ECE 445

Senior Design Laboratory

Project Proposal

Desk Learning Aid Device

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1. Introduction

1.1 Problem

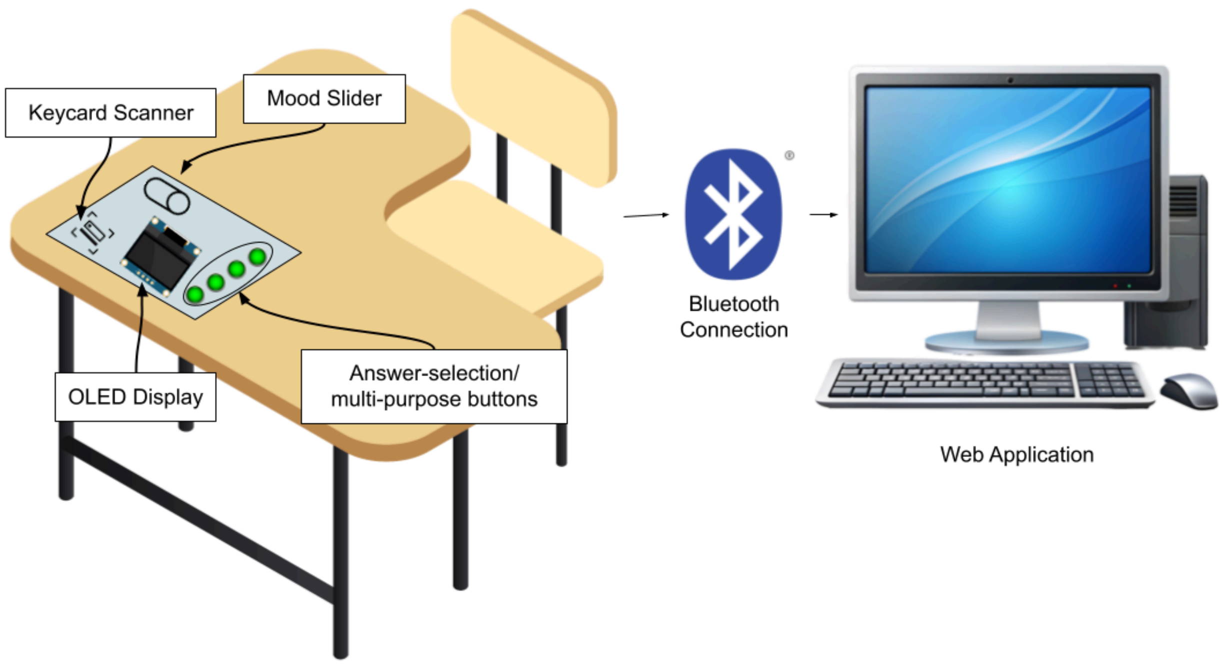
In recent years, there has been a growing trend of integrating technology into schools. This trend has been accelerated by the lasting impacts of the Covid-19 pandemic and the continuous advancements in digital devices and tools. Schools across the nation have adopted computers, tablets, and virtual 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 and a scroller connected to a customized PCB device. These buttons and the scroller 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 stronger and healthier 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

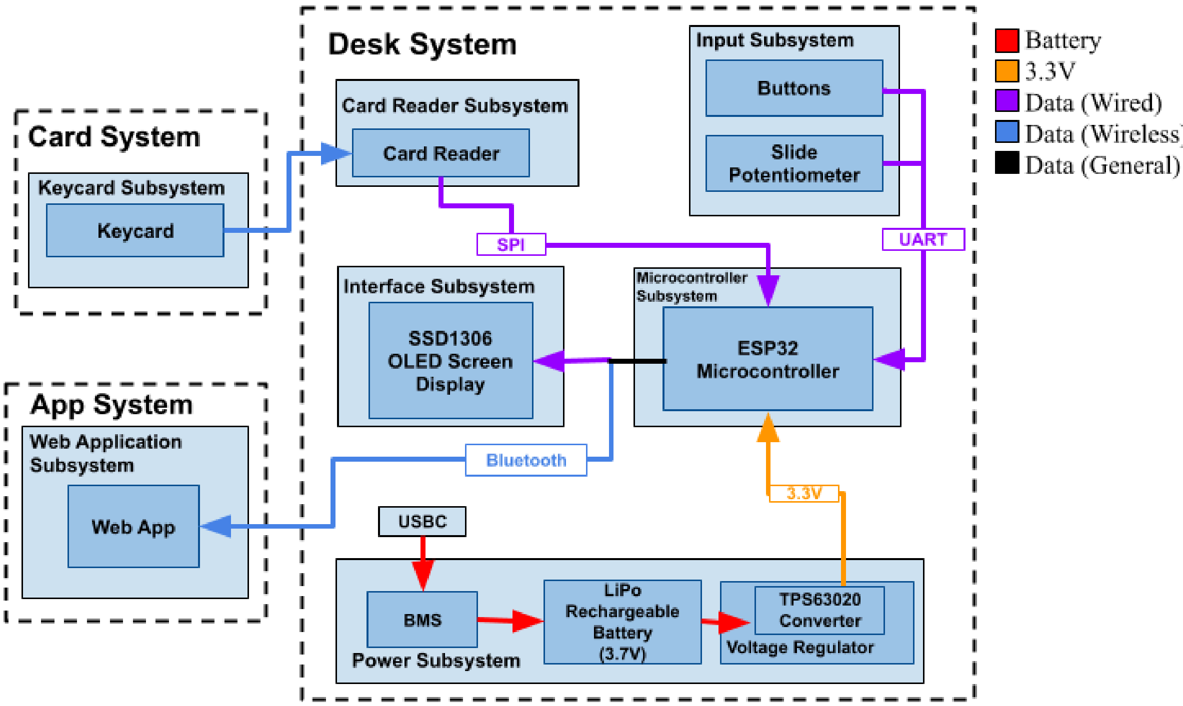


1.4 High-Level requirement list

1. The microcontroller and subsequently the PCB device must establish a low-latency and secure bluetooth connection with the web application to ensure that RFID scanning is authenticated and sent to the application and that data collected from button/scroller interaction is secure.
2. The web application must receive user data and provide personalized feedback and engagement tracking that includes; machine learning engagement analysis/feedback, notifications for participation, and a variety of dashboards.
3. The screen must be able to display the user's RFID card name when the user scans in, confirm answer selections, notify users of any errors, and relay notifications from the web application.

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 Web app run by the teacher.

2.2.3 Web Application

The Web 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 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 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

2.2.6 Interface Subsystem

(SSD1306 0.96" OLED Display (I²C))
This subsystem will include a basic interface that serves several purposes:

Will display the user's name once the user check's in thus verifying the check-in. Will display a range of emotions that students can select via their scroller. Will display the answer choice selected by the user for comprehension checks.

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 Web 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 Bluetooth, ensuring real-time updates without reliance on wired connections.

Requirements:

- Must process all inputs and transmit data to the Web 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 Web Application Subsystem

The Web 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.

The key components that need to be considered include the microcontroller, RFID system, display screen, and power subsystem. The input subsystem draws no power as it consists only of analog input devices.

The ESP32 S3 microcontroller operates at 3.3V. In deep sleep mode, it draws around 10µA of current. Since we will be using Bluetooth, it should draw lower current than if we were to be using Wi-Fi transmission. We can estimate the current draw of the ESP32 to be around 50mA at maximum.

For the RFID module, it operates at 3.3V and draws up to 26mA of current. The display also operates at 3.3V and draws up to 20mA of current. That means in total, the system will draw around 100mA of current at 3.3V, meaning that in total it will draw 0.33W of power.

Since our battery provides a 3.7V voltage to the system, we need to use a voltage regulator in order to get the 3.3V input that we desire. For this, we chose the **TPS63020 buck-boost converter** from TI. This converter would be able to provide an efficiency of about 0.92, meaning the total power supplied is equal to 0.33W/0.92 = 0.36W.

In the case where the device will operate for the maximum of an 8-hour school day, the battery will need to provide 2.87Wh of energy to the system.

The total required capacity of the battery is the daily energy needed divided by the battery voltage—or, 2.87Wh / 3.7V = 775mAh. Thus, the LiPo battery we have chosen fits this task, as it has a capacity of 2000mAh.

Requirements:

- Must supply a stable 3.3V to the ESP32-S3 microcontroller
- Must provide at least 1000mAh capacity to support continuous operation for a full school day.
- 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 Interface Subsystem (SSD1306 0.96" OLED Display, I²C)

The Interface Subsystem provides real-time visual feedback through a small OLED display, showing the student's name upon successful login, allowing them to select from a range of emotions via the scroller, and confirming their chosen comprehension check answers. By rendering these updates promptly and clearly, this subsystem ensures that students receive immediate confirmation of their actions, enhancing usability and trust in the system. It directly supports the high-level requirement of creating an intuitive, interactive learning environment that minimizes disruptions.

Requirements:

- Must be able to display the user's name within 2 seconds after authentication
- Must provide clear and legible text/icons for selected answers and emotions

2.3.7 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 **Web 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 Web application.
- The **Interface Subsystem** receives information from the microcontroller and displays real-time feedback—such as a student's name, answer selections, and emotional status—to confirm user inputs and enhance the overall user experience.

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

A primary risk in our design involves the reliability and scalability of the Bluetooth Low Energy (BLE) link when 20 student devices simultaneously connect to the teacher's console or computer in a typical classroom. If wireless communication becomes congested, student responses may fail to appear on the teacher's dashboard, undermining the core functionality.

Link-Budget Calculation

We begin by assessing whether a single device can reliably transmit and receive BLE signals in a 10 m indoor environment, which is a realistic classroom scenario:

1. **Path Loss**

    Using the log-distance path loss equation, $PL(d) = PL(d\_0) + 10n\, log\_10(d / d\_0)$

    PL(d_0) ≈ 40dB at d_0=1m for 2.4 GHz indoors.

    n≈2.7 (path loss exponent in a cluttered classroom).

    d=10m.

    Plugging in

    $PL(10\, m) = 40\, dB + 10 \times 2.7 \times log\_10(10) = 40 + 27 = 67\, dB$

2. **Transmit Power & Receiver Sensitivity**

- Typical BLE transmit power on the ESP32-S3 can be around **+4 dBm**.
- With an antenna gain near **0 dBi**, the **Effective Isotropic Radiated Power (EIRP)** is still about +4 dBm.
- Many BLE modules maintain a **receiver sensitivity of about −90 dBm** at a 1 Mbps data rate.

3. Received Power & Link Margin

$$P\_R = P\_TX + G\_TX - PL(d) = (+4\,dBm) - 67\,dB = -63\,dBm$$

$$Link\ Margin = (Receiver\ Sensitivity) - P\_R = (-90\,dBm) - (-63\,dBm) = 27\,dB$$

This 27 dB margin shows the signal remains reliably above the sensitivity threshold, even considering typical interference. Our analysis suggests the BLE signal should experience <1% packet error under normal classroom conditions at ~10 m range.

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 Web 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 Web 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.

4. References

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