LogicAR: Augmented Reality application for self-learning of digital electronics concepts as a scaffold to solve robotics design problems

A Stage 2 M.Tech Project Report submitted in partial fulfillment of the requirements for the course of

Master of Technology

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Abstract

Robotics design problems can typically be broken down into many parts spanning various separate disciplines. Students when solving such problems usually face a number of challenges. Since such design problems are interdisciplinary and complex in nature, it has been seen that students usually find it difficult to implement such problem statements. In this thesis project, we discuss two teaching-learning problems which when addressed help students develop competencies to solve complex robotics design problems. The two teaching learning problems are **bridging the gap between theory and practice** and **developing representational competence**. These two teaching learning problems are addressed by developing LogicAR- an augmented reality based learning application to act as a self-learning tool to help students solve the given design problem using the activities built into the application as a learning aid. The activities and the final robotics design problem are designed in the context of digital electronics teaching. We use pre-post research methods to test the efficacy of the application and how well it contributes to developing the above mentioned competencies.

Keywords: digital electronics, augmented reality, AR, digital logic design, robotics design, problem-solving, problem-based learning

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Chapter 1
Introduction

Electrical and electronics teaching and learning comes with its own set of challenges and difficulties for both educators and students. First of all, a lot of topics span across multiple disciplines such as mathematics, physics, electronics, power systems, control systems and communications. Studying such a broad range of concepts and topics makes it difficult for students to integrate and apply knowledge from different areas. In addition to that, a lot of topics in electrical and electronics engineering are abstract in nature which are challenging to understand and visualize. Understanding such abstract theoretical concepts require students to be able to connect between the processes happening at the microscopic scale and the macroscopic scale and also try to visualize invisible processes that can only be measured through specialized tools but not perceived. In addition to this, students are also required to visualize and translate between different representations of the same concept which is required for advanced level problem solving.

Another challenge that students face in electronics courses is connecting theoretical concepts to practical knowledge in order to solve real-world problems. In electronics and electrical engineering-related subjects, students often get bogged down by procedural and practical difficulties that distract them from the concepts and objectives of the labs and prevent deeper inquiry[4].

Various solutions have been proposed to address these challenges, including the use of electronic-based problem-based learning (PBL) materials, student-centered learning methodologies, varied learning activities, and the integration of information and communication technology in teaching and learning. Additionally, the use of practical experience, hands-on projects, virtual laboratories, and augmented reality applications have been found to enhance student engagement and conceptual understanding in electronics education. Overall, addressing these challenges is crucial for improving the quality of electronics education and ensuring effective knowledge transfer to students.

In this report, we have identified two teaching-learning problems in teaching digital electronics - **Bridging the gap between theory and practice** and **Development of**

Representational Competence These teaching-learning problems are addressed using a combination of problem-based learning (PBL) and augmented-reality technology.

For this project, we have developed an augmented-reality (AR) application called LogicAR which is a self-learning tool that can be used by students to learn concepts related to digital logic gates and combinational logic. This application's affordances help the student build logic gate circuits using physical hardware components such as logic gate IC's, LED's, resistors, push buttons etc.

Robotics design problems typically consist of many parts, each of which requires its own small-scale solution. Electronic systems for the foundation for the design and implementation of robotic systems. influencing the development of control systems, sensor integration, and communication interfaces. Hence, knowledge of digital electronics is essential for creating efficient and reliable circuits that govern the behavior of robotic components. The abstract and theoretical nature of these concepts, coupled with their dynamic and rapidly evolving nature, can pose difficulties for learners. Therefore, addressing these challenges becomes crucial for fostering a solid understanding and proficiency in the application of digital electronics in the context of robotics design.

In order to test the efficacy of our application, we designed and conducted a research study to check if the application addresses the above two teaching-learning problems.

Chapter 2
Teaching Learning Problem

In this section, we will discuss the two major teaching-learning problems that we will be addressing in this project.

The first major teaching and learning problem is **Bridging the gap between theory and practice.** Bridging the gap between theory and practice is vital for students as it cultivates a profound understanding of concepts and their real-world applications. By connecting theory to practical scenarios, students gain a deeper appreciation for the relevance and impact of their academic learning on practical challenges.

In electronics and electrical engineering-related subjects, students often get bogged down by procedural and practical difficulties that distract them from the concepts and objectives of the labs and prevent deeper inquiry[4]. For example in digital electronics, students might know the basic functioning of NOT gate but while building the circuit using hardware components on a breadboard, they will get bogged down by many of the procedural steps involved like checking voltage, connecting inputs and outputs, debugging circuits, etc. They tend to lose motivation in learning if they are not able to build the circuits properly.

The second major teaching-learning problem is the **Development of Representational Competence.** For an adequate comprehension of scientific phenomena, concepts, and experiments, it is necessary to understand several different representations and their interconnections. From a scientific point of view, representational competence (RC) can be understood as students' ability to correctly generate, interconnect, and translate several representations and use them as problem-solving tools. [1]

The importance of developing representational competence has been discussed in various contexts. For example in [2], the authors discuss the importance of representational competency in chemistry education research and how the characteristics of chemical representations affect student reasoning. The authors assert that external visual representations of chemical entities and processes, known as chemical representations, are crucial in chemical thinking and practice.

According to [3], students faced problems in translating between different chemical representations, particularly in moving across the three levels of chemistry (macroscopic, submicroscopic, and symbolic).

In the area of digital electronics, it has been observed that students often have trouble connecting between different representations of the same concept. For example, students in a digital electronics course taught in an engineering curriculum have trouble with translating between different representations of logic circuits such as truth tables, logic gate diagrams, and logic equations. Knowing how to translate between different representations of a logic circuit is an important skill required to support more complex digital design problems.

Both the above-discussed competencies are important for students because they enable them to solve higher-level complex design problems including robotics design problems. Such design problems can be broken down into smaller sub-problems each with its small-scale solution. The smaller sub-problems can be further broken down into **Concepts** and **Procedures** that the students would need to know in order to solve the sub-problems.

Concepts - They refer to theoretical knowledge that the student needs to know to solve the problem statement. For example, how different logic gates work is one theoretical concept that the student should know to solve the bigger problem.

Procedures - They refer to a sequence of steps intended to be used to solve specific problems. They would usually make use of one or more concepts. For example, to connect a logic circuit on a breadboard, the student is required to perform a set of steps such as placing the logic circuit IC, connecting the power supply, hooking up the correct pins, and so on.

For example, consider the following robotics design problem - **Building a line follower robot using only digital logic circuits.** This problem statement will consist of smaller sub-problems like controlling robot motors, deriving input from the line detection sensors, and building the logic gate circuits to implement the line follower logic algorithm. These sub-problems can be further divided into different concepts and procedures that the student should be familiar with.

Hence to solve such complex problem statements, the above-mentioned competencies should be developed. To help students translate between different representations of logic circuits and build physical hardware-based circuits, we designed an augmented reality-based application named **LogicAR** to act as a self-learning tool to help students solve the given design problem using the activities built into the application as a learning aid.

In the next section, we will delve into a brief literature survey of AR and the affordances of AR that were identified to develop the above-mentioned competencies.

Chapter 3
Literature Survey

In this section we will discuss the background required for our work. The literature review starts with an overview of augmented reality and how it has been used in education. We will discuss the different contexts in which AR has been used for teaching and learning.

3.1 What is Augmented Reality?

Augmented reality is the technology that involves overlaying virtual information and objects over the real world. The virtual data acts as a part of the user's physical environment and enhances their experience by providing them with additional information (which is not possible otherwise).

3.2 Different types of AR

AR itself is further subdivided into 3 distinct types which are:

- Marker-based AR
- Marker-less AR
- Location-based AR

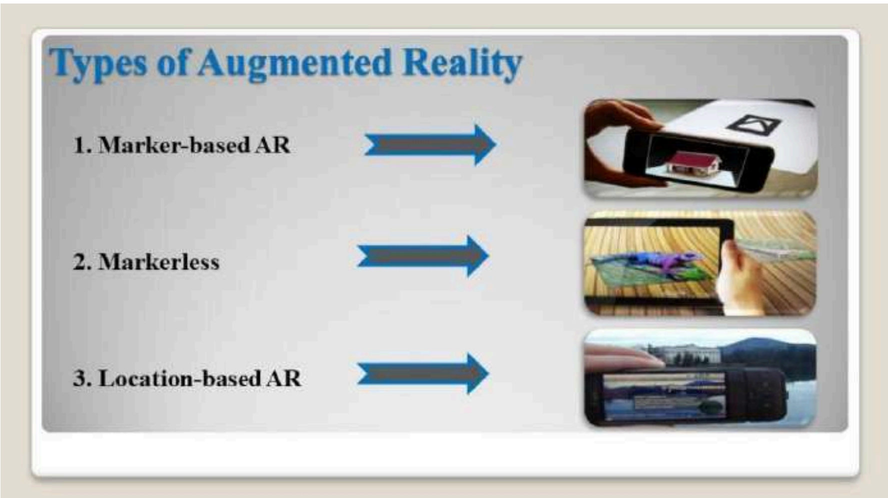


Figure 3.1: Types of AR (Source)

AR itself is further subdivided into 3 distinct types namely Marker-based, Marker-less and Location-based. Marker-based AR employs the use of fiducial markers and virtual objects are overlaid on top of these markers. Marker-less AR on the other hand uses the mobile device's camera to scan the physical environment and extract features from the environment in order to insert virtual objects in the physical environment. Location-based AR, which can also be either marker-based or markerless in addition to the camera, also makes use of GPS information from the mobile device to detect the user's location. Location-based AR has been used in informal learning environments such as museums and nature parks.

3.3 Use of AR in Teaching and Learning

In the last decade, advances in smartphone and other mobile device technology have led to an increase in the number of devices and a decrease in the cost of these devices[5]. The ease of access to mobile devices has therefore resulted in the viability of AR-based technology in education

Particularly in STEM education, AR has been used to a great effect. Numerous studies have been conducted to use AR to teach STEM fields such as Physics, Chemistry, Natural Sciences, Astronomy, and so on. The majority of these studies have been conducted in classroom and laboratory settings[6] while few have been conducted in informal learning environments such as museums and nature parks. The selected setting for the AR-based interventions mostly depends on the subject being taught. It has been noted in the literature that subjects like Physics, Chemistry, etc are generally taught using AR in classroom or laboratory settings[7] while subjects like history and natural sciences require informal out-of-school settings such as museums using location-based AR.

The use of AR in teaching and learning is very effective. Studies have shown that the use of AR has helped in concretizing abstract concepts in students[8], improving critical thinking abilities in students [6], improving student's attention and motivation[6][9][10], improving learning outcomes for students[11][12], enhancing collaboration skills [13]. Many experiment-based AR interventions have shown that AR enhances the interaction between students, teachers, and the environment[14]. The development of self-learning-based AR environments has shown how AR can be harnessed to reduce the load on teachers and instructors and allow students to conduct practical experiments on their own[15].

3.4 Affordances of AR in STEM Education

In this section, we will identify the affordances of AR for STEM education. As mentioned by Parsons et al in [16], the affordances of AR vary a lot according to the educational context that they are being used. *"For example, the users' perceived affordances of an AR system for language learning while visiting a city overseas are very different to those perceived by a medical student who needs to develop a particular clinical skill."*[16].

MacCallum et al [17] outlined four affordances of AR in the context of education:

1) visualization of the 3D and the invisible
2) contextualized information
3) portability of the device to interact with the location
4) And social and shared engagement.

Cheng et all identified the following set of affordances in [18] in the more focused domain of science learning and scientific inquiry: 1) Spatial ability, 2) Practical Skills 3) Conceptual understanding.

In the context of medical education, Parsons et al [16] have identified the following affordances: 1) Reducing negative impact (risk, cost) 2) Visualizing the otherwise invisible 3) Developing practical skills in a spatial context 4) Device portability across locations 5) Situated learning in context.

With respect to STEM education, we have identified the following affordances of AR from the literature

A1:	Dynamic Visualization to enhance conceptual understanding
A2:	Collaboration between students
A3:	Improving spatial thinking and mental rotation skills
A4:	Drawing the connection between theory and practice by facilitating an experimentation-based approach

A5:	Facilitating self-guided learning

Table 3.1: Affordances of AR in STEM education

One of the key affordances of AR is ***A1: dynamic visualization*.** In many STEM domains, students might have difficulty understanding concepts that are abstract or processes that take place on a microscopic level, or even phenomena which are invisible to the naked eye[19].

For example, in [7], the authors have demonstrated the use of an Augmented Reality Learning Environment (ARLE) to teach physics concepts such as electromagnetism, gauss law, magnetic fields, and so on. The concept of magnetic fields is tough to understand for learners since magnetic fields are invisible hence students find it hard to imagine how the direction of a magnetic field would change according to the direction of an electric current. Using an ARLE, the authors were able to help students understand these concepts by showing 3D animations of the behavior of magnetic fields. Wulandari et al [20] have similarly demonstrated the use of ARLEs in a wide range of physics topics such as fluid dynamics, light, and optics, electricity, mechanics, heat transfer, etc. In all the above domains, AR is useful in concretizing abstract concepts and consequently improving learner outcomes [8].

Similarly, it has been shown that dynamic visualization by AR can also help improve learners' spatial thinking[21][22] and mental rotation [23] skills. Dynamic visualization can also be used to help students translate between different representations. For example, for digital electronic circuits, AR animations can be used to simultaneously show different representations like truth tables, logic gate circuits, etc which will help students grasp the concepts better and improve representational competence.

Another key affordance of AR is the ***A4: connection between theory and practice.*** AR has been shown to improve learning outcomes in practical laboratory skills. Typically in laboratory settings, studies have shown [25] that learners are bogged down or get confused by procedural steps involved in performing experiments which hamper their learning experience. In [24] the author has discussed how laboratory experiments are usually reduced to just a set of instructions to be carried out from a laboratory manual and trial and error by students to get the desired readings. This defeats the purpose of why lab experiments are carried out in the first place, which is to bridge the gap between theoretical concepts learned in the classroom and how to apply those concepts in practice.

3.5 Types of Content in AR

In the book e-Learning and the Science of instruction[26], Clark et al. have defined 5 types of content and recommended the types of graphics required to be provided for explaining the given types of content. They are given in Table 3.2 and Table 3.3

Graphic-Type	**Description**
Decorative	Visuals added for aesthetic appeal or humor
Representational	Visuals that illustrate the appearance of an object
Organisational	Visuals that show qualitative relationships among content
Relational	Visuals that summarize quantitative relationships
Transformational	Visuals that illustrate changes in time or over space
Interpretive	Visuals that make intangible phenomena visible or concrete.

Table 3.2: Types of graphics [26]

Content-Type	**Description**	**Recommended Graphic Types**
Fact	Unique and isolated information such as specific applications, screens, forms, or product data	Representational Organisational
Concepts	Groups of objects, events, or symbols designated by a single name	Representational Organisational Interpretive
Process	A description of how something works	Transformational Interpretive Relational
Procedure	A series of steps resulting in completion of a task	Transformational
Principle	Guidelines that result in the completion of a task; cause-and-effect relationships	Transformational Interpretive

Table 3.3: Types of Content [26]

AR serves as a great medium for delivering representational, transformational and interpretive graphics to the learner. Hence, AR can be used to explain most of the content types given in Table 3 to the learner.

For example, as discussed in the previous sub-section, in [15], AR animation was used to give step-by-step instructions on how to connect a logic gate circuit on a breadboard. These animation/graphics can be classified as transformational graphics according to Table 3. Hence while designing AR-based graphics for interventions, one must keep in mind the content type being taught and tailor graphics/simulations/animation according to that.

Wulandari et al [20] have given an overview of the kind of AR-based content which has been used in teaching physics to students based on the subject being taught. Table 3.4 shows a few examples from that paper

Topic	**Type of AR-content**	**Classified as**
Optical Devices	3D Objects	Representational
Convex Lens	3D Objects and Animation	Representational Interpretive
Force and Motion	Simulation	Transformational
Elastic Collision	Simulation	Transformational
Heat Transfer	3D Animation	Interpretive

Table 3.4: Types of AR content used for different topics (adapted from [20])

Chapter 4
Design of AR-based Application

In this section, we will be discussing the design process for an AR-based application **LogicAR.**

4.1 Goal

The overall goal of this project is to adequately address the two teaching-learning problems that have been articulated in Section 2. We chose the subject of **Digital Electronics** and the topic chosen was **Logic Gates and Combinational Logic.**

Students in a digital electronics course taught in an engineering curriculum have trouble with translating between different representations of logic circuits such as truth tables, logic gate diagrams, logic equations and physical hardware circuits. Understanding and translating between these representations is an important skill that is required to support more complex digital design problems. Students also face problem in connecting theory and practice. While building circuits on breadboard, students often face difficulty in the numerous procedural steps like checking voltage, connecting inputs and outputs, debugging circuits, etc.

The goal of **LogicAR** application is to help students overcome these issues through specially designed activities.

4.2 Solution Approach

From the literature review, we saw that numerous studies have been done showing the advantages of integrating AR into teaching and learning. Based on the literature review, we have identified two key affordances of AR that should be taken advantage of while developing AR learning experiences.

The main affordances of AR that we made use of in this context are as follows:

1. Dynamic Visualization to enhance conceptual understanding (A1)

2. Drawing the connection between theory and practice by facilitating an experimentation-based approach (A4)

These 2 key affordances also correlate with our original two teaching-learning problems that were explained in section 2. Hence for the development of the application LogicAR, we decided to focus on these two key affordances.

For designing the activities in the application, a top-down approach was chosen. In that, we chose an initially complex problem statement that the students would learn how to implement. This problem statement is then broken down into smaller sub-problems which are then further classified into **concepts** and **procedures**.

Based on this a **Problem Map** is created and AR-based learning activities are designed for selected concepts and procedures. It is important to note here that not all subjects or topics or concepts or procedures would benefit from AR-based instruction. Hence, the whole subject /topic doesn't need to be taught using AR

In this AR intervention, the following robotics design problem statement is chosen: Design a robotic line follower using basic logic gates and combinational circuits

Once the problem statement has been reduced to a set of sub-problems, concepts, and procedures, the next step is to find out which of the concepts/problems will benefit from AR-based instruction. To do this, they are classified as content types as mentioned in Section 3.5 to decide the type of AR graphics to be provided as support. Another important aspect is to consider Mayer's multimedia principles while designing AR-based graphics or simulations, such as the Modality principle and the Redundancy principle.

Based on this breakup, learning activities are designed to teach the relevant concepts. The learning activities should be structured in order of difficulty or complexity.

4.3 Detailed Design

Based on the solution approach that was discussed in the previous section, the following problem map was constructed.

The given problem statement was divided into 3 sub-problems that the students would have to solve in the sequence. The three sub-problems are indicated in the Problem Map given in Figure 4.1.

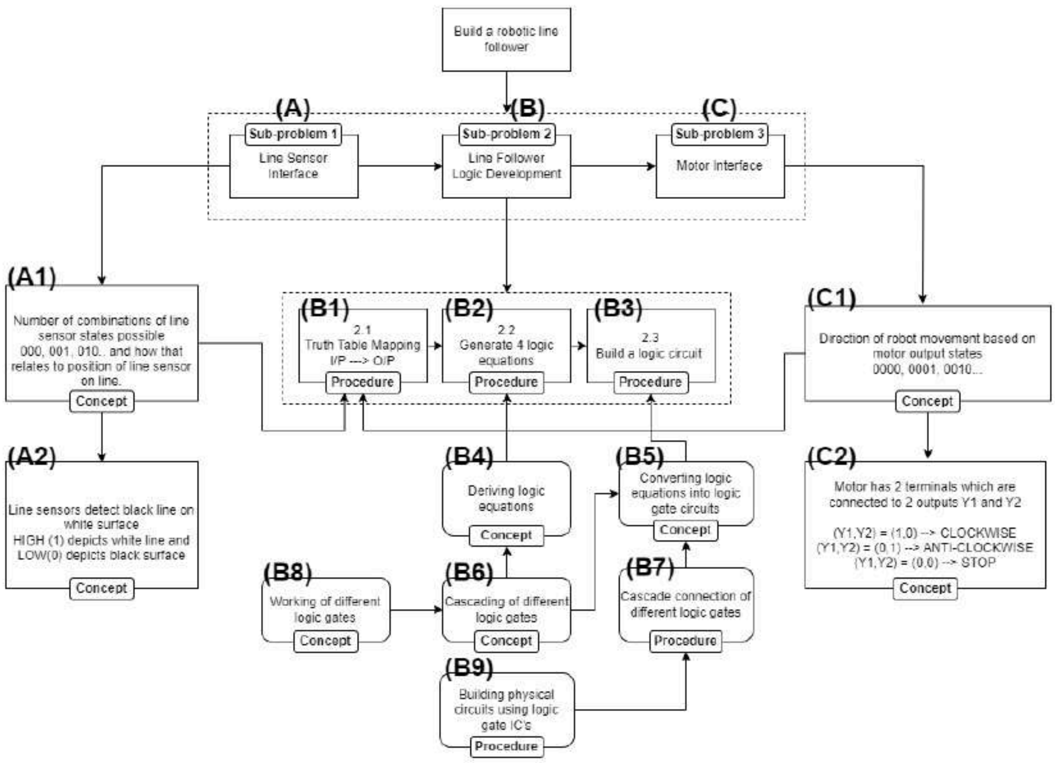


Figure 4.1 : Problem Map for given problem statement

Based on the above problem statement the following activities were designed for the application **LogicAR.**

The activities in the LogicAR application were divided into 4 Levels - L1, L2, L3, and L4 in the order of increasing complexity.

The 4 levels of LogicAR have been explained in Table 4.1:

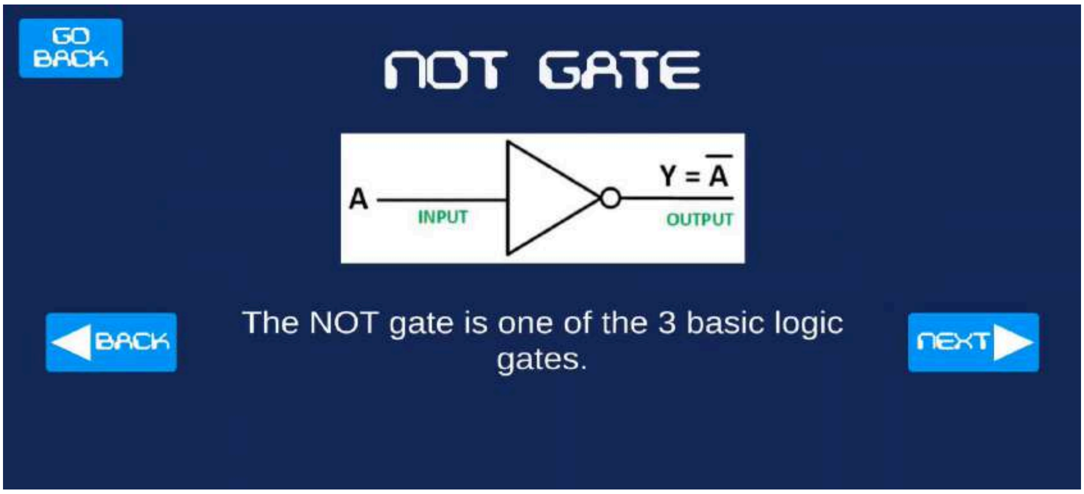
Complexity Level	Concepts covered in Level	Description
L1	Basic Logic Gates	The activities in this level discuss the three basic logic gates - NOT, AND and OR. Students are guided through various activities which show the working of the three basic logic gates and their different representations like logic circuits, truth tables and logic gate circuits. Students also learn how to build logic gate circuits for the basic gates using logic gate IC's like 7404 (NOT), 7408 (AND) and 7432 (OR) and other physical hardware components such as breadboard, push button, LEDs and resistors.
L2	Cascading Logic Gates	The activities in this level help students learn how to cascade the basic logic gates to build more complex logic circuits such as NAND and XOR gate circuits. The AR-based activities in this level are drag-and-drop activities in which students are required to complete connections between logic gates according to given logic circuits.
L3	Problem Statement Introduction	The activities in this level introduce students to the basic components of line follower and their functioning such as Line Sensor which distinguishes between white and black surface and DC motor actuator which help in robot locomotion.
L4	Problem Statement Implementation	The activities in this level help the students develop the logic for line follower robot. The consist of a series of activities related to the motion of the robot and how the robot should move according to the different line sensor outputs

Table 4.1 : Levels of LogicAR application

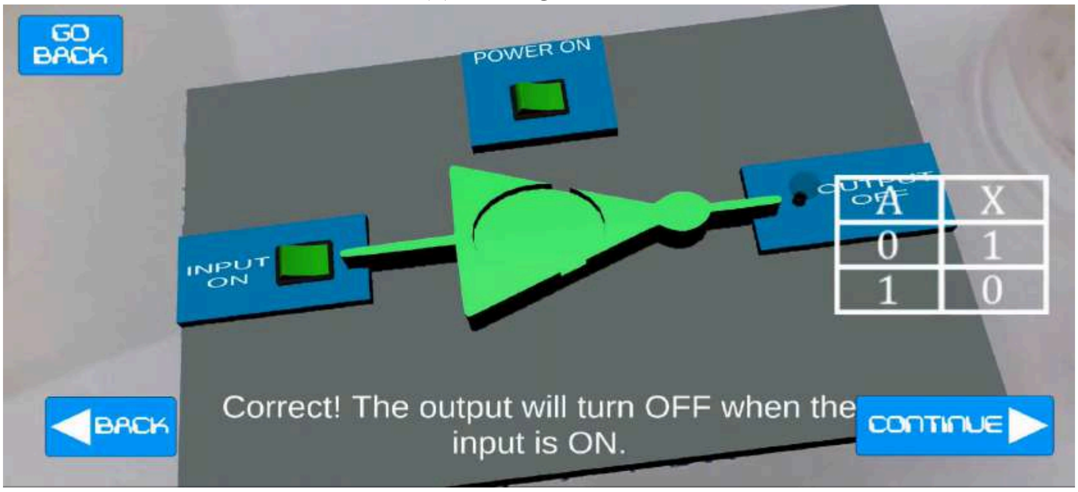
The activities for each level of LogicAR application are described in detail in the following tables 4.2, 4.3, 4.4, 4.5, 4.6 and 4.7.

Le vel	Activity Name	Intended Learning Objective	Activity Description	Illustration
L1	Underst anding NOT gate	1) Students should be able to understand the workings of the NOT gate. 2) Students should be able to draw the truth table of NOT gate	This is an AR-based activity in which the students have been explained the workings of NOT gate using AR-based 3D objects Students are asked questions related to the state of the NOT gate which they can find out by toggling the input provided in AR-based activity. The truth table of the NOT gate is a dynamically linked representation of the input and output state of the NOT gate i.e. the truth table reflects the present state of the logic gate.	Figure 4.2
L1	Predict the Answer	1) Students will learn the working of two NOT gates cascaded end-to-end	Students are provided with an AR-based activity in which they can experiment with the outputs by interacting with the input to the cascaded NOT gate. Students are required to fill the truth table of the cascaded NOT gate circuit using the AR-based activity as a guide.	Figure 4.3
L1	Building physical circuits	1) Students will learn how to build the NOT gate circuit on a breadboard using the 7404 logic gate IC and other hardware components such as LED, push button resistor, etc	Step-by-step instructions are provided to the student to assemble the circuit through an AR-based activity This L1 activity also provides the student the option to browse other concepts such as how to interface LED, push button etc which they can use if they are stuck.	Figure 4.4

Table 4.2 : L1 NOT gate - NOT gate activities

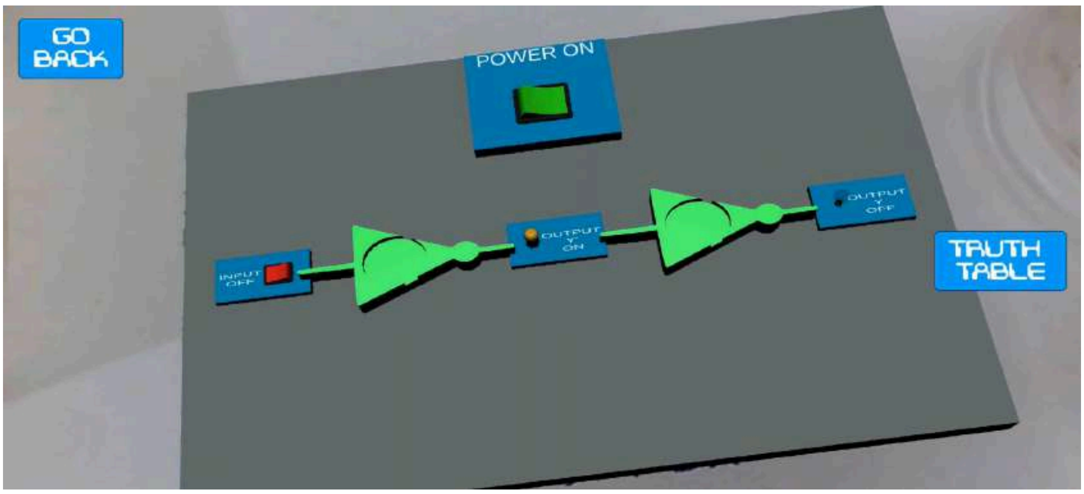


(a) NOT gate introduction

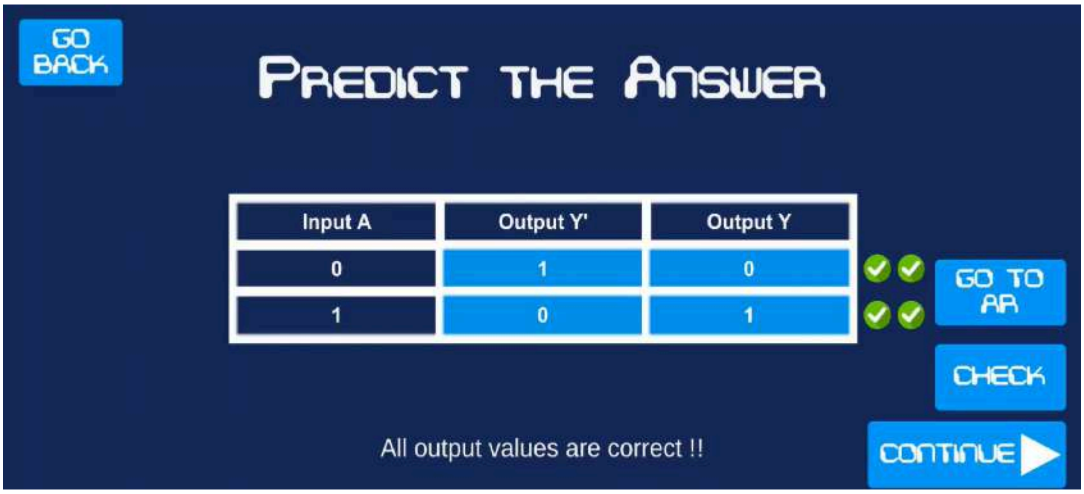


(b) Experimenting with NOT gate

Figure 4.2 : L1 - Understanding NOT gate

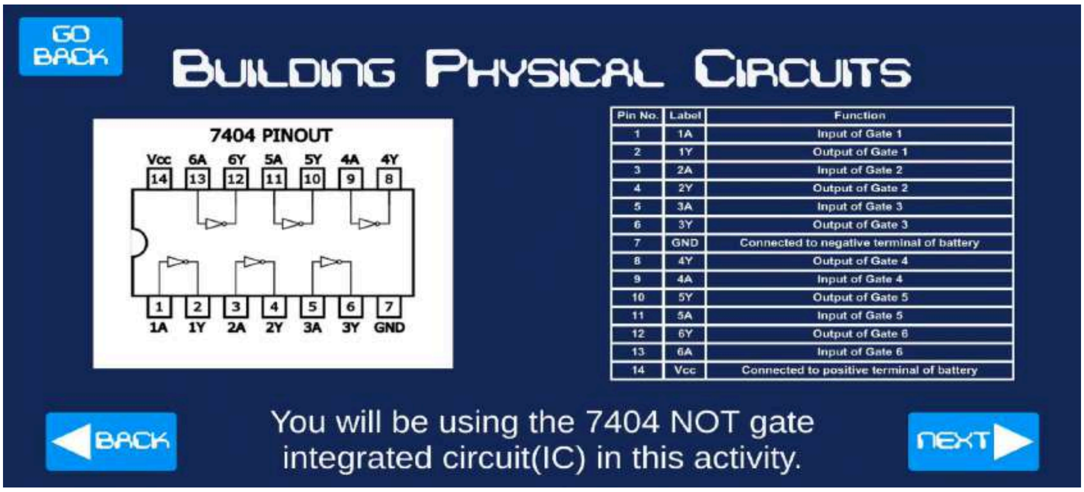


(a) Cascaded NOT gates

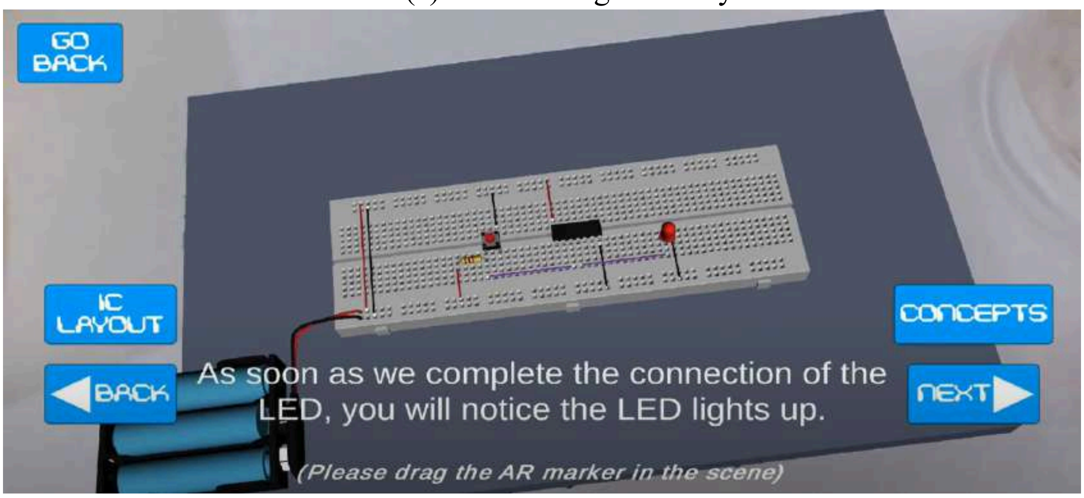


(b) Completing the truth table.

Figure 4.3 NOT gate : L1 - Predict the Answer



(a) 7404 NOT gate IC layout



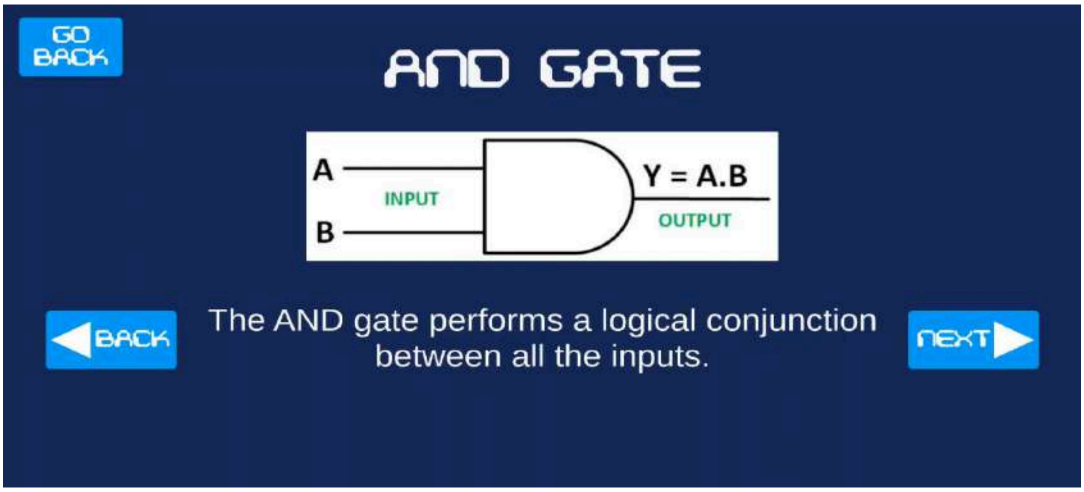
(b) AR-based guide for building NOT gate hardware circuit

Figure 4.4 : L1 NOT gate- Building Physical Circuits

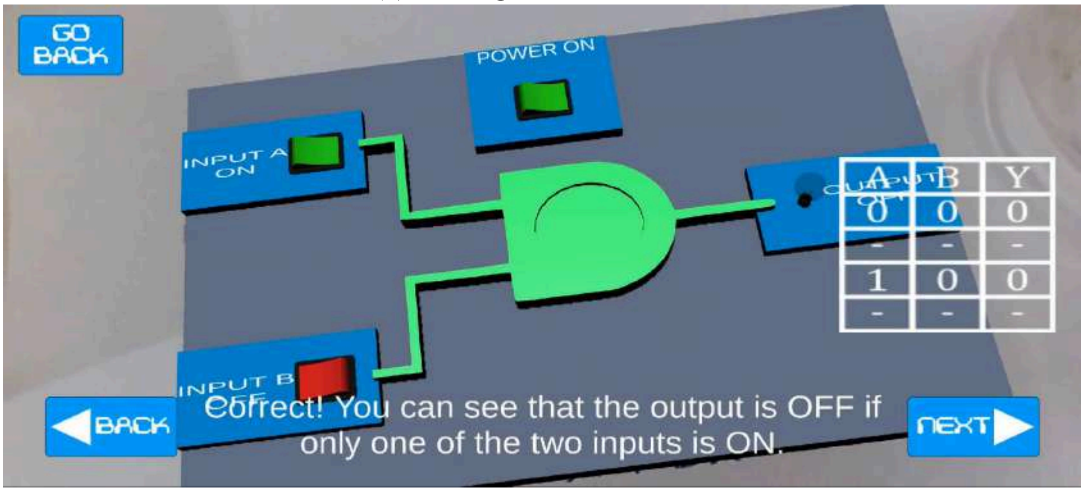
Level	Activity Name	Intended Learning Objective	Activity Description	Illustration
L1	Understanding AND gate	1) Students should be able to understand the workings of the AND gate. 2) Students should be able to draw the truth table of AND gate	This is an AR-based activity in which the students have been explained the workings of AND gate using AR-based 3D objects Students are asked questions related to the state of the AND gate which they can find out by toggling the input provided in AR-based activity. The truth table of the AND gate is a dynamically linked representation of the input and output state of the AND gate i.e. the truth table reflects the present state of the logic gate.	Figure 4.5
L1	Complete the truth table	1) Students will learn about the working of 3 input AND gate 2) Students will be able to complete the truth table of 3 input AND gate.	Students are required to complete the truth table of a 3 input AND gate. Students are provided with an AR-based activity in which they can experiment with the different inputs and output of the 3 input AND gate.	Figure 4.6
L1	Predict the Answer	1) Students will learn how to predict the output of a logic gate circuit which contains a NOT gate and an AND gate. 2) Students will be able to complete the truth table of the given logic gate circuit.	Students are required to complete the truth table of the given logic gate circuit. Students are provided with an AR-based activity in which they can experiment with the different inputs and output of the 3 input AND gate.	Figure 4.7
L1	Physical Circuits with	1) Students will learn how to build the AND gate	Step-by-step instructions are provided to the student to assemble the circuit through an	Figure 4.8

	AND gate	circuit on a breadboard using the 7408 logic gate IC and other hardware components such as LED, push button resistor, etc	AR-based activity This L1 activity also provides the student the option to browse other concepts such as how to interface LED, push button etc which they can use if they are stuck.	

Table 4.3 : L1 - AND gate activities

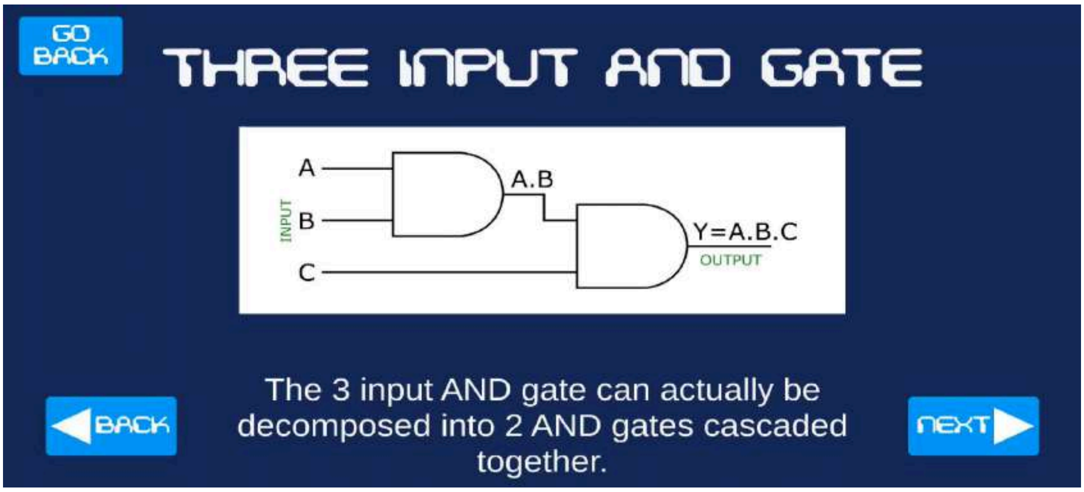


(a) AND gate introduction

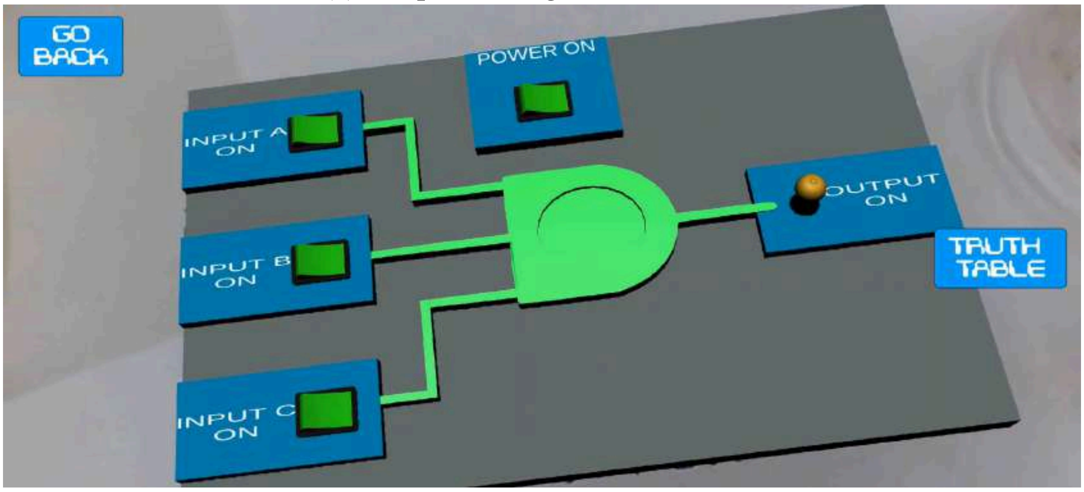


(b) Experimenting with AND gate in AR

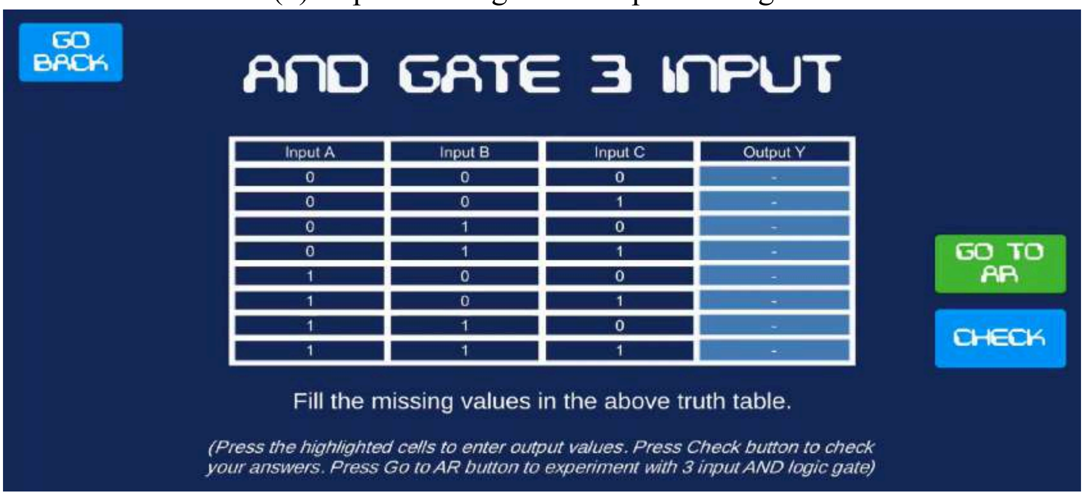
Figure 4.5 : L1 AND gate - Understanding AND gate



(a) 3-input AND gate introduction

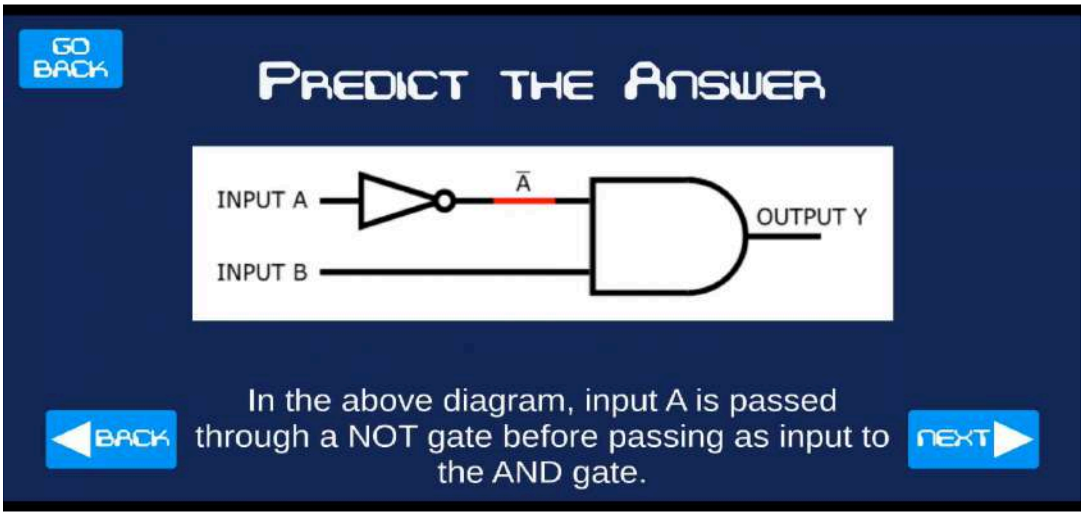


(b) Experimenting with 3-input AND gate

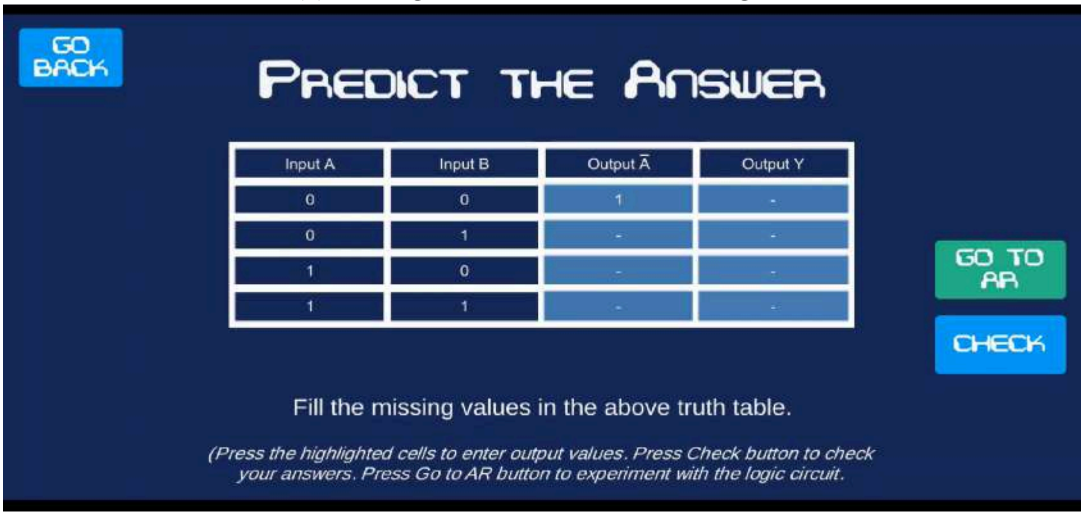


(c) Complete the truth table

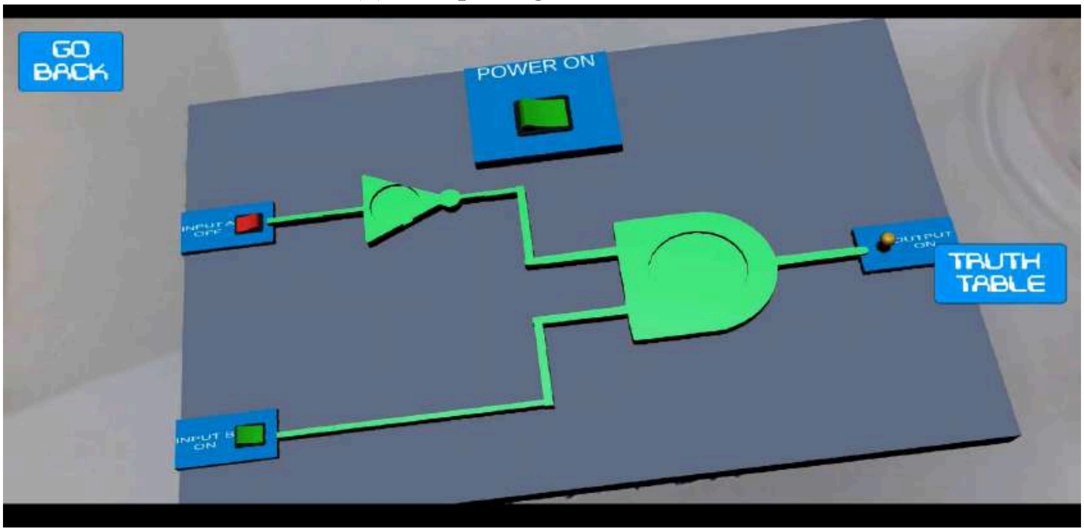
Figure 4.6 : L1 AND gate - Complete the truth table



(a) NOT gate cascaded with AND gate

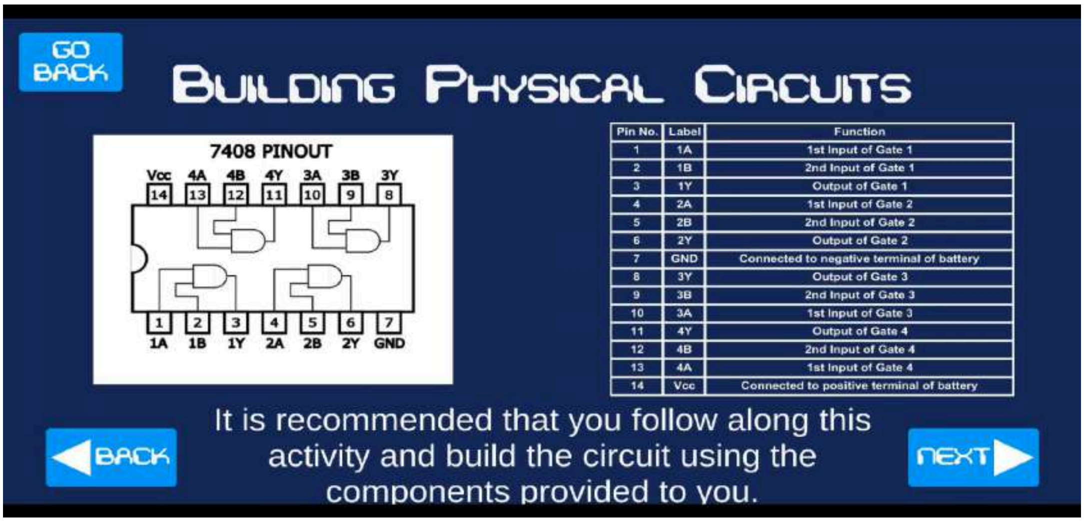


(b) Completing the truth table

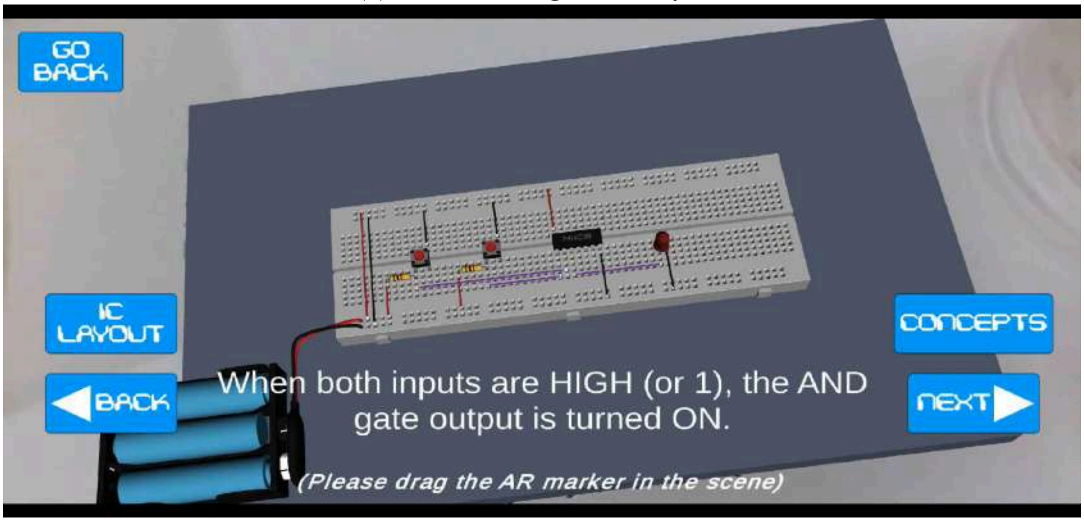


(c) AR-activity to experiment with cascaded logic gate circuit.

Figure 4.7 : L1 AND gate - Predict the Answer



(a) 7408 AND gate IC layout



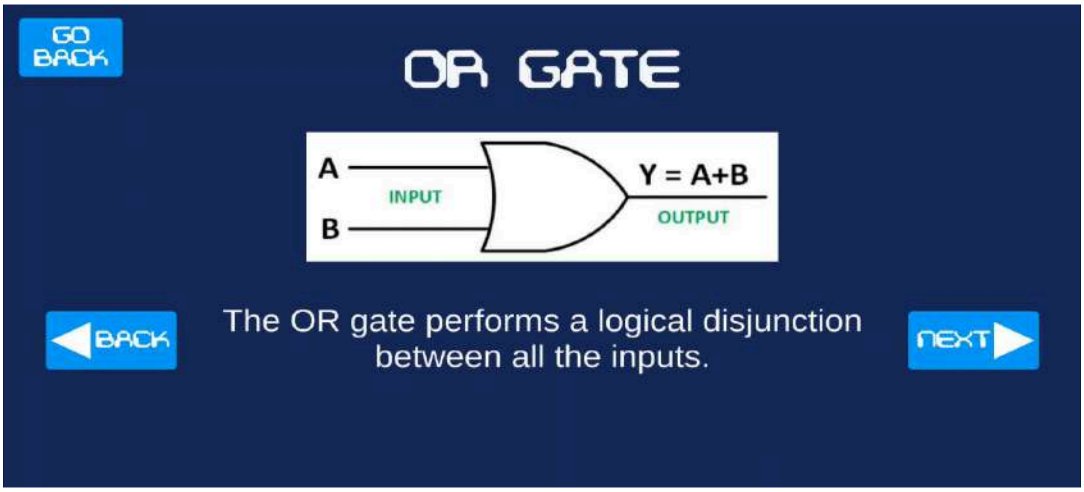
(b) AR-based guide for building AND gate hardware circuit

Figure 4.8 : L1 AND gate - Building Physical Circuits

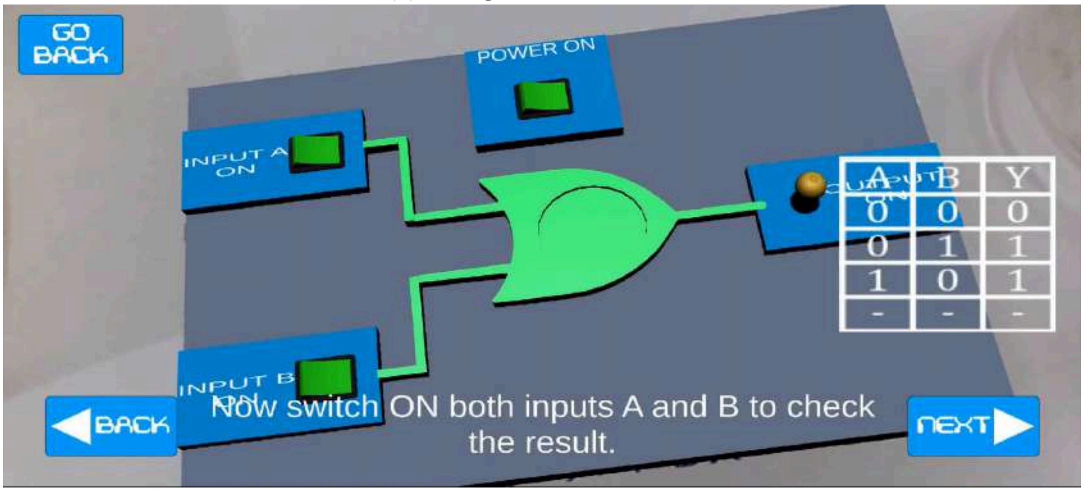
Level	Activity Name	Intended Learning Objective	Activity Description	Illustration
L1	Understanding OR gate	1) Students should be able to understand the workings of the OR gate. 2) Students should be able to draw the truth table of OR gate	This is an AR-based activity in which the students have been explained the workings of OR gate using AR-based 3D objects Students are asked questions related to the state of the OR gate which they can find out by toggling the inputs provided in AR-based activity.	Figure 4.9

			The truth table of the OR gate is a dynamically linked representation of the input and output state of the OR gate i.e. the truth table reflects the present state of the logic gate.	
L1	Complete the truth table	1) Students will learn about the working of 3 input OR gate 2) Students will be able to complete the truth table of 3 input OR gate.	Students are required to complete the truth table of a 3 input OR gate. Students are provided with an AR-based activity in which they can experiment with the different inputs and output of the 3 input OR gate.	Figure 4.10
L1	Predict the Answer	1) Students will learn how to predict the output of a logic gate circuit which contains a NOT gate and an OR gate. 2) Students will be able to complete the truth table of the given logic gate circuit.	Students are required to complete the truth table of the given logic gate circuit. Students are provided with an AR-based activity in which they can experiment with the different inputs and output of the 3 input OR gate.	Figure 4.11
L1	Physical Circuits with OR gate	1) Students will learn how to build the OR gate circuit on a breadboard using the 7432 logic gate IC and other hardware components such as LED, push button resistor, etc	Step-by-step instructions are provided to the student to assemble the circuit through an AR-based activity This L1 activity also provides the student the option to browse other concepts such as how to interface LED, push button etc which they can use if they are stuck.	Figure 4.12

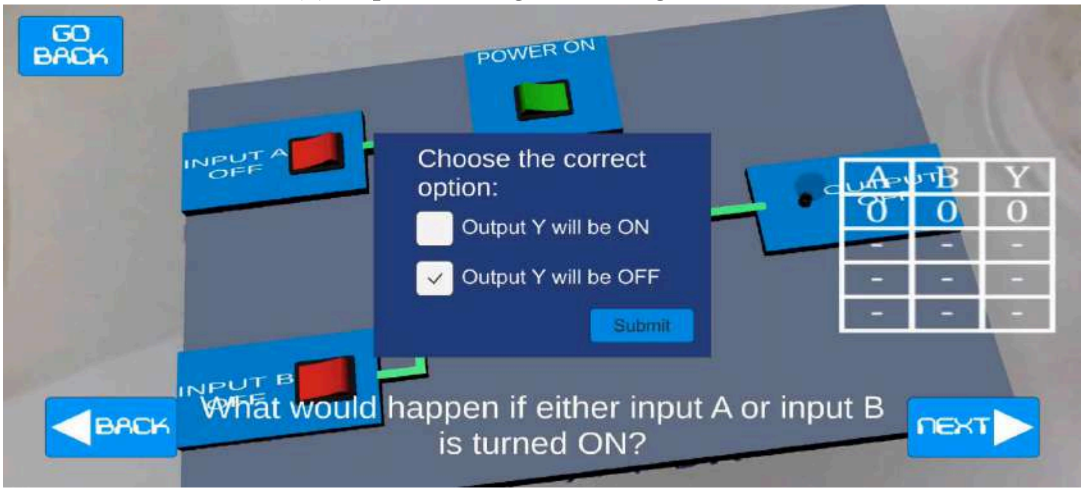
Table 4.4 : L1 - OR gate activities



(a) OR gate introduction

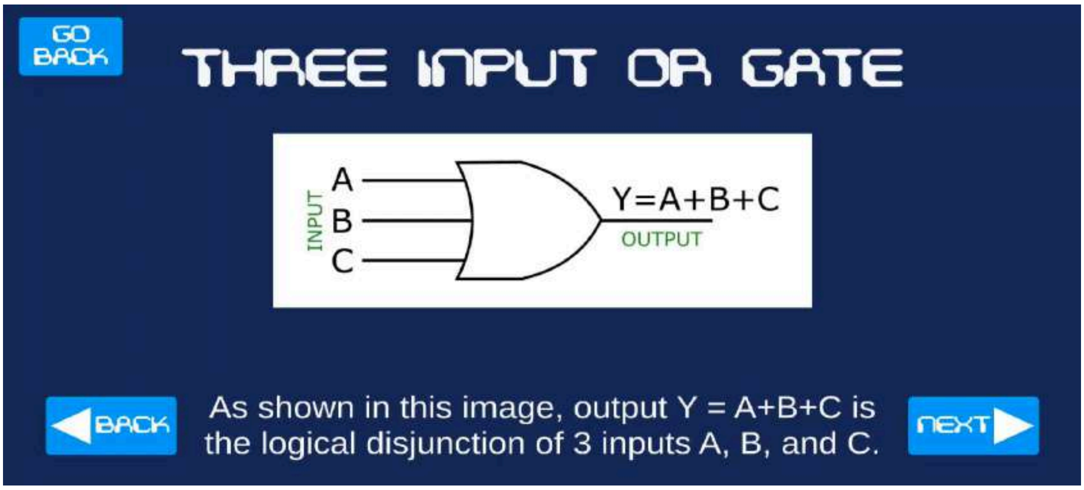


(b) Experimenting with OR gate in AR

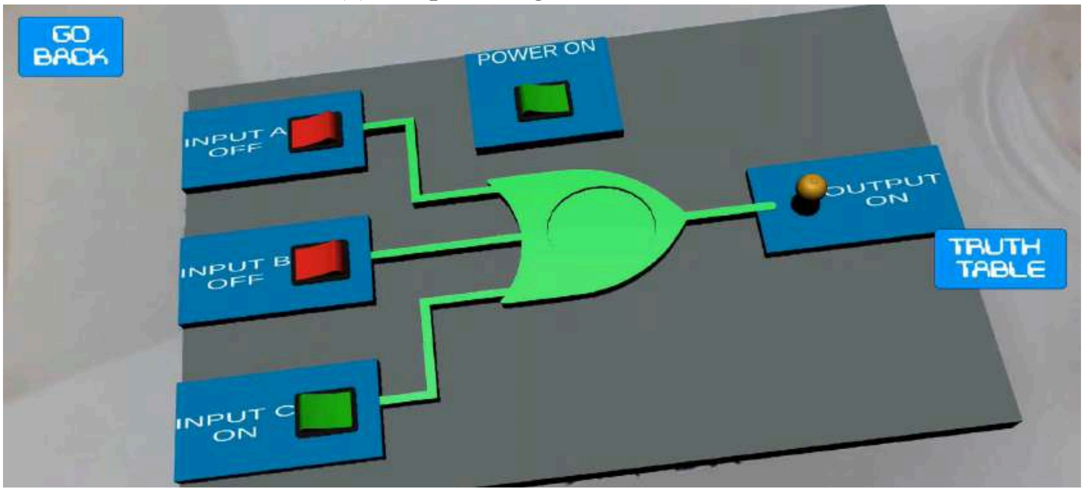


(c) Question Prompt

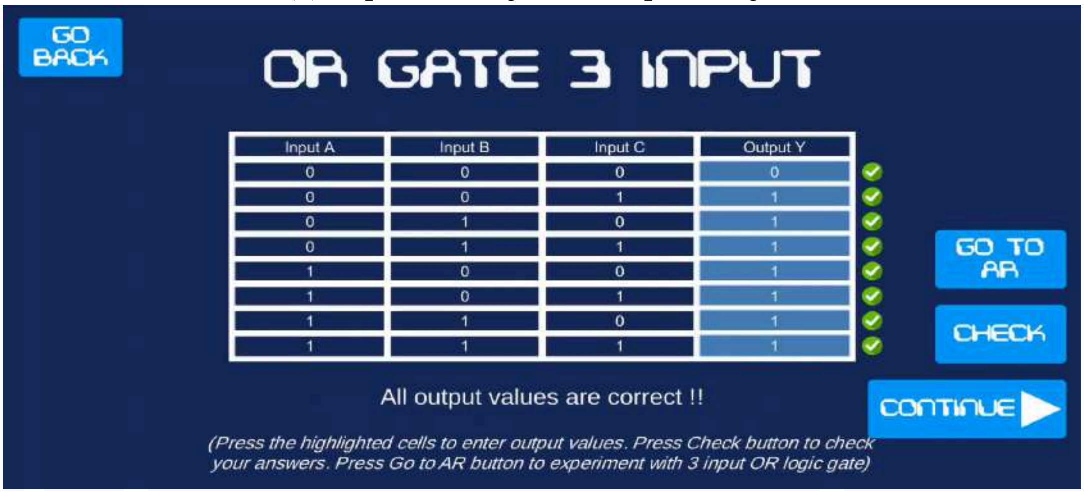
Figure 4.9 : L1 OR gate - Understanding OR gate



(a) 3-input OR gate introduction

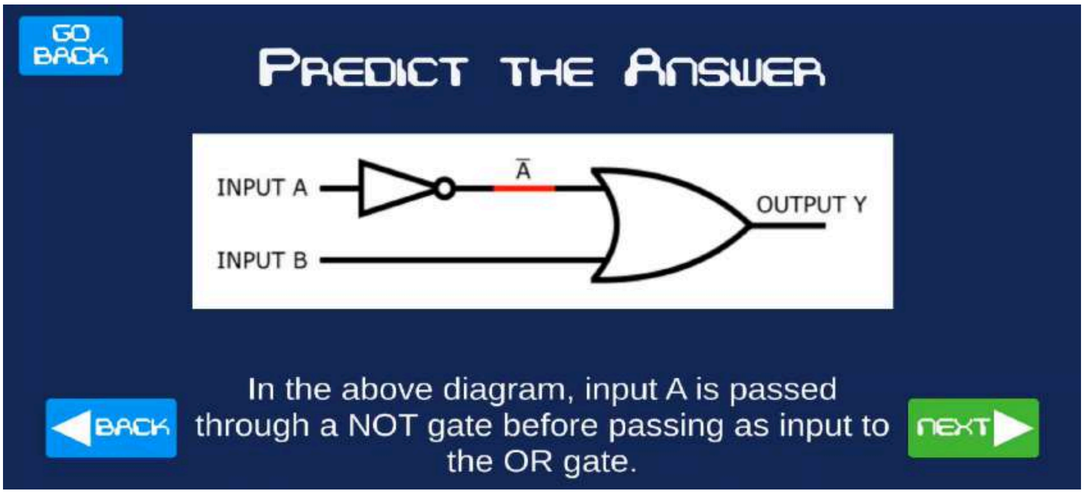


(b) Experimenting with 3-input OR gate

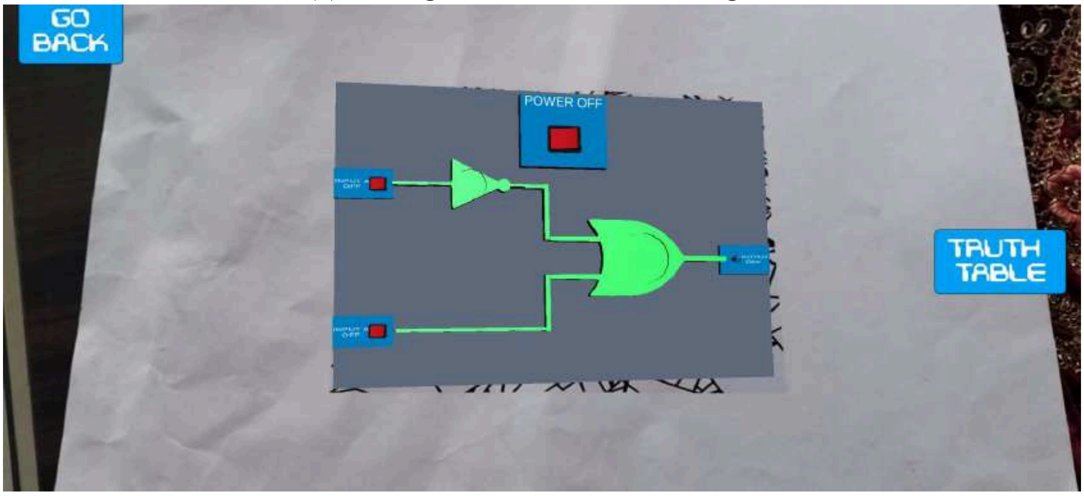


(c) Complete the truth table

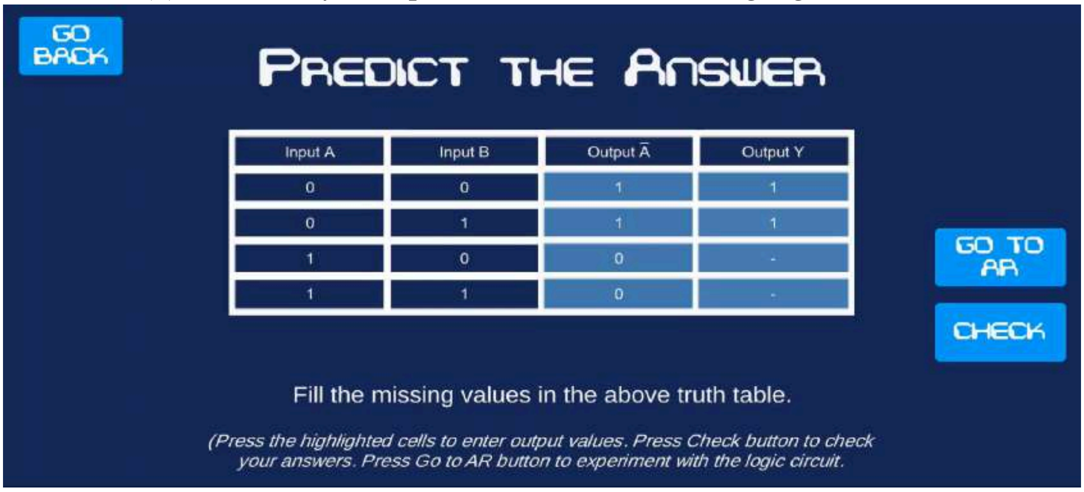
Figure 4.10 : L1 OR gate - Complete the truth table



(a) NOT gate cascaded with OR gate

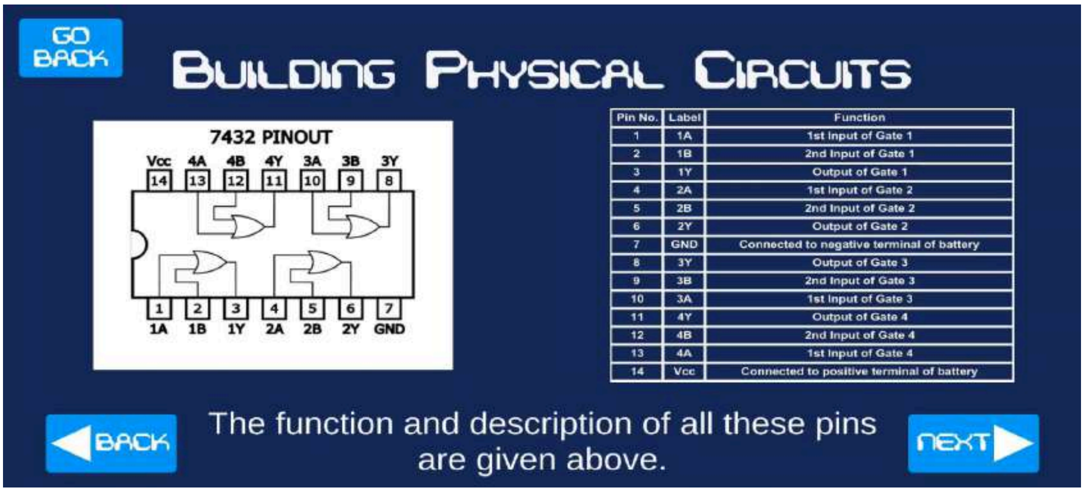


(b) AR-activity to experiment with cascaded logic gate circuit.

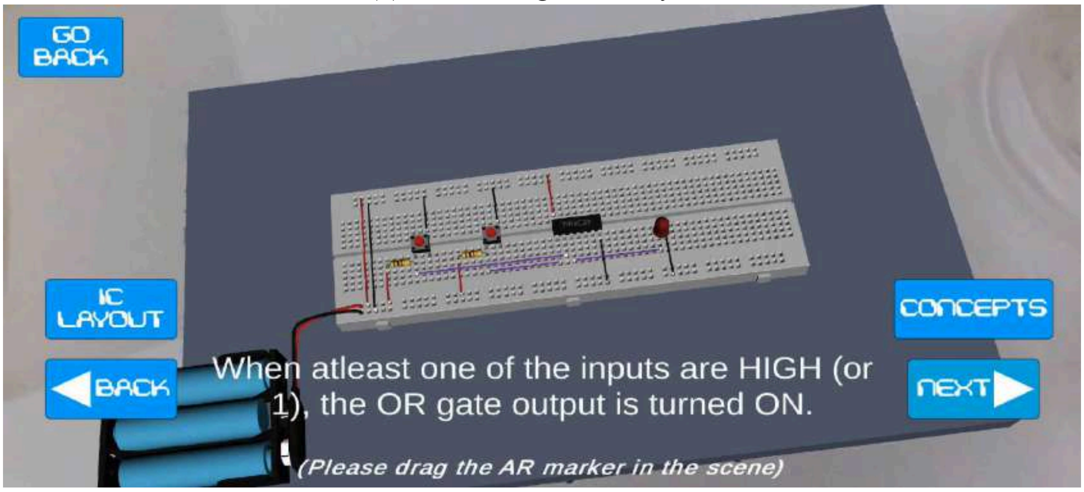


(c) Completing the truth table

Figure 4.11 : L1 OR gate - Predict the Answer



(a) 7432 OR gate IC layout



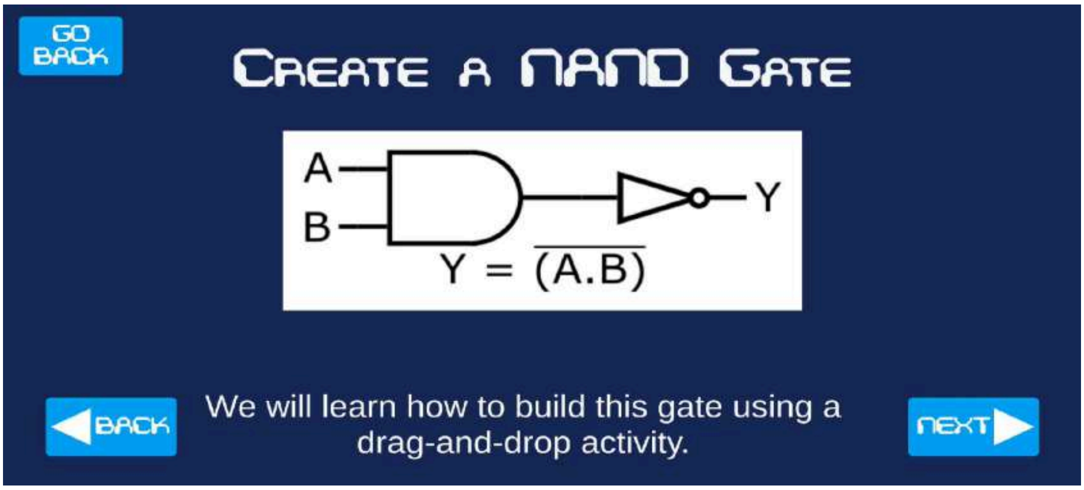
(b) AR-based guide for building OR gate hardware circuit

Figure 4.12: L1 OR gate - Building physical circuits

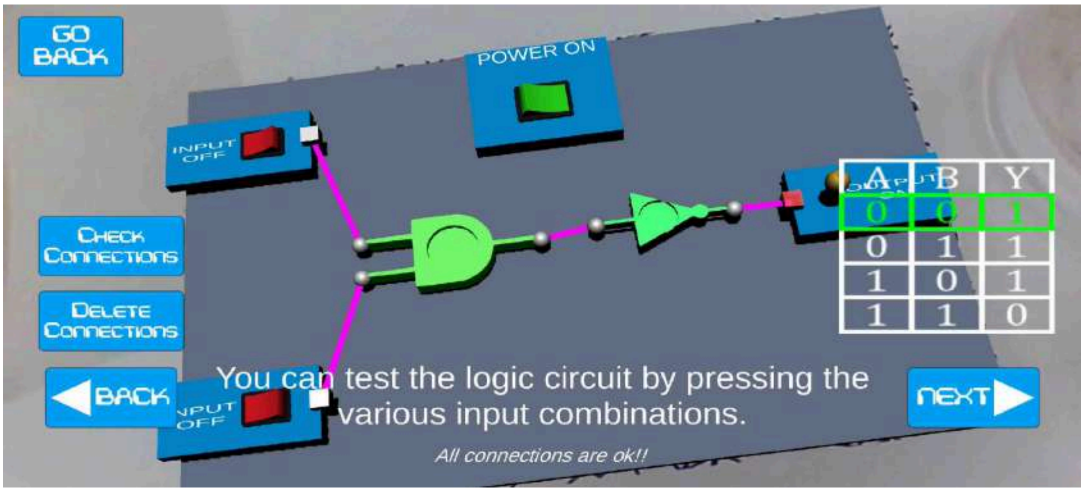
Level	Activity Name	Intended Learning Objective	Activity Description	Illustration
L2	Create a NAND gate	1) Students will learn about the working of a NAND gate and how it is constructed by cascading an AND gate and NOT gate. 2) Students will learn how to build the NAND gate	In the first part, students have to construct a NAND gate through an AR-based drag and drop activity. The students are required to position an AND gate and a NOT gate in AR and connect the inputs and outputs as indicated to get the function of the NAND gate. An associated truth table is shown to students to help them	Figure 4.13

		circuit using 7404, 7408 IC’s and other hardware components.	correlate the functioning of NAND gate to the truth table. In the second part, students have to build the NAND gate circuit using AND and NOT gate IC’s (7404 and 7408). Step-by-step instructions are provided to the student to assemble the circuit through an AR-based activity.	
L2	Cascading Multiple Gates	1) Students will learn how to cascade multiple logic gates according to a given logic circuit and logic gate diagram	Students are required to do a AR-based drag-and-drop activity in which they are required to position the logic gates and make connections between inputs and outputs according to the given logic circuit.	Figure 4.14
L2	Create a XOR gate	1) Students will learn about the working of a XOR gate and how it is constructed by cascading NOT, AND and OR gates in a particular manner.	Students are required to to do a AR-based drag-and-drop activity in which they are required to position the logic gates and make connections between inputs and outputs according to the logic equation of XOR gate.	Figure 4.15

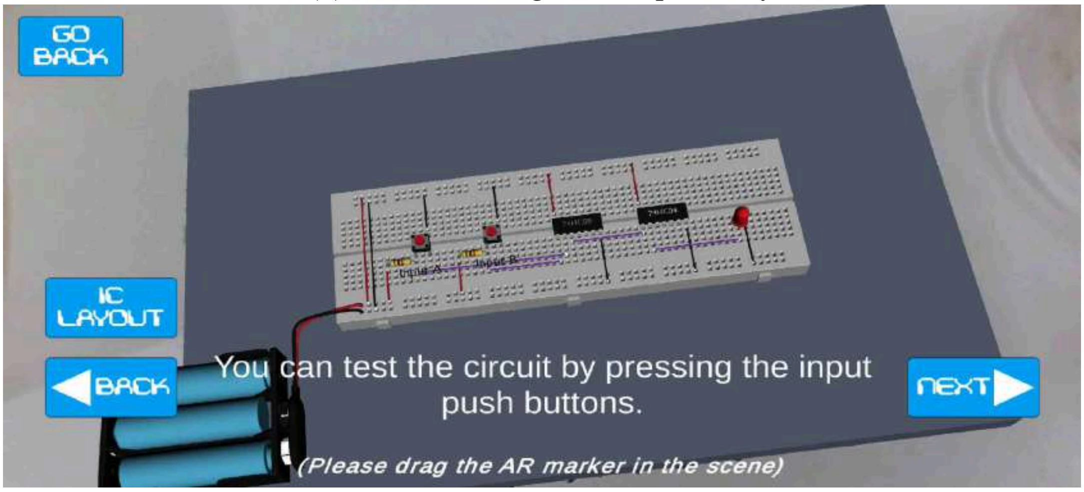
Table 4.5 : L2 activities



(a) NAND gate introduction

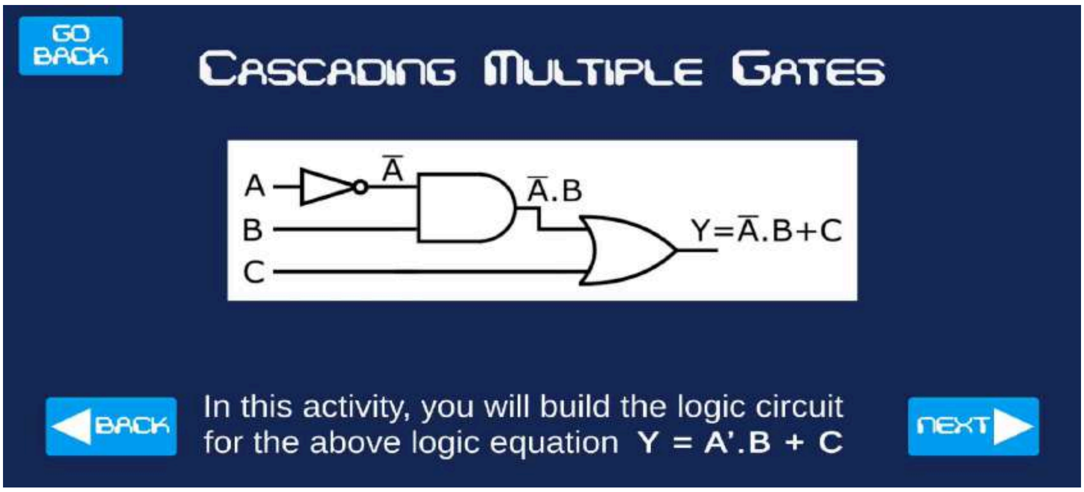


(b) AR-based drag-and-drop activity

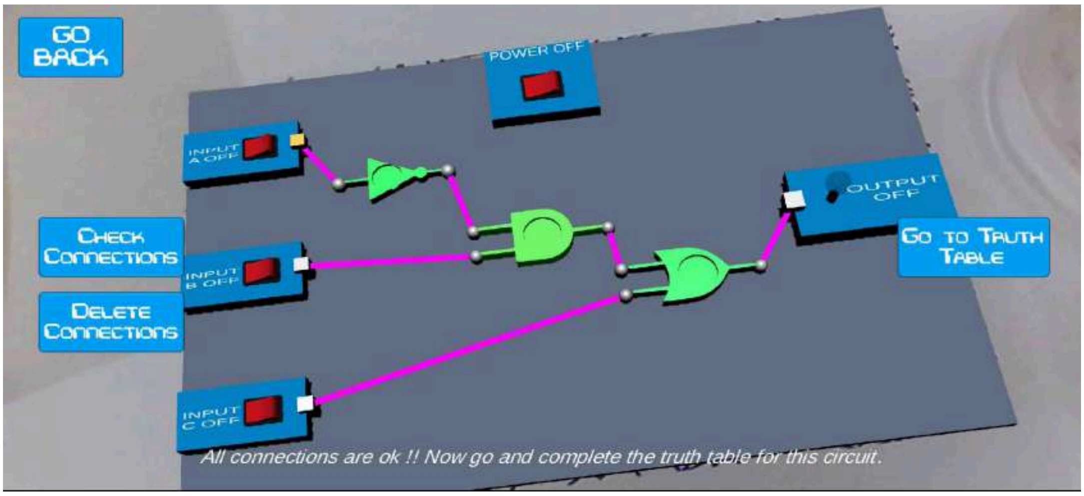


(c) AR-based guide for building physical NAND gate circuit

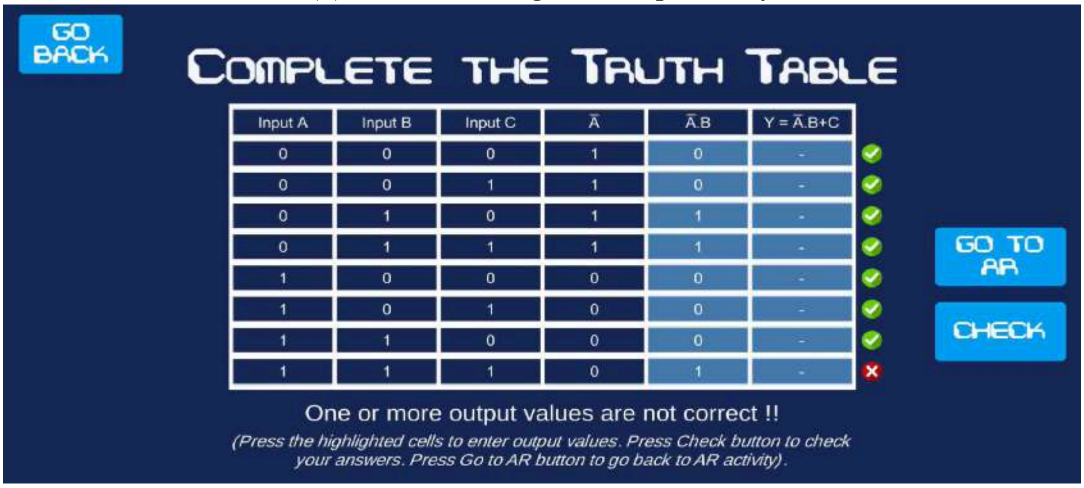
Figure 4.13 : L2 - Create a NAND gate



(a) Cascading multiple gates

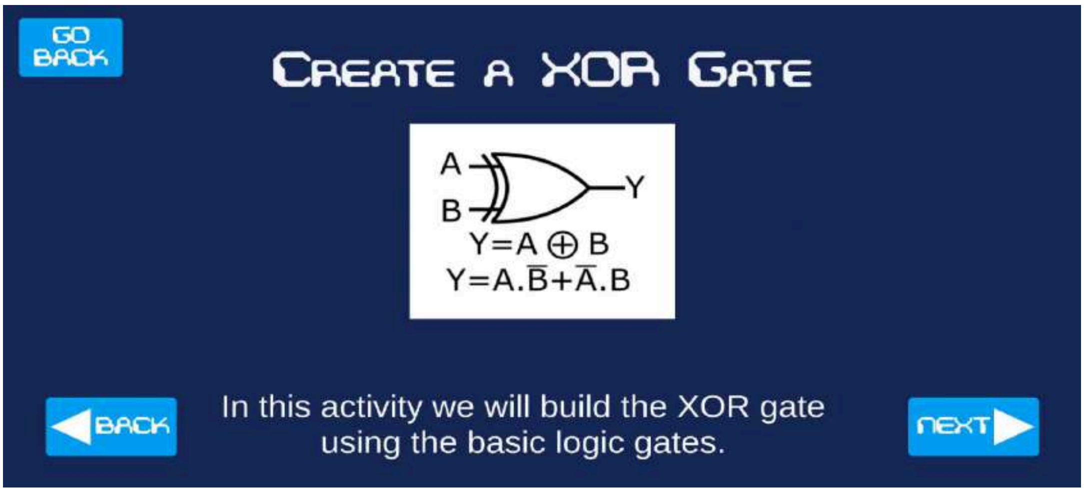


(b) AR-based drag-and-drop activity

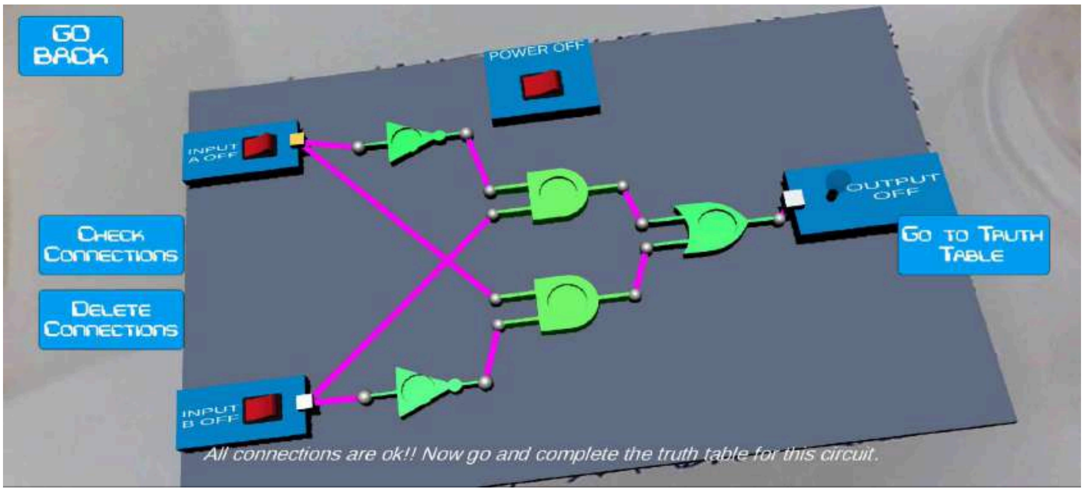


(c) Completing the truth table

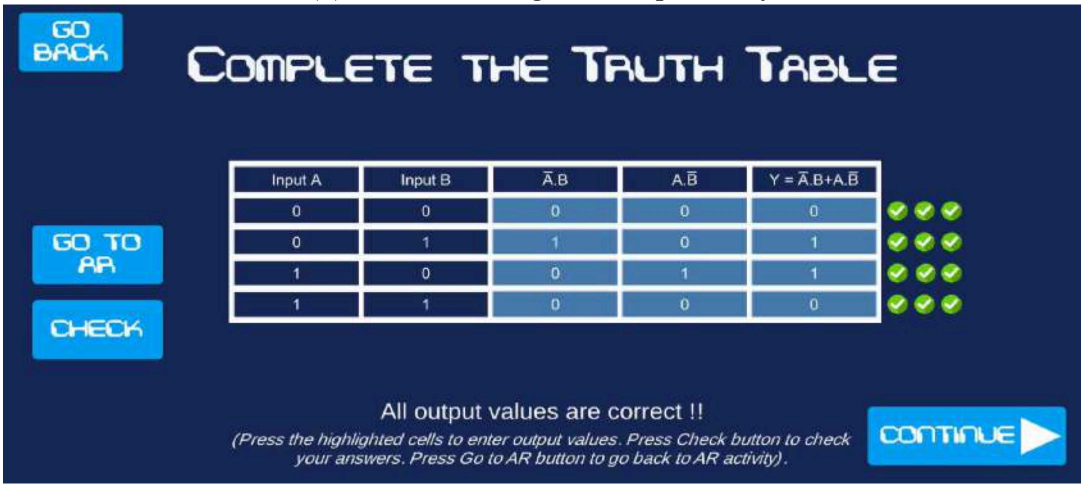
Figure 4.14 : L2 - Cascading multiple gates



(a) Create a XOR gate



(b) AR-based drag-and-drop activity



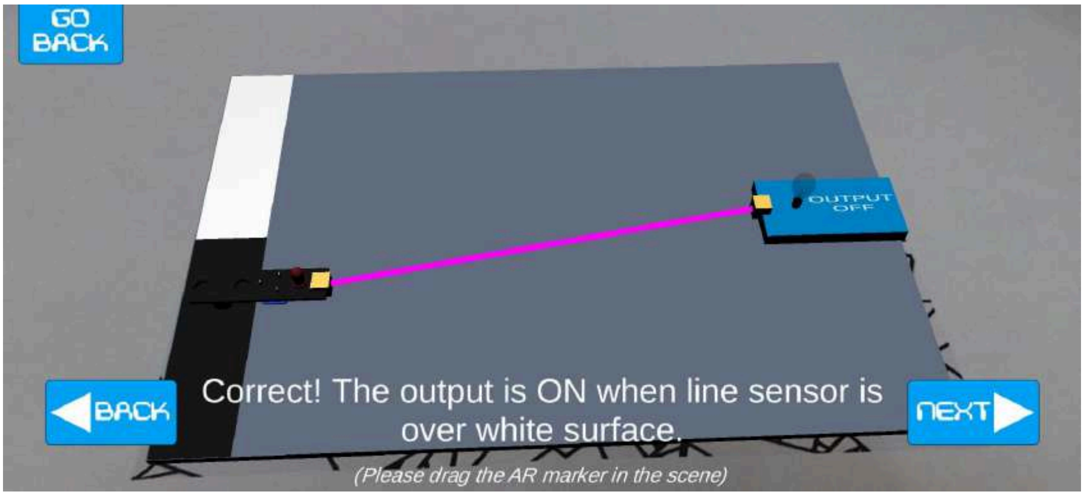
(c) Completing the truth table

Figure 4.15: L2 - Create a XOR gate

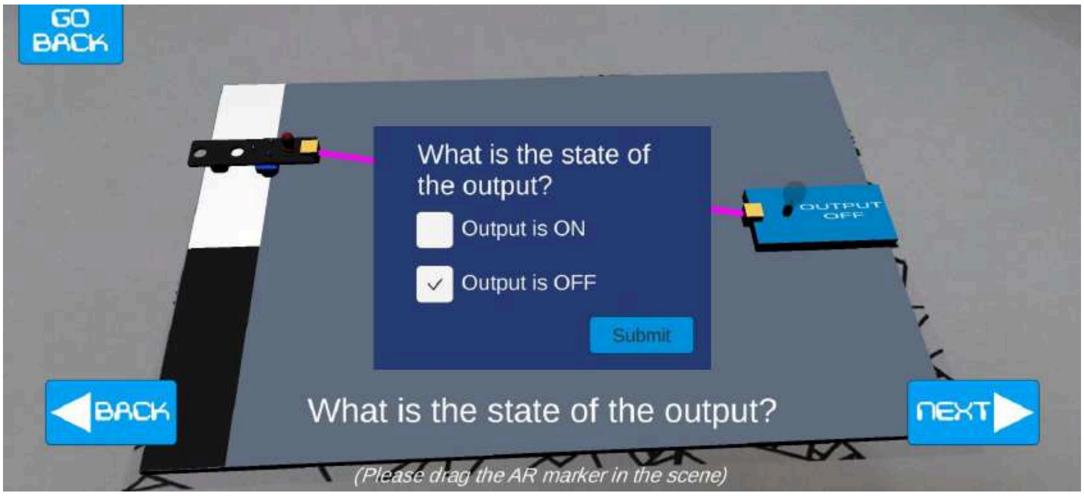
Level	Activity Name	Intended Learning Objective	Activity Description	Illustration
L3	Understanding Line Sensors	1) Students will learn about the working of line sensors and how their output changes when exposed to different white and black surfaces.	In the first part, students will learn about the working of a single line sensor and how the output value changes when detecting black or white surface. In the second part, students will learn how to manipulate the output of 2 line sensors simultaneously and implement a logic circuit based on expected output	Figure 4.16
L3	Underst	1) Students will	An AR-based activity is given in	Figure

	anding DC Motors	learn about the working of DC motors and how the rotation of DC motors change with respect to the inputs given at the two terminals.	which students are required to make connections between inputs and outputs where outputs are the terminals of the motor. The students are then required to predict the rotation direction of motor and how it changes with respect to the inputs	4.17
L3	Solve the Problem	1) Students will learn how to solve complex word problems based on a given problem statement	A world problem is given with a given truth table. Students are required to make the logic gate circuit according to the truth table using an AR-based activity in which the gates are given and they are required to make the necessary connections.	Figure 4.18

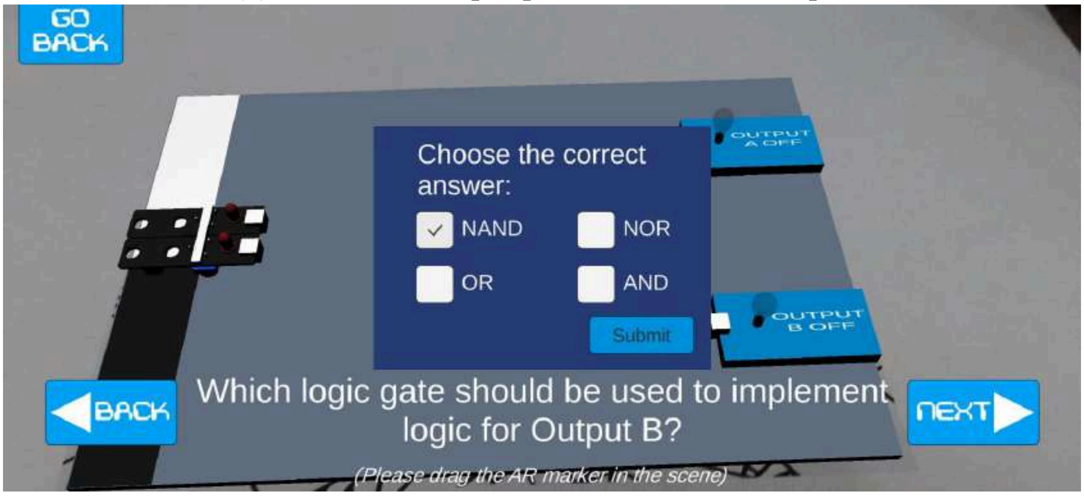
Table 4.6 : L3 activities



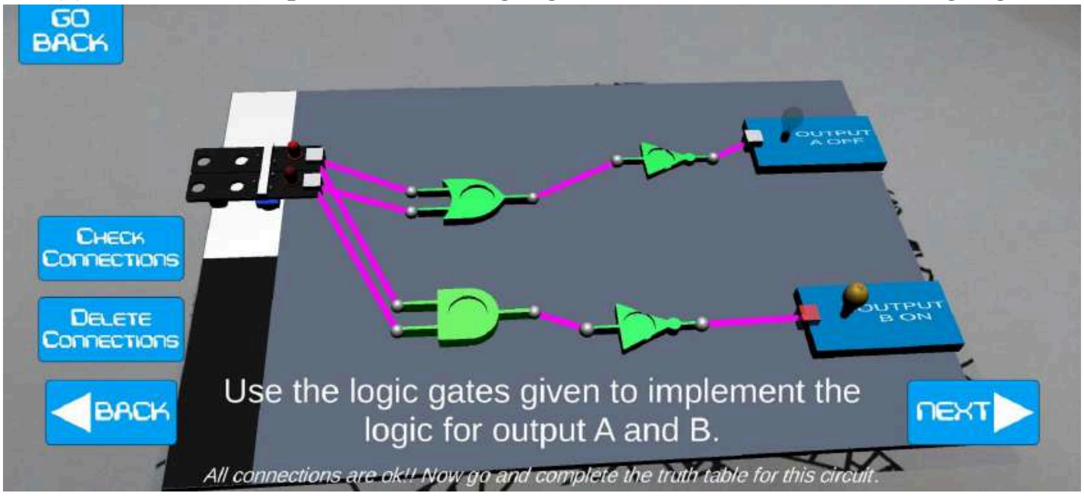
(a) Line Sensor Connection with output



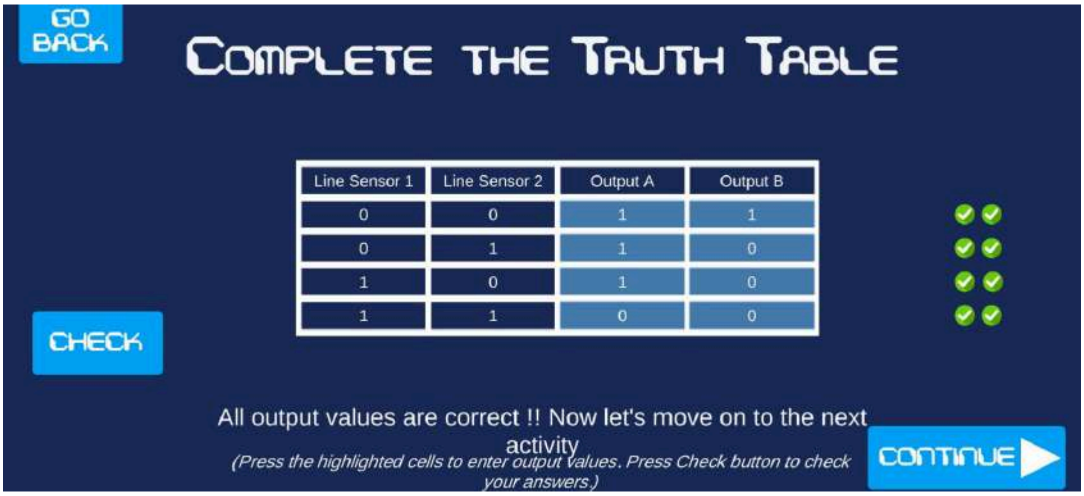
(b) Question Prompt - predict the state of output



(c) Question Prompt - Select the logic gate to be used for the following logic

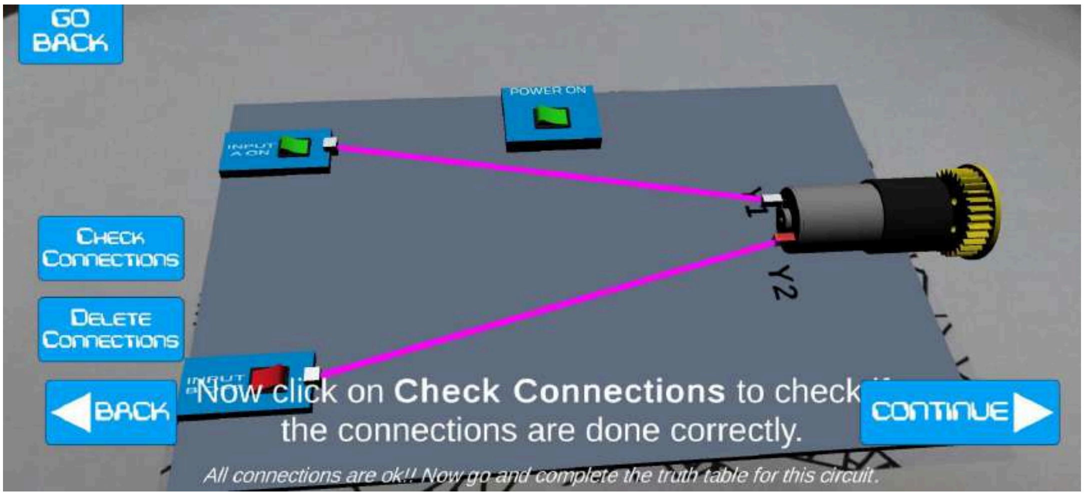


(d) Implement logic for given two outputs

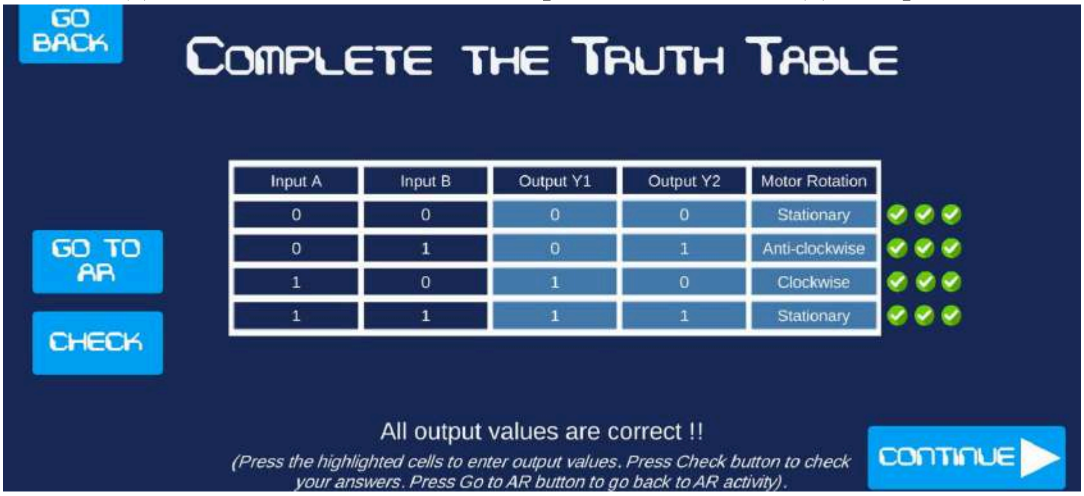


(e) Complete the truth table

Figure 4.16 : L3 - Understanding line sensors

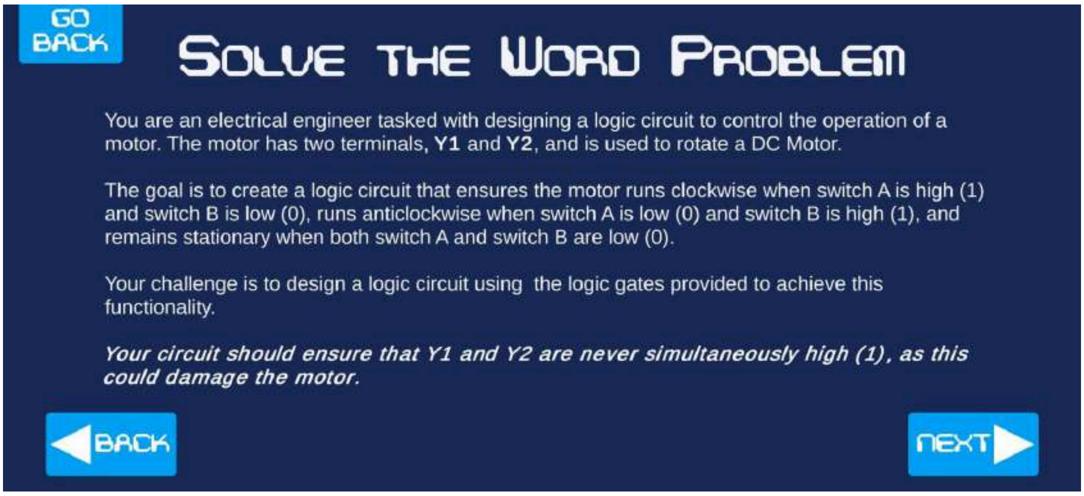


(a) Make connections between input s and DC motor(b) Complete

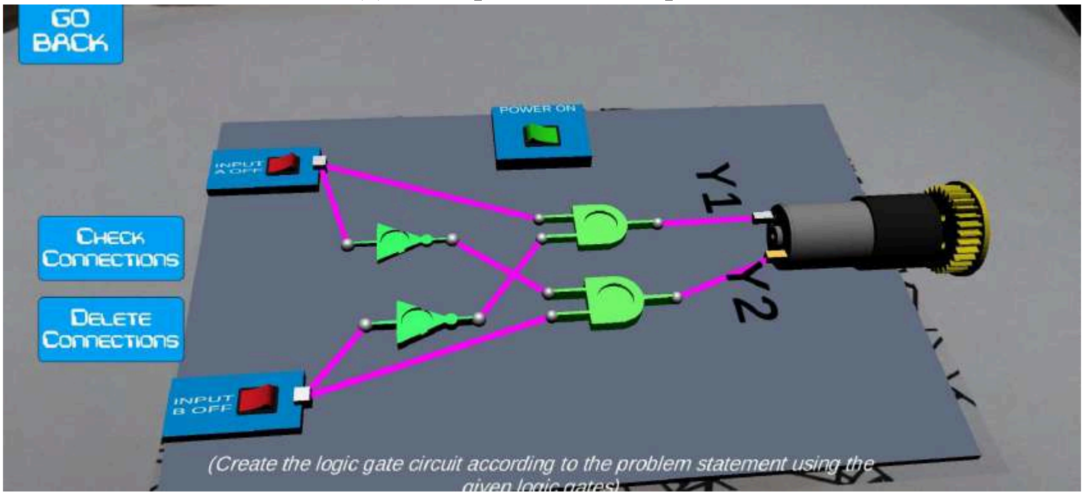


(b) Complete the truth table

Figure 4.17 : L3 - Understanding DC Motors



(a) Word problem description



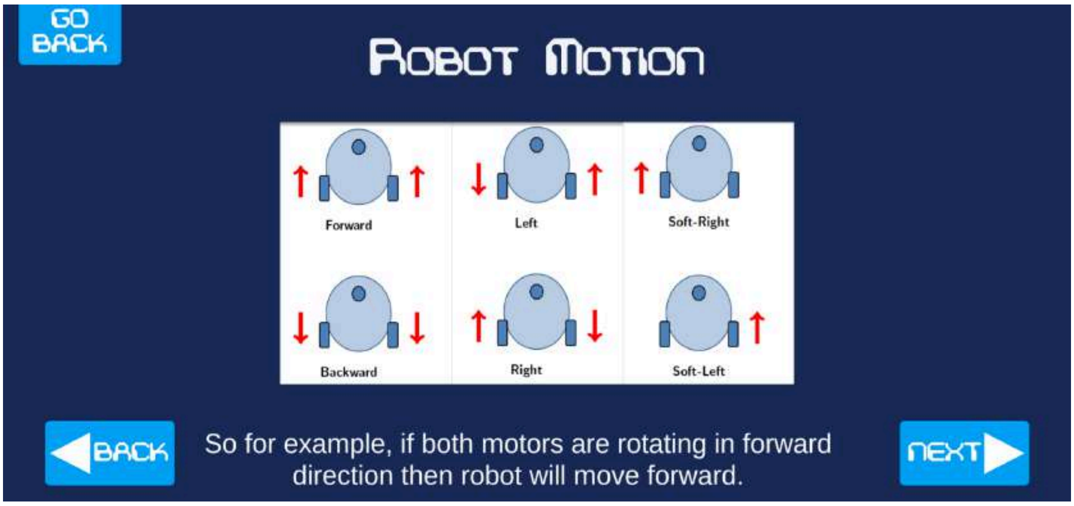
(b) Word problem solution

Figure 4.18 : L3 - Solving world problem

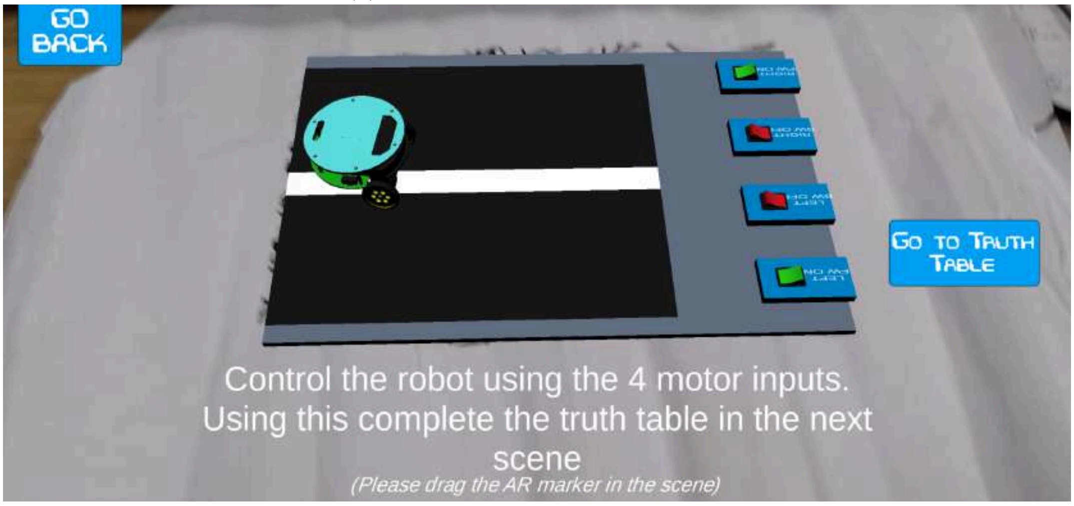
Level	Activity Name	Intended Learning Objective	Activity Description	Illustration
L4	Robot Motion	The students will learn about robot motion and how different robot motions are generated.	An AR-based activity is given in which students can experiment by manipulating the state of motor input terminals to change the direction of robot motion	Figure 4.19
L4	Line follower	The students will learn how to develop the logic for line follower by	An AR-based activity is given in which students can try to move the robot over the white line to find out the direction the robot should move under different state	Figure 4.20

		mapping out the inputs and outputs and deriving the logic gate diagram.	of line sensors. Based on that the student is required to fill a truth table based on how the line follower robot should move according to different conditions.	

Table 4.7 : L4 activities



(a) Robot motion introduction

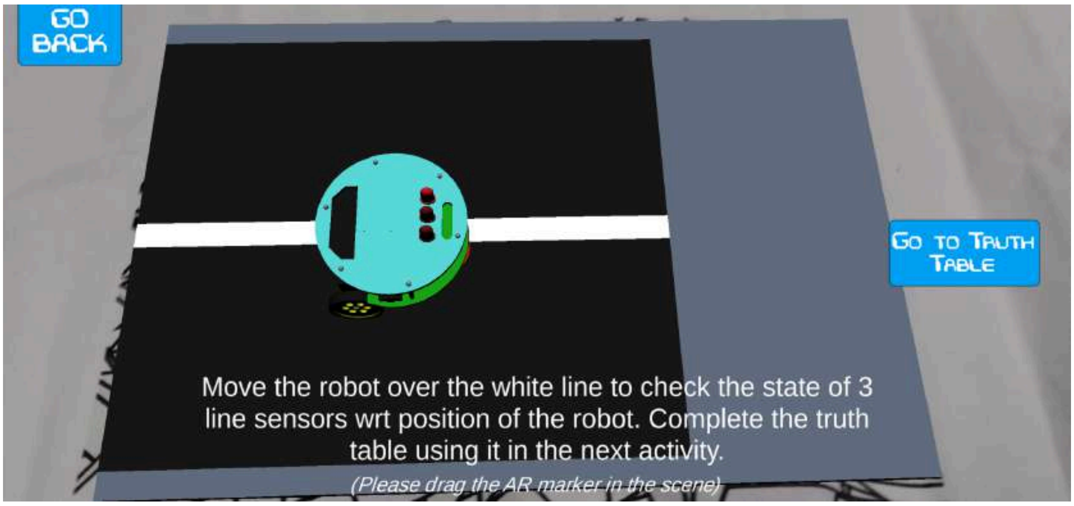


(b) AR-based activity to experiment with robot motion

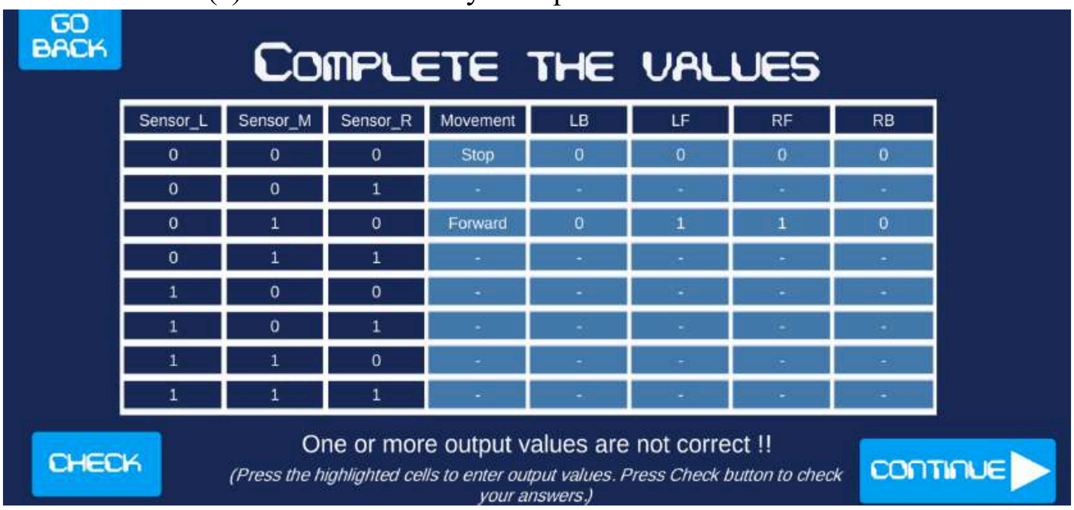
Robot Direction	LB	LF	RF	RB
Forward	0	1	1	0
Backward	1	0	0	1
Left Turn	0	0	0	-
Right Turn	-	-	-	-
Soft Left	-	-	0	-
Soft Right	-	-	-	-

(c) Complete the truth table

Figure 4.19 : L4 - Robot Motion



(c) AR-based activity to experiment with line states



Sensor_L	Sensor_M	Sensor_R	Movement	LB	LF	RF	RB
0	0	0	Stop	0	0	0	0
0	0	1	-	-	-	-	-
0	1	0	Forward	0	1	1	0
0	1	1	-	-	-	-	-
1	0	0	-	-	-	-	-
1	0	1	-	-	-	-	-
1	1	0	-	-	-	-	-
1	1	1	-	-	-	-	-

(c) Complete the truth table

Figure 4.20 : L4 - Line Follower

Chapter 5
Research Method

To understand whether we were able to address the two teaching learning problems explained in Section-2, we needed to conduct a research study with the LogicAR application. The research study was conducted in 2 separate phases - Pilot Study and Main Study. In the following subsections we have explained how both studies were conducted.

5.1 Pilot Study

The main goal of the pilot study was to validate if the activities designed for the first two levels of LogicAR - L1 and L2 are able to help students translate between different representations of logic circuits and also help them build the implement those circuits using physical hardware.

To address this, we used a pre-post study design in which we started the study with a pre-test and then started the intervention in which the students were asked to complete the activities built into the LogicAR application (L1 and L2). It was later followed by a post-test.

5.1.1 Research Questions

The research questions for the pilot study are as follows:

RQ1: Does the LogicAR application increase the representational competence by helping them translate through different representations of logic gate circuits?

RQ2: How does the LogicAR application help students build physical circuits?

5.1.2 Design of Pre-test and Post-test

The pre-test and post-test were conducted in 2 stages - Questionnaire and Hardware

The Questionnaire consisted of 16 questions designed to check the students theoretical knowledge of logic gates and how well they were able to translate between different representations of logic gates.

The 16 questions can be classified in the following categories (as per Table 5.1) based on the kind representation of logic gates the student is required to translate between:

Logic equation to Logic gate diagram	Q1, Q2
Logic gate diagram to Logic equation	Q3, Q4, Q5
Logic gate diagram to truth table	Q6, Q7, Q10
Truth table to Logic gate diagram	Q8, Q9
Logic equation to truth table	Q11, Q12, Q13
Truth table to logic equation	Q14, Q15
Word problem	Q16

Table 5.1 : Different categories of questions

The Hardware test consisted of 2 questions in which students have to build a logic circuit according to the given logic equation using physical hardware components provided to the students.

For pre-test and post-test, there were 2 Questionnaire tests and 2 Hardware tests created respectively. The corresponding questions framed in the Questionnaire were of similar type and difficulty in both Pre-Test Questionnaire and Post-Test Questionnaire.

5.1.3 Study Participants

Digital electronics is taught as a part of engineering curriculum usually in 4th or 5th semester hence the preferred target audience of the pilot study were first and second year undergraduate students from engineering colleges.

The pilot study was conducted with 7 students all of whom were in undergraduate second year. All the students were enrolled in engineering colleges around Mumbai in various engineering disciplines.

5.1.4 Study Details

Table 5.2 consists of the details on how the study was conducted and the process followed

Activity	Time Allotted
Pre-test Questionnaire	30 min
Pre-test Hardware Experiment	30 min
AR app testing by study participants (L1 and L2)	120 min
Post-test Questionnaire	30 min
Post-test Hardware Experiment	30 min
	Total time - 4 hours

Table 5.2: Pilot Study Details

5.2 Main Study

After the pilot study, the main study was conducted with a separate group of students. The goal of the main study was to validate all the 4 levels of activities designed in the LogicAR application and whether these activities helped students in developing representational competence and if they helped bridge the gap between theory and practice and help them solve complex design problems using digital logic.

We also incorporated the robotics design problem that was chosen in section 4 of this report - **Design a robotic line follower using basic logic gates and combinational circuits.**

As described in Section 4, L3 and L4 of LogicAR are designed to be specific to the problem statement and introduce the students to the different concepts which are required to implement the problem statement.

5.2.1 Research Questions

The research questions for the main study are as follows:

RQ3: How does the LogicAR application help the students solve the given problem statement.

5.2.2 Study Participants

The same demographic was targeted for the main study. The main study consisted of 7 undergraduate students from colleges across Mumbai enrolled in various engineering disciplines. All the students were from second year of engineering.

5.2.3 Study Details

The following table consists of the details on how the study was conducted and the process followed:

Activity	Time Allotted
Pre-test Questionnaire	30 min
AR app testing by study participants (L1, L2 and L3)	180 min
Robot Hardware introduction	15 min
Pre-test Problem Statement	45 min
AR app testing by study participants (L4)	30 min
Post-test Questionnaire	30 min
Post-test Problem Statement	45 min
Post-Interview	60 min
	Total time - 7 hours 15 min

Table 5.3: Main Study Details

Pre-test and Post-test Questionnaire

The pre-test and post-test questionnaire were the same as the ones that were given in the pilot study.

Robot Hardware Introduction

The students were provided with the Firebird V robot by NEX robotics to implement the line follower robot. The Firebird V is a ATMEGA2560 microcontroller based robotics research platform which provides an excellent environment for experimentation and research.

The Firebird robot consists of line sensors for detecting white lines on black surfaces (or vice versa) and 2 dc motors for robot locomotion.

The output terminals from the sensors and input terminals from the DC motors were exposed to the students on a breadboard mounted on top of the Firebird V robot.

In the Robot Hardware Introduction stage of the study, the students were given the basic information about the robot and how to access the input and output terminals of the motors and line sensors respectively.

Pre-test and Post-test Problem Statement

The students were not allowed to do any programming on the Firebird V microcontroller to implement the line follower robot. Instead they were required to implement the line follower robot's logic using a logic gate circuit.

The students were required to derive the line follower robot's logic and build the logic circuit by solving sub-problems B1, B2 and B3 indicated in the Problem Map (Figure 4.1).

Post-Interview

After the main study was completed, we did an individual interview with each of the study participants to understand their experience with using the LogicAR application and how they solved the problem statement.

The study participants were asked the following interview questions:

1. What concepts did you learn in L1 and L2 which you did not know earlier?
2. Which activities did you find the need to refer to multiple times in order to complete the physical hardware experiments?
3. Which activities covered concepts you were already familiar with?
4. In the pre-test questions, what questions do you think you spent the most time with? Do you think you were able to complete them in the post test?
5. What was your approach in solving the problem statement during the pre-test?
6. How did that approach change in the post-test?
7. What concepts did you learn in L3 and L4 which you did not know earlier?

Chapter 6
Results and Discussion

The results of the 2 research studies are discussed in this section:

6.1 Pilot Study Results

The pilot study was conducted with 7 students as per described in section 5.1

For the Pre-test and Post-test Questionnaire the scores of all students who participated in the of the study are given in Table 6.1 and Table 6.2.

Pre-test scores																	
	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10	Q11	Q12	Q13	Q14	Q15	Q16	Total
Student 1	1	0	1	1	0	1	1	0	1	1	0	0	1	0	1	1	10
Student 2	0	1	0	0	0	1	1	0	1	0	0	0	1	1	0	1	7
Student 3	1	1	1	1	0	1	1	0	1	1	1	0	1	1	0	1	12
Student 4	0	0	0	0	0	1	0	0	1	0	0	1	0	0	0	1	4
Student 5	1	0	1	1	0	1	0	0	0	0	0	1	1	0	0	1	7
Student 6	0	1	0	0	0	1	1	0	1	0	0	0	0	0	0	1	5
Student 7	1	1	1	1	1	1	1	0	1	1	1	1	1	1	1	1	15

Table 6.1: Pre-test Questionnaire scores - Pilot

	Post-test scores																
	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10	Q11	Q12	Q13	Q14	Q15	Q16	Total
Student 1	1	1	1	1	0	1	1	0	1	1	0	0	1	1	0	1	11
Student 2	0	0	1	1	0	1	1	0	0	1	0	0	1	1	1	1	9
Student 3	1	1	1	1	1	1	1	0	1	1	1	1	1	0	1	1	14
Student 4	1	1	1	1	0	0	0	0	1	0	0	1	1	1	0	1	9
Student 5	1	1	1	1	0	1	1	0	1	1	1	1	1	1	1	1	14
Student 6	1	1	0	1	1	0	0	0	1	1	1	0	1	1	1	1	11
Student 7	1	1	1	1	1	1	1	0	1	1	1	1	1	1	1	1	15

Table 6.2: Post-test Questionnaire scores - Pilot

In order to address RQ1, we want to check if there is a significant increase between the pre-test and post-test scores of the study participants. For that we need to use the two-tailed paired t-test.

The null hypothesis in this case would be

Ho := There is no difference between the pre-test and post-test scores of all the 7 students

The alternate hypothesis is:

Ha := The pre-test and post-test scores of the 7 students vary significantly.

Since the sample size of our study is small (N=7), to apply the paired t-test to test for differences between paired measurements, the following assumptions need to hold[27] :

- Subjects must be independent. Measurements for one subject do not affect measurements for any other subject.
- Each of the paired measurements must be obtained from the same subject.
- The measured differences are normally distributed.
- There is homogeneity of variance (i.e., the variability of the data in each group is similar).

To check if our measurements are normally distributed, we used the Shapiro Wilke's test on the pre-test and post-test scores. For the pre-test scores, the Shapiro Wilke's test did not depart significantly from normality ($W(7) = .94$, $p = .760$). The same was observed for post-test scores ($W(7) = .87$, $p = .222$). Hence all the measurements for pre and post were normally distributed.

To check for homogeneity of variance, we used the Levene's test for which the results were not statistically significant ($F = 1.94271$, $p = .189$) which meant the condition for homogeneity of samples was met.

Since all 4 conditions were met, we could proceed to apply the two-tailed paired t-test.

Pre-test (N=7)		Post-test (N=7)			
Mean	SD	Mean	SD	t	p
8.57	3.95	11.86	2.48	3.2312	0.0179

Table 6.3: Paired T-test results - Pilot

These results are considered statistically significant according to conventional criteria.

6.1.1 Analysis according to question type

As described in Table 5.1, the 16 questions of the questionnaire were divided into 7 categories. Table 6.4 and Table 6.5 show the pre-test and post-test scores of the 7 students divided according to the question category.

Question Category	Student 1	Student 2	Student 3	Student 4	Student 5	Student 6	Student 7
Logic equation to logic gate diagram	1	1	2	0	1	1	2
logic gate diagram to Logic equation	2	0	2	0	2	0	3
logic gate diagram to truth table	3	2	3	1	1	2	3
Truth table to logic gate diagram	1	1	1	1	0	1	1
Logic equation to truth table	1	1	2	1	2	0	3
Truth table to logic equation	1	1	1	0	0	0	2
Word problem	1	1	1	1	1	1	1

Table 6.4: Pre-test Questionnaire scores according to question category - Pilot

Question Category	Student 1	Student 2	Student 3	Student 4	Student 5	Student 6	Student 7
Logic equation to logic gate diagram	2	0	2	2	2	2	2
logic gate diagram to Logic equation	2	2	3	2	2	2	3
logic gate diagram to truth table	3	3	3	0	3	1	3
Truth table to logic gate diagram	1	0	1	1	1	1	1

Logic equation to truth table	1	1	3	2	3	2	3
Truth table to logic equation	1	2	1	1	2	2	2
Word problem	1	1	1	1	1	1	1

Table 6.5: Post-test Questionnaire scores according to question category - Pilot

		Pre-test		Post-test			
Question Category	Number of Questions	Mean	SD	Mean	SD	t	p
Logic equation to logic gate diagram	2	1.14	0.69	1.71	0.76	1.5492	0.1723
logic gate diagram to Logic equation	3	1.29	1.25	2.29	0.49	2.6458	0.0382
logic gate diagram to truth table	3	2.14	0.9	2.29	1.25	0.3536	0.7358
Truth table to logic gate diagram	2	0.86	0.38	0.86	0.38	0	1
Logic equation to truth table	3	1.43	0.98	2.14	0.9	2.5	0.0465
Truth table to logic equation	2	0.71	0.76	1.57	0.53	2.5205	0.0453
Word problem	1	1	0	1	0	0	1

Table 6.6: t-test scores according to question category - Pilot

In table 6.6 we have shown the t-test scores for each question category. In this table we can observe that while not all t-test results are statistically significant, overall the mean scores for all question categories have increased.

6.1.2 Pre-post observations

There were a few students who did well in both pre-test and post-test owing to their familiarity with basic logic gate concepts. Overall, there is an increase in the pre and post test total scores (Percent difference in mean scores =38.3%) which is statistically significant.

One particular question category where the students did not do well both in pre and post were questions related to converting a truth table into logic gate representation.

6.1.3 Hardware Experiment Observations

There were 4 hardware based activities built into the LogicAR application

- Building a NOT gate circuit (L1)
- Building a AND gate circuit (L1)
- Building a OR gate circuit (L1)
- Building a NAND gate circuit using NOT and AND gates. (L2)

Student 1 was able to complete the first 3 circuits but was not able to get the 4th circuit to work. Circuit connections seemed ok. Students 2-7 were able to complete all 4 circuits. Students spent more time completing the physical hardware based activities as compared to other activities built into the app. This can be explained by the students already being familiar with the working of basic logic gates and how to complete truth tables.

The pre-test and post-test experiment also consisted of 2 circuits each in which the students were required to write the truth tables for the circuits and build the circuits using physical hardware. Pre-test experiment was not completed by any student.
Post-test experiment students were able to write the truth tables for both circuits. Students 1-3 were able to build only the first circuit but not the second circuit. Students 4-7 were able to build both circuits in the post-test experiment.

It was observed that students spent more time interacting with the AR-based activities with hardware experiments. The students used the LogicAR application to check their connections and debug the circuit. A little bit of intervention was required to help the students stuck at some part of the circuit building activity.

6.2 Main Study Results

The main study was also conducted with 7 students as described in section 5.2
For the Pre-test and Post-test Questionnaire the scores of all students who participated in the main study are given in Table 6.7 and Table 6.8.

Pre-test																	
	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10	Q11	Q12	Q13	Q14	Q15	Q16	Total
Student 1	1	1	1	1	1	1	0	0	1	0	0	0	1	1	0	1	10
Student 2	1	1	1	1	1	1	1	0	1	1	1	1	1	0	1	1	14
Student 3	1	1	0	1	0	1	1	1	1	1	0	1	1	0	1	0	11
Student 4	1	1	1	1	1	1	1	0	1	1	0	1	1	1	1	1	14
Student 5	1	1	1	0	0	1	1	0	1	1	0	0	1	1	0	0	9
Student 6	0	0	0	0	0	0	0	0	0	0	1	0	1	1	1	0	4
Student 7	1	1	1	1	1	1	1	0	1	1	1	1	1	1	1	1	15

Table 6.7: Pre-test Questionnaire scores - Main

Post-test																	
	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10	Q11	Q12	Q13	Q14	Q15	Q16	Total
Student 1	1	1	1	1	0	1	1	0	1	1	1	0	1	0	0	1	11
Student 2	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	1	14
Student 3	1	1	1	1	1	1	0	1	1	1	1	1	1	0	1	1	14
Student 4	1	1	1	1	1	1	1	1	1	1	1	1	1	0	1	1	15
Student 5	1	1	1	1	1	1	1	1	1	1	1	1	1	0	1	1	15
Student 6	1	1	1	1	0	1	1	0	1	1	1	1	1	1	0	1	13
Student 7	1	1	1	1	1	1	1	0	1	1	1	1	1	1	1	1	15

Table 6.8: Post-test Questionnaire scores - Main

Again we want to compare the pre-test and post-test scores of the main study using paired t-test.

To check if our measurements are normally distributed, we used the Shapiro Wilke’s test on the pre-test and post-test scores. For the pre-test scores, the Shapiro Wilke’s test did not depart significantly from normality ($W(7) = .91$, $p = .420$). The same was observed for post-test scores (W(7) = .82, p = .070). Hence all the measurements for pre and post were normally distributed.

To check for homogeneity of variance, we used the Levene's test for which the results were not statistically significant (F = 3.78064, p = .075664) which meant the condition for homogeneity of samples was met.

The results of the paired t-test are given in Table 6.9. The results are not quite significant according to conventional criteria

Pre-test (N=7)		Post-test (N=7)			
Mean	SD	Mean	SD	t	p
11	3.83	13.86	1.46	2.1997	0.0701

Table 6.9: Paired T-test results - Main

6.2.1 Analysis according to question type

Table 6.10 and Table 6.11 show the pre-test and post-test scores of the 7 students divided according to the question category.

	Student 1	Student 2	Student 3	Student 4	Student 5	Student 6	Student 7
Logic equation to logic gate diagram	2	2	2	2	2	0	2
logic gate diagram to Logic equation	3	3	1	3	1	0	3
logic gate diagram to truth table	1	3	3	3	3	0	3
Truth table to logic gate diagram	1	1	2	1	1	0	1
Logic equation to truth table	1	3	2	2	1	2	3
Truth table to logic equation	1	1	1	2	1	2	2
Word problem	1	1	0	1	0	0	1

Table 6.10: Pre-test Questionnaire scores according to question category - Main

	Student 1	Student 2	Student 3	Student 4	Student 5	Student 7	Student 9
Logic equation to logic gate diagram	2	2	2	2	2	2	2
logic gate diagram to Logic equation	2	3	3	3	3	2	3
logic gate diagram to truth table	3	3	2	3	3	3	3
Truth table to logic gate diagram	1	2	2	2	2	1	1
Logic equation to truth table	2	3	3	3	3	3	3
Truth table to logic equation	0	0	1	1	1	1	2
Word problem	1	1	1	1	1	1	1

Table 6.11: Post-test Questionnaire scores according to question category - Main

		Pre-test		Post-test			
	Number of Questions	Mean	SD	Mean	SD	t	p
Logic equation to logic gate diagram	2	1.71	0.76	2	0	1	0.3559
logic gate diagram to Logic equation	3	2	1.29	2.71	0.49	1.5076	0.1824
logic gate diagram to truth table	3	2.29	1.25	2.86	0.38	1.082	0.3208
Truth table to logic gate diagram	2	1	0.58	1.57	0.53	2.8284	0.03
Logic equation to truth table	3	2	0.82	2.86	0.38	3.2863	0.0167
Truth table to logic equation	2	1.43	0.53	0.86	0.69	2.8284	0.03
Word problem	1	0.57	0.53	1	0	2.1213	0.0781

Table 6.12: Post-test Questionnaire scores according to question category - Main

In table 6.12 we have shown the t-test scores for each question category. In this table we can observe that while not all t-test results are statistically significant, overall the mean scores for all question categories have increased.

6.2.2 Pre-post observations for Main Study

In the main study the number of students who did well in both pre-test and post-test was greater. Hence the results as indicated by the t-test are not statistically significant. However, it should be noted that the mean scores of pre-test vs post-test have still increased by 26% which shows that there has been a definite improvement after the intervention.

6.2.3 Hardware Experiment and Problem Statement Observations

In the main study, we did not conduct the pre-test and post-test hardware as we did in the main study. Instead we conducted the Pre-test and Post-test Problem Statement as described in the previous Chapter.

The 4 basic logic gate hardware activities that were built into the application were still carried out by all the students. The observations for these four activities were very similar to the pilot study. The students were able to complete the 4 activities satisfactorily without much external intervention. The main study participants had a bit more practical experience then the pilot study group hence they required much less help debugging the circuits.

In the pre-test problem statement, Student 7 was able to completely implement the given robotics design problem without any external hints or interventions. Apart from student 7, nobody was able to complete the problem statement.

In the post-test problem statement as well, none of the students except Student 7 were able to implement the line follower problem statement to the full degree. Student 3, 4 and 5 were able to derive the required truth table for the logic development but were unable to convert it into a logic gate diagram and subsequently implement it. Student 1, 2 and 6 were totally clueless about the problem statement. We tried to encourage them by giving extra hints on how to solve the problem but it did not work out.

In the interview questions, we tried to probe the reasons for this failure to implement the problem statement.

6.2.4 Interview Discussion

From the interview, we gleaned a lot of insights on why the majority of the students were not able to complete the problem statement despite completing L4.

Students 3, 4, and 5 reported in the interviews that they had mainly figured out the truth table mapping by referring to the L4 activities and created the input to output mapping. However, they were stuck in converting this truth table representation into a logic circuit diagram. These students were familiar with some of the working of the line follower concepts earlier, having encountered them in robotics workshops. However, they had not only experience of solving the line follower problem statement through programming hence they were not able to derive the logic for the physical circuit without programming

Student 1, 2 and 6 were familiar with the line follower algorithm as it was taught to them in college robotics workshops. However they had not tried solving the problem without programming. During the interview they were asked to guess how they would try to solve the problem statement without using programming. Their approach to solving the problem was very much sequential like how one would solve the problem using different if-else conditions in programming.

For example, Student 1 said the following *"when the robot detects white line in only the centre sensor and black line on both left and right sensors, the robot needs to move forward. Hence we will use this logic gate for this behaviour"* However this was totally opposite to the combinational logic that they were supposed to implement.

Student 7 was able to complete the problem statement without any hints or intervention. From the interview, we were able to glean that student 7 had a fair bit of experience with practical robotics and also his theoretical concepts were very clear as indicated through his pre-test and post-test scores.

6.3 Discussion

At the start of the research study we defined 3 Research questions. We will discuss them one by one.

RQ1: Does the LogicAR application increase the representational competence by helping them translate through different representations of logic gate circuits?

RQ2: How does the LogicAR application help students build physical circuits?

RQ3: How does the LogicAR application help the students solve the given problem statement.

For RQ1, we noted that the students that during the pilot study, the pre-test and post-test scores had a significant increase according to the t-test conducted. This implies that performing the activities in LogicAR application were successful in helping students improve their concepts and translate between different representations. According to the analysis given in Table 6.6, while not all the t-tests conducted for the question categories were statistically significant, the mean scores of all the question categories increased.

Similar results were seen in the pre-test and post-test scores in the main study as well. While the results of the t-test done on the main study were not statistically significant, there was a 26% increase in the mean scores. A probable reason why the student group from the main study performed better in the pre-test could be due to the fact that the study was done in December while the pilot was done in August. By this time in the academic year, the students have already been exposed to the digital electronics curriculum hence they tend to score better in the theoretical questions.

There were two question categories where the students had the most problems as shown through the pre and post test as well as interviews and other activities..These question categories involved converting a given truth table into some other representation like logic equation or logic gate diagram. This was also evident later on because this was the main reason why the 3 students in the main study were unable to complete the problem statement.

For RQ2, we observed that while a few students in both pilot and main study had some experience building circuits, they greatly appreciated the AR-based activities in LogicAR which were used to guide them through the process of building the circuits. These students tended to spend more time with these activities and go back to refer to them multiple times in order to debug the circuits they were given to build.

One important observation to note was that the majority of the students in both pilot and main study lacked the experience in debugging circuits and required a bit of hand holding in that regard. Hence, more scaffolds could be built into the LogicAR application to help students debug circuits more effectively.

Hence overall, we can say that the LogicAR app was useful in helping students learn how to build physical circuits.

For RQ3, the LogicAR L4 activities were not helpful. Because the students were not used to tackling a complex problem like this using only digital logic design, the majority of the students failed to implement the problem statement.

The reason for failure was to some extent, the deficiencies in the application as well. Most of the students were not able to solve problems involving converting truth tables into some other logic gate representation. Hence because of this reason, the 3 out of 7 students were unable to derive the logic gate equations required for implementing the problem statement. Also another issue was that the students were used to solving problems using sequential logic hence they were not able to think how the combinational logic would work.

Hence the LogicAR application was not helpful in helping students solve the given problem statement.

Chapter 7
Conclusion

Overall, there are a lot of insights to be gained from this study. In the beginning we defined two teaching learning problems in the context of digital electronics specifically.

The first major teaching and learning problem was **Bridging the gap between theory and practice.** We found that the LogicAR application was able to address this problem to some extent. The students who participated in the study learned how to build physical hardware circuits using the application as an aid. However the application was unable to provide enough scaffolds to help students solve the robotics design problem we had defined. Hence, more scaffolds and activities should be introduced to address these deficiencies.

The second major teaching-learning problem was the **Development of Representational Competence.** We found that the application was able to develop representational competence to some degree and the students were able to translate between various representations of logic circuits. However, there were still some drawbacks and the students faced trouble with certain types of translation for which again, additional scaffolds can be provided

Chapter 8
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