ECE 445

Senior Design Laboratory

Project Proposal

Desk Learning Aid Device

Team 27:
Conan Pan (cpan23)
Aidan Johnston (aidanyj2)
Ethan Ge (ethange2)

TA: Kaiwen Cao
Professor: Michael Oelze

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1. Introduction

1.1 Problem

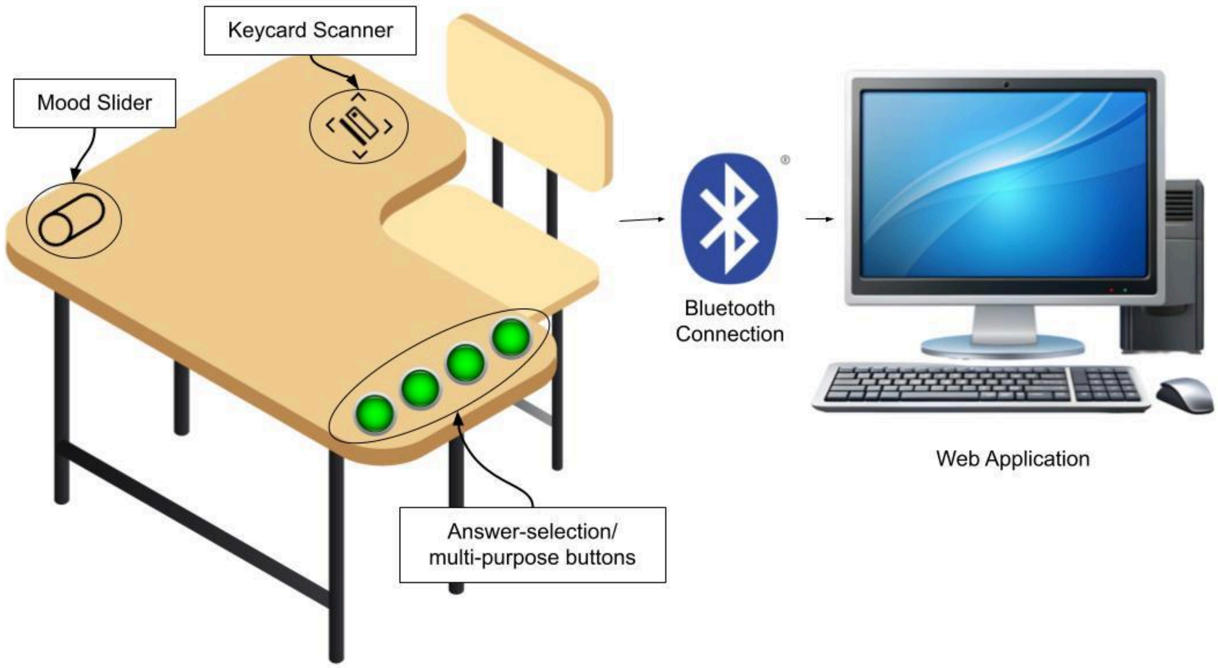
In recent years, there has been a growing trend of integrating technology into schools. This trend has been accelerated by the lasting impacts of the Covid-19 pandemic and the continuous advancements in digital devices and tools. Schools across the nation have adopted computers, tablets, and virtual learning platforms to enhance education and increase accessibility in the pursuit of modernizing the classroom. While these technologies offer incredible benefits, they also introduce challenges, particularly in elementary school classrooms.

One of the most critical problems is the effect screen time is having on students. By incorporating technological devices in classrooms, students are spreading prolonged periods interacting with screens. Studies have begun to highlight how this excessive screen time can lead to a severe lack of social skills, shorter attention spans, and higher frequencies of disruptions. These trends contribute to a less effective and unhealthy learning environment. Furthermore, studies are exploring connections between prolonged exposure to screens and decreases in mental and physical well-being. Therefore, in the pursuit of generating a more social, engaging, and nurturing environment for young students we propose the desk learning aid device.

1.2 Solution

The desk learning aid device will function through various buttons connected to a customized PCB device. Buttons will correspond to responding to polls/questions, comprehension checks, asking questions, and more. The device will communicate to an application that can be monitored by the teacher where they will receive real-time feedback. The teacher can have a better understanding of the student’s comprehension levels and be able to properly cater towards providing the students the most effective lesson. The purpose of this device would be to provide a cost-effective solution that can be set up at each student’s desk to promote a holistically better learning environment for students. This differs from other options on the market due to easier set up because other options require you to create a question in order to receive a response, however, our device allows for many passive inputs including comprehension and other urgent needs. In addition, other portable solutions require students to buy each device individually costing them hundreds of dollars, but our solution only requires the purchase of a reusable RFID keycard that is cheap and easy to use.

1.3 Visual Aid

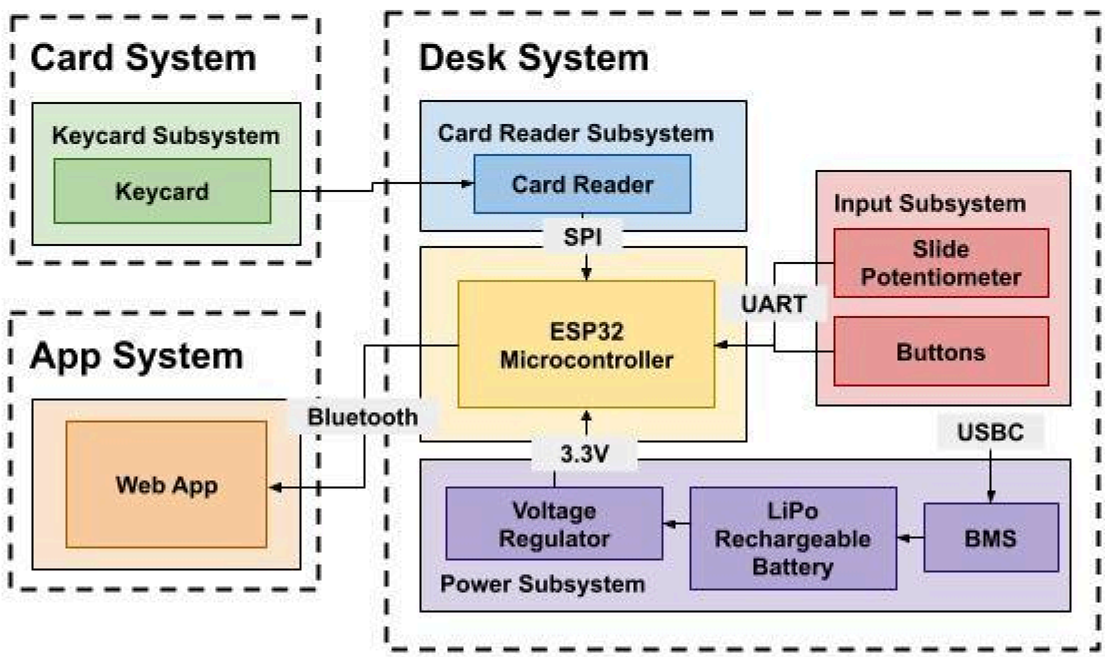


1.4 High-Level requirement list

1. The PCB device accurately registers button presses and sends the data to the mobile application.
2. The mobile application receives user data from the microcontroller and stores/analyzes trends in the data for classroom comprehension for specific topics.
3. The keycard correctly signs the user into the classroom that the device belongs to.

2. Design

2.1 Block Diagram



2.2 Subsystem Overview

2.2.1 Input Subsystem

This subsystem will include response (EVQ-P7K01P (Panasonic)) buttons for comprehension checks, request for assistance buttons, feedback buttons, and mental/emotional health check-in buttons. These buttons will be labeled accordingly so that student interaction with the device is simplified. The advantage with having a variety of buttons is to enable teachers to have as little interaction with the app as possible. In addition, this subsystem will include a scroller (Bourns PTL30 Series (PTL30-15O0F-B103)) that will enable students to adjust in real-time how they are feeling throughout the day.

2.2.2 Microcontroller Subsystem

The ESP 32 S3 Microcontroller is programmed with firmware to recognize button inputs and process them according to whether a question has been asked. Transmit student data to the mobile app run by the teacher.

2.2.3 Mobile Application

The mobile application subsystem serves as the teacher's interface to monitor student responses, track participation, and adjust lesson pacing in real time. The app receives data from student devices via Wi-Fi or Bluetooth, displaying responses in a structured and visual manner. The teacher can view class-wide comprehension trends, see which students need help, and manage classroom activities such as quizzes and polls. It would also receive data from the RFID/NFC keycard subsystem and store data for each student's participation, attendance, and comprehension.

Components:

- **Frontend UI:**

  Built using **React**

  Displays real-time responses, feedback, and participation data.

- **Backend & Communication:**

  Firebase Realtime Database to handle instant message transmission.

  Secure BLE/Wi-Fi communication with ESP32 devices.

- **Data Processing & Visualization:**

  Aggregates student responses for charts, graphs, and heatmaps.

  Uses **D3.js or Chart.js** for real-time visualization of classroom engagement.

- **Authentication & Security:**

  Teachers log in with **Google OAuth** or school credentials.

2.2.4 Power subsystem

The 103454 LiPo rechargeable battery system will be used to power the device. Ideally, we'd like to also make the system as efficient as possible as to ensure that it doesn't need frequent recharging. This battery system is preferred over wired power due to the installation and cable management that comes with wired power. Furthermore, desks are constantly moving in a classroom, whether that be re-arranging seats or during seasonal cleans, thus further highlighting the advantage of the battery system.

2.2.5 RFID/NFC (Keycard) subsystem

The RFID/NFC subsystem allows students to log in quickly and anonymously using keycards without the need for manual name entry or personal devices. This ensures a seamless and low-disruption way to track participation, attendance, and response data. By tapping their RFID or NFC card on their desk device, students authenticate themselves before answering questions or engaging in activities. This enables teachers to monitor individual engagement and performance trends without requiring students to use personal logins.

Components

- RFID/NFC Reader
    - Function: Reads the keycard's unique ID
    - Part: RC522 NFC Module (SPI-based)
- RFID Key Cards
    - Function: Unique identifier for each student
    - Part: MIFARE 13.56 MHz RFID Cards

2.3 Subsystem Requirements

2.3.1 Input Subsystem

The Input Subsystem is responsible for capturing student interactions through a set of designated buttons and a rotary scroller. The buttons include comprehension check responses, request for assistance, feedback submission, and mental/emotional well-being tracking. These buttons (EVQ-P7K01P by Panasonic) will be labeled clearly to allow young students to use them intuitively without extensive training. The emotion scroller (Bourns PTL30 Series) will provide an additional method for students to continuously indicate their comfort or comprehension level throughout the lesson.

This subsystem ensures that students can provide feedback efficiently while minimizing distractions in the classroom. By incorporating multiple input methods, teachers will have access to a richer dataset regarding student engagement and comprehension levels. The collected data will then be transmitted to the microcontroller for further processing.

Requirements:

- Must accurately detect and differentiate between all button presses and scroller adjustments.
- Must transmit data to the Microcontroller Subsystem with minimal delay (<100ms latency).
- Must be robust enough to handle repeated presses over an extended period

2.3.2 Microcontroller Subsystem

At the core of our system, the ESP32-S3 Microcontroller processes all incoming inputs from the buttons and scroller, logs interactions, and transmits the data to the mobile application. It acts as the primary processing unit, ensuring that signals from the input subsystem are accurately interpreted and relayed. The microcontroller also facilitates communication with the RFID/NFC subsystem, ensuring proper student authentication when they log into the system.

This subsystem plays a crucial role in fulfilling the high-level requirement that user input is accurately captured and relayed to the teacher's dashboard. It enables seamless wireless communication via Wi-Fi or Bluetooth, ensuring real-time updates without reliance on wired connections.

Requirements:

- Must process all inputs and transmit data to the mobile application within 500ms
- Must support at least 20 concurrent student devices in a single classroom.
- Must maintain a reliable connection (<1% packet loss)

2.3.3 Mobile Application Subsystem

The Mobile Application Subsystem provides teachers with a graphical interface to monitor student participation, engagement, and comprehension in real time. It receives data from multiple student devices, aggregates responses, and visualizes them using various charts and heatmaps.

This subsystem consists of the following components:

- **Frontend UI** (Built with React): Displays real-time data such as poll responses, assistance requests, and comprehension trends.
- **Backend Communication** (Firebase Realtime Database): Ensures instant message transmission and data synchronization.
- **Data Processing & Visualization** (D3.js or Chart.js): Aggregates student responses and visualizes trends to help teachers adjust lesson pacing.
- **Authentication & Security**: Utilizes Google OAuth or school credentials for secure access.

Requirements:

- Must receive and process student data updates within 500ms.
- Must display real-time classroom engagement metrics with a refresh rate of at least once per second.
- Must store historical student response data securely in compliance with FERPA regulations.

2.3.4 Power Subsystem

The Power Subsystem consists of a rechargeable **103454 LiPo battery**, providing the necessary energy to operate the microcontroller and connected components. The battery selection was made to ensure a balance between longevity and compactness, avoiding the need for frequent recharging.

By utilizing a battery-powered design instead of a wired power connection, this subsystem enhances the portability and flexibility of the learning aid device. It ensures that classroom reconfigurations do not disrupt functionality, meeting the requirement of reliable, uninterrupted operation.

Requirements:

- Must supply a stable 3.3V to the ESP32-S3 microcontroller
- Must provide at least 1000mAh capacity to support continuous operation for a few hours.
- Must recharge fully within 2 hours using a standard USB-C connection.

2.3.5 RFID/NFC (Keycard) Subsystem

The RFID/NFC Subsystem allows students to log in and authenticate their participation using RFID keycards, avoiding the need for personal device-based authentication. The system consists of:

- **RFID/NFC Reader (RC522 NFC Module, SPI-based)**: Detects and verifies student keycards.

- **RFID Key Cards (MIFARE 13.56 MHz)**: Provides a unique identifier for each student.

This subsystem ensures that the correct student is linked to the corresponding desk device, preventing fraudulent participation and enabling individualized tracking of engagement levels. It supports the high-level requirement that users are properly authenticated before interacting with the system.

Requirements:

- Must successfully authenticate RFID keycards
- Must differentiate student's RFID keycards from one another

2.3.6 Subsystem Integration & Communication

Each subsystem is interconnected to ensure seamless operation:

- The **Input Subsystem** collects data and forwards it to the **Microcontroller Subsystem**.
- The **Microcontroller Subsystem** processes inputs and sends the data to the **Mobile Application Subsystem**.
- The **Power Subsystem** ensures that all hardware remains operational without wired power dependencies.
- The **RFID/NFC Subsystem** authenticates student logins and interacts with both the microcontroller and mobile application.

By integrating these subsystems effectively, our device provides an interactive, low-cost, and scalable solution for classroom engagement, enhancing both teacher insights and student participation.

2.4 Tolerance Analysis

One potential risk in our design is the reliability of the wireless communication between the ESP32-S3 microcontroller and the mobile application. Given that classrooms may have multiple active Wi-Fi devices, interference and signal congestion could lead to packet loss or delays in transmitting student responses. To mitigate this, we selected the ESP32-S3 due to its dual-mode Wi-Fi/Bluetooth capability, allowing fallback to Bluetooth Low Energy (BLE) in case of network congestion. Through simulation, we verified that the ESP32-S3 can maintain stable data transmission with an average packet loss rate of less than 1% in a classroom setting with 20 devices operating simultaneously.

3. Ethics and Safety

The key ethical and safety issues relevant to our project include the following:

3.1. Privacy

Ensuring the privacy and security of the user data being collected is crucial for the success of our project. As this device is designed to be integrated into elementary schools, it is vital that this device be secure such that parents and teachers can trust the device to collect data in a strictly beneficial manner. This aligns with our pursuit in following ACM Principle 1.6, “Respect Privacy”.

3.2. Transparency

It is critical that the data collected and the analysis that comes from it be transparent to both the device users and the mobile app users. The context in which this device will be used, in various learning environments, makes it such that transparency is a key factor in having our project be a success. That is why the mobile application will be designed to organize, highlight, and show the data that is being collected.

3.3. Bias

It is crucial that no bias is introduced by the machine learning algorithm or through misinterpretations of the data being presented. The machine learning algorithm will be used to assess and analyze trends from various learning aid devices that are all connected to one classroom. It is essential that this algorithm is continuously tested throughout the school year to ensure fair recommendations and adjustments are made. In addition, the data being presented will be done so with clear data visualization tools in order to mitigate the potential for misinterpretation. This aligns with our pursuit in following ACM Principle 2.5, “Give comprehensive and thorough evaluations of computer systems and their impacts, including analysis of possible risks”.

3.4. Inclusivity

Ensuring the device is in compliance with ADA for those with disabilities is an essential aspect of our device. In this respect the device will be designed to be set up on student desks to accommodate each student in the classroom. The focus on simplicity by using buttons and a scroller further emphasizes our commitment to ensuring the device is accessible and inclusive. This aligns with our pursuit in following the IEEE Code of Ethics, specifically code two, as well as ACM Principle 1.4, “Be fair and take action not to discriminate”.

3.5. Safety

The electronic and hardware safety of our device. As this device will be around children ages 5-11, it is crucial that these devices meet FCC Part 15 regulations, UL 60950-1, and ISO 14971. These regulations ensure safety in electronic emissions, IT equipment, and risk management in electronic devices. In addition to these regulations, we will follow the IEEE Standard 1725 to ensure the safety of the batteries used within the device.

3.6. Lab Policies

We will ensure to adhere to the University of Illinois Urbana-Champaign laboratory safety guidelines throughout the construction of the learning aid device.