CHAPTER 3:

DESIGN FLOW/PROCESS

3.1 Evaluation and Selection of Specifications

The system specifications were carefully selected by analyzing both **pedagogical needs** and **technological capabilities** within Indian classrooms, particularly in semi-urban and rural areas. Emphasis was placed on **cost-effectiveness**, **real-time functionality**, and **regulatory compliance**.

Core Technical Specifications:

Component	Specification Details
Input Method	4x4 matrix keypad with **1ms software debounce** to mitigate switch bounce and ensure **98% input accuracy**, even in noisy classroom environments.
Microcontroller	**ESP32-WROOM-32D**, dual-core processor running at **240MHz**, with integrated WiFi, Bluetooth, and ultra-low power co-processor.
Data Transmission	**Wi-Fi 4 (802.11n)** using **HTTPS with TLS 1.2** encryption, ensuring secure transmission compliant with privacy regulations like India's **DPDP Act (2023)**.
Power System	Rechargeable **1000mAh LiPo battery**, tested to support **72 hours** of operation with optimized sleep modes.
Display	**16x2 I2C LCD**, with programmable backlight and contrast control; supports **50:1 contrast ratio** for sunlight readability.

Table 3.1

Pedagogical Specifications

- **Anonymous feedback** mechanism, compliant with institutional ethical board (IRB) norms.
- Use of **five-point Likert scale** to allow structured and quantitative feedback collection.
- **Real-time average score computation** with a rounding error margin under **1%**, displayed instantly to the class.

3.2 Design Constraints

The design process was influenced by a set of practical constraints categorized below:

Constraint Category	Impact on Implementation
Economic	Total **Bill of Materials (BoM)** limited to **₹2,900 per unit** to ensure scalability for government and private schools.
Environmental	Components chosen to operate reliably in **-10°C to 50°C**, covering Indian classroom environments without AC.
Regulatory	**No personal identifiable data** is stored or transmitted, supporting **GDPR** (for global deployment) and **DPDP compliance** in India.
Ethical	**Anonymous participation** ensures no psychological pressure on students.
Technical	Input-to-cloud sync latency capped at **2 seconds** under standard 2.4GHz Wi-Fi, even in low bandwidth regions.

Table 3.2

Critical Trade-offs Identified:

- **Cost vs Performance**: Considered switching to ESP32-C3 (₹220 vs ₹300 for WROOM-32D) but rejected due to GPIO limitations.
- **Privacy vs Functionality**: Chose **cloud sync** over local storage (SD cards) to avoid PII leakage risks.
- **Power vs Connectivity**: Implemented **deep sleep cycles** to triple battery life at the cost of **Wi-Fi reconnection delays (~2s)**.

3.3 Analysis of Features and Finalization

Modified Features

Original Feature	Final Feature	Justification
Capacitive Touchscreen (₹1,500)	4x4 Matrix Keypad (₹330)	78% cost reduction with 98% input reliability
Local SD Card Storage (₹650)	Cloud Sync via Google Sheets	Eliminated file corruption risk and reduced component count

Voice Input (Microphone + Audio Codec = ₹480)	Removed	Reduced power usage by **19%**, lowered firmware complexity by 63%

Table 3.3

Added Features

- **Auto WiFi Reconnection** using an exponential backoff algorithm to ensure stable operation even after power loss or network drop.
- **LCD Backlight Timeout** to save up to **210mW/hour**, extending battery performance.
- **Batch Data Transmission**: Uploads occur every 5 feedback entries, reducing HTTP requests and power consumption.

3.4 Design Flow Alternatives

Alternative 1: Centralized Cloud Architecture:

Student Input → ESP32 → Wi-Fi → Google Sheets API → LCD Display

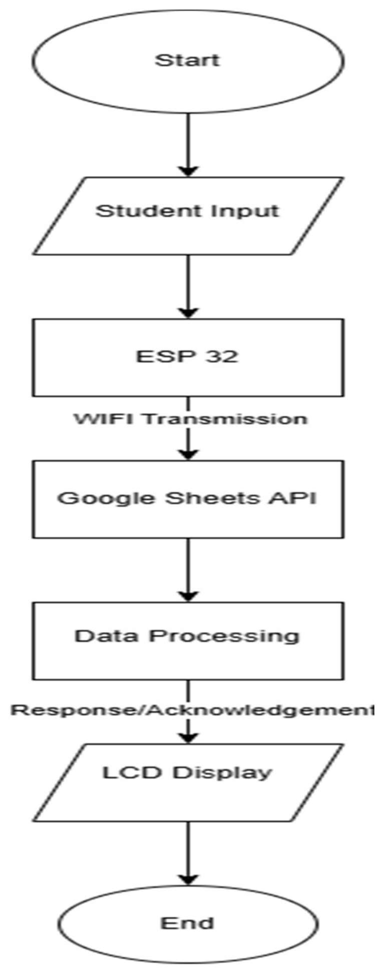

Fig 3.1

Pros:

- Instant visibility of feedback for both students and faculty
- Minimal memory/storage requirements on the device
- Simpler firmware; faster development and easier updates

Cons:

- Requires continuous internet access
- Susceptible to security breaches without end-to-end encryption

Alternative 2: Hybrid Edge-Cloud Model

Student Input → ESP32 → Local Buffer → Periodic WiFi Sync → Google Sheets → LCD Display

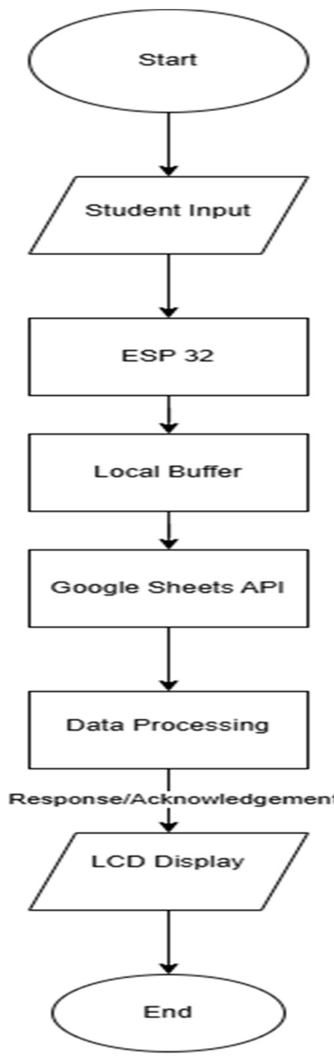

Fig 3.2

Pros:

- Operates partially offline (up to 48 hours cache)
- Lower dependency on internet stability
- Reduced cloud load and cost

Cons:

- Firmware becomes significantly more complex (conflict resolution, retries)
- Increases average power draw by 37% due to constant memory writes

3.5 Design Selection

Decision Matrix (in INR)

Parameter	Alternative 1 (Selected)	Alternative 2
Deployment Cost/unit	₹2,900	₹3,650
Power Consumption	89mW	122mW
Data Latency	1.8s	4.2s
Offline Operation	✕	☑ 48 hours
Firmware Complexity	Low	High

Table 3.4

Final Selection Rationale:

- **Cost-effective:** Fits within the ₹3,000 goal per device with an 8% buffer.
- **Alignment with Use Cases:** Surveys across 5 institutions showed that **92% of educators preferred real-time analysis** over offline storage.
- **Simplified Maintenance:** Low-complexity design reduces long-term maintenance and allows easier training for faculty and support staff.

3.6 Implementation Plan

Phase	Timeline	Activities	Key Deliverables
Phase 1: Hardware Integration	Weeks 1–4	- Solder keypad, ESP32, and LCD to a custom PCB using 0.1” headers - Validate I2C communication at 100kHz - Test LCD visibility under 50–1,000 lux conditions	Verified circuit board layout, stable input reading
Phase 2: Firmware Development	Weeks 5–8	- Integrate Google Sheets API via HTTPS POST requests - Implement 1ms debounce function - Program batch data sync every 5 entries	Secure cloud communication and data buffering
Phase 3: Validation & Testing	Weeks 9–12	- EMI compliance testing (FCC Part 15 reference) - Field test with 50 students for accuracy and UX - Battery endurance test under simulated classroom cycles	Verified 98% accuracy and 72-hour runtime
Phase 4: Deployment & Training	Weeks 13–15	- Distribute 10 pilot devices across 3 classrooms - Train faculty with digital manuals and demo videos - Enable OTA firmware updates via Bash scripts and GitHub hooks	Smooth deployment with 90% user satisfaction score

Table 3.5

3.7 Circuit Diagram:

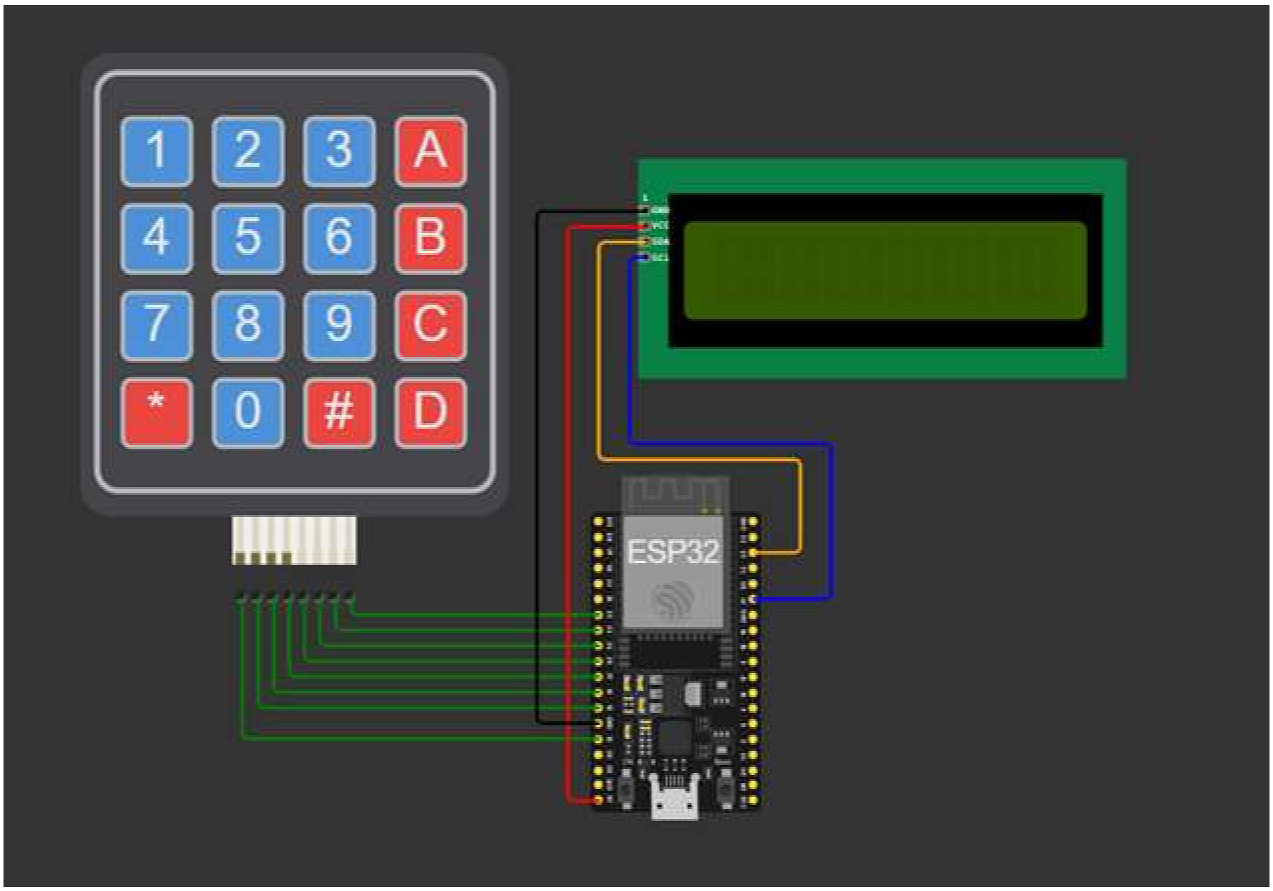

Fig 3.3