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Research Article

Develop AR-based Virtual Labs to Provide a Safe and Accessible Learning Environment for Students

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ABSTRACT

Augmented Reality (AR) use in learning is transforming conventional teaching approaches, particularly in laboratories. AR improves student learning by superimposing digital material onto the actual environment, resulting in interactive and immersive experiences that explain difficult ideas and give practical chances to learn without requiring physical resources. This renders abstract scientific ideas more concrete, allowing students to grasp better and remember material via visual & interactive participation.

AR greatly increases student interest and involvement by catching their attention via interactive elements, increasing academic achievement. It also makes education more accessible to children in rural or underserved places. AR-based tools, such as pendulum and projectile motion simulations, and half-adder and full-adder circuits, have been shown to improve understanding of physics and electronics. Furthermore, virtual AR laboratories provide exceptional educational experiences available from any location, removing the need for physical infrastructure.

Keywords: Augmented Reality, AR, Laboratory Experiments, Educational Technology, Remote Learning, Student Engagement, etc

INTRODUCTION

Improvements in information and communication technology (ICT) during the last decade have opened the door for researchers, students, and teachers to experiment with new approaches to intelligent learning. Students pay close attention in AR and VR classes because these methods combine traditional teaching methods with cutting-edge technological design to create an immersive and engaging educational experience (Li et al., 2017). Augmented reality (AR) is a popular technology that many believe greatly improves students' educational experiences. Augmented reality (AR) is a technologically-supported teaching strategy that promotes enhanced learning interactions. To meet the unique requirements of hardware operations in electronics engineering laboratories, this study suggests an interactive AR framework to develop an ARLE (Dhalmahapatra et al., 2021).

With the advent of the metaverse, augmented reality (AR) has become a game-changer, improving HCI and transforming our lives. Engineering is one of the most prominent areas of use for augmented reality in both academic and commercial settings. Seeking to reduce social costs and improve human well-being, this area goes beyond simple mechanization (Dembe, 2024).

The use of AR and VR in the classroom has expanded traditional educational practices into exciting new frontiers. The introduction of AR and VR into the classroom has been game-changing because of the engaging and thrilling experiences they provide (Woods et al., 2016). The revolutionary role that modern technologies play in the classroom, demonstrates how they can make lessons more interesting and interactive for students. For example, virtual reality (VR) allows students to experience information more sincerely by transferring them to virtual worlds where they may explore and manipulate it. In addition to raising participation, this immersive experience helps students remember more information and gain more useful skills (Le et al., 2015).

Enhancing conventional learning techniques is only one way that augmented reality (AR) is changing education.

By facilitating online communication between teachers and students, these technologies foster collaborative learning settings (Bhardwaj, 2023). Building a feeling of belonging and teamwork among students is fundamental to successful education, and this feature of AR plays a pivotal role in achieving just that. Although augmented reality (AR) has great promise, there are still obstacles to its widespread use in classrooms. Considerations of cost, the need for appropriate technological infrastructure, and the complexity of content generation all act as brakes on their broad adoption (Swargiary, 2023). Furthermore, educators and institutions continue to face the problem of incorporating new technologies into current curriculum and matching them with educational goals (Zhou et al., 2024).

Concerns about security and confidentiality as well as obstacles to accessibility for those with disabilities are among the many obstacles to the widespread use of augmented reality technology (Tawfik et al., 2015). Manufacturers, politicians, managers, and stakeholders from all walks of life must work together in a concerted effort to overcome these obstacles. To get past these obstacles, we need to make things more private and secure, make them more affordable and easier to use, solve health problems, and make sure everything is done ethically (Khanal et al., 2022). For augmented reality experiences to gain traction, it is essential to make them accessible and inclusive. The future of augmented reality (AR) in education and other fields depends on solving these problems as the technology develops further (S. Patel, 2024).

LITERATURE REVIEW

There has been a lot of buzz in recent years about how to use cutting-edge tech like Augmented Reality (AR) in the classroom and beyond (Potkonjak et al., 2016). As a result of this change, conventional wisdom has given way to novel approaches that improve accessibility, engagement, and learning results. The ability of augmented reality (AR) to connect theoretical ideas with real-world applications has been the subject of a great deal of research, which has looked at AR's effects in several contexts, including classrooms, laboratories, and virtual worlds (Geschwind et al., 2024).

However, there is still a need for more research since problems including technology constraints, accessibility concerns, and implementation costs remain despite the expanding corpus of material (Heradio et al., 2016). To help steer future studies, this literature review will compile what is now known about augmented reality (AR) in the classroom, highlight what needs more study, and provide a thorough overview of the subject (Akçayir et al., 2016).

Gurjinder Singh, et.al. [2024] examined data from an experiment with 80 engineering students to see how augmented reality (AR) affected operational skills, ease of use, and customer experience. There were 40 people in total: 20 in the control group and 20 in the experimental group. Aside from the control group, which followed the directions in a conventional instrument manual, the experimental group received training on electronic equipment utilizing ARLE. Forty users filled out the user experience questionnaire (UEQ) and the system usability scale (SUS) to rate ARLE's usability and overall quality of use. Based on the SUS ratings, ARLE was deemed "good" with a score of 80.9, as shown in the results. In comparison to the benchmark dataset, the UEQ findings showed much better scores on all six measures. The results of the research show that augmented reality (AR) is a valuable tool for improving students' operating abilities in electronics labs.

Afiya Dembe H. [2024] investigates how AR and VR might be used in the classroom, drawing attention to how they can revolutionize teaching and learning. Students are more engaged, and motivated, and achieve better results in their learning when they use VR and AR to build dynamic and immersive learning environments. We will go over the main points of virtual reality and augmented reality, as well as their respective strengths and uses. Cost, accessibility, and technical competence are some of the obstacles, in contrast to the advantages, such as better learning outcomes and more engagement. Successful applications are shown by case studies, and future patterns indicate that learning technology will be significantly impacted. The conclusion highlights the revolutionary possibilities of augmented and virtual reality in the classroom, even if there are certain obstacles.

Babajide Tolulope Familoni, et.al. [2024] offer a comprehensive evaluation of AR and VR's influence, efficacy, and potential outcomes in the classroom. The main goal was to investigate how these immersive technologies are changing the face of education. The study examined current academic publications and reports on augmented reality and virtual reality applications in education from 2014 to 2024 using a comprehensive literature review and content analysis technique. The results show that by providing interesting, interactive, and immersive settings, AR and VR greatly improve educational opportunities. Student engagement, information retention, and skill development may all be enhanced with the help of these technologies. Augmented reality (AR) enhances conventional teaching tools by superimposing digital data onto physical locations, while virtual reality (VR) allows for hands-on experience in controlled settings. Research from this research points to a future where augmented and virtual reality systems will keep developing, with an emphasis on making them more accessible, better user experiences, and easily integrated into school programs.

Nitin Liladhar Rane, et.al. [2023] investigates the effects of four-dimensional, five-dimensional, and six-dimensional printing on the speeding up of iterative design, the reduction of time-to-market, and the materialization of conceptual ideas. Additionally, the IoT is evaluated for its ability to enhance product functioning by connecting smart sensors, enabling continuous evaluation, and enabling data-driven design changes at every stage of the product lifecycle. As a bonus, we look at how Blockchain technology may be used to build safe and transparent collaboration frameworks. In a decentralized ecosystem, blockchain promotes confidence among participants, protects intellectual property, and guarantees that design iterations can be tracked. Redefining conventional paradigms in product design and development is proposed via the holistic integration of various technologies. In its last section, the study delves into the possible future outcomes of this integrated strategy, stressing the need for continuous R&D to realize these technologies' innovation-boosting and game-changing capabilities.

Rubina Dutta, et.al. [2023] examined the effects of an augmented reality educational system on the critical thinking abilities, desire to study, and information acquisition of 128 undergraduate engineering students. Two groups of sixty-four students each were formed: an experimental group & a control group. In flipped learning mode, the augmented reality learning system was used to deliver in-class activities as students learned. In class, students in the experimental group used an augmented reality learning system, while those in the control group used more conventional methods. Students' critical thinking abilities, learning motivation, and information acquisition are all positively affected by the employment of augmented reality technology, according to the trial results. Students' knowledge growth in the control group was positively correlated with their critical thinking abilities and learning desire, according to the research.

Opeyeolu Timothy Laseinde, et.al. [2023] gives an account of the steps used to create a functional virtual reality (VR) program for use in STEM (Science, Technology, Engineering, and Mathematics) laboratories. Higher education institutions have recently begun to use virtual reality (VR) platforms to improve the learning experience by seamlessly communicating abstract concepts. The author built a virtual reality platform to teach induction motor technologies to engineering students. Through the use of virtual reality (VR), students engage in collaborative activities in 3D and multi-dimensional virtual spaces. Since virtual reality (VR) simulations allow the understanding of imagined notions, it is my proposal that educators investigate the boundless potential of VR.

Abdullah M. Al-Ansi, et.al. [2023] strives to provide a framework for the evolution of augmented and virtual reality in the field of education throughout the past twelve years. Fifteen hundred thirty-six articles were chosen for further study using methods of text mining and theme analysis. After identifying relevant papers in the Scopus database, we used WordStat to analyze their titles, keywords, and abstracts. The current state of the art of augmented and virtual reality literary development, uses, benefits and potential developments were uncovered by formulating, processing, and evaluating hypotheses based on previous works of AR and VR in education. Wearable devices have accounted for a disproportionate share of the meteoric rise in the use of augmented and virtual reality in classrooms in recent years, according to the results. The findings also show that there is a disparity in how fast educational institutions can integrate and customize these innovations, based on secondary data. More and more educational uses for augmented and virtual reality technologies are appearing as these technologies mature and expand at a fast pace. To fully reap the advantages of AR and VR's evolution in the classroom, researchers should move quickly to identify any gaps in the current state of the technology and to build adaptable strategies.

Neha Tuli, et.al. [2022] created an AR-powered educational tool to instruct students in the fundamentals of electrical engineering and study how the use of AR affected their performance in the classroom, their outlook on studying the topic, and their feelings regarding AR in general. A total of 107 first-year engineering students were divided into two groups one to serve as a control and one to experiment using a quasi-experimental research design. 53 students in the control group taught electronics basics the old-fashioned way and 54 students in the experimental group learned the same material using an AR-based lab manual. Based on the results of the experiment, the experimental group outperformed the control group on the post-test and achieved higher academic scores. Additionally, the research discovered a strong positive correlation between students' learning perspectives on courses in electronics and their educational accomplishments. This led to a more positive outlook on the electronics course and AR technology among students who used it to study.

N. Sasikumar, et.al. [2022] investigated the methods of using augmented reality in the classroom to help students in higher education grasp physics' more complex ideas. The term "augmented reality" describes a technology that superimposes digital information on top of our physical surroundings, allowing us to engage with features like as dynamic haptic feedback, stunning visual overlays, and more. The term "augmented reality" (AR) refers to the practice of combining digital information with a user's actual physical surroundings in real-time. Curiosity, the development of appropriate interests, attitudes, and values, the establishment of study routines, and the ability to think critically and assess are more important goals of education than the simple transmission of information or the production of a final product. The ability to ask pertinent questions, provide relevant examples and explanations, and organize and sequence ideas rationally are just a few of the many talents necessary for successful communication. Systematic learning may lead to the development of these online experiences, abilities, and mindsets.

Amit Kumar, et.al. [2021] study conducted a processor unit, a display device, augmented reality markers, and a USB camera to make up the physical user interface of the suggested framework, which aims to provide students with an augmented reality learning experience. The system that was built was evaluated for use by the engineering school faculty members. Using a Google form, twenty instructors provide their thoughts and experiences with the system's usability. An overall usability score of 79.5% indicates that the system is well-suited for more student deployment for exploratory work.

Harun Faridi, et.al. [2021] the purpose of this experimental research was to assess the effect of an augmented reality intervention on the analytical thinking and learning capacities of students. Eighty engineering students participated in the research; forty students from the AR group and forty from the standard education group made up the two groups. A traditional teaching strategy was used to educate the students in the traditional instruction group, whereas the AR teaching group received instruction using an AR-based environment for learning. Students' analytical abilities and educational progress are markedly improved by the AR-based learning environment, according to the trial findings. Students were able to better grasp the physics material by using the augmented reality experience to picture the more abstract ideas.

Joanna Jesionkowska, et.al. [2020] look at the Active Learning approach to teaching STEAM courses, with a focus on a structure that has students create an augmented reality app as a component of their coursework. Using a qualitative, case study method, the author assesses the usefulness of Active Learning for STEAM courses. We used the workshop format as an extracurricular activity with students from several secondary schools in Oxford. The author goes over the format's inner workings, outlining the instructional modules and reasoning behind it, so that it may be integrated into standard curricula rather than treated as an after-school activity. Except for a few complicated apps, every team in our case study preview audience was able to complete their projects and release them to the public. The classes were fun, and the students thought that augmented reality helped them study more effectively. Through the use of the Active Learning approach, students were able to hone their coding, ray-tracing, geometry, physics simulation engine, team management, and interpersonal skills, as well as create a functional game prototype, all of which are documented in the case study. According to the author, a more well-rounded and interesting education may be achieved by integrating STEM disciplines with the arts via the suggested Active Learning approach.

Iulian Radu, et.al. [2019] have developed a HoloLens-based system that teaches participants about the unseen mechanics of audio speakers via an unstructured learning exercise. They gained knowledge in both concrete and abstract areas, like the geometry of magnetic fields and the connections between magnetism and electricity. Through a series of experiments with varied AR information layers, the author contrasted how participants learned, felt, and collaborated with a physical interface. Research by the author shows that augmented reality (AR) instructional representations help students learn new material and boost their confidence in their abilities (i.e., their capacity to grasp complex physics topics). Contrarily, we discovered that individuals in settings devoid of augmented reality instructional material exhibited more interest in and grasp of some physical concepts than those in other groups. The author delves into the distinctions between learning and collaboration, while also exploring the pros and cons of using augmented reality in unstructured learning environments.

Table 1. Comparison of Previous Work Done

Author & Year	Aim	Methodology	Results & Conclusion
Singh et al., 2019	To evaluate the influence of ARLE on the electronics laboratory competencies, cognitive load, and learning motivation of engineering students.	Sixty students were separated into experimental (ARLE-based) and control (conventional instruction) groups for the experiment. Preliminary and subsequent assessments evaluated performance.	ARLE significantly enhanced laboratory skills decreased cognitive load, and elevated motivation relative to conventional techniques. The research promotes augmented reality for improving engineering education.
Yip et al., 2018	To improve comprehension of intricate activities (sewing) via a comparison of standard and augmented reality video instructional approaches.	Comparative research included 46 freshmen, separated into two groups: one used handout, while the other engaged with augmented reality films. Post-assessments and evaluations gauged comprehension.	Augmented reality movies significantly enhanced task comprehension, shortened learning duration, and elevated engagement relative to handouts. The research substantiates augmented reality as an efficacious pedagogical tool.
Li et al., 2017	To examine augmented reality applications in engineering analysis, emphasizing visualization, tracking, and integration with mobile platforms.	Thorough literature study of augmented reality applications from 2004 to 2017. The investigated categories include tracking methodologies, visualization, and mobile augmented reality integration.	Augmented Reality provides intuitive visualization and effective involvement in engineering simulations. Nonetheless, obstacles such as efficient monitoring and continuous integration persist. Emerging trends indicate mobile augmented reality platforms and hybrid tracking methods.
Chennam Vijay, 2017	To establish a KBEd framework using augmented reality to automate tutor expertise for delivering and evaluating practical engineering competencies in remote education.	Rapid prototyping was used to build the KBEd system, which was verified via expert input and assessed via a welding assignment involving 46 students categorized into augmented reality and conventional groups.	The KBEd system effectively provided AR learners with practical abilities comparable to those acquired in conventional environments. Minor performance deficiencies were attributed to hardware constraints. The research underscores the scalability of KBEd to other fields necessitating practical abilities.
Akçayır et al., 2016	To examine the impact of augmented reality on laboratory competencies and disposition.	Quasi-experimental pretest/posttest design using augmented reality-assisted instructions.	Augmented reality enhanced laboratory competencies and fostered favorable dispositions towards laboratory work. Augmented reality promotes practical skills and participation in scientific education.
Chang et al., 2014	To design and assess the ARFlora system for botanical education.	Quasi-experimental design contrasting augmented reality with video-based learning.	Augmented reality improves memory and motivation relative to videos. Augmented reality is efficacious for constructivist learning in botanical education.
Fonseca et al., 2013	To assess augmented reality technology for three-dimensional visualization in architecture.	A case study using pre-tests and post-tests for augmented reality visualization.	Augmented reality enhanced motivation and academic achievement. Augmented reality enhances spatial comprehension and fosters collaborative learning.

Research Gap

Research on creating virtual laboratories using Augmented Reality (AR) to make learning accessible, interesting, and safe for students is severely lacking at the moment (Dutta et al., 2023). The integration of these laboratories as a standardized and scalable solution in educational institutions has not been addressed in much research, even though augmented reality can increase practical skills, decrease cognitive load, and enhance user experience (Babajide Tolulope Familoni & Nneamaka Chisom Onyebuchi, 2024). Thorough studies are urgently required to develop augmented reality (AR) virtual laboratories that can scale, improve operational safety and usability and guarantee fair access (Singh & Ahmad, 2024). By closing the gap between theory and practice, these initiatives would pave the road for augmented reality's revolutionary effects in making classrooms more engaging, secure, and accessible to all students (Chennam Vijay, 2017).

METHODOLOGY

There are several ways that Augmented Reality (AR) apps might be made more accessible and inclusive (Faridi et al., 2021). Full participation by students with disabilities is possible when augmented reality apps are designed with accessible features such as alternate interaction modes and interoperability with assistive technology (Sasikumar et al., 2022). To help instructors promote inclusive teaching techniques, combat discriminatory actions, and build inclusive classrooms, they must get training in these areas (Sharma et al., 2015). The goal of augmented reality (AR) content should be to make all people feel included and appreciated by promoting varied representation rather than perpetuating prejudices and preconceptions (Al-Ansi et al., 2023). To keep tabs on student participation and quickly address any instances of discrimination, tracking, and feedback mechanisms should be put in place (Jesionkowska et al., 2020). Finally, encouraging students to speak freely about diversity, equality, and inclusion helps them learn more about these topics and creates an atmosphere of acceptance and respect in the classroom (Chiang et al., 2014).

Several methods exist within the realm of augmented reality (AR) that may be used to better student learning and laboratory studies. With augmented reality, students may explore abstract scientific ideas via interactive 3D simulations, where they can control simulated items and see controlled occurrences (Tuli et al., 2022). Furthermore, it offers real-time, step-by-step guidance during experiments, which helps students follow procedures correctly, reduces mistakes, and improves safety with immediate feedback (Fonseca et al., 2014). Students may perform experiments without the expense or danger of utilizing costly or dangerous equipment thanks to augmented reality's virtual equipment (Radu & Schneider, 2019). With this method, kids from diverse socioeconomic backgrounds may participate in rigorous laboratory activities (Adeyeye, 2024). By using these tactics, augmented reality (AR) may revolutionize laboratory instruction (Chang et al., 2016).

Gathering thorough data to guide the design, development, and assessment of an AR system to aid students in conducting laboratory tests was the main objective of the data-gathering procedure (del Castillo-Olivares et al., 2023). The augmented reality system improved learning experiences in areas including half and full adders, pendulum motion, and projectile motion by using Vuforia, ARCore (Android), and Microsoft HoloLens (Rane et al., 2023). User needs, system usability, learning efficacy, and technical performance were among the many areas that were measured (Yip et al., 2019). A wide range of students and teachers participated in the experiments that yielded the findings (O'Shea, 2011).

An augmented reality (AR) system may be easily designed and evaluated using this simple flow diagram. The process's essential phases and components are graphically organized (Laseinde & Dada, 2023). Notify me if you require any more adjustments (Jagatheesaperumal et al., 2024).

The framework's primary goal is to facilitate the active participation of all relevant parties including students, teachers, technical specialists, and school administrators in the development and assessment of an AR system for use in experimental settings (Fernandez, 2017). To guarantee a thorough comprehension of user requirements and encounters, data is gathered from a variety of sources, including focus groups, interviews, surveys, observations, and use records (Singh et al., 2019). Successful data collection and evaluation methods include pre- and post-implementation surveys, organized interviews, user testing sessions, and evaluations of learning outcomes. (Jha & Masurkar, 2024). Forms for surveys, interview guides, checklists for observations, and tools for keeping user logs are all part of the data-gathering process that this method depends on. To make sure the data is representative of the user population, a representative sample approach is used to choose teachers and students (Faiz et al., 2024).

User needs, system usability, learning efficacy, and technical evaluation are some of the goals of this structure. Iteratively incorporating stakeholder feedback allows us to enhance the AR system and ensure it aligns with educational aims. (Ibáñez et al., 2014). Both quantitative and qualitative insights, as well as suggestions for enhancing the AR system, are generated by analyzing the acquired data. (Suhail et al., 2024). Lastly, the assessment looks at how well the AR system works to improve pupil participation and educational results, comparing it to more conventional approaches (Kumar et al., 2021). By following this methodical procedure, we can build an augmented reality system that is both user-friendly and successful in its instructional goals (Hadjistassou & Avgousti, 2024).

RESULTS AND DISCUSSION

Data Analysis

Quantitative Data Analysis

Descriptive Statistics: Using statistics like frequencies, percentages, and averages, they synthesize data from use logs and surveys. Frequencies reveal the frequency with which a specific behavior occurs, while means might provide average user satisfaction levels.

Inferential Statistics: The impact on learning outcomes and satisfaction with users after AR system implementation is determined by this. To determine whether there are statistically significant differences, methods such as analysis of variance (ANOVA) and t-tests are used.

Qualitative Data Analysis

Thematic Analysis: Finding and analyzing themes in qualitative data is what this does. It is useful for finding similarities and contrasts in replies from participants, particularly in focus groups and interviews.

Content Analysis: Textual data, such as free-form survey replies, may be organized and understood in this way. We may use it to summarize data and spot trends.

Both methods are useful for understanding participant perspectives and drawing conclusions based on data.

Data Processing

An augmented reality system combines sensor data with human inputs to provide an interactive educational environment. Sensors monitor motion, while cameras record the surrounding area. Taps and gestures allow users to engage with augmented reality information, which in turn provides immediate feedback and in-depth explanations. Students can explore and grasp complicated ideas via this dynamic engagement, which improves their educational experience overall.

Communication with Components

Using Vuforia and other components to communicate improves augmented reality. Accurate movements like swipes, pinches, and touching to zoom are made possible by Vuforia's technologies like object tracking and picture recognition. This makes augmented reality experiments more interesting and aids in the enhancement of laboratory instruction.

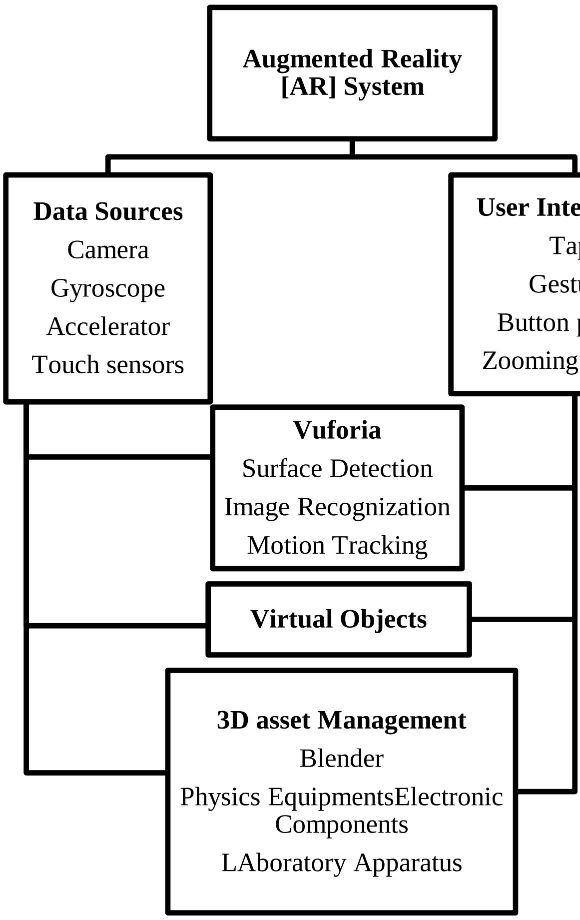


Figure 1. Data processing flowchart

AR-based Half Adder

A digital circuit known as a half adder may add two binary digits. The binary digits to be added may be entered into its two inputs, which are usually identified as A and B. Summing and carrying are the two results that come out of the half-adder. Two main parts make it up: an AND gate and an XOR (exclusive OR) gate. The output of the binary addition is represented by the sum (S) of the two input bits, which the XOR gate computes. On the other hand, if both input bits are set to 1, the AND gate will decide the carry (C).

Table 2. Half Adder

Input		Output	
A	B	Sum	Count
0	0	0	0
0	1	1	0
1	0	1	0
1	1	0	1

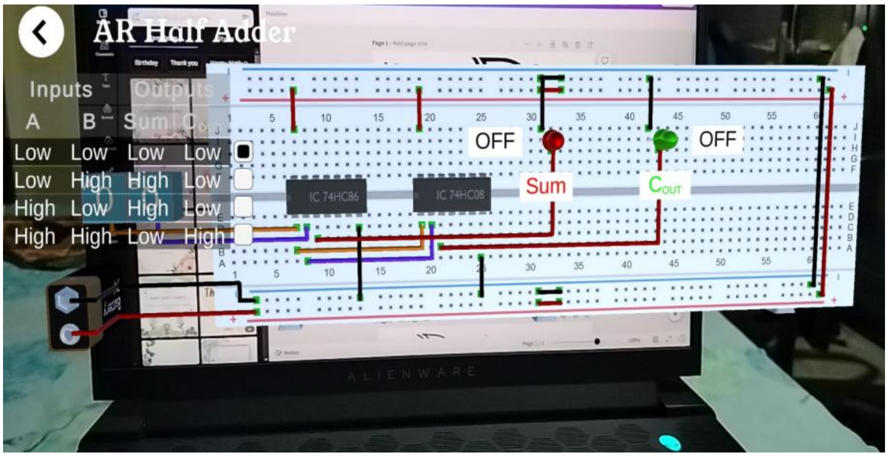


Figure 2. AR Half Adder

A half adder circuit with an augmented reality (AR) interface is shown in the figure. The augmented reality overlay makes the breadboard's circuitry parts and connections easy to see and manipulate. Two integrated circuits (ICs) with the part number 74HC08 attached to different locations on the breadboard make up the half-adder circuit. The illustration shows two inputs, A and B, on the left side. Both might be in a Low (0) or High (1) condition. Input signals are sent into integrated circuits (ICs), which then process the signals and produce outputs. By using colorful lines, the augmented reality interface graphically depicts the connections, making it easier to follow the route of electrical impulses. On the right side of the picture, you can see the half adder's outputs, which represent the sum and carry out (C_out). A red LED is linked to the Sum output and a green LED is linked to the Carry Out in this specific configuration. Input circumstances determine which LEDs light up, illustrating how the half-adder works. The augmented reality overlay does a good job of showcasing the circuit's functioning by displaying the effects of various input combinations on the output states. Students may see the direct impact of their input adjustments on the output of the circuit with this visual assistance, which improves the learning experience.

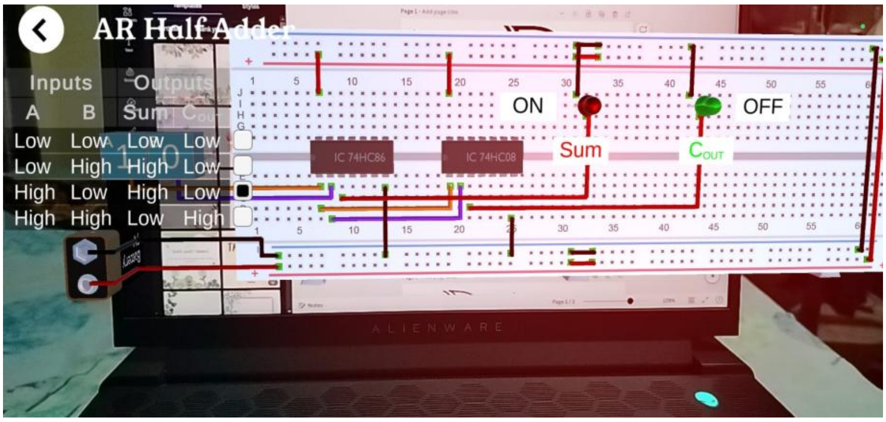


Figure 3. AR Half Adder with Sum LED ON and Carry LED OFF

You can see how various input combinations impact the outputs of a half-adder circuit in the figure, which provides an augmented reality (AR) interface for the circuit. The half-adder is assembled on a breadboard, and its connections and essential components are brought to light via augmented reality. The statuses of inputs A and B, Low and High, appear on the left side of the screen. Two integrated circuits (ICs), ICs 74HC86 and IC 74HC08, are linked to different locations on the breadboard in this circuit. The electrical connections are shown by colored lines in the augmented reality overlay, which helps to comprehend the circuit's structure and performance. On the right side, you can see the half adder's output, which is Sum and Carry Out (C_out). A green LED is linked to the Carry Out output in this setup, while a red LED is linked to the Sum output. According to the present input combination (Low-High), the Sum output is in a high state (red LED ON) and the carry-out output is in a low state (green LED OFF). The augmented reality overlay does a good job of depicting the circuit's activity by displaying the outputs as a function of the inputs. Students may see the circuit's behavior alter in real time with this interactive visual aid, which helps them learn digital logic and half-adder operation better.

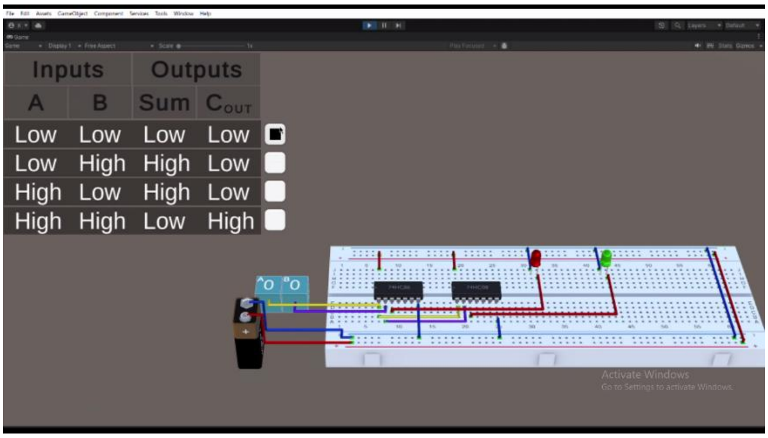


Figure 4. AR Half Adder with Both Input Low value

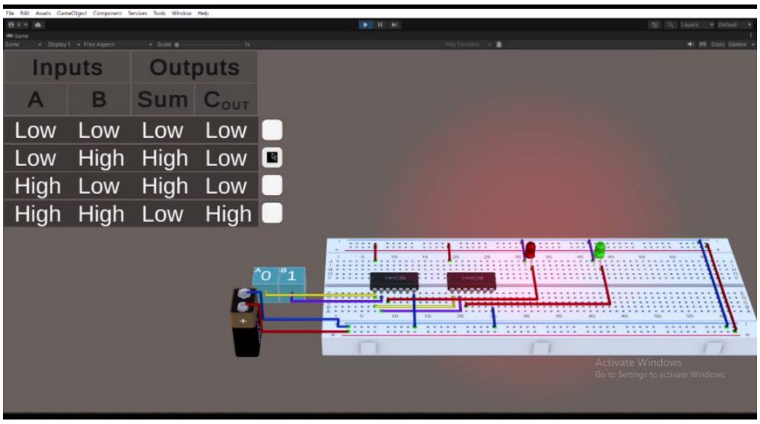


Figure 5. AR Half Adder with Sum LED ON and Carry LED OFF

Both the SUM and Cout outputs are low (0) in the half adder given, suggesting that there is no carry or extra signal, as both A and B are inputs that are low (0). The result is that the green light is also off. When the red light is out, it means the output is low, and when the green light is off, it means there is no high output. Based on the inputs, this scenario depicts how the half-adder is predicted to operate.

Here is the setup shown in the half-adder image: The outputs are SUM as high (1) and Cout as low (0) when A is low (0) and B is high (1). Just as the green light is off when the SUM output is high, the red light is on when the Cout output is low. This graphical depiction verifies that the half adder, according to the predicted operation of this digital circuit, generates an anticipated low Cout and high SUM for the supplied inputs.

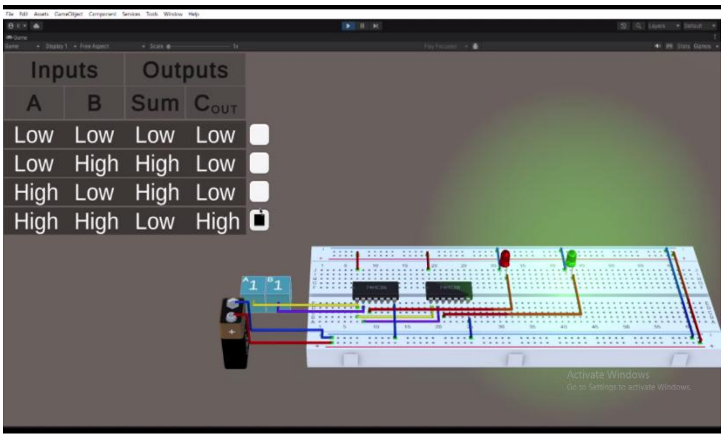
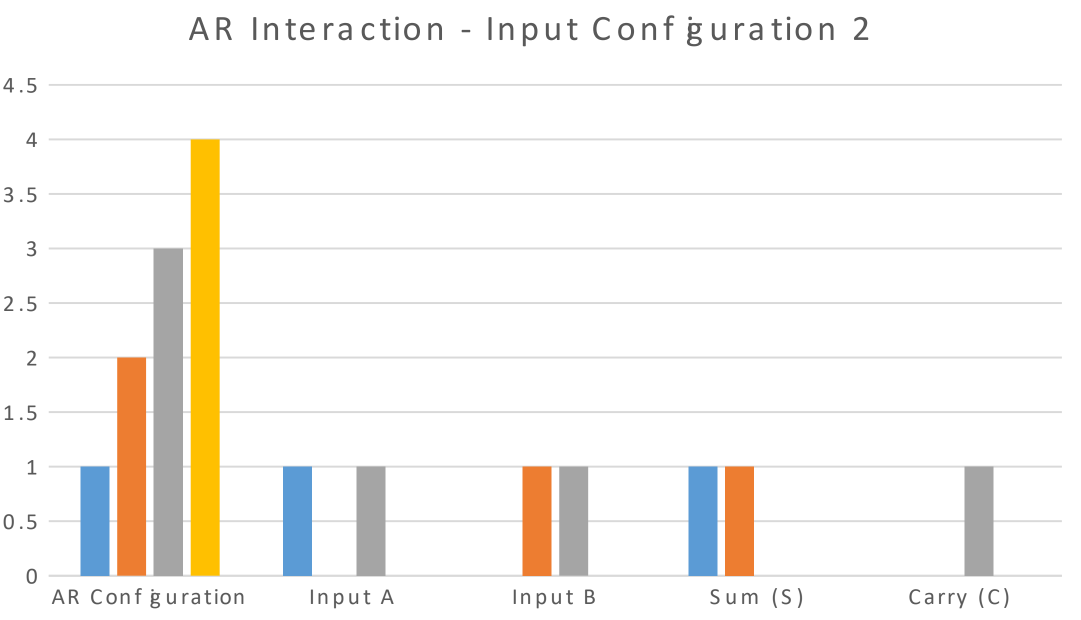


Figure 6. AR Half Adder with Sum LED OFF and Carry LED ON

Table 3. AR Interaction - Input Configuration 1

AR Configuration	Input A	Input B	Sum (S)	Carry (C)
1	0	0	0	0
2	1	0	1	0
3	0	1	1	0
4	1	1	0	1

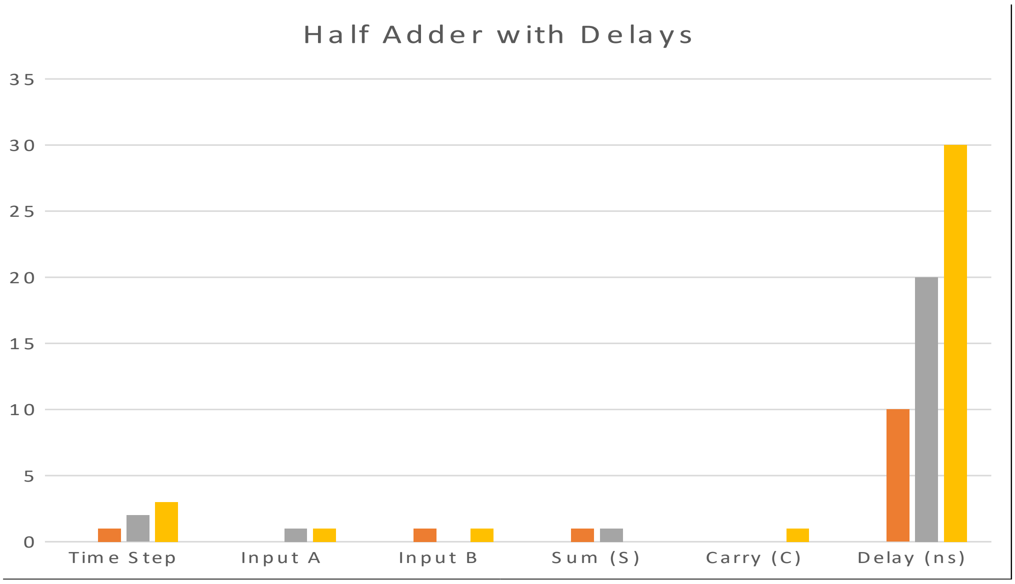
Inputs A and B are two bits in the fundamental arithmetic operation, and the table provides the sum and carry outputs for these two bits. Here we see the operation of a whole adder circuit with one bit of data. The adder's process of calculating the sum (S) and carry (C) is shown in each row, which corresponds to a distinct combination of the inputs.



Graph 1. AR Interaction - Input Configuration 1

Table 4. AR Interaction - Input Configuration 2

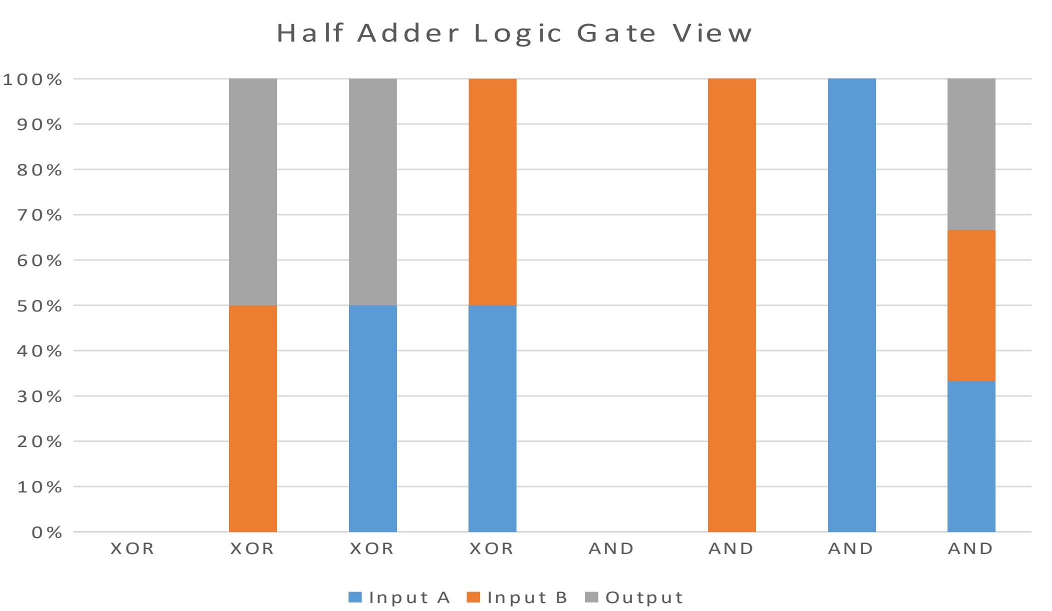
AR Configuration	Input A	Input B	Sum (S)	Carry (C)
1	1	0	1	0
2	0	1	1	0
3	1	1	0	1
4	0	0	0	0



Graph 2. AR Interaction - Input Configuration 2

When the inputs are zero, for example, the total and carry are zero as well. When both inputs are zero, the result is one, but the carry is zero as well. But when both inputs are 1, the result is a carry of 1, and the total is 0. Digital circuits rely on the basic logic of binary addition, which is shown by this setup.

A basic digital adder circuit set up for AR interaction is shown in the table with its input-output behavior. The 'Sum (S)' column indicates the result of combining the two inputs, while the 'Carry (C)' column shows the carry bit that is a consequence of the addition. Each row represents a distinct combination of binary inputs A and B. The total is 0 with a carry of 1, which indicates an overrun in binary addition, when both inputs are 1. On the other hand, when there is only one 1 input, the total is also 1 without carry, which is the same as regular binary addition without overflow. When both inputs are 0, the result is a sum and carry of 0, indicating that nothing has changed.



Graph 3. Half Adder Logic Gate View

Table 5. Half Adder Logic Gate View

Gate	Input A	Input B	Output
XOR	0	0	0
XOR	0	1	1
XOR	1	0	1
XOR	1	1	0
AND	0	0	0
AND	0	1	0
AND	1	0	0
AND	1	1	1

Here we can see how the two most basic logic gates—XOR and AND—operate inside the framework of a Half Adder in the table. Because the XOR gate takes into account bitwise addition without carry, the total output is 1 only when inputs A and B are different. On the other hand, a carry is formed when both bits are set to 1, because the AND gate, which produces the carry output, only returns 1 when both A and B are 1. For the Half Adder logic circuit, this shows how the XOR gate adds bits and the AND gate generates a carry.

AR-based Full Adder

Two inputs, A and B, denote the bits to be added; a third input, Cin, represents the carry-in from a previous stage; thus, a complete adder is a digital circuit that adds three binary digits. There are two outputs from a complete adder: sum (S) and carry-out (Cout). Because it considers the likelihood of a carry from the prior stage, it is more complicated than a half-adder. In a common implementation, it uses a series of logic gates, such as an OR gate to combine the results of the sum and intermediate carry computations, two AND gates to compute the carries, and an XOR gate to compute the total.

Table 6. Full Adder

Input			Outputs	
A	**B**	**CIN**	**Sum**	**Count**
0	0	0	0	0
0	0	1	1	0
0	1	0	1	0
0	1	1	0	1
1	0	0	1	0
1	0	1	0	1
1	1	0	0	1
1	1	1	1	1

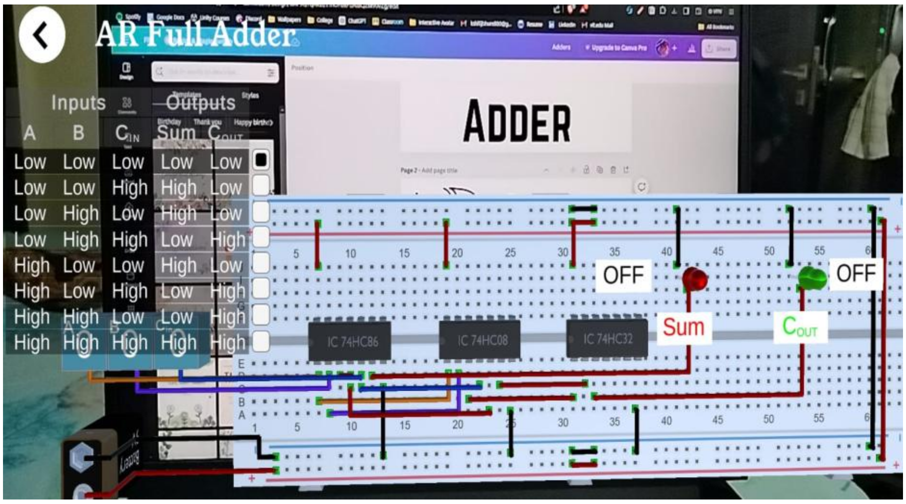


Figure 7. AR Full Adder

To execute binary addition, the figure depicts a complete adder circuit that has been placed on a breadboard. The "AR Full Adder" label indicates that the circuit is combined with an AR interface. The 74HC08 and 74HC32, two quad 2-input AND gates and an OR gate, accordingly, are the two primary integrated circuits (ICs) in the configuration. The logic gates required to make the complete adder are not possible without these integrated circuits. The components are connected to the breadboard in a well-organized manner using wires of different colors. This helps to identify the various connections and paths. Outputs (Sum and Carry Out) and inputs (A, B, and C) are labelled with precision, and LEDs show the current state of the outputs. The picture shows the current setup with the Sum and Carry Out LEDs disabled. You can see several input value combinations (Low and High) for A, B, and C in the table on the left side of the picture. To verify that the entire adder works as intended, we utilize these permutations to test its ability to add and carry out calculations accurately for all inputs. The most probable purpose of this arrangement is to serve as a visual and interactive demonstration of digital logic and binary addition for the benefit of students.

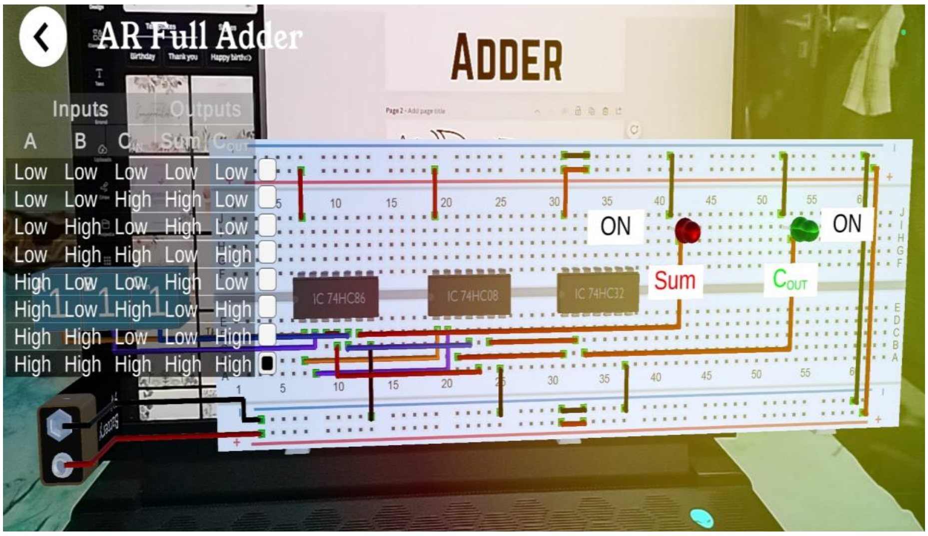


Figure 8. Augmented Full Adder

Figure shows how real monthly influenza incidence relates to the XGBoost model's projections.

In the figure, we can see a breadboard-built full adder circuit that has been upgraded with an AR interface called "AR Full Adder." A quad 2-input AND gate (74HC08) and a quad 2-input OR gate (74HC32) are the main integrated circuits used in this configuration. The basic logic gates needed for the whole adder's functioning are formed by these integrated circuits. The circuit connections are visible and simple to draw on the breadboard because of the multi-colored wires that link all of the parts. For the complete adder to work, the circuit requires three binary inputs, denoted as A, B, and C. To see how well the adder works, we may try out various combinations of the two input values

(Low and High) in the table on the image's left side. The inputs are configured with A=High, B=Low, and C=Low in this particular setup. Two LEDs show the outputs: one is green for Carry Out (Cout), and the other is red for Sum. The Sum and Carry Out are both lit up, meaning they are set to High for the inputs that have been provided.

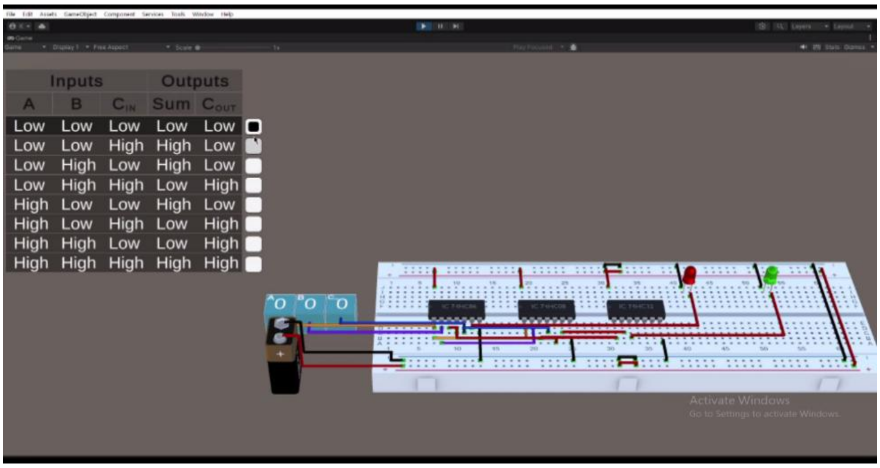


Figure 9. Augmented Full Adder with Sum LED OFF

This setup is designed to show students how digital logic circuits may be used to execute binary addition. The diagram schematically depicts the processing of A, B, and C as they pass through the logic gates of the integrated circuits to generate the carry-out and Sum outputs. To better comprehend how the complete adder works, the LEDs are lit up to provide instant indications of the output states. Students have a much easier time understanding digital reasoning and binary addition with this visual and participatory method.

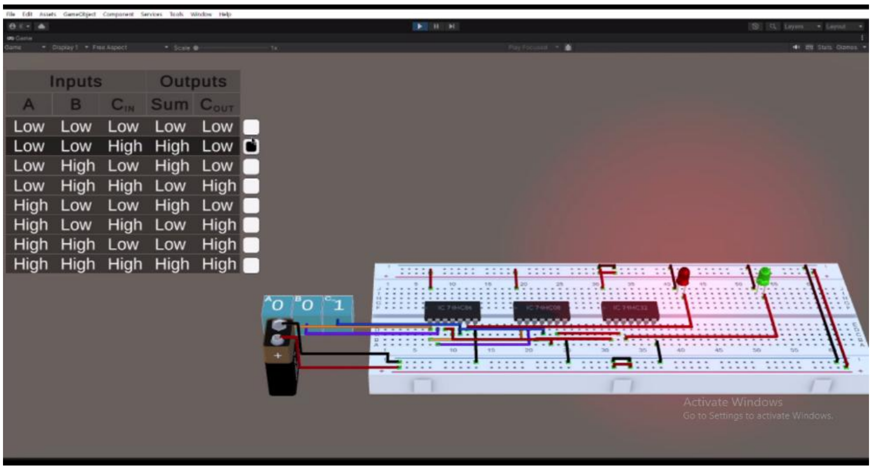


Figure 10. Augmented Full Adder with Sum LED ON

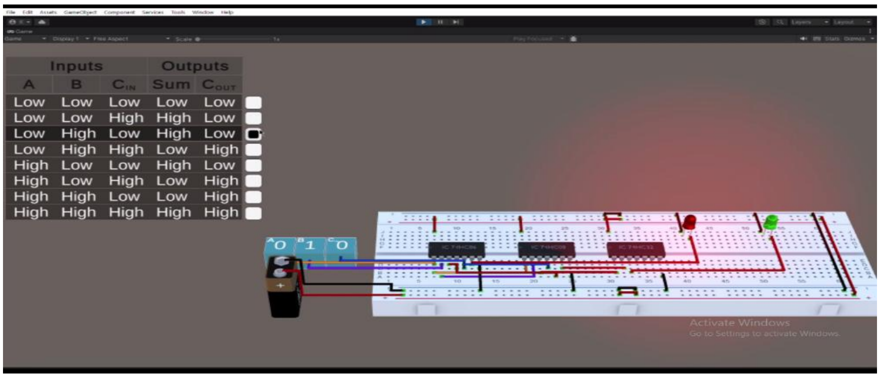


Figure 11. Augmented Full Adder with Sum (Red LED) ON

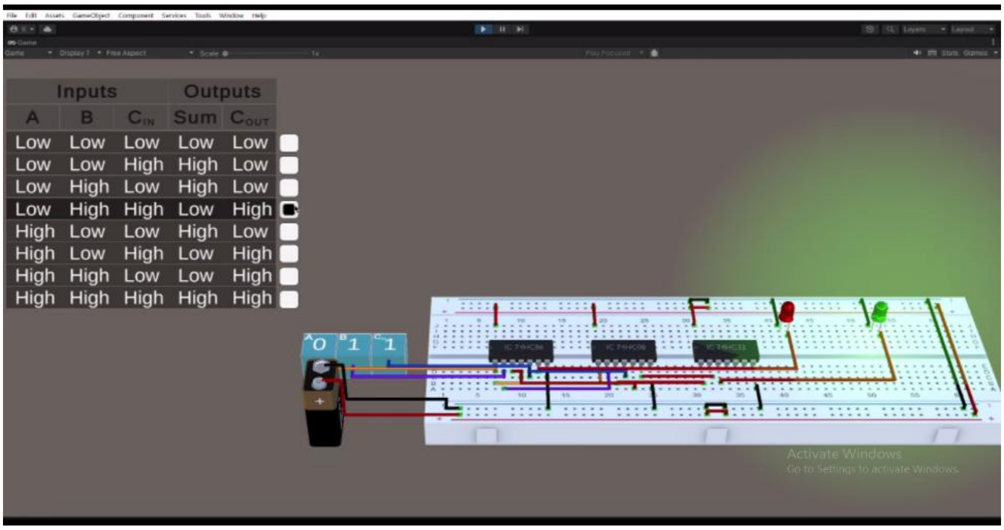


Figure 12. Augmented Full Adder with Carry (Green LED) ON

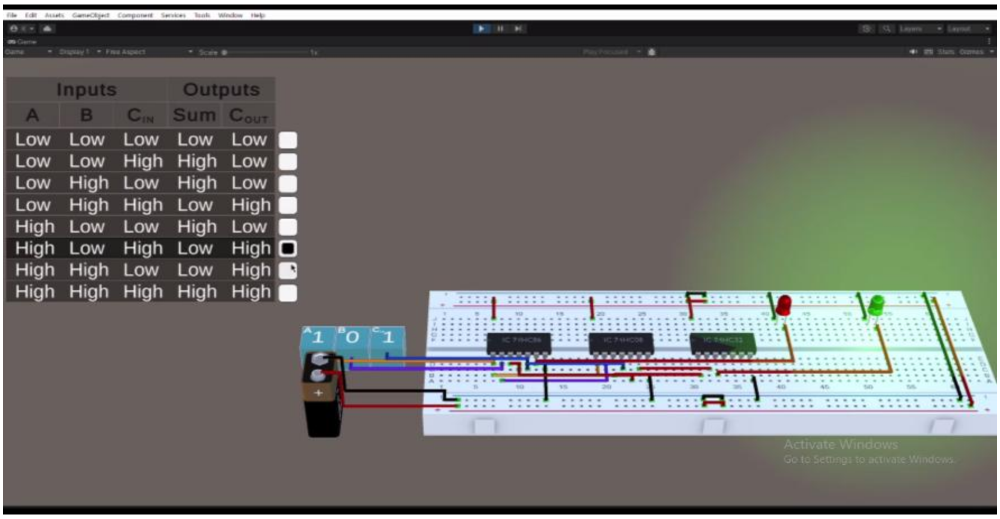


Figure 13. Full Adder with A and B input high and low

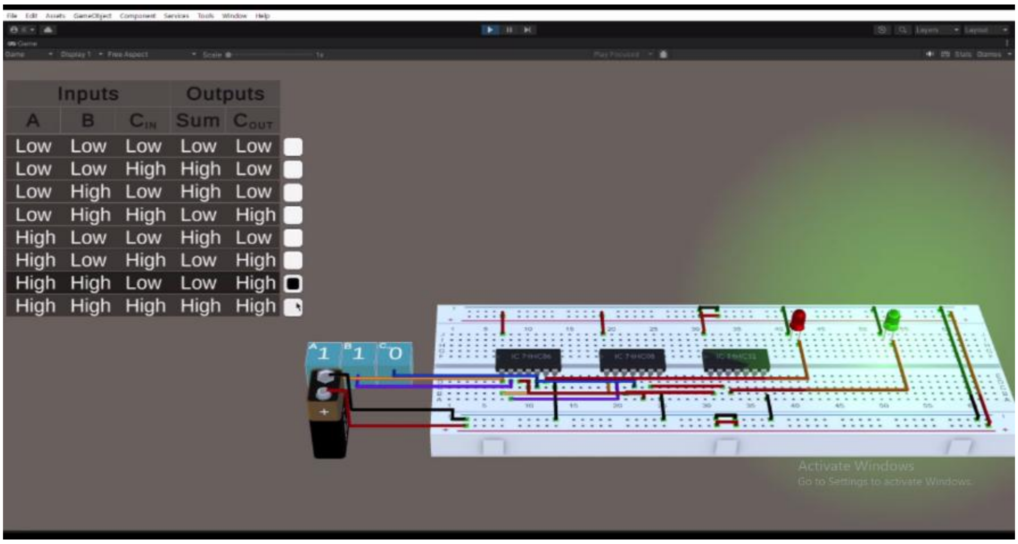


Figure 14. Full Adder input configuration

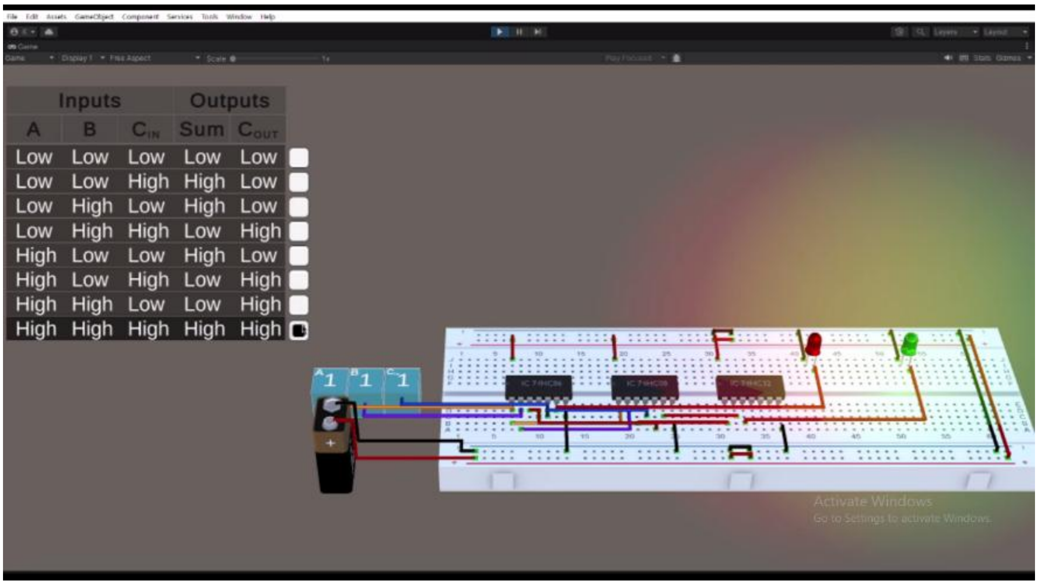
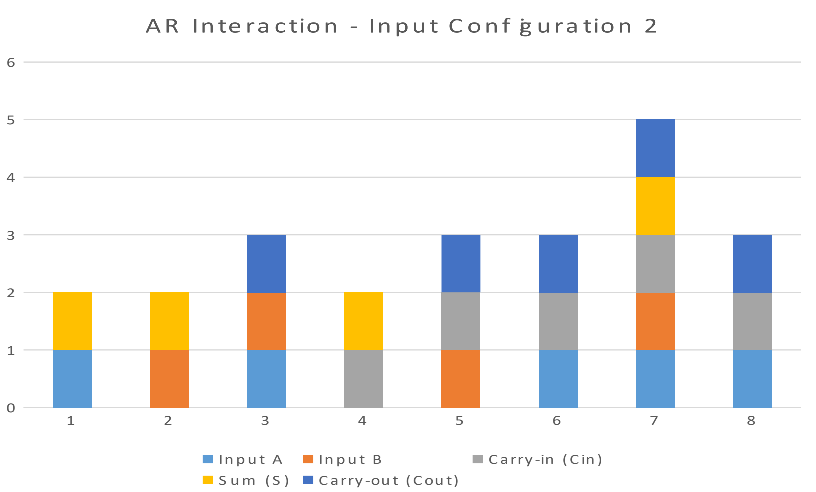


Figure 15. Full Adder input configuration with both input HIGH

Table 7. AR Interaction – Input Configuration 1

AR Configuration	Input A	Input B	Carry-in (Cin)	Sum (S)	Carry-out (Cout)
1	0	0	0	0	0
2	0	1	0	1	0
3	1	0	0	1	0
4	1	1	0	0	1
5	0	0	1	1	0
6	0	1	1	0	1
7	1	0	1	0	1
8	1	1	1	1	1



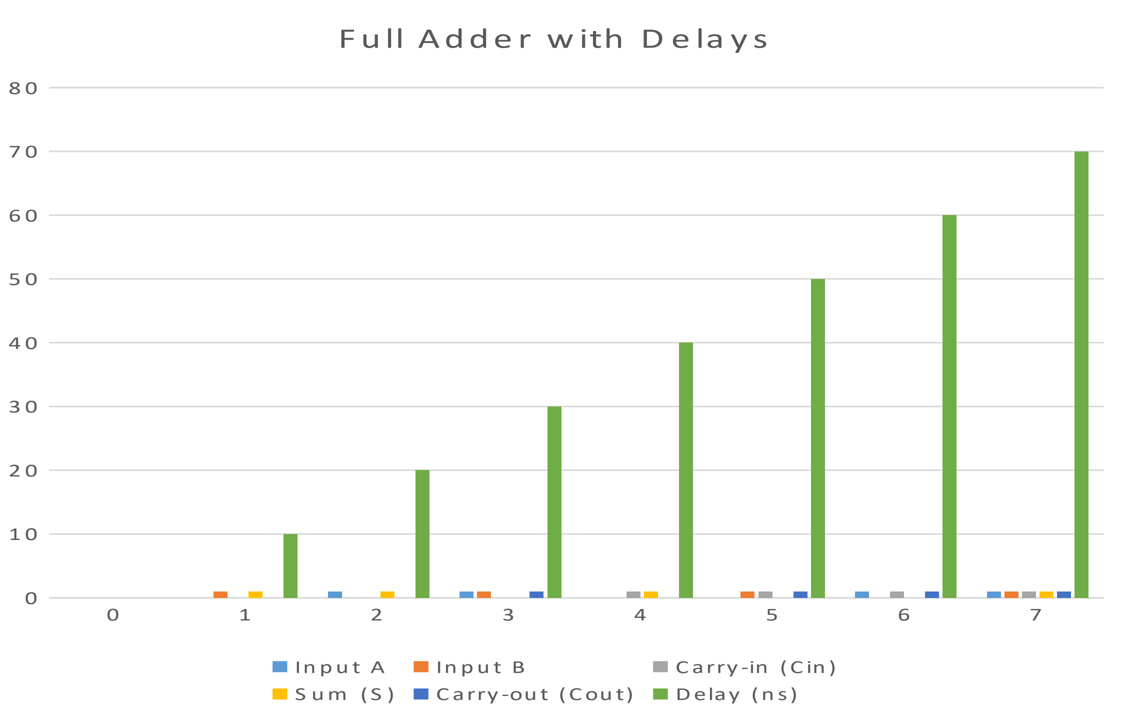
Graph 4. AR Interaction

An entire adder circuit, which calculates the sum & performs values for binary addition, is shown in the table as it operates. Two binary inputs, Inputs A and B, and a carry-in value, Cin, are shown in each row in a different arrangement. By combining these inputs, we get the sum (S) and the carry-out (Cout). Consider the following scenario: A = 1, B = 0, and Cin = 1. In this case, S = 0, and Cout = 1. To illustrate the binary adding process for all potential input situations, the table shows how the entire adder's output varies depending on various combinations of the inputs.

Table 8. AR Interaction – Input Configuration 2

AR Configuration	Input A	Input B	Carry-in (Cin)	Sum (S)	Carry-out (Cout)
1	1	0	0	1	0
2	0	1	0	1	0
3	1	1	0	0	1
4	0	0	1	1	0
5	0	1	1	0	1
6	1	0	1	0	1
7	1	1	1	1	1
8	1	0	1	0	1

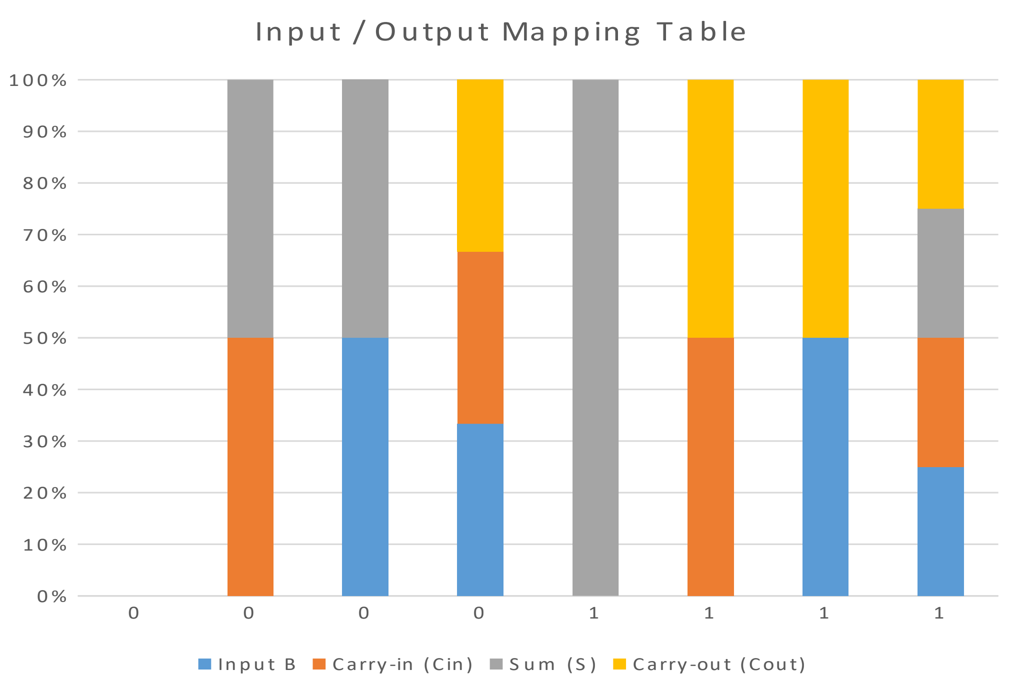
The binary adder circuit's behavior is seen in the table for various input combinations. Two input values (Input A and Input B) plus a carry-in (Cin) are represented by each row in this table. Sum (S) and Carry-out (Cout) are the output values that are affected by these inputs, as shown in the table. Consider the following row 6 scenario: Input A = 1, Input B = 0, and Cin = 1, whereby the Sum = 0 and the Carry-out = 1. You can see the basic operations of digital arithmetic the adder circuit processing binary inputs to create matching sums and carry-outs in this table.



Graph 5. Full Adder input configuration with both input HIGH

Table 9. Full Adder Logic Gate View

Gate	Input A	Input B	Carry-in (Cin)	Sum (S)	Carry-out (Cout)
XOR	0	0	0	0	0
XOR	0	1	0	1	0
XOR	1	0	0	1	0
XOR	1	1	0	0	1
AND	0	0	0	0	0
AND	0	1	0	0	0
AND	1	0	0	0	0
AND	1	1	0	0	1
OR	0	0	0	0	0
OR	0	1	0	1	0
OR	1	0	0	1	0
OR	1	1	1	1	1



Graph 6. Full Adder Logic Gate View

Experiment design

In this study, the authors use a quantitative analytic strategy known as a quasi-experimental design. This framework is used in investigations when both the control and the experimental groups are formed using pre-existing classes rather than randomly chosen.

Before the instructional intervention, both the experimental and control groups take a pre-test to see how they stack up academically and in terms of knowledge. During their first year of engineering, students take a course that covers the fundamentals of electronics. While one group used AR to learn the fundamentals of electronics, the other used a more conventional approach based on an instructional manual. To determine how the instructional strategy affected the students' knowledge acquisition, a post-test was administered to both groups after the intervention. Students in both groups were given a post-test and then asked to rate their overall satisfaction with the introductory electronics course. On top of that, we had the experimental set of students fill out a survey on their feelings about AR. Questions about the experimental group's background and thoughts on augmented reality technology were posed.

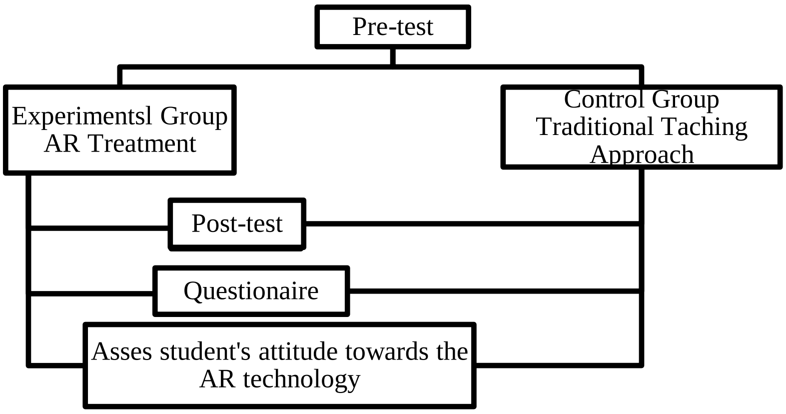
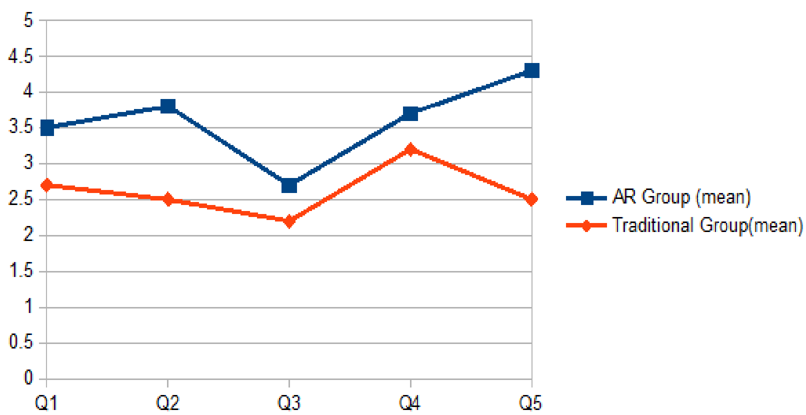


Figure 16. Experimental design

Table 10. Response of questionnaire for both groups

Sr. No.	Question	AR group (mean)	Traditional group
Q1	I would like to use this system frequently, according to my thoughts.	3.5	2.7
Q2	I found the system unnecessarily complex.	3.8	2.5
Q3	I found the system was easy to use	2.7	2.2
Q4	A technical person's support is necessary for me to use the system.	3.7	3.2
Q5	The system made me feel very confident.	4.3	2.5



Graph 0037. Comparison of AR Group [mean] & Traditional Group [mean]

Table shows that across all questions, the AR-based approach had higher mean values than the conventional technique group. Compared to the traditional way, the AR approach to education yields better results.

CONCLUSION

By providing immersive and engaging educational experiences that boost engagement, understanding, and practical abilities, augmented reality (AR) is revolutionizing education, particularly in laboratories. Augmented reality (AR) offers a secure, virtual setting with dynamic; 3D images that assist students in understanding complicated ideas and making connections between theory and practice. Through gamification and immediate input, it increases motivation and promotes inclusion by adapting to varied learning demands. Augmented reality also encourages teamwork and analytical thinking. Despite some hiccups along the way (such as price and technological difficulties), augmented reality is becoming an increasingly important tool in today's classrooms.

Finally, AR makes teaching more dynamic and interesting, which substantially improves learning. By connecting theory and practice, AR improves students' comprehension of abstract ideas. The advantages of AR surpass the disadvantages, even if the latter are real. Learners have made more progress with augmented reality pendulum & projectile movement experiments. The use of augmented reality (AR) in the classroom has also been fruitful in using half-and full-adder circuits. Thanks to augmented reality virtual laboratories, students may get a high-quality education regardless of their location.

FUTURE SCOPE

Augmented reality's (AR) potential for use in the classroom is vast, with game-changing applications in many fields. Beyond the realm of science and engineering, augmented reality has the potential to revolutionize language instruction via conversation simulations, arts education via virtual galleries, and social science through interactive re-enactments. Tackling availability for students with impairments can encourage creativity, critical thinking, and problem-solving skills. Through the integration of topics such as geography and health, AR may also facilitate multidisciplinary study, resulting in more comprehensive educational opportunities. Future educators will have a potent weapon in augmented reality (AR) thanks to collaborative AR settings that facilitate cooperation and communication.

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