018**
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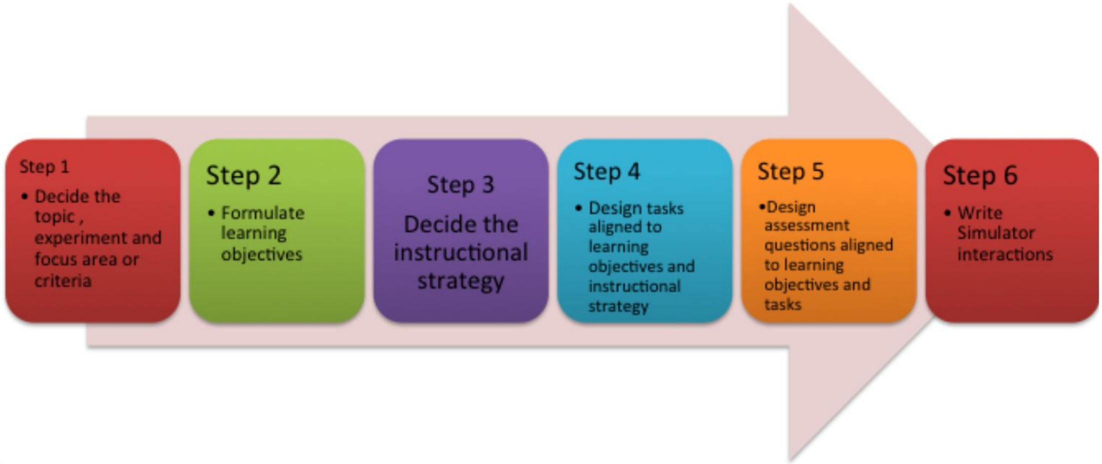

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Guidelines to design experiments for development of effective virtual laboratories

These guidelines cover the five important steps in the design of experiments for effective virtual laboratories. These steps are as follows:

a. Selection of topic, experiment and focus area or criteria
b. Formulate learning objectives
c. Selection of instructional strategy
d. Design tasks aligned to learning objectives and instructional strategy
e. Design assessment questions aligned to learning objectives and tasks

Step 1 – a. Guidelines for selection of topic, experiment and focus area or criteria

This is the most important step in the development of the virtual lab as all the decisions in the preceding steps depend on this decision. In order to arrive at the decision the following procedure may be followed.

1. Select the topic in your course for which you wish to develop virtual lab experiment. After you have selected the topic for which you wish to design a virtual laboratory experiment classify the content in the topic as per the table given below. The following is illustrated with an example for the topic PN Junction diode.

Facts	Concepts	Procedures	Metacognition
Basic elements used to communicate, understand, organize a subject: terminology, scientific terms, labels, vocabulary, jargon, symbols or representations; and specific details such as knowledge of events, people, dates, sources of information.	Knowledge of classifications and categories, principles, theories, models or structures of a subject.	Knowing how to do something: performing skills, algorithms, techniques or methods.	The process or strategy of learning and thinking; an awareness of one's own cognition, and the ability to control, monitor, and regulate one's own cognitive process.
Definition, Symbols,	Construction and internal Working, Diode current equation, Piecewise linear model, Space charge capacitance C_T of diode, Breakdown mechanism,	V-I Characteristics, Diode operating point, Diode under no bias, forward bias and reverse bias, Relationship between Diode Current and Diode Voltage, Effect of temperature on diode characteristics,	
	Reinforce theoretical concepts, Modeling	**Practical skills, Data Analysis,**	**Experiment, Learn from failure**

Selection of the focus area/criteria

When the engineering faculties wish to integrate virtual laboratories in their teaching one of the most important decision is the selection of virtual lab to be used. This selection depends on learning objectives to be achieved using the virtual lab. In order to achieve the desired learning objectives the students will be asked to perform certain tasks and answer certain questions. The virtual lab selected must have the necessary features so that the tasks can be performed using the selected virtual lab. If the lab does not have certain features then that particular learning objective will not be achieved. In order to help the faculties in this particular decision we provide guidelines giving the mapping between the learning objectives and the virtual lab features.

As per ABET the broad categories of laboratory learning objectives are as follows.

1. Instrumentation
2. Models
3. Experiment
4. Data Analysis
5. Design
6. Learn from Failure
7. Creativity
8. Psychomotor
9. Safety
10. Communication
11. Teamwork
12. Ethics in the Lab
13. Sensory Awareness

We provide guidelines for the following ABET laboratory learning objectives.

1. Reinforce theoretical concepts
2. Instrumentation
3. Models
4. Experiment
5. Data Analysis
6. Learn from Failure

1. Reinforce theoretical concepts: This refers to the ability of the students to be able to understand various concepts taught in the theory class.

2. Instrumentation: This skill implies developing technical and practical laboratory skills and techniques such as constructing experimental setup and other manipulative skills, various standard procedures to be followed, learn how to use a standard laboratory instrument or apparatus or equipment. To familiarize students with the use of important instruments, equipment, and techniques.

3. Models: This skill implies use of various models according to the type of investigation to be carried out.

4. Experiment: This skill implies how to plan an investigation to address a specific question or problem, designing experiments for the same and carrying out the investigation and solve the problem.

5. Data Analysis: This skill implies analyzing and visualizing data, organizing and processing data (including graphs, how to process data and how to use data to support a conclusion.

6. Learn from failure: This skill implies basic troubleshooting that is finding out errors or faults leading to undesired results, rectifying the faults and coming up with a correct solution.

Focus area/ Criteria	**Guideline for selection**	**Example**
Reinforce theoretical concept	Select this criterion for 1. Knowledge type concepts. 2. Interactive exploration of unobservable phenomena. 3. If there are some abstract concepts which students can understand after visualization in the selected topic	Simulated electric circuits showing moving electrons acquired more conceptual knowledge than those using physical materials.
Instrumentation and Practical skills	Select this criterion for 1. Knowledge type procedure. 1.Students are using the components or equipment for the first time. 2. Students have used the components or equipment but have not understood in physical labs. 3. A new component or equipment is introduced in the topic. 4. Develop the skill of using the various components and equipment. 5. Develop the skill of carrying out various lab procedures such as building circuits/systems, data gathering.	1. Develop skill of using ammeter, voltmeter, power supply, CRO etc. 2.Understand the specifications of diodes, BJTs, FETs 3. Understand the ranges, resolutions of voltmeter, power supply, CRO etc.
Experimentation	Select this criterion for 1.Knowledge type metacognition 2.After the students have understood the theoretical concepts and procedures and developed the practical skills. This criterion should be selected after the students have performed a few experiments in the virtual lab and are well conversant with the affordances.	You wish to find out if the students can design and carry out the properly designed experiment to find the diode most suitable for a certain application – rectification, switching, etc. You wish the students to understand their level of understanding.
Data Analysis	Select this criterion for 1.Knowledge type procedure. 2.The development of the skill of data analysis. This should be given after the students have understood the theoretical concepts and procedures and developed the practical skills. 3.The students should have	You wish to find out if the students can predict the outputs for various inputs applied to circuits, changes in the plots with changes in the specifications of components, etc.

	performed an experiment using virtual lab and have understood the procedures of plotting, observing and measuring data from plots.	
Modeling	Select this criterion for 1.Knowledge type concepts. 2.After the students have understood the various theoretical models for the devices based on various specifications. Students should also have knowledge of the mathematical representations and the relation between the two. 3.The students should have performed an experiment using virtual lab and have understood the procedures of adding equations and plotting them.	You wish the students to understand the piece-wise linear model of PN junction diode. You wish the students to understand the significance of choice of BJT models depending on the input frequency.
Learn from failure	Select this criterion for 1.Knowledge type concepts, procedures, metacognition. 2.After the students have understood the theoretical concepts, performed a few experiments, have understood the various procedures, have understood the relations between various parameters in a circuit, have developed practical skills.	Given a circuit identify the faults. Give reasons for the faults. Rectify the faults.

Step 2 – b. Formulate the laboratory learning objectives

After you have selected the focus area and criteria the next step is either the selection or formulation of the laboratory learning objectives. The following paragraphs discuss the guidelines for formulating or selecting learning objectives

What are valid learning objectives?

Learning objectives are goal statements which includes specific measurable performance outcomes of learner.

Learning objectives – Don'ts & Do's

As per the definition of learning objectives they need to be very specific and measurable hence you should not use verbs such as understand, visualize etc instead use action verbs such as identify, list,describe,solve etc.

Similarly the learning objective should be concerned with the learner and not the teacher hence avoid using verbs such as teach,show,demonstrate etc.

Revised Bloom's taxonomy

Bloom's taxonomy was developed in the 1950's and is still used today to categorize ways of learning and thinking in a hierarchical structure. A revised model was developed in the 1990's to better fit educational practices of the 21st century. A group of cognitive psychologists, curriculum theorists and instructional researchers, and testing and assessment specialists published in 2001 a revision of Bloom's Taxonomy with the title *A Taxonomy for Teaching, Learning, and Assessment*.

The authors of the revised taxonomy underscore this dynamism, using verbs and gerunds to label their categories and subcategories (rather than the nouns of the original taxonomy). These "action words" describe the cognitive processes by which thinkers encounter and work with knowledge:

- Remember :
    - Recognizing
    - Recalling
- Understand
    - Interpreting
    - Exemplifying
    - Classifying
    - Summarizing
    - Inferring
    - Comparing
    - Explaining
- Apply
    - Executing
    - Implementing
- Analyze
    - Differentiating
    - Organizing
    - Attributing
- Evaluate
    - Checking
    - Critiquing
- Create
    - Generating
    - Planning
    - Producing

In the revised taxonomy, knowledge is at the basis of these six cognitive processes, but its authors created a separate taxonomy of the types of knowledge used in cognition:

- Factual Knowledge
    - Knowledge of terminology
    - Knowledge of specific details and elements
- Conceptual Knowledge
    - Knowledge of classifications and categories
    - Knowledge of principles and generalizations
    - Knowledge of theories, models, and structures
- Procedural Knowledge
    - Knowledge of subject-specific skills and algorithms
    - Knowledge of subject-specific techniques and methods
    - Knowledge of criteria for determining when to use appropriate procedures
- Metacognitive Knowledge
    - Strategic Knowledge
    - Knowledge about cognitive tasks, including appropriate contextual and conditional knowledge
    - Self-knowledge

A complete set of verbs which can be used to formulate learning objectives at the various levels of Bloom's taxonomy are given in the following table.

Level	**Action Verbs**
Create	design, combine, devise, modify, plan
Evaluate	assess, conclude, contrast, evaluate
Analyse	analyze, infer examine, dissect ascertain,
Apply	Apply, calculate, solve, predict
Understan d	Describe, Explain, Give example of, Select
Recall	List, Identify, Define, State

Step 3 - c. Guidelines for selection of instructional strategy

Instruction is a combination of teaching and learning activities. Instruction is a whole process that includes facilitating the learning process and guiding the pupils. Strategies determine the approach a teacher may take to achieve learning objectives. The five main instructional strategies used in traditional laboratories are: Expository, Guided Inquiry or Discovery, Inquiry, Problem-based and Project-based. We propose the use of one more strategy, which is the Structured problem solving.

Guidelines to design an Expository laboratory experiment

For decades, the dominant laboratory instructional style has been expository laboratories in which the instructor defines the topic to be investigated, provides a context for the investigation, has students repeat instructions or follow them from a manual, and then compare results with a predetermined outcome known to both student and instructor. This instructional style gives little emphasis to critical thinking and conceptual change, which is unfortunate given the current consensus that conceptual learning is the most important outcome of laboratory instruction. It has been suggested that laboratory instructional style may affect learning, with a particular laboratory format being better suited for meeting a given goal. For example, conceptual learning may benefit from an inquiry-based or questioning approach, whereas skills are best taught by more direct instructional techniques.

The main components of the expository laboratory instruction are as follows:

Aim/Purpose
What is the reason for doing the experiment?

Learning Objectives
What is there to be learned from doing the experiment?

Hypothesis
What "you think" will be the final outcome of the experiment. This is generally based on prior knowledge or observations. In other words, you are not just pulling this "out of thin air"; you have some logical reason for thinking this. If you have no prior knowledge of the concept, you will need to do research before making a hypothesis. Also, explain exactly "why you think this".

Apparatus/Materials
A list of equipment and supplies that will be needed to complete the lab procedure. List the major pieces of equipment first.

Procedure
1. The step by step process that is followed in carrying out the experiment. Preferably, the steps are sequentially listed in the order they need to be followed to complete the experiment successfully. Be very exact with each step in case someone else wants to repeat your procedure. It's like telling someone how to find your house. The least little mistake or detail left out could be critical to the outcome of the experiment.
2. Using the safety symbols, identify any precautions that may need to be followed in completing this experiment.
3. Identify the variables in the experiment:
    - Controlled - factors that remain constant throughout the experiment.
    - Independent - the one factor that will be manipulated or changed during the experiment.
    - Dependent - the variable that becomes altered as a result of the change that was made in the independent variable.

Observations

Observations are of two categories:
- Qualitative - information gathered through the senses such as smell, taste, touch, hear, shape, etc.
- Quantitative - information gathered due to precise measurements, such as height in cm, width in cm, mass in g, volume in cm3, density in g/cm3, time in seconds, speed in kph, etc.

Observations are organized in:
- Data tables or charts.

Results
Graphs are visual representations of the data so that it can be easily studied, interpreted, and analyzed. Circle, bar, and line are examples of kinds of graphs.

Conclusion

This is a written summary of what was actually learned from doing the experiment. The conclusion will either support or reject the proposed hypothesis.

Examples of Expository Laboratory Experiment Design

Sample Laboratory Experiment Design #1

Construct the given circuit. Measure the current flowing through the diode at various values of applied DC voltage. Note down the readings for ten values. Plot the graph of current Vs. voltage to obtain the V- I Characteristics of the PN junction diode. Calculate the static and dynamic resistance of the diode from the formulae given.

Guidelines to design a Discovery or Guided Inquiry based laboratory experiment

Inquiry means that students are handling science; they are manipulating it, working it into new shapes and formats, integrating it into every corner of their world, and playing with it in unknown ways. Inquiry implies that students are in control of an important part of their own learning where they can manipulate ideas to increase understanding.
"Scientific inquiry refers to the diverse ways in which scientists study the natural world and propose explanations based on the evidence derived from their work. Inquiry also refers to the activities of students in which they develop knowledge and understanding of scientific ideas, as well as an understanding of how scientists study the natural world."

Alan Colburn suggests three levels in inquiry based learning – Structured Inquiry, Guided Inquiry and Open Inquiry. Discovery learning or Guided Inquiry is the most fundamental form of inquiry-oriented learning. The focus of discovery learning is not on finding applications for knowledge but, rather, on constructing concepts and knowledge from experiences. As such, discovery learning employs reflection as the key to understanding. The teacher introduces an experience in such a way as to enhance its relevance or meaning, uses a sequence of questions during or after the experience to guide students to a specific conclusion, and questions students to direct discussion that focuses on a problem or apparent contradiction. Employing inductive reasoning, students construct simple relationships or principles from their guided observations.

Phases of Inquiry
According to Nancy T. Davis, Associate Professor of Science Education at Florida State University (personal interview, 2002), there are four phases within each of the inquiry approaches. Each phase is characterized by questions that guide students to make their own discoveries.

Initiation Phase

The Initiation Phase is the first phase in all levels of inquiry. It is primarily designed to stimulate and motivate students' curiosity through questioning. This phase provides students with an opportunity to experience a phenomenon or something new that challenges a previous belief or assumption.

- **Have you ever seen…?**
- **Did you notice…?**
- **What did you observe…?**

Exploration Phase

The Exploration Phase is the second phase of inquiry. In this phase, questions are eliminated or narrowed down to those types of questions students can actually physically answer through experimentation or research.

- What happened when…?
- What did you…?
- What could we do to find out…?
- What questions do you have…?

Experimentation Phase

The third phase of inquiry is the Experimentation Phase. This is where students form into groups to conduct an experiment. Students collect data and information, and then formulate a method of presentation.

- What did you find out about…?
- How is it the same as or different from…?
- What do you know about the characteristics of…?

Presentation Phase

The last phase of inquiry is the Presentation Phase. Groups or individuals take the information gathered in the experiment and put it into some form of presentation. *PowerPoint* presentations or project display boards are types of presentations that may be used. The group or individual will share the data with an audience and allow time for questions concerning procedures, data, information, etc.

- Can you explain why…?
- Why do you think…?
- What other factors may be included in…?
- Can you find a way to…?
- How did you arrive at a solution to…?

Problems in Inquiry Instructions:

Provide students enough time to complete an investigation.
Be aware that often students have difficulty identifying a problem to investigate.
Students may be disinterested, apathetic, or will not engage in the inquiry.
Be aware that students may have difficulty mastering or designing procedures.

Examples of Guided Inquiry/Discovery Laboratory Experiment Design

Sample Laboratory Experiment Design #1

The experiment design should have the following components:

- Focus Question:
- Learning Objectives:
- Background Information
- Experimental Procedure
- Materials needed
- Guided Inquiry list of questions

Example:

Focus Question: How does the resistance of a PN Junction diode vary?
Procedure: To carry out this analysis what procedure will you follow? What circuit will you use? What are the observations necessary to carry out the experiment? What data will you gather? How will you represent the data? What type of data analysis will you carry out? What can you infer from the analysis of the data? Do the results answer the focus question? What can you conclude from the results?

Sample Laboratory Experiment Design #2

THE JUNKYARD

In a junkyard, Mr. X, the owner of the junkyard, uses big electromagnet cranes to move old cars. The electromagnet crane he uses is able to lift standard-sized cars easily. However, Mr. X has realized that it is not appropriate for holding bigger cars, such as SUVs, which are two times heavier than usual cars. Because Mr. X cannot afford to buy a new electromagnet crane, he tries to make a more powerful electromagnet crane by doing some changes using the materials that are available in his junkyard.

Can you give some advice to Mr. X on this issue as a physicist?
What can be the physics concepts related to this situation? □
What is the main problem of Mr. X when you look at from a physicist's perspective? Write a hypothesis that may provide a solution to the problem: □
Design an experiment to test your hypothesis in the laboratory:
What are the variables that can affect your experiment? Manipulated:□
Responding: □
Controlled:
Uncontrolled: □
Your results and observations:
Interpretation of your results and observations: What is your recommendation to Mr. X?

Guidelines to design a Structured problem solving laboratory experiment

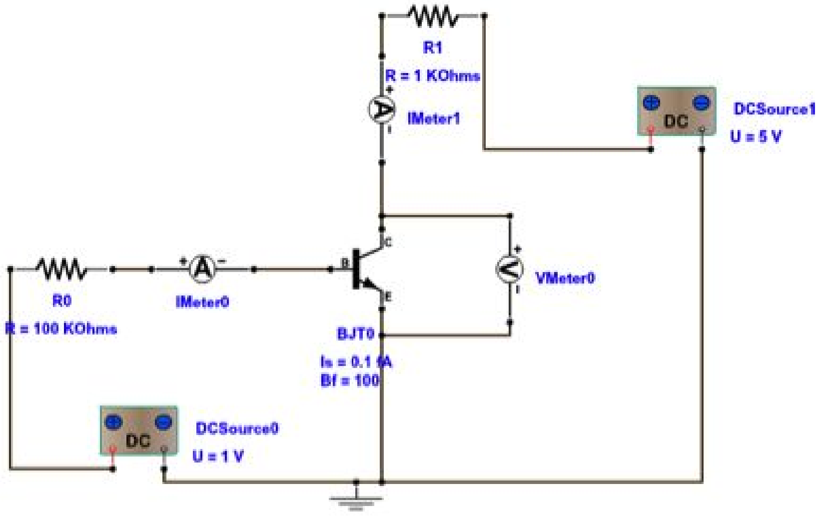
Well structured problems are problems that always use the same step-by- step solution. The characteristics of well structured problems are : Solution strategy is usually predictable, convergent (one right answer) and all starting information is usually part of the problem statement. So the experiment design for such a problem solving is simple. The structured problem is given to the students as the laboratory exercise and the students are required to come up with the solution using the experimental procedures, collect data, analyse the data and arrive at the desired solution.

Examples of Structured problem solving Laboratory Experiment Design

Sample Laboratory Experiment Design #1

In the CE Transistor circuit shown VBB= 5V, R0= 107.5 k Ω, R1 = 10 k Ω,
VCC = 10V. Construct the circuit and obtain the DC Characteristics.
Find IB, IC, VCE, β and the transistor power dissipation using the characteristics.

- Compare the theoretical and practical values obtained.
- Also compare your values with that of your neighbour.



Sample Laboratory Experiment Design #2

Design a Mod 8 counter, implement the design in the virtual lab and obtain the output waveforms.

Guidelines to design a Problem-based laboratory experiment

Problem-based learning (PBL) is a student-centered approach in which students learn about a subject by working in groups to solve an open-ended problem. The problem is what drives the motivation and the learning.

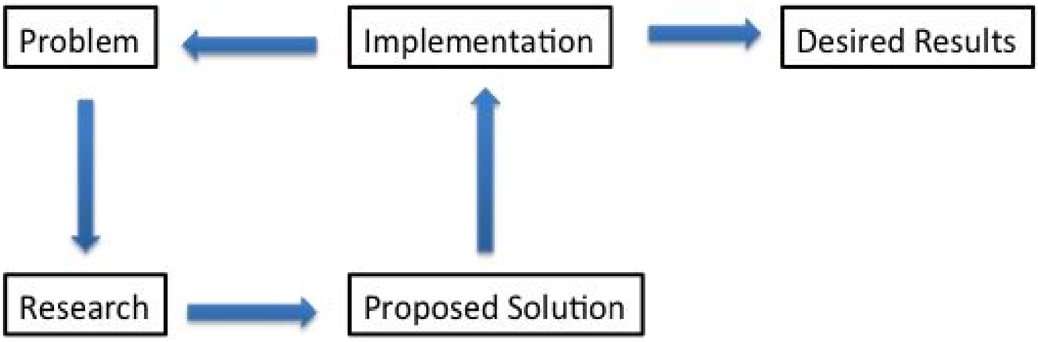
Rather than teaching relevant material and subsequently having students apply the knowledge to solve problems, the problem is presented first. Students generally must:

1. Examine and define the problem.

2. Explore what they already know about underlying issues related to it.
3. Determine what they need to learn and where they can acquire the information and tools necessary to solve the problem.
4. Evaluate possible ways to solve the problem.
5. Solve the problem.
6. Report on their findings.

PBL assignments can be short, or they can be more involved and take a whole semester.
The basic steps in designing PBL experiment/project are:

- Articulate the learning outcomes of the project. What do you want students to know or be able to do as a result of participating in the assignment?
- Create the problem. Ideally, this will be a real-world situation that resembles something students may encounter in their future careers or lives. Cases are often the basis of PBL activities.
- Establish ground rules at the beginning to prepare students to work effectively in groups.
- Establish how you will evaluate and assess the assignment. Consider making the assessments students make of their own work and that of their peers part of the assignment grade.



The figure illustrates the steps in a problem based laboratory experiment.

Examples of Problem-based Laboratory Experiment Design

Sample Laboratory Experiment Design #1

1. An assembly line has 3 failsafe sensors and 1 emergency shutdown switch. The Line should keep moving unless any of the following conditions arise:

- If the emergency switch is pressed.
- If sensor 1 and sensor 2 are activated at the same time.
- If sensor 2 and sensor 3 are activated at the same time.
- If all three sensors are activated at the same time.

(a) Derive the truth table for this system.
(b) Design, using Karnaugh Map techniques, a minimum AND-OR gate network for this system.
(c) Draw the resulting digital circuit diagram.
(d) If the time delay experienced by a NAND gate is 8ns and the time delay experienced in a NOR gate is 10ns. Which implementation of (c) is faster? By how long?
(c) Design, a digital circuit that will implement the minimal AND-OR gate network found in (b) using both
(i) NAND gates only
(ii) NOR gates only.
Assume that each logic gate can have any number of inputs and that inverted inputs are available.

Sample Laboratory Experiment Design #2

2. A warning buzzer is to sound when the following conditions apply:

- Switches A, B, C are on.

- Switches A and B are on but switch C is off.
- Switches A and C are on but switch B is off.
- Switches C and B are on but switch A is off.

1. Draw a truth table for this situation and obtain a Boolean expression for it.
2. Minimize this expression and draw a logic diagram using only a) NAND b) NOR gates.
3. If the delay of a NAND gate is 15ns and that of a NOR gate is 12ns, which implementation is faster.

Sample Laboratory Experiment Design #3

3. A bank has 3 locks with a key for each lock. Each key is owned by a different person. In order to open the vault door at least two people must insert their keys into the assigned locks at the same time. The trainee (i.e. person 3) can only open the vault when the manager (i.e. person 1) is present in the opening. The signal lines (A,B,C) are 1 if the key is inserted into locks 1,2,3 respectively.

Determine the truth table for such a digital locking system

Design, using Karnaugh Map techniques, a minimum AND-OR gate network to realize this locking system.

Implement the minimal circuit found in the previous section using:

Two input NAND gates only.

Two input NOR gates only.

If a two input NAND has a delay of 1.5ns, a two input NOR gate has a delay of 1.1ns, which of the locking system implementations is the fastest.