ERA of Students: A Class-Wise Virtual Electronics and Microcontroller Learning Platform with an AI Tutor for Classes 8–10

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***Abstract*—The cost of the kit, lack of lab time, supervision and damaged components limit the hands-on approach to electronics teaching in schools. This paper describes ERA of Students, an LMS implemented using a web-browser interface which allows students in classes 8, 9 and 10 to learn sensors, actuators and microcontrollers with the help of virtual experiments. After logging-in with their names and classes, the students get access only to the material pertaining to their classes: 30 different experiments per class (totally 90 experiments), lessons and notes, quizzes and their individual progress history. The students design their circuits by dragging-and-dropping the components on the board and connecting the wire between the component pins and the microcontroller pins. They can select from the five available boards (Arduino UNO, NodeMCU, ESP32, ESP8266 and PIC18F47Q10) with their pin layouts shown and run a threshold-based simulation with live graphs and auto-generated Arduino code. The features include context aware AI tutor accessible from every page, animated video lectures that have their scripts generated using AI technology, four ten question quizzes based on questions specific to the learner and do not repeat until they have been used up, badges for experiment and quiz and finally a certificate upon completion of all the experiments. The software is built in the form of a single page web application which requires neither installation nor any hardware component. This research paper will talk about the design and functionality of this project and discuss its limitations as well.**

Keywords—virtual laboratory, learning management system, microcontrollers, Arduino, ESP32, sensors, AI tutor, gamification, school education, STEM

I. INTRODUCTION

The areas such as electronics, sensors, and programming are important subjects to be taught in STEM education currently prevailing, whereas the national policy focuses on hands-on learning and computational thinking from the middle school onward [1]. It is not always possible for the school to offer every learner the opportunity to get practical experience. This is because of the cost involved in the parts of the kits, limited lab hours, presence of only one instructor for many students, and even the danger posed by the wrong connections.

Open-source microcontroller development boards such as Arduino are now widely used in introductory electronics and engineering courses [2], and virtual laboratories are an alternative when physical means are not available [3], [4]. The virtual laboratory experiments can be repeated as many times as one likes, they cost nothing, they can never harm the student and always give immediate feedback. To students in school, a web-based application is especially attractive because it works with devices that they already have on hand.

There are simulation softwares, such as Tinkercad Circuits [5], that can be used by students without restriction, although they don't consider any school curriculum at all. This is according to the research we conducted; no software takes into account the following aspects in one place: a specific path of experiments for each class, interactive wiring and checking its validity, support of various families of microcontrollers, an AI tutor who understands the circuits that are developed by the students, testing and rewarding, and certification.

This paper deals with the study on ERA of Students, which is an LMS, which can be employed to fill up this gap in Classes 8-10. The contribution made by this research is: (i) catalog of 90 experiments for each class with sensor and output; (ii) drag and drop circuit design interface with live wire checker and threshold simulation engine for five different microcontroller families with pin list; (iii) AI tutor, video tutorials and non-repeating quizzes for each student; and (iv) badges and certificates.

II. LITERATURE SURVEY

Virtual laboratories are simulations of experiments or other hands-on activities that allow students to explore scientific concepts and principles in a virtual environment. In a scoping review of 23 articles published between 2012 and 2023, Sellberg et al. identified common characteristics in the definitions of virtual laboratories in STEM higher education and three theoretical traditions that influence work on them, and they concluded that further studies of what happens in such settings are needed [6]. Building a circuit, observing how the sensor input affects the output, and then adjusting the threshold value is a hands-on cycle of exactly this kind, and it is the motivation for ERA of Students.

Virtual laboratories are mainly adopted because of teaching constraints such as limited time, high costs, safety concerns and inadequate infrastructure, and because they allow experiments to be repeated at the student's own pace. In a systematic review of 20 studies on virtual labs in science education, Rosli and Ishak reported improvements in cognitive, psychomotor and affective outcomes in most of the studies [3]. They also noted that two studies found physical laboratories gave better science process skills, and that one study found that starting with virtual labs before moving on to real experiments helped to prepare students for the real thing [3].

The accessibility and reach of virtual laboratories have also been reviewed. Deriba et al. synthesised 36 empirical studies published between 2000 and 2023 and describe virtual laboratories as having transformed traditional approaches to

scientific experimentation; in electrical engineering they are used, for example, to analyse electrical circuits and to measure voltage, current and resistance [4]. This supports the choice of a browser-based design for ERA of Students, which needs no installation and no laboratory equipment.

Guidance is another important consideration. Rosli and Ishak report that instructional approaches such as feedback, scaffolding and inquiry-based learning are built into virtual labs to enable meaningful learning [3]. Pejcinovic et al. similarly stress that students with limited technical background need substantial scaffolding, especially in programming, and they use Tinkercad to simulate both Arduino programming and electric circuits in introductory electrical and computer engineering courses [2]. ERA of Students gives the student a list of actions needed to connect all wires, a built-in circuit for beginners, and an AI tutor.

In today's times, microcontrollers have become common among educational setups. Arduino boards are widely used for educational purposes [2], [7]; the ATmega328P microcontroller which resides in the Arduino UNO is described in its data sheet by the manufacturer [8]. Wi-Fi supported boards such as the ESP32 and ESP8266 boards operate at 3.3 volts and have unique pin configurations along with analog pins [9]; the PIC18F47Q10 microcontroller manufactured by Microchip Technology Inc. has input-output lines which are arranged into ports denoted as RA to RE [10]. A student who studies only a single board may think that the pin configuration and voltages are common for all boards. That is why ERA of Students enables users to switch between different boards.

The national curriculum framework emphasises experiential learning, computational thinking and coding [1]. The IF-THEN principle used in all the experiments of ERA of Students, in which an output is turned on when a sensor reading reaches a certain value, is a small and concrete example of this kind of thinking.

Feedback and multimedia influence how much students learn from digital material. Rosli and Ishak note that virtual experiments can be effective when the learning material uses multimedia representations such as text, pictures and animations, and they report that interactive simulation, gamification and quiz questions with immediate feedback were among the components of a chemistry virtual lab that influenced students' self-efficacy [3].

Students working on their own need help at the moment they get stuck, and AI chatbots are being studied as a way of providing it. Labadze et al. reviewed the role of AI chatbots in education and describe benefits such as immediate support for students, as well as threats that need to be managed [11]. In the tutor of ERA of Students, a language model receives the information on the student's class and the current state of his/her experiment as context.

Large language models have introduced several opportunities within the field of educational discourse. Current large language models are capable of responding to open-ended queries from diverse subject matters without requiring specific task training [12]. The strengths and weaknesses that large language models pose in education were pointed out by Kasneci et al. The strengths include the personalization of explanation and helping the teacher, while the weaknesses include factual mistakes, biases, overreliance on language models, and the need for critical usage [12]. That is why the ERA of Students tutor is instructed to give explanations suited to the age of the learner, to use the experiment context only when relevant, and to warn about the dangers of electricity.

Lastly, motivation and perseverance should be encouraged in self-paced digital learning. In a multi-level meta-analysis of gamification in programming learning (studies above school level), Costa et al. found that gamification led to a significant increase in results overall, mainly through the use of levels, whereas points, badges, avatars and leaderboards on their own showed no significant effect on learning, which suggests that such elements may be more useful for motivating and engaging students [13]. Hence, ERA of Students uses badge levels and certificates as a simple system for recognising achievements, such as completed experiments and good quiz scores, rather than as a substitute for learning.

III. METHODOLOGY

A. Design Approach and Methods

The design process used in developing this system used an iterative design approach based on the need. The requirements gathered included the inclusion of class specific information, circuitry construction, selection of popular microcontrollers, support at every level, assessment and achievement recognition. 20 virtual component and experiment list were generated, and improvements made in the design using screenshots and previous prototypes. Each of the experiments uses one input to output relationship, which involves one sensor, one output, a comparison and a value. In each of the classes, the experiments are such that two experiments do not have the same name or sensor/output/comparison combination and thus have 30 experiments per class totaling to 90 experiments.

B. Technologies Used

The application is a one-page application built with HTML5, CSS3, and JavaScript, which means that it is accessible in any modern browser without downloading or installing anything. Scalable Vector Graphics (SVG) is used for the logo and the wire drawing between pins, the HTML5 canvas is used for the real-time sensor plotting, and HTML5 drag-and-drop is used for placing components on the board. Narrated lessons are made with the help of the speech synthesis of the Web Speech API [14] of the browser. The profile of a student, their progress, quiz results, selected board are stored in the local storage of the browser with the username and the class of a student. The artificial intelligence tutor and scripts of the lessons created by artificial intelligence are generated using a large language model Claude by calling its sampling interface through the hosting platform, which means that there is no need to use API keys in the page itself [15]. The seed of pseudo-random number generator from a string hash is used to generate quizzes for students.

C. System Architecture and Block Diagram

The architecture of ERA of Students is shown in Fig. 1. Firstly, the student logs into the sign in module which stores the name and class thus determining the courseware. Next comes the dashboard which displays the experiment catalog, virtual lab, lessons & notes, quiz & progress. The virtual lab includes a components library, microcontroller board with full pin-out of the board, wiring validator, simulator, output visualizer with live graph and code generator. The AI tutor and the lesson player are available in all modules. Progress module receives the scores in the quizzes and number of experiments performed and badge points calculation takes place after which the certificate is generated.

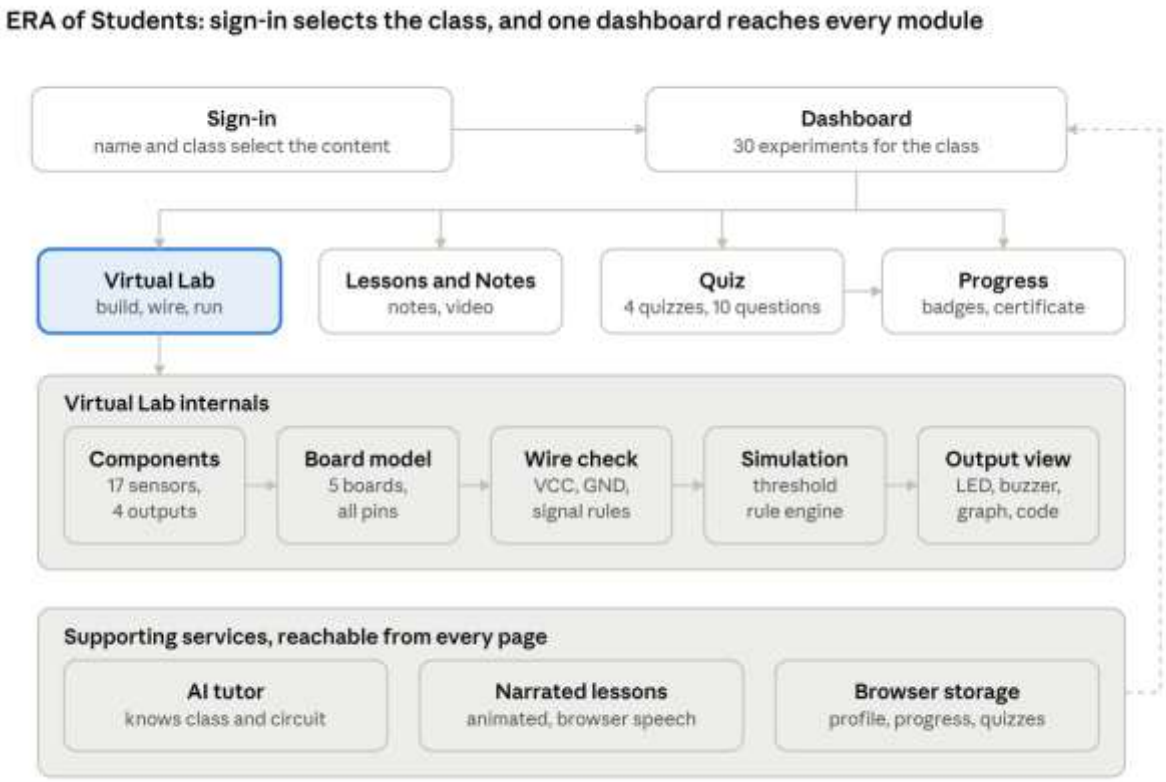


Fig. 1. Block diagram of ERA of Students: sign-in, dashboard, the four modules, the virtual lab internals and the supporting services.

D. Simulation, Validation, Quiz and Reward Logic

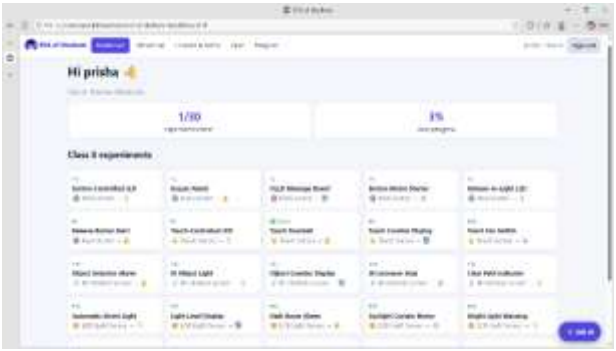
All pins of each board are either power, ground, analog enabled input/output, digital input/output or special. A connection will be made between a component pin and a board pin, and the checklist will verify that VCC pin of the component is connected to a power pin, GND pin of the component is connected to a ground pin, and its signal pin is connected to an appropriate pin; analog sensors use analog enabled pins while all others use digital enabled pins. Simulation will only be initiated when the sensor and the output are properly connected. In the simulation, the value of the sensor, set using a slider or switch, will be compared with the threshold value after a fixed interval of time. The quizzes are designed on the basis of the templates prepared for the components, experiments and fundamental principles that are taught in that particular class of the student. It is more desired to ask an unseen question; however, the pool gets refreshed if there are less than ten unseen questions. Badges are awarded on the basis of the number of experiments and quizzes of scores of 5/10, 7/10 and 9/10 respectively.

IV. RESULTS AND DISCUSSION

All the features mentioned in Table I are available in the implemented system. The three classes contain all the experiment trails; the circuit workbench contains five types of microcontrollers with all the pins; and all the learning features (i.e., AI tutor, recorded lesson, quiz, badge, and certificate) are included in one interface. All the experiments can be opened, manually/wired through the circuit, run, and completed after the firing of the output.

TABLE I
IMPLEMENTED SYSTEM OUTCOMES

Item	Outcome
Classes supported	3 (Classes 8, 9 and 10)
Experiments	30 per class, 90 in total, all unique
Virtual components	17 input sensors and 4 output devices
Microcontrollers	5 (Arduino UNO, NodeMCU, ESP32, ESP8266, PIC18F47Q10), all pins shown
Quizzes	4 per student, 10 questions each, student-specific sets
Rewards	5 experiment badge levels, Bronze/Silver/Gold quiz badges, completion certificate
Support	AI tutor on every page, narrated animated lessons with AI-generated scripts



In the process of doing any experiment like the Automatic Street Light, the student is required to position the LDR light sensor and the LED in the board and connect the pin. He is unable to begin the simulation until he makes sure everything is okay with the checklist. Once he begins the experiment and

lowers the light slider to less than the threshold level, the LED lights and the experiment is completed. The code generated for the process includes the analog read and digital write code. The student can change the microcontroller whenever he wishes to.

This design is directly inspired from the literature that has been surveyed above. The checklist and packaged circuits are the kind of guidance and scaffolding discussed for virtual labs [2], [3]; the real-time validation and output give instant feedback [3]; the animated and narrated lectures use the multimedia representations that the literature associates with effective virtual experiments [3]; the context-aware tutoring system offers some of the immediate support described for AI chatbots [11], [12]; and the badge levels and certification are used as a method of recognizing learners [13]. The class-based design ensures that the student is not given any information that belongs to another class, and the individualized quiz prevents any exchange of information between students.

It is important to highlight the limitations of the present project. The simulation program employs threshold logic but does not deal with complete electrical circuits, does not compile firmware, and does not upload firmware to the microcontroller and therefore it should be considered a preparatory tool for real practical training. Each task includes only one sensor and one output; there are no multiple sensor systems developed yet; heart rate sensor employs only artificial data and does not perform medical measurements; progress is tracked at the level of the student's browser and, therefore, is dependent on the specific device; finally, AI tutor requires access to the platform and, like any language model, may produce errors. There is no research regarding learning gains, and we, therefore, do not claim any improvements achieved by the learners. Pilot test of the performance of students based on pre-test and post-test evaluations, questionnaire, and log files will be conducted

V. CONCLUSION

It is necessary to point out some limitations of the current project. Simulation program uses threshold logic but does not work with real electrical circuits, does not compile firmware and does not upload firmware into the microcontroller and hence it can be seen as the preparatory tool for practical training. Every exercise contains only one sensor and one output; there are no multiple sensors' systems currently developed; heartbeat sensor uses only the artificial data and does not perform the medical measurements; progress is tracked on the level of the student's browser and hence is dependent on the particular device; finally, AI tutor needs access to the platform and, just like any language model, can make mistakes. No research on the learning gains was done and hence we cannot say that the learners benefit from using the tool. Pilot testing of the student performance will be performed based on the pre-test/post-test evaluation, questionnaire and log files.

Future goals include expanding the scope of the platform by experimenting with several sensors and several outputs, better electrical modeling, teacher dashboards, server-based saving of information so that progress is saved despite different devices being used, and linking with real boards is not mandatory. What is essential is that classroom experiments will be done to see the results of learning and engagement, and it will help improve the experiments, quizzes, and behavior of the tutor.

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