# DESK AID LEARNING DEVICE

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# Abstract

The following report provides an overview of the Desk Learning Aid Device. It also provides a walkthrough of its construction through the design decisions that our team made.

The Desk Aid Learning Device is intended to facilitate learning in elementary and middle school classrooms by providing a streamlined method for student participation. Furthermore, it allows teachers to collect useful data regarding student comprehension of various subjects. The advantage of the Desk Aid Learning Device in comparison to other methods of integrating technology in the classroom is that it serves only its intended purpose, which is to facilitate learning, rather than also providing potential distractions that can disrupt the learning environment.

# Contents

# 1. Introduction

## Purpose and Functionality

### 1.1.1 Problem Statement

The integration of technology into schools is largely seen as a positive in terms of facilitating learning. Schools across the nation have begun to adopt computers, tablets, and other virtual learning platforms to enhance the educational experience. However, these technologies also introduce various problems, such as providing potential distractions for younger students. Studies show that prolonged interactions with screens can lead to worse social skills and shorter attention spans, as well as a decrease in mental or 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.

### 1.1.2 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 with 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.

### 1.1.2 Functionality

Successful design and construction of the device should result in the device's functionality satisfying the following high-level requirements:

1. The microcontroller and subsequently the PCB device must establish a low-latency and secure Wi-Fi 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. This requirement ensures that our device can interact with the web application to facilitate the transfer of data.
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. This requirement ensures that the web application enhances the learning environment by providing analysis of the input data to the teacher.
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. This requirement engages students in an active learning environment by providing feedback and facilitating discussion in the classroom.

## 1.1 Subsystem Overview

1.2.1 Visual Aid

The following images highlight the visual aid for our device and the final device design itself.

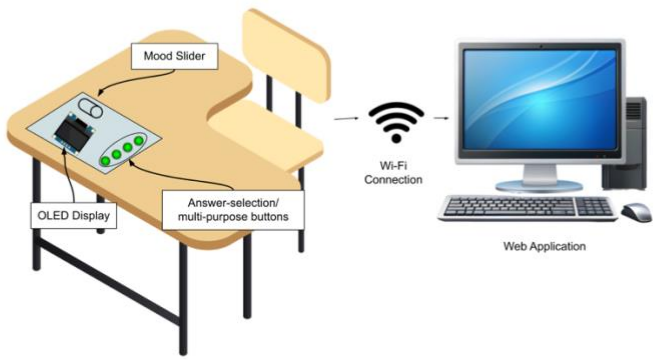


Figure 1: Visual representation of the device setup

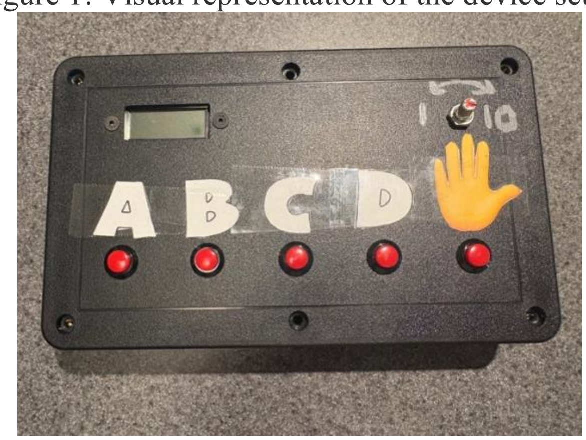


Figure 2: Visual Picture of the final device

## Block Diagram and Subsystem Descriptions

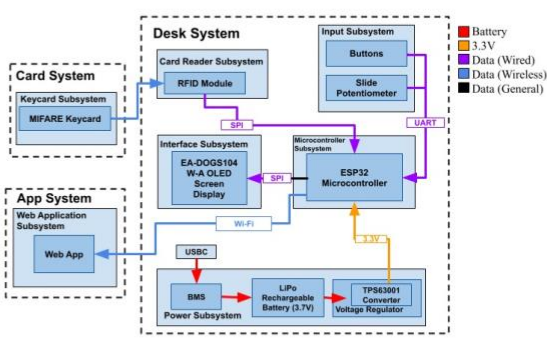


Figure 3: The device block diagram

The block diagram above accurately depicts the three main systems of the Desk Learning Aid Device. The Card System is composed of the keycard subsystem which will interact with the card reader to transmit user data to the microcontroller. The Desk System is composed of several subsystems including the card reader, input, interface, microcontroller, and power subsystems. The card reader and input subsystems transmit data via wired connection to the microcontroller while the power subsystem is used to power the microcontroller and the card reader. In turn, the microcontroller transmits data to the interface and web application. The App System is composed of the web application that will receive user data from the microcontroller and perform data cleansing, analysis, and display data visualizations.

# 2 Design

## 2.1 Input Subsystem

### 2.1.1 Input Subsystem Diagrams & Schematics

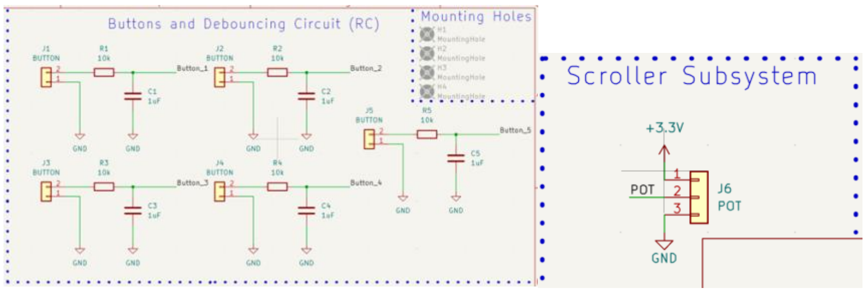


Figure 3: The input subsystem schematic including the scroller and the five buttons

### 2.1.2 Input Subsystem Design Description & Justification

This subsystem will include response buttons for comprehension checks, request for assistance buttons, feedback buttons, and mental/emotional health check-in buttons. The advantage of 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 turntable knob that will enable students to indicate in real-time how they are feeling throughout the day, on a scale from 0 to 10. The Input Subsystem is responsible for capturing student interactions through a set of designated buttons and a rotary scroller.

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.

### 2.1.3 Input Subsystem Design Alternatives

Design alternatives implemented for this subsystem include the following:

- RC Low-Pass Debouncing Circuits to stabilize input from the buttons
    - These circuits ensure each button is connected in series with a 10K resistor and a 1uF capacitor to capture an RC time constant of t = R*C = 10,000 * 1 x 10^-6 = 10ms. This is a reasonable and effective time constant to ensure bounces are suppressed and button presses feel responsive.

## 2.2 Microcontroller Subsystem

### 2.2.1 Microcontroller Subsystem Diagrams & Schematics

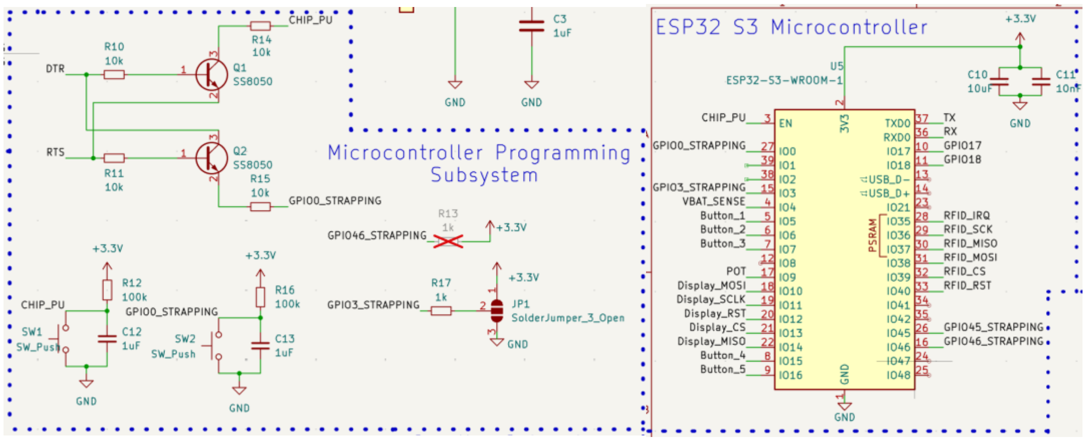


Figure 4: The ESP32 S3 Microcontroller Schematic

### 2.2.2 Microcontroller Subsystem Description & Justification

The Microcontroller Subsystem is the core processing unit of the Desk Learning Aid Device. It is responsible for receiving inputs from the Input Subsystem, processing RFID/NFC authentication, and transmitting data to the Web Application Subsystem via a low-latency wireless connection. The microcontroller also interfaces with the Power Subsystem to ensure efficient energy consumption and proper power regulation.

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 is responsible for receiving inputs from our input subsystem, processing RFID/NFC authentication, and transmitting data to the Web App Subsystem via Wi-Fi. The microcontroller also interfaces with the Power Subsystem to ensure efficient energy consumption and proper power regulation.

We have chosen the ESP32-S3 as the microcontroller for this project due to its built-in Wi-Fi capabilities, low power consumption, and sufficient processing power to handle real-time student interactions. The ESP32-S3 facilitates seamless communication with all connected components while maintaining reliable data integrity.
The microcontroller plays a pivotal role in ensuring the seamless operation of the Desk Learning Aid Device. It performs the following functions:

- **Processing Input Signals:** Captures, processes, and classifies button presses and scroller adjustments from the Input Subsystem.
- **Wireless Data Transmission:** Transmits processed student data, including response selections and engagement metrics, to the Web Application Subsystem over Bluetooth Low Energy (BLE).
- **RFID/NFC Authentication:** Interfaces with the RFID/NFC Subsystem to authenticate students and ensure secure login via their assigned keycards.
- **Display Control:** Sends processed input data to the Interface Subsystem (OLED display) to provide real-time visual feedback.
- **Power Management:** Efficiently manages power consumption by utilizing deep sleep modes when idle to prolong battery life.

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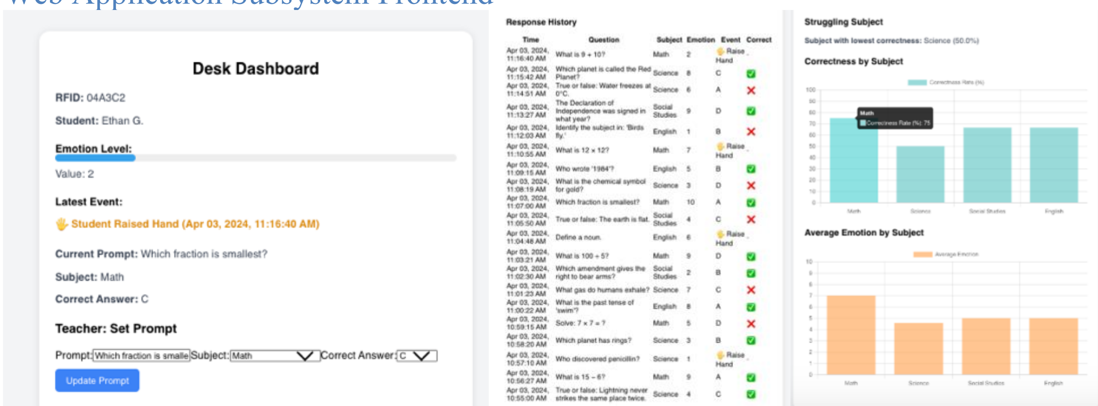
### 2.2.3 Microcontroller Subsystem Design Alternatives

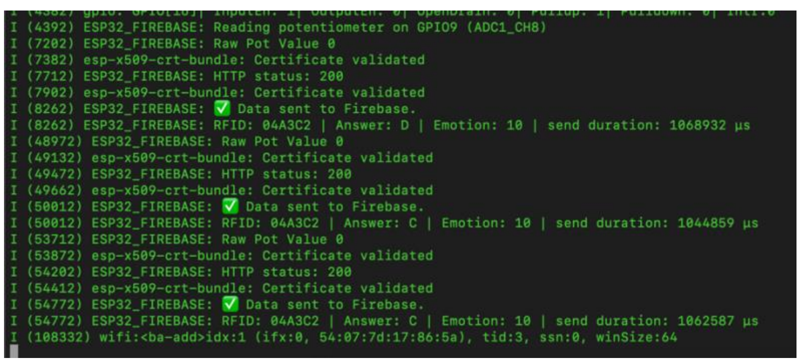
For the microcontroller's communication with the web application, we switched from using a Bluetooth connection to a Wi-Fi one primarily for ease of use. Since we were using a web application, a Wi-Fi connection made sense, since most schools have access to Wi-Fi capabilities.

## 2.3 Web Application Subsystem

### 2.3.1 Web Application Subsystem Frontend




### 2.3.2 Web Application Subsystem Backend




### 2.3.3 Web Application Subsystem Description

The Web Application Subsystem serves as the central interface for teachers to monitor student engagement, track participation, and adjust lesson pacing in real time. The application receives live data from student devices via Wi-Fi, aggregates responses, and presents the information in a structured and visual manner. The teacher's dashboard provides insights into student comprehension trends, assistance requests, and overall participation.

This subsystem is crucial to the overall Desk Learning Aid Device as it ensures that data collected from students is efficiently processed, stored, and displayed for meaningful classroom insights. Additionally, the RFID/NFC authentication system is integrated into the web app, allowing teachers to track attendance and student engagement over time.

1. **Frontend UI:**
   - Built with React for modular, scalable, and real-time updates.
   - Intuitive dashboard with easy-to-read visual indicators.
2. **Backend & Communication:**
   - Firebase Realtime Database provides instant synchronization between student devices and the teacher's dashboard.
   - Wi-Fi integration with ESP32-S3 devices ensures low-latency data transfer.
3. **Data Processing & Visualization:**
   - D3.js or Chart.js generates engagement heatmaps, comprehension graphs, and response summaries.
4. **Authentication & Security:**
   - Google OAuth and school credentials provide secure access.

### 2.3.4 Web Application Subsystem Design Alternatives

We initially considered using Bluetooth Low Energy (BLE) for communication between the student devices and the web application. We switched from BLE to Wi-Fi due to the limited range and unreliable connectivity for the final design. This ensured stable, low-latency communication and better integration with Firebase Realtime Database. We also explored using a custom backend server for storing and processing student responses, but opted for Firebase to reduce complexity, accelerate development, and leverage its native support for real-time updates. If future scaling demands exceed Firebase’s capabilities, migration to a dedicated backend can be quantitatively evaluated.

## 2.4 Power Subsystem

### 2.4.1 Power Subsystem Diagrams & Schematics

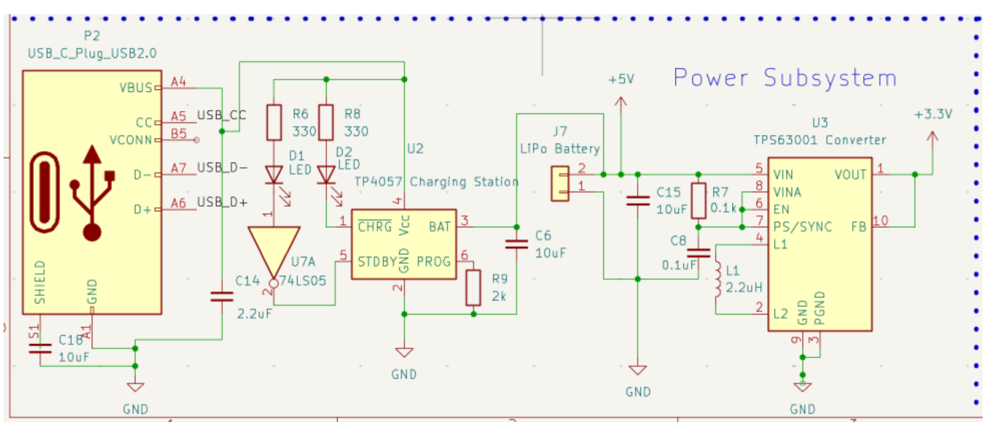



Figure 6: The Power Subsystem Schematic

### 2.4.2 Power Subsystem Description

The power subsystem should provide power to the rest of the device and allow it to operate, aside from the web application. This should include the microcontroller system, RFID system, and display system. It should include a rechargeable battery so that the device can be in operation throughout the school day and recharged afterwards. This is preferable in comparison to wired power for installation and cable management reasons.

For these purposes, we have chosen the following parts:

- 103454 LiPo rechargeable battery
- TPS63001DRCR buck-boost converter

The LiPo battery has a capacity of 2000mAh and provides a 3.7V input. This is more than enough power for our purposes:

- ESP32 S3 microcontroller: 3.3V input, 50mA maximum current draw (BLE mode)
- RFID module: 3.3V input, 26mA maximum current draw
- OLED display module: 3.3V input, 20mA maximum current draw
- Total current draw: <100mA → capacity needed: <800mA

### 2.4.3 Power Subsystem Design Alternatives

The choice of the battery was based on the need to supply voltage for an entire school day while being able to fit unobtrusively within the device itself. Since the battery provided a 3.7V output, we chose the buck-boost converter for its efficiency in converting that to the 3.3V we needed for the ESP32.

One oversight when designing the power subsystem occurred when we placed the USB-C port on the PCB layout. Placing the port too far from the edge of the PCB meant that we were unable to plug an external power supply to the PCB, and thus were unable to complete the circuit that would have allowed the device to recharge.

### 2.4.4 Power Subsystem Equations & Simulations

The buck-boost converter is used to convert the 3.7V battery input to the 3.3V operating voltage we need for our parts. This converter has roughly ~90% efficiency and thus the total power supplied will be equal to the following:

(3.3V x 100mA) x 90% efficiency = 0.36W

Thus, the total battery capacity required is equal to the total daily energy needed divided by the battery voltage:

0.36W x 8h / 3.7V=1086mAh

Thus, the battery has enough capacity to support the full operation of the device.

## 2.5 RFID/NFC (Keycard) Subsystem

### 2.5.1 RFID/NFC (Keycard) Subsystem Diagrams & Schematics

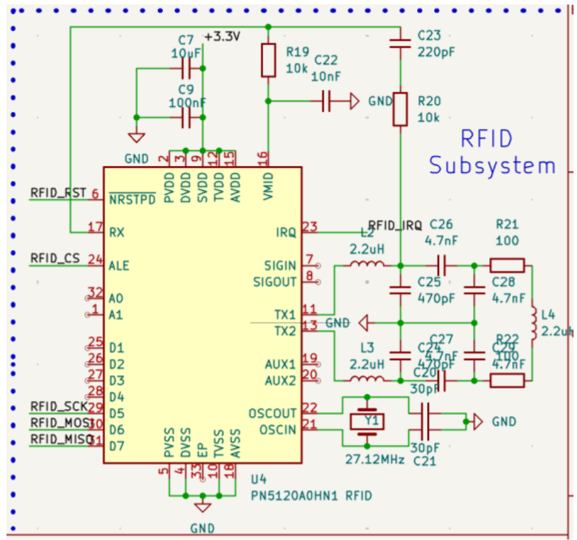



Figure 7: The RFID Subsystem Schematic

### 2.5.2 RFID/NFC (Keycard) Subsystem Description

The RFID/NFC Subsystem provides a seamless and low-disruption authentication method for students using RFID keycards. This eliminates the need for manual name entry or personal devices, ensuring quick and anonymous login. By simply tapping their keycard, students authenticate their presence, enabling teachers to monitor participation and engagement trends efficiently.

This subsystem plays a critical role in ensuring that only authenticated students can interact with the system, linking each student to their corresponding desk device. It prevents unauthorized participation, ensures accurate attendance tracking, and integrates directly with the Web Application Subsystem for real-time updates.

The RFID subsystem functions through a circuit that is centralized around the PN512 electrical component.

- Oscillator Circuit:
    - There is a crystal oscillator circuit with a 27.12 MHz crystal (the electrical component that we were unable to receive)
    - C21 and C24 are used to stabilize the crystal oscillator
- Matching Network:
    - L2, L3, L4, C25, C26, C27, C28, C29, C20, C22 are used for impedance matching and filtering network
    - This network ensures efficient RF energy transfer by tuning transmitter output and improving RFID tag detection
    - The RF signal paths that interface with this network invoice SIGIN, SIGOUT, and TX1 and TX2
- The oscillator circuit generates a 27.12 MHz clock that feeds the internal logic and the RF carrier generation circuit of the PN512. The microcontroller then sends commands to the PN512 which enables the PN512 to begin transmitting a 13.56 MHz RF signal from TX1/TX2. The LC network acts as a matching network and antennae driver that emits an RF field to energize passive RFID tags. A nearby passive RFID tag receives the RF field

and powers up. The tag modulates its load, which changes the current in the field (load modulation). The PN512 senses this modulation through SIGIN/SIGOUT paths. It then sends the RFID tag data to the microcontroller.

### 2.5.3 RFID/NFC (Keycard) Subsystem Design Alternatives

For the RFID reader, we considered both the RC522 and PN512 modules. While the RC522 was more cost-effective, it lacked robust support for ISO/IEC 14443 Type B and had weaker signal reliability in preliminary tests. The PN512 offered greater compatibility, more reliable range, and a faster data transfer rate via SPI, making it better suited for our real-time classroom environment.

## 2.6 Interface Subsystem

### 2.6.1 Interface Subsystem Diagrams & Schematics

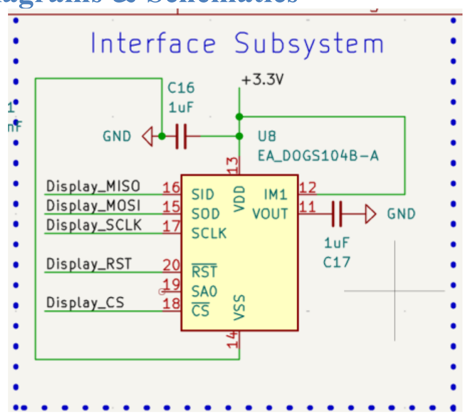



Figure 8: The Interface Subsystem Schematic

### 2.6.2 Interface Subsystem Description

This subsystem will include a basic interface that serves several purposes:

- Will display the user's name once the user checks 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.

The Interface Subsystem is comprised of a small LCD display to provide real-time visual feedback to students. It shows students' names upon successful login as well as displaying answer choices and comprehension ranges. It provides students with immediate confirmation of their actions, leading to enhanced usability and trust in the system.

The EA-DOGS104W-A display is controlled through a dedicated firmware program running on the microcontroller, continuously monitoring input from the RFID, potentiometer, and buttons. The program fetches the student's name from the database and updates the display accordingly. Upon button presses, it displays the corresponding input as well as the emotion level. The display communicates with the microcontroller via an SPI interface to ensure low-latency and efficient data transfer.

### 2.6.3 Interface Subsystem Design Alternatives

We initially considered using an OLED screen (e.g., SSD1306) for the student interface due to its wide availability and existing Arduino support libraries. However, after evaluating screen size, resolution, and compatibility with our SPI-based communication setup, we chose the EA-DOGS104W-A LCD display. Its segmented structure offered better legibility for static text like names and answer choices, and its contrast and sunlight visibility were better suited for varied classroom lighting conditions. In addition, originally the connector for the interface subsystem was incorrect as well so we had to change it to a surface mount part.

# 4. Costs

## 4.1 Parts

The following table lists the key components and estimated costs required for the project:

| Part | Manufacturer | Part # | Qty | Cost | Total |
|---|---|---|---|---|---|
| ESP32-S3 Microcontroller | Espressif Systems | ESP32-S3-WROOM-1-N16R2 | 2 | 5.53 | 11.06 |
| Lithium Polymer Rechargeable battery | EEMB | LP103454 | 2 | 11.89 | 23.78 |
| Buck-Boost Converter Voltage Regulator | TI | TPS63001DRCR | 2 | 1.95 | 3.90 |
| Near-Field Communication Front-End module | NXP | PN512 | 1 | 8.97 | 8.97 |
| Character Display Screen | Mouser | EA-DOGS104W-A | 2 | 16.27 | 32.54 |
| Hex Inverter | TI | SN74LS05 | 6 | 0.75 | 4.50 |
| Charging Station | EVVO | TP4057 | 4 | 0.41 | 1.64 |
| USB-Serial Converter | JESSINIE | CH340G SOP-16 | 1 | 6.95 | 6.95 |
| USB Plug | JAE Electronics | DX07S016JA1R1500 | 2 | 1.51 | 3.02 |
| Potentiometer | Bourns | PDB181-E415K-102B | 1 | 1.30 | 1.30 |
| LiPo Rechargeable Battery | EEMB | LP103454 | 1 | 11.99 | 11.99 |
| Illuminated Push Buttons | Adafruit | 492 | 5 | 3.95 | 19.75 |
| 1uF capacitor | KEMET | C0805C105K5PACTU | 9 | 0.28 | 1.81 |
| 10uF capacitor | KEMET | C0805C106K8PACTU | 10 | 0.07 | 0.67 |
| 0.1 uF capacitor | KEMET | C0805C104M5RACTU | 3 | 0.10 | 0.30 |
| 10nF capacitor | KEMET | C0805X103K1RAC3316 | 2 | 0.16 | 0.32 |
| 2.2uF capacitor | KEMET | C0805C225K8RACTU | 1 | 0.20 | 0.20 |
| 30pF capacitor | KEMET | C0805C300M5HACTU | 2 | 0.10 | 0.20 |

| | | | | | |
|---|---|---|---|---|---|
| 220pF capacitor | Samsung Micro-electronics | CL21C221JBANNNC | 1 | 0.10 | 0.10 |
| 470pF capacitor | KEMET | C0805C471K5RACTU | 2 | 0.10 | 0.20 |
| 4.7nF capacitor | KEMET | C0805C472K1GECTU | 4 | 0.22 | 0.88 |
| 2.2uH inductor | TDK corporation | MLZ2012M2R2HT000 | 4 | 0.10 | 0.40 |
| 10kΩ resistor | Panasonic | ERJ-P06F1002V | 11 | 0.086 | 0.95 |
| 330Ω resistor | Bourns | CR0805-JW-331ELF | 2 | 0.10 | 0.20 |
| 100Ω resistor | Panasonic | ERJ-6ENF1000V | 3 | 0.11 | 0.33 |
| 2kΩ resistor | Stackpole | RMCF0805FT2K00 | 1 | 0.10 | 0.10 |
| 100kΩ resistor | YAGEO | RC0805FR-07100KL | 2 | 0.10 | 0.20 |
| 1kΩ resistor | YAGEO | RC0805FR-071KL | 2 | 0.012 | 0.12 |
| 5.1kΩ resistor | YAGEO | RC0805JR-075K1L | 1 | 0.08 | 0.08 |
| Push button switch | Same Sky | TS02-66-60-BK-160-LCR-D | 2 | 0.10 | 0.2 |
| 27.12 MHz crystal oscillator | NDK | LNCD1-25M | 1 | 0.54 | 0.54 |
| Red LED | Cree LED | C5SMF-RJF-CT0W0BB2 | 2 | 0.17 | 0.17 |
| NPN Epitaxial Silicon Transistor | Comchip | SS8050 | 2 | 0.24 | 0.48 |

**Total Cost of Parts**: $137.85

Machine Shop & Equipment Costs
Some components require custom machining or soldering:

| Service | Estimated Hours | Hourly Rate ($) | Total Cost ($) |
|---|---|---|---|
| PCB Assembly | 5 | 42.55 | 212.75 |

Total Machine Shop Cost: $212.75

## Grand Total Cost

| Category | Total Cost ($) |
|---|---|
| Labor | 21,600 |
| Parts | 137.85 |
| Machine Shop | 212.75 |

| | |
|---|---|
| Final Cost | 21,950.60 |

## 4.2 Labor

To estimate labor costs, we assume an average salary for an ECE graduate at UIUC. According to recent salary surveys, the median starting salary for an Electrical and Computer Engineering graduate from UIUC is approximately $45 per hour. The labor cost formula is:

Assuming each team member works 10 hours per week over 12 weeks:

- **Total Hours per Person** = 10×16=160
- **Total Labor Cost**= 45×3×160= $21,600

## 4.3 Schedule

| Week | Date | Task | Team Members |
|---|---|---|---|
| 1 | 2/26 - 3/3 | - Finalize architecture & system design (Block Diagram, High-Level Requirements)<br>- Select and order key components for the first prototype<br>- Prepare for Design Document submission | All |
| 2 | 3/4 - 3/10 | - Design Document Due (3/3)<br>- First Round PCBWay Order (Must Pass Audit by Today, 3/3)<br>- Start initial breadboard prototyping and circuit validation<br>- Develop firmware skeleton for microcontroller functionality | All |
| 3 | 3/11 - 3/17 | - Breadboard Demonstration with Instructor & TA (3/10)<br>- Test basic component functionality (buttons, RFID reader, OLED display)<br>- Validate Bluetooth Low Energy (BLE) communication with web app<br>- Second Round PCBWay Order (Must Pass Audit by Today, 3/10) | All |
| 4 | 3/18 - 3/24 | No work scheduled | None |
| 5 | 3/25 - 3/31 | - Refine PCB design and address any issues from breadboard testing<br>- Test battery power consumption and efficiency<br>- Start developing microcontroller drivers for all subsystems | Ethan, Aidan |
| 6 | 4/1 - 4/7 | - Third Round PCBWay Order (Must Pass Audit by Today, 3/31)<br>- Individual Progress Reports Due (3/31)<br>- Assemble first PCB and perform functional testing<br>- Debug BLE communication and integrate with the web application | Conan, Ethan |
| 7 | 4/8 - 4/14 | - Fourth Round PCBWay Order (Must Pass Audit by Today, 4/7)<br>- Begin full system integration and initial software debugging<br>- Conduct power management tests and optimize battery life | Ethan, Aidan |
| 8 | 4/15 - 4/21 | - Team Contract Assessment Due (4/14)<br>- Start testing real-time classroom interactions with the web application<br>- Optimize PCB and firmware for responsiveness and low latency | Conan |

| | | | |
|---|---|---|---|
| 9 | 4/22 - 4/28 | - Mock Demo During Weekly TA Meeting<br>- Verify all high-level requirements are met<br>- Debug remaining issues in hardware/software integration | Conan, Aidan |
| 10 | 4/29 - 5/5 | - Final Demo with Instructor & TAs (4/28)<br>- Conduct system-wide performance testing<br>- Prepare presentation materials for final submission | All |
| 11 | 5/6 - 5/12 | - Final Presentation with Instructor & TAs (5/5)<br>- Final Papers Due (5/5)<br>- Lab Notebook Due (5/5)<br>- Award Ceremony (5/5)<br>- Perform final documentation and lab checkout | All |

# 5. Conclusion

## 5.1 Accomplishments

The finalized design of the Desk Aid Learning Device accomplished two high level requirements:

- The device establishes a low latency and secure Wi-Fi connection with the Web Application.
- The Web Application provides the proper analysis and feedback of student input through charts and machine learning.

The final functionality includes a device that can effectively process button presses and potentiometer changes. It can establish a Wi-Fi connection with the web application to send input information. The web application can then process, analyze, and provide feedback on the data. The backend of the application ensures data is stored so that the application can utilize a student's history to provide accurate analysis. Overall, the device is suitable for a classroom environment.

## 5.2 Uncertainties

Unsatisfactory results include the following:

- Failure to complete the RFID Subsystem:
    - We were unable to complete this subsystem since we were unable to obtain the 27.12 MHz crystal oscillator. This electronic component is crucial for the oscillator circuit that makes up the RFID Subsystem by generating an internal clock source for the PN512. We were unable to obtain this part due to it being put on backorder by the time the ECE 445 staff were able to accept the order.
- Failure to complete the Screen Subsystem:
    - We were unable to complete the subsystem and unable to display text on the screen due to improper initialization of the LCD display and improper pin connections for SPI communication with the ESP32. We need to add an external circuit to set up active Reset for the LCD display and set MOSI to SID and MISO to SOD from the microcontroller to the LCD display.
- Failture to complete the Power Subsystem:

- We were unable to complete the charging portion of the power subsystem due to the design of the PCB and the placement of the USB-C. A simple design error by not placing the USB-C on the edge of the board resulted in our design not allowing the full functionality of the charging circuit.

## 5.3 Ethical considerations

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".

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. **Bias**

It is crucial that no bias is introduced by the machine learning algorithm or through misinterpretations of the data being presented. It is essential that this algorithm is continuously tested throughout the school year to ensure fair recommendations and adjustments are made. 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".

4. **Inclusivity**

Ensuring the device follows ADA for those with disabilities is an essential aspect of our device. 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".

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.

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.

### 5.4 Future work

Based on our experience building the Desk Aid Learning Device, we have identified several areas for future improvement that would further enhance the usability of the device in the classroom setting. These improvements address critical lessons learning during the prototyping of the device:

**Active Reset Circuit for the Screen Subsystem:** The current LCD device design does not include an external active reset mechanism. Instead, this function is controlled by the microcontroller. This contributes to the initialization issues that our team faced when attempting to display text on the LCD device. Incorporating an external reset circuit will ensure consistent power-on behavior and improve overall system stability.

**Correct SPI Port Connections for Screen Subsystem:** During evaluation of the LCD device design, we recognized that the SPI port connections were misaligned: the MISO line was incorrectly connected to SID, and the MOSI line to SOD. In future revisions of the PCB design, these connections must be reversed to enable proper communication between the microcontroller and the LCD display.

**Haptic Feedback Functionality:** To streamline accessibility and enhance classroom engagement, we plan to integrate haptic feedback into the next version of the device. This would further the inclusivity of our device by enabling students with visual impairments to utilize the device. It would also improve engagement across different learning styles.

These improvements are critical in increasing the usability, reliability, and inclusivity of the device in a real-world classroom deployment.

## References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# Appendix A Requirement and Verification Table

**Table 1: Input Subsystem Requirements and Verifications**

| Requirements | Verification | Status |
|---|---|---|
| The input subsystem must transmit button and scroller data to the microcontroller with less than 100 ms latency. | 1. Connect an oscilloscope to the button/scroller input lines and the corresponding microcontroller GPIO pins.<br>2. Measure the time difference between input signal detection and GPIO response through button presses / scroller adjustments.<br>3. Ensure that the time difference is less than 100 ms for 100 consecutive trials of button presses / scroller adjustments. | Y |
| The input subsystem must effectively debounce and filter out noise. | 1. Connect an oscilloscope to the button/scroller input lines.<br>2. Perform rapid button presses and scroller adjustments.<br>3. Verify that no spikes or bouncing occurs and that the inputs remain stable. | Y |
| The input subsystem must be robust enough to handle repeated presses over an extended period. | 1. Connect an oscilloscope to the button/scroller input lines and the corresponding microcontroller GPIO pins.<br>2. Setup an automated actuator that will press buttons and make scroller adjustments at repeated intervals of time.<br>3. Record input data logs over an 8-hour session.<br>4. Review the input data logs to ensure that the inputs remained stable with low latency and no bouncing over the course of the session. | Y |

**Table 2: Microcontroller Subsystem Requirements and Verifications**

| Requirements | Verification | Status |
|---|---|---|
| The microcontroller must process all button and scroller inputs and transmit data to the Web Application within 1500ms. | 1. Connect an oscilloscope to a button GPIO pin and monitor the time delay between button press and BLE transmission.<br>2. Measure the time difference between input signal detection and data reception in the Web Application logs to ensure that total difference is less than 500ms. | Y |
| The microcontroller must reliably interface with the RFID/NFC Subsystem to authenticate student keycards within 2 seconds of scanning. | 1. Tap an RFID keycard on the reader.<br>2. Measure the time taken for the student's name to appear on the OLED display.<br>3. Ensure it is within the 2-second threshold. | N |
| The microcontroller must operate continuously for a full 8-hour school day on battery power. | 1. Fully charge the 2000mAh LiPo battery.<br>2. Continuously operate the microcontroller under normal classroom conditions.<br>3. Measure battery voltage at the end of 8 hours and ensure it remains above 3.3V. | Y |

**Table 3: Web Application Subsystem Requirements and Verifications**

| Requirements | Verification | Status |
|---|---|---|
| The web application must receive and process student data updates within 500ms. | 1. Set up a test environment with an ESP32-S3 sending timestamped BLE packets.<br>2. Log timestamps upon reception in Firebase.<br>3. Calculate the time difference and ensure it is ≤500ms. | Y |
| The web application must display real-time classroom engagement metrics with a refresh rate of at least once per second. | 1. Simulate 20 student devices using a single ESP32-S3 by cycling through 20 virtual device IDs and sending 20 BLE packets per second (one per virtual student).<br>2. Ensure that each packet contains a unique student ID and a sample button press or scroller value.<br>3. On the web application dashboard, log received student responses and timestamps.<br>4. Verify that the dashboard updates at least once per second, displaying the latest engagement metrics.<br>5. Introduce random packet delays or drops to simulate real-world BLE interference and check if the dashboard still maintains accurate updates. | Y |
| The system must authenticate users correctly before allowing access to student data, ensuring only authorized teachers can view responses. | 1. Implement Google OAuth and school credential authentication.<br>2. Attempt to access the system without authentication and verify that access is denied.<br>3. Ensure that only registered teachers with valid credentials can log in and view student data.<br>4. Conduct a session expiration test to confirm that users must re-authenticate after a timeout or logout. | Y |

**Table 4: Power Subsystem Requirements and Verifications**

| Requirements | Verification | Status |
|---|---|---|
| The battery continually provides at least a 3.0V output over the duration of the school day (8 hours) | 1. Fully charge the 2000mAh LiPo battery.<br>2. Continuously operate the microcontroller under normal classroom conditions.<br>3. Measure battery voltage at the end of 8 hours and ensure it remains above 3.0V. | Y |
| The voltage regulator system maintains the input voltage between 3.0V and 3.6V as indicated by the microcontroller datasheet. | 1. Set the input voltage (Vin) to the typical expected operating value (3.7V).<br>2. Measure and record the output voltage (Vout) at the regulator output.<br>3. Verify that Vout is within 3.0V to 3.6V. | Y |

**Table 5: RFID/NFC (Keycard) Subsystem Requirements and Verifications**

| Requirements | Verification | Status |
|---|---|---|
| The system must successfully authenticate RFID keycards when tapped on the reader. | 1. Power on the system and tap a valid MIFARE 13.56 MHz keycard on the PN512 reader.<br>2. Verify that the ESP32-S3 microcontroller correctly receives and displays the UID. | N |

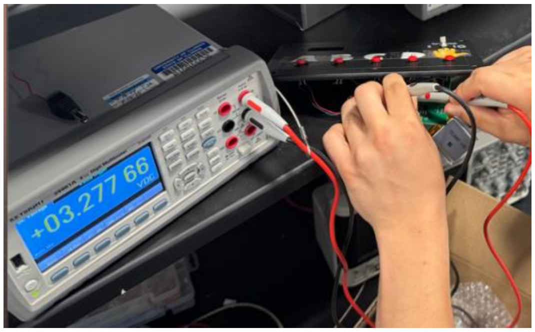
| Requirements | Verification | Status |
|---|---|---|
| | 3. Ensure that the UID is transmitted to the Web Application and correctly linked to a student profile. | |
| The system must differentiate students' RFID keycards to prevent duplicate logins. | 1. Assign two students RFID keycards with different UIDs.<br>2. Tap each card and verify that the system correctly distinguishes between the two students.<br>3. Attempt to use the same RFID card for two different students and ensure that the system rejects duplicate registrations. | N |
| The authentication process must complete within 2 seconds of tapping a keycard. | 1. Use a timestamp logger to record when the card is tapped and when the student name appears on the LCD display.<br>2. Ensure that the time difference is ≤ 2 seconds. | N |

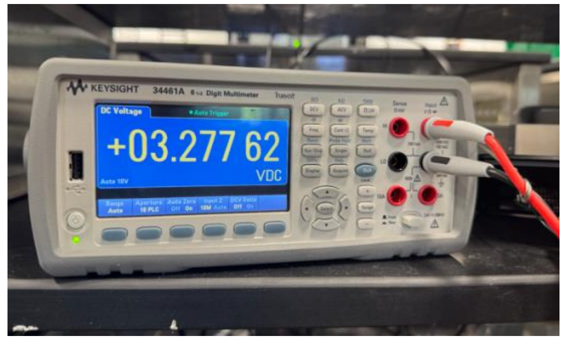
**Table 6: Interface Subsystem Requirements and Verifications**

| Requirements | Verification | Status |
|---|---|---|
| The interface subsystem must be able to display the user's name within 2 seconds after authentication with the RFID keycard. | 1. Scan the RFID keycard with the scanner.<br>2. Use a logic analyzer to accurately measure the time it takes from when the keycard is scanned to when the name appears on the interface.<br>3. Repeat this procedure for 100 trials.<br>4. Ensure that for at least 95% of cases (95 trials) that the name appears within 2 seconds. | N |
| The interface subsystem must provide clear and legible text/icons for selected answers and emotions | 1. Load test images of selected answers and emotions onto the display.<br>2. Conduct readability tests with various students.<br>3. Ensure that at least 95% of students correctly identify text/icons. | N |
| The interface subsystem must refresh within 100ms after receiving new data. | 1. Perform independent button presses and scroller adjustments.<br>2. Use an oscilloscope to accurately measure the time it takes from when an independent event occurs to when the display is updated.<br>3. Repeat this procedure for 100 trials per each independent event.<br>4. Ensure that for at least 98% of cases (98 trials) that the update delay is less than 100ms. | N |

# Appendix B Quantitative Results

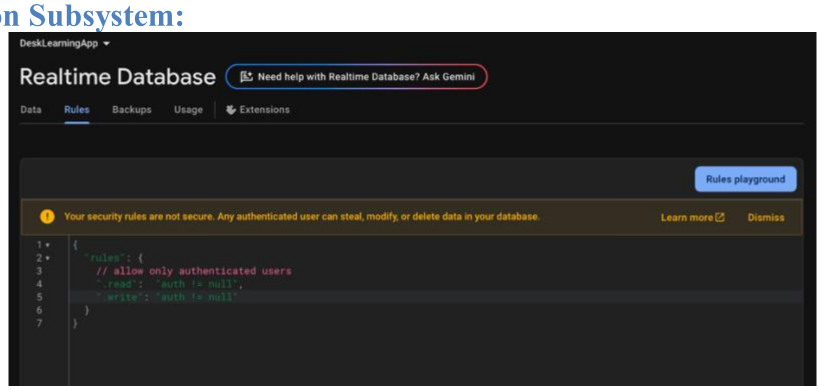
## Power Subsystem:



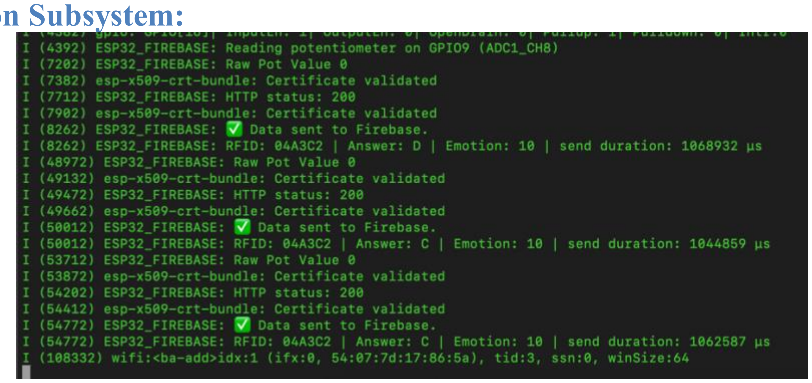

- The voltage regulator system maintains the input voltage between 3.0V and 3.6V at exactly 3.277 V to supply voltage to the microcontroller
- The battery continually provides at least a 3V output over the duration of the school day (8 hours)

## Web Application Subsystem:




- The system authenticates users correctly before allowing access to student data, thus ensuring only authorized teachers can view responses
- Updates front end within 500ms
- Refreshes at least once per second

## Web Application Subsystem:




- The microcontroller must process all button and scroller inputs and transmit data to the Web Application within 1500ms.
- Operates for full 8 hour school day

### Input Subsystem:

```
I (6352) gpio: GPIO[18]| InputEn: 1| OutputEn: 0| OpenDrain: 0| Pullup: 1| Pulldown: 0| Intr:0
I (6362) ESP32_FIREBASE: Reading potentiometer on GPIO9 (ADC1_CH8)
I (8572) ESP32_FIREBASE: Raw Pot Value 0
I (8572) ESP32_FIREBASE: RFID: 04A3C2 | Answer: D | Emotion: 10 | detect→send_start: 647 µs
I (8752) esp-x509-crt-bundle: Certificate validated
I (9082) ESP32_FIREBASE: HTTP status: 200
I (9282) esp-x509-crt-bundle: Certificate validated
I (9622) ESP32_FIREBASE: ✅ Data sent to Firebase.
```

- The button and scroller data is transmitted with less than 100 ms latency and the subsystem effectively debounces and filters out noisy input
- Supports repeated button presses and debouncing