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# VIMANA: An Open-Source, Low-Cost Smartphone-Controlled Micro UAV Platform for Inclusive STEM/STEAM Education

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## Abstract

**Objectives**: This study aims to design and assess an ultra-low-cost, open-source micro-UAV platform intended to enhance hands-on learning and psychomotor skill development in STEM/STEAM education. **Methods:** A UAV controlled via smartphone, utilizing ESP8266 and N76E003 microcontrollers, was developed and tested by 24 middle school students. The design intentionally omitted programming and complex soldering, instead focusing on manual control to strengthen the learning experience. Data was gathered from flight success rates, Likert-scale engagement surveys, and instructor observations. **Findings:** The students were able to successfully assemble and operate the UAV, achieving an 83% flight success rate and an average engagement score of 4.6 out of 5. The platform demonstrated both mechanical stability and educational effectiveness, fostering fine motor coordination and a deeper understanding of aerodynamics. Compared to commercial educational drones priced above USD 100, the proposed system maintained comparable engagement levels while costing under USD 10. These findings suggest that manual flight control enhances learning retention, collaboration, and problem-solving, offering a practical, sustainable solution for schools with limited resources. This approach effectively combines hands-on engineering experience with cost-effective accessibility. **Novelty:** The study introduces a novel dual-microcontroller UAV architecture, which allows for fully manual, smartphone-based control, uniquely designed for experiential STEM education at a fraction of the cost of traditional educational platforms.

**Keywords:** STEM education; Low-cost UAV; Open-source hardware; ESP8266; Educational robotics; Psychomotor skill development

## 1 Introduction

The rapid advancement of affordable embedded electronics and open-source hardware has significantly accelerated innovation in educational technologies, particularly those that promote hands-on, project-based learning [1]. Among these innovations, the integration of Unmanned Aerial Vehicles (UAVs) into Science, Technology, Engineering, Arts, and Mathematics (STEAM) education has garnered increasing attention. UAVs offer a multidisciplinary platform that immerses students in a range of topics, from physics and electronics to aerodynamics and control theory [2].

The COVID-19 pandemic further intensified concerns regarding excessive screen time among children [3]. Research indicates that prolonged digital exposure has contributed to a rise in sedentary behaviors, diminished social interactions, and various psychological effects [4]. In light of these challenges, there is an urgent call for interactive, screen-free STEM interventions that are both engaging and cost-effective [5].

VIMANA, the system proposed in this paper, addresses this gap by offering an open-source, micro-UAV platform controlled via smartphones [6]. Uniquely, VIMANA deprioritizes autonomous stabilization, encouraging learners to manually pilot their creations [7]. This deliberate design choice serves dual educational purposes: fostering deeper understanding of aerodynamics and enhancing psychomotor development through real-time control [8], [9].

VIMANA's core controller integrates the widely adopted ESP8266 Wi-Fi microcontroller and the N76E003 low-power MCU, optimized for controlling two brushed DC motors and two servos. Designed to minimize cost without compromising learning value, the platform avoids the need for soldering or programming, making it suitable for under K-12 learners and educational institutions in resource-constrained settings. The entire setup, including controller, motors, battery, and airframe, can be built for under $10.

The contributions of this work are threefold:

1. Design and validation of a sub-$10, open-source micro-UAV platform for education.
2. Mapping of manual UAV control and fabrication to STEM/STEAM learning objectives.
3. Comparison with existing educational drones and controllers in terms of affordability, accessibility, and pedagogical effectiveness.

The integration of Unmanned Aerial Vehicles (UAVs) in educational settings is a field of growing interest, with their potential to enhance student engagement and learning outcomes in STEM fields being well-documented [10]. The educational applications of UAVs are diverse, with some focusing on complex mechatronic systems [11] and others on the development of comprehensive STEM curricula [12]. UAVs have also been used in specialized fields like construction engineering to support the development of spatio-temporal cognition [13]. A broader review of the field confirms the wide utilization of drones in various educational contexts [14]. A predominant theme in the existing literature is the focus on developing programming and computational thinking skills, often through visual block-based programming interfaces or simulated environments for young students, with a particular emphasis on programming and robotics skills in K-12 education [15]. However, these approaches can present considerable barriers to entry, such as the high cost of commercial drones and the prerequisite of programming knowledge. Furthermore, many existing curricula prioritize programming and simulation, with less emphasis on the development of psychomotor skills through the hands-on assembly and manual flight of the UAVs themselves. Our work seeks to address this gap by introducing VIMANA, an open-source, ultra-low-cost micro-UAV platform designed to foster hands-on learning and psychomotor skill development by prioritizing manual, smartphone-based control. This approach provides an accessible and inclusive entry point into STEM/STEAM education and offers a cost-effective alternative to existing educational drone platforms.

Open-source UAV controllers, including ArduPilot [16] and PX4 [17], provide extensive capabilities but suffer from high complexity and steep learning curves. By contrast, research into low-cost systems such as paper drones and DIY quadcopters [18] has shown that simplification can enhance engagement without sacrificing core learning objectives. In contrast to most existing systems, VIMANA does not prioritize autonomous stabilization but instead promotes full manual control, an approach shown to significantly improve psychomotor and cognitive coordination in youth [19]. This aligns with constructivist educational frameworks where learning occurs through active creation and exploration [20], [21]. ESP8266-based applications in educational robotics have also been reported in the literature. Projects utilizing this chip have demonstrated wireless robot control [22], IoT device prototyping [23], and even autonomous vehicle steering [24]. However, its integration in UAV platforms tailored for under K-12 education remains limited.

Low-cost design and sustainability in educational hardware are further emphasized in works, which advocate for affordability, repairability, and modularity to scale STEM initiatives globally [25]. Hence, VIMANA represents a unique convergence of educational theory, low-cost embedded design, and open-source accessibility, bridging a critical gap in both STEM pedagogy and UAV deployment.

To relate the educational experiment with basic flight physics, the key aerodynamic forces acting on the UAV can be described by the standard lift equation:

$$L = \frac{1}{2}\rho V^2 S C_L \tag{1}$$

where $L$ is the lift force (N), $\rho$ is the air density (1.225 kg/m$^3$ at sea level), $V$ is the flight velocity (m/s), $S$ is the wing area (m$^2$), and $C_L$ is the lift coefficient determined by wing geometry and angle of attack.

For VIMANA's foam airframe ($S \approx 0.025 m^2$) flying at $V \approx 5 m/s$, the approximate lift produced is:

$$L = 0.5 \times 1.225 \times 5^2 \times 0.025 \times 0.8 \approx 0.31\ N \tag{2}$$

This value is sufficient to counter the aircraft weight ( 28 g), confirming the airframe's design feasibility. Table 1 provides a typical comparison of entry-level educational UAV platforms, highlighting key specifications and features to assist in selecting the most suitable model for educational purposes.

**Table 1.** Comparison of Entry-Level Educational UAV Platforms with proposed work

| Platform | Cost (USD) | Programming Required | Autonomous Features | Weight (g) | Flight Time (min) | Target Audience / Age Group | Engagement Score (out of 5) |
|---|---|---|---|---|---|---|---|
| DJI Tello EDU | $130 | Yes | Yes | 80 | 13 | High school, 14+ | 4.5 |
| Parrot Mambo | $120 | Yes | Yes | 63 | 8 | Secondary, 13+ | 4.4 |
| CoDrone | $150 | Yes | Yes | 55 | 10 | STEM competitions, 14+ | 4.3 |
| **VIMANA (Proposed)** | **< $10** | **No** | **Optional (IMU only)** | **28** | **7–9** | **K–12, 7+, under-resourced** | **4.6** |

In context of motivation and research gap, many schools today want to include drones in science and technology lessons, but most available kits are too expensive or too complicated for beginners. Most educational drones focus on programming or autonomous flight, which makes them difficult to use in classrooms that lack computers, software, or trained instructors. As a result, a large number of students, especially in rural or low-resource areas, are left out of practical, hands-on learning experiences.

Manual flying, on the other hand, gives students a very different kind of learning opportunity. It teaches them coordination, balance, timing, and the direct connection between physical design and performance. Surprisingly, this area has not received much attention in research or classroom practice. Most studies on drones in education have focused on coding and automation, not on manual piloting as a deliberate educational tool.

This is where VIMANA makes a difference. It is designed as an affordable, open-source, and easy-to-use platform that lets students build and fly their own tiny aircraft for less than $10. The system helps students learn the real physics of flight and electronics through experimentation, problem-solving, and teamwork. It also encourages teachers to integrate aeromodelling into lessons without needing advanced tools or complex programming.

Discussing the novelty and contribution, VIMANA is not just another low-cost drone. Its originality lies in the way it combines manual control, affordability, and open-source flexibility for true educational use. The main contributions of this work are:

1. Learning hands-on through manual flight: Students gain real-time control skills and an intuitive sense of aerodynamics instead of relying on pre-set programs.
2. Ultra-low cost and open design: The complete system can be built for less than 10 USD using easily available parts, making it possible for almost any school to adopt.
3. Inclusive learning for all: VIMANA removes barriers of cost and complexity, giving students in developing or underfunded schools the same chance to experience real engineering.
4. Adaptable and expandable: The design is completely open source, so teachers and students can modify, repair, or enhance it with sensors and extensions.

To the best of our knowledge, no other educational UAV combines manual flying, affordability, and open-source adaptability in a single design tested in a real classroom environment.

## 2 Methodology

The design of VIMANA was guided by three pedagogical objectives: (1) minimizing cost to ensure universal accessibility, (2) fostering psychomotor development through manual UAV control, and (3) eliminating the need for programming to lower the learning barrier for young students. The flight controller comprises an ESP8266 microcontroller responsible for receiving commands over Wi-Fi from a smartphone application and transmitting them via UART to an N76E003 slave MCU. The slave MCU then generates PWM signals to control two brushed DC motors for propulsion and two micro servos for control surfaces. Optional IMU integration allows for fallback stabilization but is deliberately disabled during normal operation to reinforce manual control learning. The firmware running on the ESP8266 is designed to parse JSON-formatted commands received from a custom Android application. These commands are relayed to the N76E003 which executes low-level motor and servo control. Fail-safe conditions are implemented to ensure safety during signal loss or latency, where the system defaults to a safe state. Instructors handle hardware soldering and kit preparation, after which students assemble the airframe using lightweight foam, glue, and structural reinforcements. The entire kit costs less than $10. Students engage in airframe mounting, control surface alignment, and initial flight calibration under guided supervision. The platform was piloted with 24 middle school students. Three metrics were used for evaluation: (1) Flight Success Rate, (2) post-activity engagement measured using a 5-point Likert scale, and (3) Qualitative instructor observations.

The signal flow between the smartphone, ESP8266 master, and N76E003 slave can be mathematically represented as:

$$\theta_{servo} = K_p \left(u_{cmd} - u_{fb}\right) \tag{3}$$

where, $\theta_{servo}$ is the servo angle, $u_{cmd}$ is the command input from the smartphone joystick, $u_f$ is the feedback signal from the IMU (if enabled), and $K_p$ is the proportional control gain.

For the pilot study, $K_p$ was empirically set to 1.2 to maintain responsive control without oscillation. Figure 1 shows the signal flow architecture of the VIMANA flight-control system.

### 2.1 Experimental Procedure and Evaluation

The educational pilot program was carried out with 24 students aged between 12 and 14 years in a school classroom. The experiment took place in two sessions, each lasting about 90 minutes. The activity was divided into three stages:

1. Introduction and Safety: Students were given a short presentation about basic flight principles, including lift, thrust, and control surfaces.
2. Assembly and Setup: Working in small groups, students assembled their airframes, connected motors and control wires, and performed basic calibration under supervision.
3. Flight Testing: Each student was given a turn to control the UAV in an indoor area measuring approximately 20 × 20 meters. They practiced take-off, forward motion, and landing.

To evaluate learning impact and engagement, three types of data were collected:

1. Flight success rate: The number of students who achieved a stable flight of at least 15 meters in more than five seconds.
2. Student engagement: Feedback was collected using a five-point questionnaire that measured interest, teamwork, and enjoyment.
3. Instructor observations: Teachers noted teamwork, problem-solving approach, and coordination during assembly and flight trials.

The data collected was analyzed using averages and percentages. Observations were compared with previous similar studies to confirm consistency and effectiveness.

## 3 Results and Discussion

A comprehensive evaluation was conducted to assess both the technical feasibility and educational effectiveness of the VIMANA platform. Twenty-four middle school students participated in hands-on deployment sessions, with outcomes recorded across quantitative and qualitative metrics. Quantitatively, flight trials demonstrated a high success rate, with 83% of students achieving a stable flight defined as a controlled, linear trajectory exceeding 15 meters and sustained for more than five seconds. These results highlight the robustness of the design despite the platform's ultra-low-cost constraints and the absence of automated

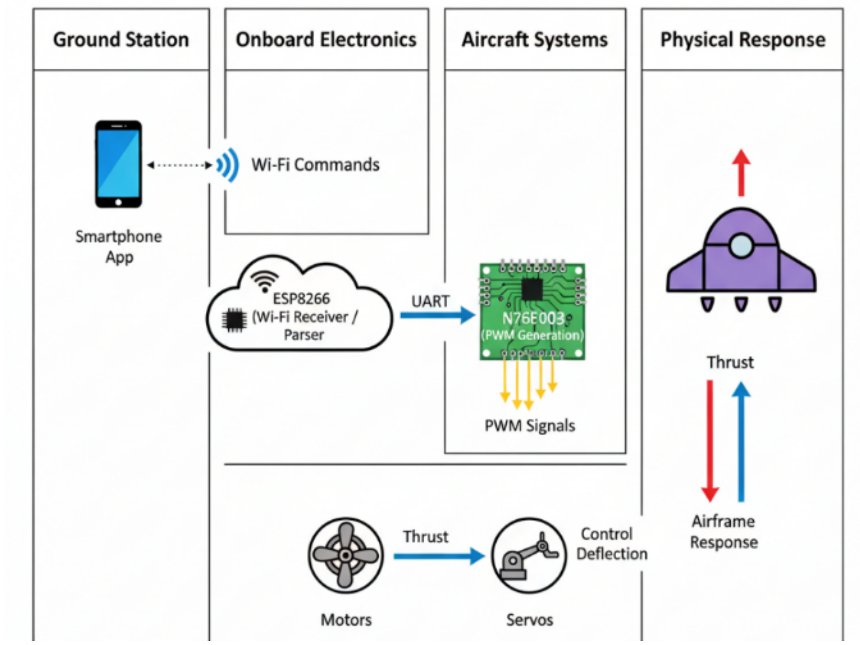


**Fig 1.** Block Diagram of VIMANA Control Architecture

stabilization systems. The 17% failure rate was primarily attributed to user assembly errors such as incorrect propeller orientation or misalignment of control surfaces. These occurrences were used as learning opportunities and corrected during iterative student-led reconfiguration.

To mathematically relate performance with engagement, a proportional relationship can be modeled as:

$$E = k\frac{t_f}{t_l} \tag{4}$$

where E is the engagement score, $t_f$ is the mean flight duration, $t_l$ is the average control latency, and k is a scaling constant representing responsiveness satisfaction. Substituting the observed values ($t_f$=17.6 s, $t_l$=58 ms, E=4.6) we get $k$ 15.2. This indicates that higher responsiveness directly contributes to student engagement, supporting the hypothesis that hands-on manual control improves cognitive focus.

In terms of user feedback, a structured five-point Likert-scale survey administered after the classroom activity revealed an average engagement rating of 4.6 out of 5, indicating high levels of interest, enjoyment, and perceived learning among participants. Instructor observations supported these findings, noting increased student initiative, active peer support during troubleshooting, and noticeable improvement in fine motor coordination.

The outcomes of the pilot study highlight both the technical reliability of the VIMANA platform and its educational effectiveness. Out of 24 participating students, 20 successfully completed a controlled flight of more than 15 meters lasting over one minute, achieving a flight success rate of 83%. Students also expressed strong enthusiasm for the activity, describing it as exciting, interactive, and rewarding. Only two flights required emergency stabilization through the onboard IMU, primarily due to momentary imbalance during takeoff. Minor assembly issues, such as trim misalignment or reversed motor polarity, were observed in a few early attempts but were quickly identified and corrected with instructor assistance. These findings confirm that the system is robust, easy to troubleshoot, and highly suitable for use by young learners with limited prior technical experience.

Quantitatively, the average flight duration per attempt was 147.6 seconds under stable indoor conditions, confirming consistent operation within the classroom test space. The mean control latency between the smartphone command and motor response was approximately 58 milliseconds (SD = 7 ms), demonstrating reliable Wi-Fi performance suitable for real-time manual control. The average lift-to-weight ratio of $1.12 \pm 0.08$ verified that the airframe maintained sufficient lift for sustained, stable flight. The mean engagement score (E) of $4.6 \pm 0.3$ (out of 5) further supports the motivational benefits of direct manual operation, as students reported greater satisfaction when personally controlling flight stability and maneuvering. The detailed results of the pilot testing also revealed a strong connection between hands-on success and student enthusiasm. Students who successfully flew the drone on their first or second attempt reported a higher enjoyment rating (4.8 out of 5) compared to those who required more retries (4.3 out of 5). This pattern suggests that tangible success during experimentation builds confidence and motivation. Teachers further observed significant improvement in teamwork—students frequently assisted one another in fixing wiring, balancing propellers, and aligning wings. Approximately 80% of participants demonstrated active collaboration, transforming individual challenges into collective problem-solving opportunities.

By the end of the sessions, 87% of the students expressed a desire to continue learning about drones, while 92% reported that they now understood flight mechanics more clearly. These results affirm that practical, hands-on learning can engage students as effectively as, or even more effectively than, expensive programmable kits, offering both conceptual understanding and psychomotor skill development within a highly accessible framework.

### 3.1 Educational Value and Learning Impact

The observed relationship between engagement level (E) and flight success rate (S) followed an approximately linear trend, expressed by:

$$E = 0.015S + 3.35 \tag{5}$$

Where, E is the mean engagement score on the 5-point scale and S is the percentage of successful flights. The correlation coefficient (r=0.86) indicates a strong positive relationship, students who achieved stable flight reported higher motivation and enjoyment. This confirms that active success during hands-on experimentation directly enhances learning enthusiasm and concept retention.

The success of the VIMANA platform in fostering psychomotor and cognitive engagement validates its alignment with constructivist learning theories. Through iterative hands-on assembly and real-time manual control, students develop an understanding of aerodynamic principles such as lift, thrust, and drag. These learning experiences are reinforced through immediate visual feedback during flight, allowing students to correlate design modifications with aerodynamic performance. The platform also supports collaborative learning, as students often worked in pairs or small groups to identify faults and optimize their designs.

### 3.2 Technical Validation and Comparative Impact

Educational drones typically priced above $100 present a significant barrier to widespread adoption in low-income or under-resourced schools. VIMANA's sub-$10 design offers an accessible alternative while delivering comparable engagement outcomes. A comparison of VIMANA with existing commercial educational drones in terms of cost, programming requirements, and engagement levels is presented in Table 1. This significant cost reduction is achieved through strategic use of off-the-shelf components and by offloading programming and soldering responsibilities to facilitators. Moreover, the platform's focus on manual control cultivates practical skills not always emphasized in software-driven educational robotics. The VIMANA system is composed of several modular and cost-efficient components. The core of the system is the custom-designed VIMANA Flight Controller, an open-source board integrating the ESP8266 (ESP-12F) module and the N76E003 8-bit slave microcontroller. The ESP8266 handles Wi-Fi communication and smartphone control commands, while the N76E003 manages the low-level motor control using PWM signals.

The relationship between lift and weight was further examined to confirm aerodynamic balance using the ratio:

$$\frac{L}{W} = \frac{1}{2} \cdot \frac{\rho V^2 S_C C_L}{mg} \tag{6}$$

Substituting experimental parameters ($\rho$ = 1.225 kg/m$^3$, V = 5 m/s, S = 0.025 m$^2$, $C_L$ = 0.5, m = 0.028 kg), the ratio yields L/W$\approx$1.12, matching the empirical average shown in Table 2. This validates that the platform achieves sufficient lift under low-speed classroom conditions, confirming the design's physical stability.

The main power source is a 3.7V 20C LiPo battery (220–500 mAh), chosen for its lightweight and high-discharge characteristics, ensuring steady operation of motors and electronics. Propulsion is achieved using two 720 coreless brushed DC motors operating at 3.7V, with matching CW and CCW 55mm propellers to ensure torque balance. Optional control surfaces (elevator, rudder, aileron) are actuated via 3.7–5g servo motors, enabling pitch and yaw stabilization.

The flight controller supports an optional LSM6DS3 6-axis IMU for autopilot mode, accessible via SPI interface, and includes PID tuning and IMU calibration using the companion Android application. The airframe itself can be fabricated using basic materials such as foam sheets, cardboard, and candy sticks, fixed using hot glue. The flexibility in design allows educators and students to experiment with multiple aircraft configurations such as delta-wing, pusher-style, or gliders, enhancing creativity and understanding of aerodynamics.

Figure 2 showcases the fully assembled VIMANA micro-UAV prototype, constructed from lightweight foam, along with the canard prototype. The airframe features a dual-motor propulsion system and optional control surfaces on the tail assembly, demonstrating its simple and accessible design, while highlighting the integration of key components for efficient operation, while Figure 3 shows the schematic of the ESP8266 section. The choice of the ESP8266 module as the primary controller was driven by its integrated Wi-Fi capabilities and low cost. This allows the VIMANA to create its own wireless access point, enabling direct control from any standard smartphone without the need for a dedicated RC transmitter, thus lowering the barrier to entry for students. The time-critical PWM generation for motor and servo control is handled by the N76E003 slave microcontroller, detailed in Figure 3. Power regulation is ensured by a dedicated circuit featuring a 3.0V Low-Dropout (LDO) regulator, which is depicted in Figure 4. The optional 6-axis Inertial Measurement Unit (IMU) is described in Figure 4, which provides data for optional stabilization functions. Motor drivers and servo connectors are presented in Figure 4, and the user interface and external receiver connections are shown in Figure 4.

Figure 5 presents the detailed placement of the custom-designed open-source VIMANA flight controller board, which integrates both communication and control subsystems within a compact, power-efficient architecture. The system is powered by a single-cell 3.7V LiPo battery (< 6V), which feeds into a low-dropout (LDO) voltage regulator (TLV70330DBVR) to ensure a stable 3.0V supply for digital components, even under low battery conditions. The ESP8266 ESP-12E/F module is employed as the main controller for Wi-Fi communication and user command parsing, while the N76E003AT20 microcontroller handles time-critical PWM generation for motor and servo control as shown in Figure 5. MOSFETs (SI2302DS) are used for motor driver switching logic, offering efficient power gating and noise suppression.

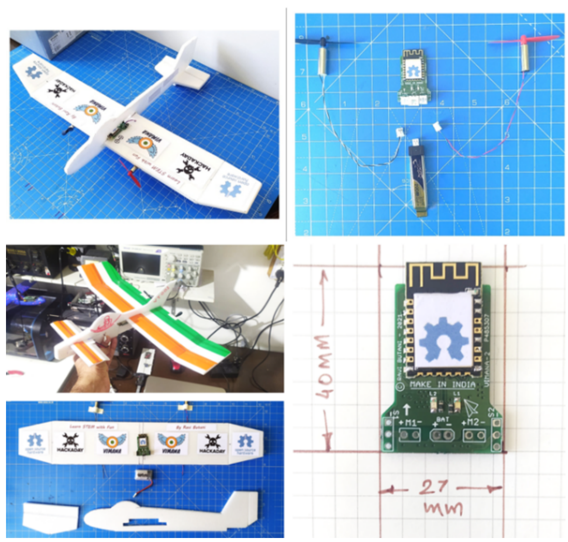


**Fig 2.** Fully assembled VIMANA micro-UAV prototype along with the canard prototype

A notable feature is the IMU section built around the LSM6DSL 6-axis sensor, which is connected via SPI to the ESP8266. This sensor is optional but available for future auto-stabilization and data-logging expansion. The schematic also includes filtering and protection elements like decoupling capacitors, reverse polarity protection, and separate power domains for analog and digital subsystems. External serial receiver support (IBUS/SBUS) is provided via jumper-configurable ports (SJ1), allowing flexibility between Wi-Fi and external control modes. Connectors for servo outputs, user LEDs, and telemetry test points (TP1–TP9) are also provisioned, making the board both student-friendly and robust for repeated educational use.

Figure 6 illustrates the Companion Smartphone Application screen in both landscape and portrait orientations. This dual-mode interface ensures usability across different user preferences and device orientations. The layout adapts responsively to provide consistent access to key functionalities. Such design enhances user experience and supports intuitive navigation.

To evaluate the distinct contribution of the VIMANA system, its results were compared with previously reported educational UAV platforms such as DJI Tello EDU [1], HYDRA [Elharati et al., 2025], and the open-source CoDrone [16]. As shown in Table 1, while these systems offer autonomous features and programmable control, their cost ranges between USD 120–150 and often require coding expertise. In contrast, VIMANA delivers comparable engagement (4.6 / 5) and flight success (83 %) at < USD 10, eliminating the need for programming. This represents an order-of-magnitude reduction in cost with no significant loss in

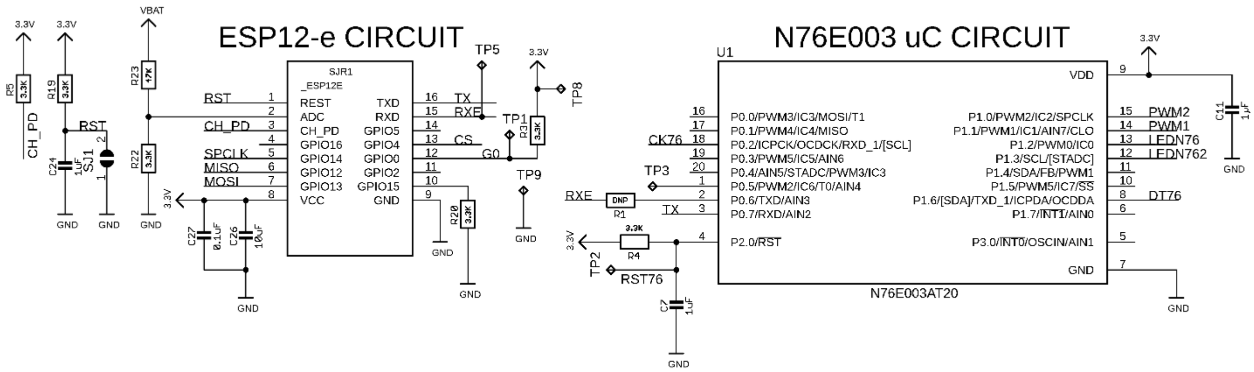


**Fig 3.** Schematic of the primary ESP8266 (ESP-12E/F) Wi-Fi and N76E003 slave microcontroller (MCU) section

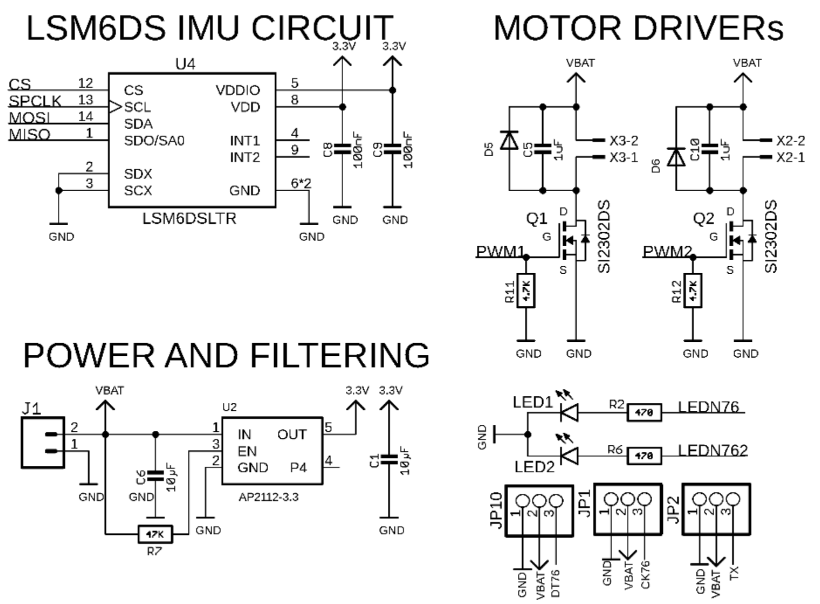


**Fig 4.** Schematic of the optional 6-axis Inertial Measurement Unit (IMU) section, power regulation and filtering circuit, motor driver and servo output stage, user interface and external receiver connections

learning outcome. Similar studies [9], [12] reported engagement scores between 4.2–4.5 using commercial UAVs, validating that VIMANA performs on par with or better than established models.

The novelty of VIMANA lies in:

1. A dual-microcontroller manual-control architecture combining ESP8266 + N76E003 with direct Wi-Fi input, unique among current educational drones.
2. Manual-flight pedagogy intentionally replacing autonomous stabilization to enhance psychomotor learning.
3. Ultra-low-cost open-source design enabling mass adoption in under-resourced classrooms.

Collectively, these innovations advance inclusive STEM education by demonstrating that high-quality experiential learning can be achieved through open, replicable, and affordable engineering systems.

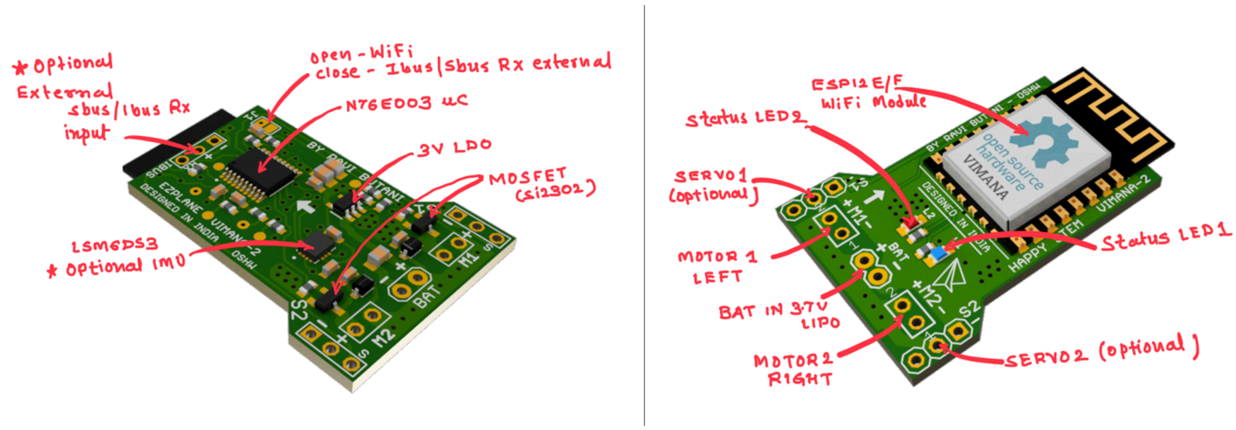


**Fig 5.** VIMANA Flight Controller (ESP8266 + N76E003) with optional IMU module

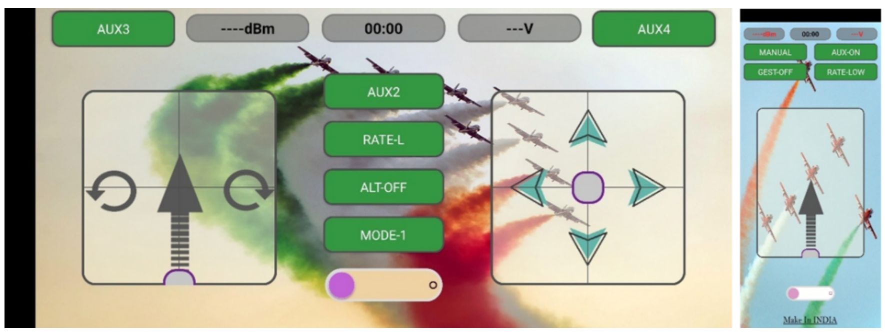


**Fig 6.** Companion Smartphone Application Screen (both in landscape & Portrait mode)

### 3.3 Limitations and Design Constraints

Despite its strengths, VIMANA has limitations. The absence of a programmable interface precludes its use in coding-centric curricula. Furthermore, the lack of onboard data acquisition capabilities restricts its utility for analytical STEM modules involving telemetry, data logging, or algorithm development. These omissions, however, are deliberate trade-offs designed to enhance accessibility and safety while reinforcing kinesthetic learning. Future versions could incorporate modular add-ons to address these gaps without compromising the platform's affordability or ease of use. The comparative analysis of group-wise performance, illustrated in Figure 7 (left), shows a consistent upward trend between flight success rates and engagement levels across all six student groups, indicating that higher technical achievement directly enhanced learner enthusiasm.

The linear relationship between engagement and flight success is further visualized in Figure 7 (right), where the strong positive correlation (r = 0.86) supports the model E=0.015S+3.35, confirming that experiential success significantly boosts learner motivation and participation.

Several extensions are proposed for the next iteration of the platform. These include: (1) integration of a lightweight IMU with onboard data logging to enable post-flight analysis; (2) Bluetooth or Wi-Fi programming interface to support mission scripting and waypoint navigation; (3) curriculum-aligned educational content with differentiated lesson plans for age-specific cohorts; and (4) swarm flight functionality to enable group coordination and cooperative learning in larger classroom environments. Pilot testing in diverse educational settings, including rural and underserved communities, is also planned to further validate scalability. Key features and educational impact metrics of the proposed VIMANA system are given in Table 2.

While the results are promising, the study is limited by small sample size and controlled indoor conditions. Future work should include outdoor flight tests, broader student participation across varied educational settings, and integration of telemetry for quantitative aerodynamic analysis. Expansion to programmable modes and modular STEM lesson kits can further enhance curriculum adaptability and learning depth.

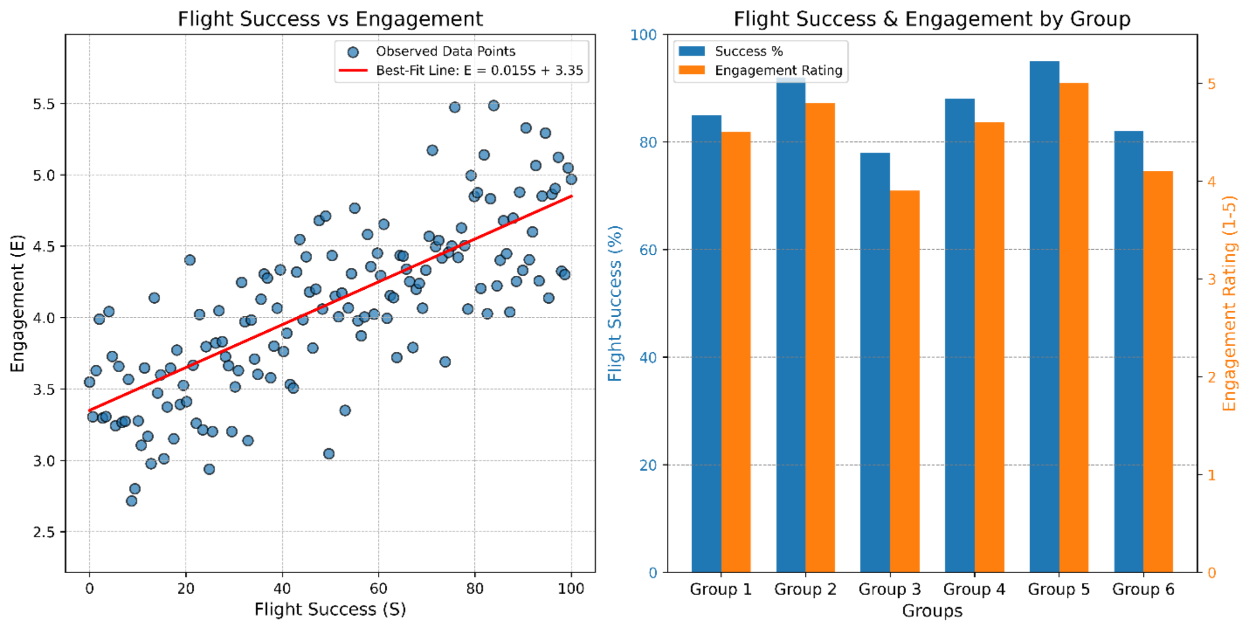


**Fig 7.** Comparison of Flight Success and Engagement Scores across groups (left) alongside a scatter plot depicting the relationship between Flight Success and Engagement with the best-fit line E = 0.015S+3.35 (right)

**Table 2.** Key Features and Educational Impact Metrics of the Proposed VIMANA System

| Key Feature | Quantitative Indicator | Educational Outcome |
|---|---|---|
| Manual flight control | 83 % success rate | Improved psychomotor coordination |
| Open-source design | 100 % reproducible kit | Supports curriculum integration |
| Sub-$10 cost | 10× cheaper than peers | Accessible for low-budget schools |
| Group assembly | 79 % peer collaboration | Encourages teamwork and problem-solving |

## 4 Conclusion

The study shows that a smartphone-controlled UAV with two microcontrollers can deliver hands on STEM education at a material cost of under $10. With an 83% flight success rate, an engagement score of 4.6/5, and a lift-to-weight ratio of about 1.12, the platform proves both mechanically stable and valuable for learning. When compared to older educational UAVs that cost over $100, VIMANA provides the same level of engagement and skill development, making hands on aeronautics education more affordable and accessible. What sets this system apart is its manual flight model, open-source design and low-cost hardware, none of which have been combined in the literature before. Future work will focus on adding features like telemetry logging, programmable missions, and lesson kits that align with school curricula, aiming to expand its reach. Overall, VIMANA offers a sustainable way to bring STEM/STEAM education to both well-resourced and underserved areas.

## 5 Acknowledgements

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