The Use of Truth Table, Logical Reasoning and Logic Gate in Teaching and Learning Process

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Abstract: The concept of truth table is based on the content to analyze in teaching and learning logical reasoning and logic gate, which is a visual representation of possible combination of input and output information of Boolean prepositions in logical reasoning and Boolean functions in logic gate plotted into a table. It adopts Boolean algebra for problem solving as a method or science of reasoning, or ability to argue and convince. In the teaching and learning processes of logic, formal and informal reasoning tasks are used in a variety of ways, including using symbols and entirely in plain language without symbols where symbolic logics are commonly referred to as mathematical logic. This paper therefore considers the Use of Truth Table, Logical Reasoning and Logic Gate in Teaching and Learning Process It highlighted the benefits of using the truth table and compared logical reasoning and logic gate connectives and concluded that, there exist similarities, differences and peculiarities in the interactive features of the content of the truth table. The paper suggested that teachers should vividly state the similarities, differences and peculiarities in the interactive features of truth table in logical reasoning and logic gate while incorporating thought in teaching and learning process to avoid confusion.

Keywords: Teaching and Learning, Logical Reasoning, Logic Gate, Truth Table

I. Introduction

Teaching and learning interventions are required in educational settings in order obtain favourable outcomes from the exercise. Education is a continuous process that promotes learning via instructors' efforts in subject delivery of their respective teaching methods. Teachers employ various methods and strategies in structuring and comprehending students' different learning styles in the attainment of students' academic performance in school subjects and their attitude towards the subjects. The structure of learning and its domains build the meaning, purpose, and lesson of the learning activities (Leovigildo, 2022).

Learning is a transactional communication process that is effective and efficient between teachers and students as well as between students and other students in order to attain the specified goals. The transmission of different sorts of ideas, thoughts, and messages are the core of transactional communication. Students show little interest in learning when the pre-determined learning objectives are not met, and at such instances, there is a need for teachers to put in more creative efforts in their roles order to arouse students’ interests in learning and to accomplish stated learning objectives in line with curricular criteria (Sariaman, Ahmad & Andres, 2020; Aziz & Kazi, 2019).

At the planning stage of the process of teaching and learning, a teacher must take into considerations three important things which are; what to teach, how to teach, and why to teach. What to teach is decided by selecting and organizing the lesson plan, selecting the teaching resources, and evaluating their value. In order to handle how to teach, the methods, resources, and environments where the teaching is taking place coupled with the targeted group of learners the resources are meant for must be considered. The classroom management skills of the teachers are directly tied to how they do their subject delivery in teaching-learning settings. In the traditional sense, management's primary goal is to bring people together around common goals and ideas in order to motivate them and develop their skills. The issue of "what to teach" is not an issue in today's educational system as much as to how individuals learn. Why to teach has to do with the objectives of the subject matter and its content, which is synonymous to the relevance of the ideas being disseminated for the purpose(s) such ideas are meant for (Süleyman, 2018).

Considering the concept of truth table, it is based on the content to analyze in teaching and learning logical reasoning and logic gate, which is a visual representation of possible combination of input and output information of Boolean prepositions in logical reasoning and Boolean functions in logic gate plotted into a table. Evidently, truth table exists in both logical reasoning and logic gate which adopt Boolean algebra for problem solving on a table. Boolean logic is used to determine whether propositions are true or false. Combining Boolean propositions can result in Boolean functions that can be categorized as true or false, where the functions often transfer true propositions to the value 1 and false propositions to the value 0 (Joshua, 2019).

Logic is the study of the methods and the principles used to distinguish good from bad reasoning (correct and the incorrect). It is seen as a method or science of reasoning, or ability to argue and convince. A statement in a logical context is a declaration, verbal or written, that is either true or false, but not both; and the words which combine simple statements to form compound statements are called logical connectives or simply connectives (Odogwu, Obono, Jimoh, Adebisi, Usman, Arigbabu, Salau, Salaudeen, Salaam & Bot, 2018). In the teaching and learning processes of logic, formal and informal reasoning tasks are used. Formal reasoning tasks can be given in a variety of ways, including using symbols and entirely in plain language without symbols where symbolic logic are commonly referred to as mathematical logic (Adel, 2021; Hugo, Gerrit, Cor & Martin, 2020).

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A subfield of symbolic logic is known as propositional logic which is built on the bivalence of classical logic and initially focused on two major issues with formal logic. It helps to decide on conclusions derived from certainty premises of valid or invalid argument, used in other fields such as in engineering and computer science applications. Logical knowledge is required in order to decide certain known facts about mathematical argument and structural programming (Adel, 2021). Logical reasoning is seen as selecting and interpreting information from a given context, connections such as: negation "not", conjunction "and", inclusive dis-junction inclusive ''or", exclusive disjunction "nor", conditional "if ...then", bi-conditional "if and only if" etcetera, which hinges on verifying and drawing conclusions based on provided and interpreted information and the associated rules and processes (Hugo, Gerrit, Cor & Martin, 2020). While Logic gate is a general purpose electronic device used to construct logic circuits. All logic gates have inputs and outputs. The state of the output is set by the input states based on different rules depending on the type of gate. The different types of gates have different shaped circuit symbols. The standard single logic gates are AND, OR and NOT gates and the alternative logic gates are exclusive – OR, exclusive – NOR, NAND and NOR gates (Ibrahim & Kazeem, 2015). Since truth table exist in both teaching and learning of logical reasoning and logic gate, hence, this study on Comparative Analysis of Truth Table in Teaching and Learning Logical Reasoning and Logic Gate sought to find their similarities differences and peculiarities through their interrelatedness.

Truth tables are instruments for assessing logical claims and substantiating arguments. The term refers to the mathematical table's factual representation of all conceivable possibilities. The Tractatus Logico-Philosophicus, a book Ludwig Wittgenstein wrote in 1918 and released in 1921, is primarily responsible for the invention and widespread use of the truth table. Truth tables are used in Boolean logic-based Mathematics and science to demonstrate the truth or falsity of expressions and operations. The truth table provides a breakdown of logical functions by giving all the various values that the function might arrive at. It is a type of chart that is used to evaluate the truthfulness of assertions and the validity of arguments (Phalguni, Saniya, Akshay, Vinay & Pranavraj, 2023).

Using connectives, a compound proposition is created by joining simple propositions. Connectives are an operation from the perspective of structure. The connectives must first be defined and symbolized before we can investigate the proposition (Liu, 2020). In logical reasoning, the following are the connectives regarded as logical operator: (1) Negation "∼", (2) Conjunction "∧", (3) Disjunction "∨", (4) Implication "⇒", (5) Bi-implication "⇔", (6) Equivalence "≡", which are in order of precedence as numbered; For instance, the conjunction of $p \vee q$ and $\sim r$ is $(p \vee q) \wedge (\sim r)$. However, we specify that the negation operator is used before all other logical operators in order to minimize the number of parentheses. This indicates that $\sim p \wedge q$ is not the negation of the conjunction of p and q, namely $\sim(p \wedge q)$, but rather the conjunction of $\sim p$ and q, namely $(\sim p) \wedge q$. It is generally the case that unary operators that involve only one object precede binary operators (Dvornichenko & Lysenko, 2022).

In Logic Gate, the following are the connectives regarded as Bit Operator: NOT "¯", AND "·", OR "+", NAND "$\overline{\cdot}$", NOR "$\overline{+}$", XOR "⊕" and XNOR "$\overline{\oplus}$". In computers information is represented by bits. A bit is a symbol that may have either the value 0 (zero) or 1 (one). The digits used in binary representations of numbers, zeros and ones, are where the word "bit" gets its current meaning. The word was first used in 1946 by renowned statistician John Tukey. There are two truth values, true and false, thus a bit may be used to represent either of them. A 1 bit is used to represent true and a 0 bit to indicate false, as is customary. In other words, 1 stands for T (true), and 0 for F (false). If a variable's value is either true or false, it is referred to as a Boolean variable. As a result, a bit may be used to represent a Boolean variable (Dvornichenko & Lysenko, 2022).

Just like the study in discrete Mathematics carried out by Liu Yu 'e where a set of thoughts were incorporated into connectives used in truth table and important equivalent formulas as thus: Firstly, the universal set U of the set is treated as the truth value 1 (or T) of the true proportion, while the empty set ∅ of the set is viewed as the truth value 0 (or F) of the false proposition. Secondly, logical operator is treated as follows: (1) Negation "∼" is treated as set complement "ð", (2) Conjunction "∧" is treated as intersection operation "∩", (3) Disjunction "∨" is treated as Union operation "∪", (4) Implication "⇒" is treated as proper subset "⊆", (5) Bi-implication "⇔" is treated as equivalence "=" (Liu, Y., 2020).

In the same vein, Logic Gate thoughts can be incorporated into teaching and learning logical reasoning since there is equivalent in symbols used in Boolean and propositional arguments as thus:

Table 1: Equivalent in symbols used in Boolean and Propositional arguments

Propositional	**Boolean**
T	1
F	0
∧ (AND)	·
∨ (OR)	+
∼C (NOT C) where C is a proposition	$\bar{C}$ where C is a Boolean input

Example using equivalent symbols $\mathbf{1 \cdot 0 + \overline{(1+0)} = 0}$ is the Boolean representation of $\mathbf{(T \wedge F) \vee \sim(T \vee F)} \equiv F$ which shows the similarities between propositional logic equivalences and Boolean identities such as: Identity laws, Domination laws, Idempotent laws, Double Negation/Complement law, Commutative laws, Associative laws, Distributive laws, De Morgan's laws, Absorption laws and Negation/Unit/Zero property (Joshua, 2019).

II. Connectives in Logical Reasoning

Table 2: Logical Reasoning Truth Table Chart

Connectives	Negation	Conjunction	Disjunction	Implication	Bi-implication
Words	"Not"	"And"	"Or"	"If... then"	"If and only if"
Symbols	~	∧	∨	⇒	⇔
Names	Curl	Cap	Cup	Implies	If
Inputs	Outputs				
P	Q	~P	~Q	P ∧ Q	P ∨ Q
-----	-----	-----	-----	-------	-------
T	T	F	F	T	T
T	F	F	T	F	T
F	T	T	F	F	T
F	F	T	T	F	F
Inc.	Exc.				

Source: The Researcher, 2023

NOTE: Input $\begin{Bmatrix} P = first\ simple\ statement/antecedent \\ Q = second\ simple\ statement/consequence \end{Bmatrix}$ i.e Compound statements

Output $\begin{Bmatrix} T = True \\ F = False \end{Bmatrix}$ i.e Truth values

From table 2, the following are the definitions of each connective:

1. Negation

The Negation of any statement is the reverse of such statement (Odogwu…et al, 2018). It uses *'not'* statement as a word and the symbol is Curl (~) e.g ~P = reverse/opposite of P. i. e Curl (~) = reverse/opposite. Thus, ~P is False if P is True and vice versa.

2. Conjunction.

This is a compound statement formed by joining two simple statements with *'and'*. *Note! In Conjunction; other words which can be used are: *but, yet, also, still, although, moreover, nevertheless, even* and *semicolon* (;). The symbol is Cap (∧) e. g P ∧ Q = P $\times$ Q i.e Cap (∧) = $(\times)$ multiplication. Hence; let T = 1 and F = 0. Thus, P ∧ Q is True if P and Q are both True; otherwise they are False (Odogwu…et al, 2018).

3. Disjunction

This is a compound statement formed by joining two simple statements with *'or'*. The symbol is Cup (∨) e. g P ∨ Q = P $+$ Q i. e Cup (∨) = $(+)$ addition. Note that the English word *'or'* is commonly used in two distinct ways. (Odogwu…et al, 2018).

(a) <u>Inclusive disjunction</u>

When the English word *'or'* used in the sense of 'P or Q or both', then one can consider the statement such as: *'it is cold or it is raining'*, the *'or'* is used in an <u>inclusive sense</u>, because it is possible to be cold as well as raining (Odogwu…et al, 2018). Since, Cup (∨) = $(+)$ addition. Hence; let T = 1 and F = 0. Note: $1 + 1 = 1$. Thus, P ∨ Q is False if P and Q are both False otherwise they are True.

(b) <u>Exclusive disjunction</u>

When the English word *'or'* used in the sense of 'P or Q but not both', then one can look at an example like this statement: *'Jide will go to Abuja or London'*, the *'or'* is used in an <u>exclusive sense</u>, because it is not possible for Jide to go to Abuja and at the same time be in London (Odogwu…et al, 2018). Since, Cup (⊻) = $(+)$ addition. Hence; let T = Male and F = Female. Note;

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Male + Female = Baby (i.e True), But since same gender cannot produce baby (∴ Male + Male ≠ Baby (i.e False). Thus, P ⊻ Q is False if P and Q are both True or both False. Otherwise, it is True.

4. Implication

This is a compound statement formed when two simple statements are combined by *'if… then'*, such that the first statement implies the second, they are not denoted by P ⇒ Q. The *if* clause statement (i. e P) is sometimes called the antecedent while the *then* clause (Q) is called the consequent. The conditional statement P ⇒ Q can also be read as: P implies Q; Q only if P; P is sufficient for Q; P is necessary for Q. Thus, The P ⇒ Q column is False only when P is True and Q is False (Odogwu…et al, 2018).

Starting with the conditional statement P ⇒ Q, we can create several other conditional statements. Three related conditional expressions in particular are used so frequently that they have unique names. The **Converse** of P ⇒ Q is the statement Q ⇒ P. The proposition ~Q ⇒ ~P is the **Contrapositive** of P ⇒ Q. The statement ~P ⇒ ~Q is known as the **Inverse** of P ⇒ Q. We shall observe that only the contrapositive, out of the three conditional assertions derived from P ⇒ Q, is guaranteed to have the same truth value as P ⇒ Q (Dvornichenko & Lysenko, 2022).

Table 3: Other Conditional Statement (Converse, Inverse and Contrapositive) Truth Table Chart

Proposition	**Implication**	**Converse**	**Negation**	**Inverse**	**Contrapositive**
P Q	P ⇒ Q	Q ⇒ P	~P ~Q	~P ⇒ ~Q	~Q ⇒ ~P
T T	T	T	F F	T	T
T F	F	T	F T	T	F
F T	T	F	T F	F	T
F F	T	T	T T	T	T

We refer to two compound propositions as being equivalent if their truth values are always the same, regardless of the values of the propositional variables. As a result, a conditional statement and its contrapositive are equal. A conditional statement's converse and inverse are also both equal, as the reader may attest, but neither is the same as the original conditional statement (Dvornichenko & Lysenko, 2022).

5. Bi – implication

This is a compound statement formed when two simple statements are combined by *'if and only if',* i. e such a relation implies equivalence. e. g *if P stands for John speaks English fluently and Q stands for John was born and raised in England*, then the bi – conditional statement 'P ⇔ Q' or 'P *if* Q' reads 'P *if and only if* Q'. It also reads '*if* P *then* Q', and '*if* Q *then* P'. Thus, P ⇔ Q is True if P and Q are both True or both False. Otherwise, it is False (Odogwu…et al, 2018).

6. Tautology

This is a compound statement or proposition whose end result is True despite the value of its sub – statements (Odogwu…et al, 2018). Since, cup (∨) = (+) addition and Curl (~) = reverse/opposite Let T = 1 and F = 0. Hence, The Truth table of Q ∨ (~ Q):

Table 4: Tautology Truth Table

Q	~ Q	Q + (~ Q)	Q ∨ (~ Q)
1	0	1	T
0	1	1	T

Thus, the Q ∨ (~ Q) column is always True.

7. Contradiction

This is a compound statement or proposition whose end result is False despite the value of its sub – statements (Odogwu…et al, 2018). Since, Cap (∧) = (×) multiplication. and Curl (~) = reverse/opposite. Let T = 1 and F = 0. Hence, The Truth table of Q ∧ (~ Q):

Table 5: Contradiction Truth Table

Q	~ Q	Q × (~ Q)	Q ∧ (~ Q)
1	0	0	F
0	1	0	F

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Thus, the Q ∧ (∼ Q) column is always False.

8. Equivalence

This is a compound statement or proposition denoted by P ≡ Q using *'is'* as word and congruent ≡ as symbol said to be logically equivalent if they have the same or identical truth values for every set of truth values of their components (Hugo, Gerrit, Cor & Martin, 2020). To verify this; let use truth table technique to show that P ⇒ Q ≡ ∼ Q ⇒ ∼ P

Table 6: Equivalence Truth Table

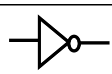
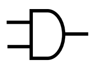
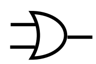
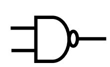
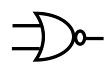
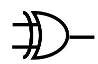
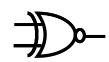
P	∼ P	Q	∼ Q	P ⇒ Q	∼ Q ⇒ ∼ P
T	F	T	F	T	T
T	F	F	T	F	F
F	T	T	F	T	T
F	T	F	T	T	T

Thus, P ⇒ Q ≡ ∼ Q ⇒ ∼ P

III. Connectives in Logic Gates

There are three (3) fundamental types of Gate; namely: NOT, AND, OR. Other four (4) Gates are derived from the first three (3) basic Gates; these include: NAND, NOR, XOR, XNOR.

Table 7: Logic Gate Truth Table Chart

Gate Name		**NOT**		**AND**	**OR**	**NAND**	**NOR**	**XOR**	**XNOR**
Gate Symbol									
Inputs		Boolean Expression Outputs							
A	B	$\overline{A}$	$\overline{B}$	A · B	A + B	$\overline{A \cdot B}$	$\overline{A + B}$	A ⊕ B	$\overline{A \oplus B}$
0	0	1	1	0	0	1	1	0	1
0	1	1	0	0	1	1	0	1	0
1	0	0	1	0	1	1	0	1	0
1	1	0	0	1	1	0	0	0	1

Source: The Researcher, 2023

From table 7, the following are the definitions of each gate:

1. NOT GATE

This is an electronic circuit with a single input and output that performs the operation of logic negation as an inverted circuit; that is, it produces an inverted version of the input at its output. Therefore, it gives a high output (1) if its input is low and vice versa (Ibrahim & Kazeem, 2015). A bar (¯) is used to show the NOT operation in the Boolean expression of output $\overline{A}$. Let True = 1 and False = 0. Thus, $\overline{A}$ is True if A is False and vice versa.

2. AND GATE

This is an electronic circuit that gives a high output (1) only if all its inputs are high. It has two or more inputs and produces a single output. A dot (·) is used to show the AND operation in the Boolean expression of output A · B. Note, this dot is sometimes omitted that is, AB. Let True = 1 and False = 0. Thus, the output is "True" when both inputs are "True." Otherwise, the output is "False." That is, the AND gate acts in the same way as the logical "and" operator (Ibrahim & Kazeem, 2015).

3. OR GATE

This is an electronic circuit that gives a high output (1) if one or more of its inputs are high. It has two or more inputs and produces a single output. A plus (+) is used to show the OR operation in the Boolean expression of output A + B. Let True = 1 and False = 0. Thus, the output is "True" if either or both of the inputs are "True." If both inputs are "False," then the output is "False." That is, the OR gate acts in the same way as the logical inclusive "or" operator (Ibrahim & Kazeem, 2015).

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4. NAND GATE

NAND gate denotes "NOT – AND gates." It is derived from AND gate followed by NOT gate. It is an electronic circuit that gives high (1) if any of the inputs are low. A dot (·) and a bar (‾) is used to show the NAND operation in the Boolean expression of output $\overline{A \cdot B}$. Let True = 1 and False = 0. Thus, the output is "False" when both inputs are "True." Otherwise, the output is "True." That is, the gate acts in the manner of the logical operation "and" followed by negation (Ibrahim & Kazeem, 2015).

5. NOR GATE

This is a NOT – OR gate which is equal to an OR gate followed by a NOT gate. It is an electronic circuit that gives low (0) if any of the inputs are high. A plus (+) and a bar (‾) is used to show the NOR operation in the Boolean expression of output $\overline{A + B}$. Let True = 1 and False = 0. Thus, the output is "True" if both inputs are "False." Otherwise, the output is "False". The gate acts in the manner of the logical inclusive "or" operator followed by an inverter (Ibrahim & Kazeem, 2015).

6. XOR GATE

The 'Exclusive – OR' gate is an electronic circuit that gives a high (1) output if either, but not both, of its two inputs are high. An encircled plus sign (⊕) is used to show the XOR operation in the Boolean expression of output $A \oplus B$. Let True = 1 and False = 0. Thus, the output is "True" if the inputs are different, but "False" if the inputs are the same. That is, the XOR (Exclusive – OR) gate acts in the same manner of the logical exclusive "or" operator (Ibrahim & Kazeem, 2015).

7. XNOR GATE

XNOR gate denotes "Exclusive – NOR gates." It is derived from XOR gate followed by NOT gate. It is an electronic circuit that does the opposite to the XOR gate. It gives a low (0) output if either, but not both, of its two inputs are high. An encircled plus sign (⊕) and a bar (‾) is used to show the XNOR operation in the Boolean expression of output $\overline{A \oplus B}$. Let True = 1 and False = 0. Thus, the output is "True" if the inputs are the same and "False" if the inputs are different. That is, the XNOR (Exclusive – NOR) gate does the opposite to the XOR gate (Ibrahim & Kazeem, 2015). Having spread out the relevance of the truth table in both teaching and learning of logical reasoning and logic gate, this study sought to do a comparative analysis of truth table, logical reasoning and logic gate in order to find their similarities differences and peculiarities through their interrelationships.

In planning learning activities to support the achievement of curriculum goals, misconceptions and misunderstandings were observed by teachers and learners when relating various areas of knowledge to each other in a way that brings out their sequence and logic in teaching and learning process. A similar challenge exists in teaching and learning truth table in Mathematics logical reasoning and in teaching logic gate in Computer Studies at the secondary school level. This paper hereby focused on the use of truth table, logical reasoning and logic gate in teaching and learning process, thereby investigating the similarities, differences and peculiarities of this area of study in teaching and learning process in order to clarify the misconceptions and misunderstandings involved.

In order to facilitate the focus of this paper, the following questions are considered:

1. What are the main features of logical reasoning truth table in teaching and learning process?
2. What are the main features of logic gate truth table in teaching and learning process?
3. What are the similarities between the interactive features of logical reasoning and logic gate truth table in teaching and learning process?
4. What are the differences between the interactive features of logical reasoning and logic gate truth table in teaching and learning process?
5. What are the peculiarities between the interactive features of logical reasoning and logic gate truth table in teaching and learning process?

In proffering answers to the questions that are stated above, the following features of Truth table are considered:

(i) Input properties and Output type
(ii) Connectives name
(iii) Adopted Notation/Symbol
(iv) Definitions and type of Truth values used

1: What are the main features of logical reasoning truth table in teaching and learning process?

(i) Input properties and Output type **Input properties:**

- Traditionally, propositions are used as Input and represented by the letters a, b, and c, or A, B, C as variables.
- There are 2^n potential assignments for each of the n atomic propositions since each proposition has two alternative values.

Output Type:

- This is determined by connective given such as: **$\sim P$, $\sim Q$, $P \wedge Q$, $P \vee Q$, $P \veebar Q$, $P \Rightarrow Q$, $P \Leftrightarrow Q$…**

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(ii) Connectives name

In logical reasoning, the following are the connectives regarded as logical operator: Negation "∼", Conjunction "∧", Disjunction "∨", Implication "⇒", Bi-implication "⇔", Equivalence "≡"…

(iii) Adopted Notation

- Curl (∼) for Negation using word "Not"
- Cap (∧) for Conjunction using word "And"
- Cup (∨) for Disjunction using word "Or" inclusively
- Underscore Cup (⊻) for Disjunction using word "Or" exclusively
- Implies (⇒ or →) for Implication using word "if… then"
- If (⇔ or ↔ or iff) for Bi-implication using word "if and only if"
- Congruent (≡) for Equivalence using word "is"

(iv) Definitions and type of Truth values used

A proposition's truth value can only be either True or False. We use the letters T or F to signify a proposition's truth value. The truth values of the two atomic propositions (P and Q) in all conceivable truth assignments are listed on the left side of the truth table as input combination. The truth values of the compound propositions under the respective assignments are shown on the right as output on Truth table and their definitions are as follow:

- ∼P is False if P is True and vice versa
- P ∧ Q is True if P and Q are both True; otherwise they are False.
- P ∨ Q is False if P and Q are both False otherwise they are True.
- P ⊻ Q is False if P and Q are both True or both False. Otherwise, it is True.
- P ⇒ Q is False only when P is True and Q is False.
- P ⇔ Q is True if P and Q are both True or both False. Otherwise, it is False.

2: What are the main features of logic gate truth table in teaching and learning process?

(i) Input properties and Output type

<u>Input properties:</u>

- Traditionally, Boolean are used as Input and represented by the letters x, y, and z, or X, Y, Z as variables.
- Boolean function of (x_1, x_2, x_3,…, x_n), is a mapping $\{0,1\}^n \rightarrow \{0,1\}$ where $x_i's$ are Boolean variables.

<u>Output Type:</u>

- This is determined by Boolean expression given such as: $\overline{\mathbf{A}}$, $\overline{\mathbf{B}}$, $\mathbf{A \cdot B}$, $\mathbf{A + B}$, $\overline{\mathbf{A \cdot B}}$, $\overline{\mathbf{A + B}}$, $\mathbf{A \oplus B}$, $\overline{\mathbf{A \oplus B}}$**…**

(ii) Connectives name

In Logic Gate, the following are the connectives regarded as Bit Operator: NOT "$\overline{\ }$", AND "·", OR "+" , NAND "$\overline{\cdot}$", NOR "$\overline{+}$", XOR "⊕" and XNOR "$\overline{\oplus}$". Note, majority of logic gates have one output and two inputs except NOT gate.

(iii) Adopted Symbol

- A bar (¯) is used to show the NOT operation
- A dot (·) is used to show the AND operation
- A plus (+) is used to show the OR operation
- A dot (·) and a bar (¯) is used to show the NAND operation
- A plus (+) and a bar (¯) is used to show the NOR operation
- An encircled plus sign (⊕) is used to show the XOR operation
- An encircled plus sign (⊕) and a bar (¯) is used to show the XNOR operation

(iv) Definitions and type of Truth values used

A bit can only accept one value between "0 and 1" because, every terminal is always in one of the two binary states, low (0) or high (1), which are each represented by a distinct voltage level. The combination of these terminals from input variables through Boolean expression result to output as truth value adopted in this concept for truth table and their definitions are as follow:

- $\overline{\mathbf{A}}$ gives a high output (1) if its input is low and vice versa.

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- $\mathbf{A \cdot B}$ gives a high output (1) only if all its inputs are high.
- $\mathbf{A + B}$ gives a high output (1) if one or more of its inputs are high.
- $\overline{\mathbf{A \cdot B}}$ gives high (1) if any of the inputs are low.
- $\overline{\mathbf{A + B}}$ gives low (0) if any of the inputs are high.
- $\mathbf{A \oplus B}$ gives a high (1) output if either, but not both, of its two inputs are high.
- $\overline{\mathbf{A \oplus B}}$ gives a low (0) output if either, but not both, of its two inputs are high.

3: What are the similarities between the interactive features of logical reasoning and logic gate truth table in teaching and learning process?

(i) Input properties and Output type

Their Inputs are both aligned at the top Left Hand Side (LHS) while their Outputs are also aligned at the top Right Hand Side (RHS) of the Truth table in rows.

<u>Input properties:</u>

- Traditionally, Their Inputs are both represented by the letters a, b, and c, or A, B, C as variables.
- Since they both had two alternative values; hence, there are 2^n potential assignments for each of the n atomic variable.

<u>Output Type:</u>

The following outputs types are the connectives and Boolean expressions that act in the same manner of operations:

- $\mathbf{\sim P \longrightarrow \overline{A}}$
- $\mathbf{P \wedge Q \longrightarrow A \cdot B}$
- $\mathbf{P \vee Q \longrightarrow A + B}$
- $\mathbf{P \veebar Q \longrightarrow A \oplus B}$
- $\mathbf{P \Leftrightarrow Q \longrightarrow \overline{A \oplus B}}$

(ii) Connectives name

(iii) The following are the name of operators regarded as connectives that act in the same manner as stated above:

- Negation "∼" ⟶ NOT "‾"
- Conjunction "∧" ⟶ AND "•"
- Inc. Disjunction "∨" ⟶ OR "+"
- Exc. Disjunction "⊻" ⟶ XOR "⊕"
- Implication "⇒" ⟶ XNOR "$\overline{\oplus}$".

(iv) Adopted Notation/Symbol

The name of Notation/Symbol adopted as connectives that act in the same manner as stated earlier are as follow:

- Curl (∼) act in the same manner as bar (‾) in operation.
- Cap (∧) act in the same manner as dot (·) in operation.
- Cup (∨) act in the same manner as plus (+) in operation.
- Underscore Cup (⊻) act in the same manner as encircled plus (⊕) in operation.
- If (⇔) act in the same manner as encircled plus (⊕) and a bar (‾) in operation.

(v) Definitions and type of Truth values used

There are two truth values, true and false, thus a bit may be used to represent either of them. We will use a 1 bit to represent true and a 0 bit to indicate false, as is customary. In other words, 1 stands for T (true), and 0 for F (false). Therefore, their outputs related manner of operation in Truth table are defined as follow:

- $\mathbf{\sim P \longrightarrow \overline{A}}$
  $\overline{\mathbf{A}}$ is True if A is False and vice versa. That is, it performs the operation of logic negation **∼P** as an inverted circuit.
- $\mathbf{P \wedge Q \longrightarrow A \cdot B}$
  $\mathbf{A \cdot B}$ output is "True" when both inputs are "True." Otherwise, the output is "False." That is, the AND gate acts in the same way as the logical "and" operator $\mathbf{P \wedge Q}$.
- $\mathbf{P \vee Q \longrightarrow A + B}$
  $\mathbf{A + B}$ output is "True" if either or both of the inputs are "True." If both inputs are "False," then the output is "False." That is, the OR gate acts in the same way as the logical inclusive "or" operator $\mathbf{P \vee Q}$.
- $\mathbf{P \veebar Q \longrightarrow A \oplus B}$

A ⊕ B output is "True" if the inputs are different, but "False" if the inputs are the same. That is, the XOR (Exclusive – OR) gate acts in the same manner of the logical exclusive "or" operator **P ⊻ Q**.

- **P ⇔ Q** ⟶ $\overline{\mathbf{A \oplus B}}$

  $\overline{\mathbf{A \oplus B}}$ output is "True" if the inputs are the same and "False" if the inputs are different. That is, the XNOR (Exclusive – NOR) gate does the opposite to the XOR gate but acts in the same manner of the logical "if and only if" operator **P ⇔ Q**.

4: What are the differences between the interactive features of logical reasoning and logic gate truth table in teaching and learning process?

(i) Input properties and Output type

Though, there exist similarities in some areas in input properties and output type but there also exist differences in array; that is, in rows and columns of Truth values assigned to each variable under input and combination result through connectives under output in the interactive features of logical reasoning and logic gate Truth table in teaching and learning process. The truth values of the two atomic variables (P and Q) using 2^n potential assignments formula to proof differences in array of Truth values in interactive features stated above can be simplified as thus:

Since n = 2; therefore $2^n = 2^2 = 4$. This shows that we having four (4) truth values in column and these can be subdivided in sequence into equal half before the corresponding truth values assigned in column under each input variable as follows: There are two truth values, either T (1) or F (0) and we are given two atomic variables P and Q. That is; With/Without Negation/Inverter: the four (4) truth values in column

P Q ~P ~Q

$$4 = \frac{1}{0} = \frac{T}{F} = \frac{2}{2} = \frac{1}{1} \qquad\qquad 4 = \frac{0}{1} = \frac{F}{T} = \frac{2}{2} = \frac{1}{1}$$

Table 8: Logical Reasoning Input Truth Table

Column 1 **Column 2** **Column 3** **Column 4**

Without If **T = 1;** **With** **If T = 1;**

Negation **F = 0** **Negation** **F = 0**

P	Q	P	Q	~P	~Q	~P	~Q
T	T	1	1	F	F	0	0
T	F	1	0	F	T	0	1
F	T	0	1	T	F	1	0
F	F	0	0	T	T	1	1

Source: The Researcher, 2023

Table 9: Logic Gate Input Truth Table

Column 5 **Column 6** **Column 7** **Column 8**

Without **If 1 = T;** **With** **If 1 = T;**

Inverter **0 = F** **Inverter** **0 = F**

A	B	A	B	$\overline{A}$	$\overline{B}$	$\overline{A}$	$\overline{B}$
0	0	F	F	1	1	T	T
0	1	F	T	1	0	T	F
1	0	T	F	0	1	F	T
1	1	T	T	0	0	F	F

Source: The Researcher, 2023

Through critical observation of Table 8 and Table 9 above; we will discovered that there exist differences in their interaction features of input with effect on output through the following relation of columns:

- **Column 1** can be related to **Column 8**
- **Column 2** can be related to **Column 7**

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- **Column 3** can be related to **Column 6**
- **Column 4** can be related to **Column 5**

Thus, this relation shows that the input in both Table 8 and Table 9 are **Converse in array** (that is, reverse in order of rows and columns) and **Inverse in manner** (that is, change in state of values) which proof equivalence when integrating ideas in teaching and learning Truth table in Logical reasoning and Logic gate using interactive features.

In other words; the propositional inputs truth table in logical reasoning are the inverse Boolean inputs truth table in logic gate and vice versa. Thus, there exist differences in array of input truth values with effect on output between logical reasoning truth table and logic gate truth table.

(ii) Connectives name

Some connectives in interactive features are similar in operation as it was stated in previous result; but their names are quite distinct through their main features as thus; in logical reasoning, the following are the connectives regarded as logical operator: Negation "∼", Conjunction "∧", Disjunction "∨", Implication "⇒", Bi-implication "⇔", Equivalence "≡". While in Logic Gate, the following are the connectives regarded as Bit Operator: NOT "¯", AND "·", OR "+" , NAND "$\overline{\cdot}$", NOR "$\overline{+}$", XOR "⊕" and XNOR "$\overline{\oplus}$".

(iii) Adopted Notation/Symbol

Despite the fact that some symbols in interactive features act in the same manner, their names and signs are also quite distinct through their main features as thus; in logical reasoning, the following are the names and signs of Notation adopted: Curl (∼), Cap (∧), Cup (∨), Underscore Cup (⊻), Implies (⇒), Congruent (≡). While in logic gate, the following are the names and signs of Symbol adopted: bar (¯), dot (·), plus (+), dot (·) and bar (¯), plus (+) and bar (¯), encircled plus sign (⊕), encircled plus sign (⊕) and bar (¯).

(iv) Definitions and type of Truth values used

In logical reasoning, True (T) and False (F) are used as propositional truth values. While in logic gate, High (1) and Low (0) are used as Boolean truth value. Since there is difference in truth values name used in their main features; hence, there definition will be different in terms of their truth values name used in their main features.

5: What are the peculiarities between the interactive features of logical reasoning and logic gate truth table in teaching and learning process?

(i) Input properties and Output type

The output result that cannot be used to compare and contrast in manner of operations and output result definitions, there exist peculiarities between their interactive features. Such as NAND and NOR outputs result in logic gate and Implication, Tautology and Contradiction outputs result in logical reasoning. Though, their input properties can be compared and contrasted.

(ii) Connectives name

The connectives names that are peculiar in interactive features are as follow: In logical reasoning, it includes; Implication "⇒", Tautology ∨ (∼) and Contradiction ∧ (∼) regarded as logical operator. And in logic gate, it includes; NAND "$\overline{\cdot}$" and NOR "$\overline{+}$" regarded as Bit operator.

(iii) Adopted Notation/Symbol

In logical reasoning:

- Implies (⇒) used as notation for Implication
- Cup (∨) and Curl (∼) used as notation for Tautology
- Cap (∧) and Curl (∼) used as notation for Contradiction In logic gate:
- A dot (·) and a bar (¯) is used to show the NAND operation
- A plus (+) and a bar (¯) is used to show the NOR operation

(iv) Definitions and type of Truth values used

Though, their truth values can be compared and contrasted, but in their output result definitions; there exist peculiarities as follow:

In logical reasoning:

- P ⇒ Q is False only when P is True and Q is False.
- Q ∨ (∼ Q) column is always True.
- Q ∧ (∼ Q) column is always False. In logic gate:
- $\overline{\mathbf{A} \cdot \mathbf{B}}$ gives high (1) if any of the inputs are low.

- $\overline{\mathbf{A} + \mathbf{B}}$ gives low (0) if any of the inputs are high.

Note, the peculiarities definitions output result in the interactive features can be adopted in proving algebraic laws and logical equivalence on truth table using important equivalent formula. Also, since the conditional statement $P \Rightarrow Q$ (that is, Implication) output result definition is peculiar in interactive features; hence, other three related conditional expressions (namely: **Converse** statement $Q \Rightarrow P$, **Contrapositive** statement $\sim Q \Rightarrow \sim P$ and **Inverse** statement $\sim P \Rightarrow \sim Q$) are also peculiar in interactive features.

IV. Highlights on the Responses to the Questions

The responses to the questions above are categorically base on Truth table features, such as: Input properties and Output type, Connectives name, Adopted Notation/Symbol, Definitions and type of Truth values used.

The main features of logical reasoning truth table in teaching and learning process. In line with the first research question; findings show the main features exist in logical reasoning truth table base on the above named categories through the following connectives: Negation "$\sim$", Conjunction "$\wedge$", Disjunction "$\vee$", Implication "$\Rightarrow$", Bi-implication "$\Leftrightarrow$", Equivalence "$\equiv$"etc.

The main features of logic gate truth table in teaching and learning process. In agreement with the second research question; findings show the main features exist in logic gate truth table base on the aforementioned categories through the following gates: NOT "$\overline{\ }$", AND "$\cdot$", OR "+" , NAND "$\overline{\cdot}$", NOR "$\overline{+}$", XOR "$\oplus$" and XNOR "$\overline{\oplus}$".

The similarities between the interactive features of logical reasoning and logic gate truth table in teaching and learning process. In line with the third research question; the findings indicate that in terms of input properties, output type, manner of operations and truth values type and their corresponding definitions, there exist similarities in their interactive features.

The differences between the interactive features of logical reasoning and logic gate truth table in teaching and learning process. In agreement with the forth research question; the findings indicate that in regardless of similarities in input properties, output type, manner of operations and truth values type and their corresponding definitions; there exist differences in truth values types assigned in rows and columns for each input variable with effect on output, which are convey in array and inverse in logical manner. Also, connectives names and signs adopted as notation/symbols in interactive features are quite distinct.

The peculiarities between the interactive features of logical reasoning and logic gate truth table in teaching and learning process. In line with the foregoing research question; findings indicate that main features that cannot be compared and contrasted in the manner of operations and output result definitions, there exists peculiarities in their interactive features.

V. Conclusion

Based on the highlights from this paper; it is concluded that despite the fact that idea can be integrated for teaching and learning truth table in logical reasoning and logic gate. There exist similarities, differences and peculiarities in their interactive features needed against misconception and misunderstanding of concept while incorporating thought in teaching and learning process.

VI. Suggestions

Based on the findings of this study, the following suggestions are made for teaching and learning truth table in logical reasoning and logic gate.

1. Teachers should be pro-active in assessing entry behavior (that is, previous knowledge) of students in the main features of truth table in either logical reasoning or logic gate so to avoid misunderstanding while integrating ideas in teaching and learning process.
2. Teachers should vividly state the similarities, differences and peculiarities in the interactive features of truth table in logical reasoning and logic gate while incorporating thought in teaching and learning process to avoid confusion.
3. Students should be encouraged by teachers to be more careful in relating ideas from interactive features of truth table in logical reasoning and logic gate against misconception in examination.

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