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A Novel CubeSat Education Model and Emulation Tool

Logan Thompson[1], Michael Harrigan[1], Keith Jacobs Jr. [2], Michael Lembeck[1]
[1]Laboratory for Advanced Space Systems at Illinois, University of Illinois Urbana Champaign
[2]4-H Youth Development, University of Illinois Urbana Champaign
104 S Wright St, Urbana, Illinois 61801; (847)-431-7104
loganjt2@illinois.edu

ABSTRACT

This paper introduces the Illinois Educational Development Unit (iEDU), a platform kit enabling middle and high school students to develop CubeSat mission payload concepts. Through interactive lessons prepared by graduate and undergraduate students at the Laboratory for Advanced Space Systems at Illinois (LASSI) for the University's 4-H/Extension unit, students learn the basics of CubeSat systems, programming control software, and executing payload operations. With these skills in hand, students are coached in designing their own experiments for interfacing with the iEDU.

The iEDU kit is based on a 3D-printed frame holding laser-cut 20 cm x 20 cm x 20 cm polycarbonate side panels that transparently encapsulate an avionics stack emulating a CubeSat. The satellite's command and data handling system is based on a standard Raspberry Pi interfaced to a custom LASSI-designed board hosting a commercial microcontroller (an STM32 or an RP2040) to interface with the payload. The four sockets on the interface board are configured to MIKROE's mikroBUS™ standard. Over 1000 off-the-shelf mikroBUS™ compatible Click Boards™ are available for taking measurements (e.g., attitude determination, temperature, magnetic field, lux, etc.) and generating various outputs (e.g., data, servo control, etc.). Using Click Boards™ allows for the rapid prototyping and integration of payload components without soldering. The selected payload interface microcontroller communicates to the boards over a serial interface and can be programmed in one of three languages: MicroPython, C, or Rust.

LASSI students initially created four experiment lesson plans. Thermal management, attitude and position determination, solar power generation, and magnetic field measurement are available to familiarize students with the iEDU's capabilities. Each experiment includes background information and code development guidance for students to learn about the critical functions CubeSats perform in accommodating payloads. After a student has gone through the four initial experiments, they can draw on the catalog of available mikroBUS™ Click Boards™ to design their own experiments.

To verify the utility of the iEDU, a weekend workshop was sponsored by LASSI for over forty middle and high school students. Small groups of students were each provided with an iEDU. LASSI student lesson assistants guided progress and provided opportunities for additional engagement during question-and-answer breaks. After working with the iEDU, feedback forms were collected from the students indicating their interest in learning more about aerospace engineering and STEM in general. With minor modifications to the lessons and kits based on the student feedback, the kits will soon be distributed to several local schools. A future payload design competition is envisioned, with the winning concept offered an opportunity to fly on a future LASSI mission.

INTRODUCTION

In 2023, 2,860 small satellites (SmallSats) were launched, the most so far in a year. This brings the total number of launches since 2014 to 10,052.[1] With this increase in SmallSat launches, the Laboratory for Advanced Space Systems at Illinois (LASSI) introduces the Illinois Educational Development Unit (iEDU) (**Figure 1**), a novel educational model and emulation tool designed to teach students of all ages about the CubeSat system.

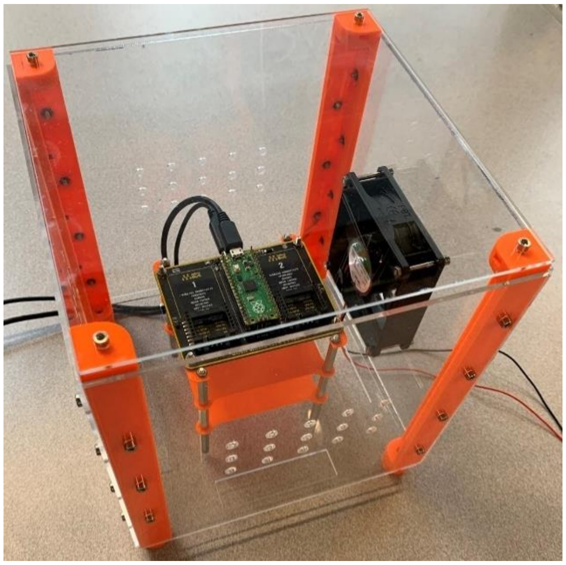

Figure 1: Illinois Educational Development Unit

CubeSats are standardized small satellites classified by size rather than weight. The standard unit of a CubeSat is 1U, which measures 10 cm x 10 cm x 10 cm. Depending on the mission requirements and constraints, standard form factors exist where multiple units are combined to form larger CubeSats, such as 3U, 6U, 12U, and larger. This modularity provides a platform for a cost-effective and efficient means to launch payloads into space, making it possible to test new technologies, facilitate communication, and conduct space research.

A CubeSat typically incorporates all the same subsystems as a regular satellite (**Figure 2**) although they are typically implemented uniquely due to the small volume. These major subsystems include command and data handling (C&DH), electrical power system (EPS), communication (COMM), thermal control (TC), attitude determination and control system (ADCS), structure/ mechanical (STRC), and propulsion system (PROP).

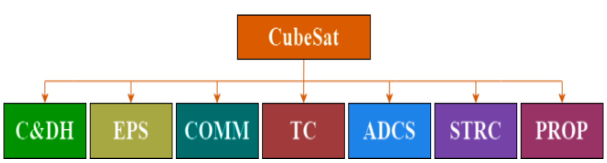

Figure 2: CubeSat Subsystem Diagram

The purpose of this iEDU is to educate middle and high school students about the fundamentals of CubeSats and satellite technology. The main goal is to get the students excited about entering the STEM (Science, Technology, Engineering, and Math) fields. Students will achieve a greater understanding of STEM fields through interactions with the iEDU and are exposed to new experiences including hands-on assembly of the structure, programming of the various experiments, and an understanding of satellites through the background information provided along with each experiment. The iEDU allows students to obtain an understanding of all the standard satellite subsystems.

DESIGN

The iEDU kit's major components include the structure, the Raspberry Pi (powered by USB interface connected "ground control" laptop), the payload interface board, assorted Click Boards^{TM}, and assembly and lessons documentation.

Students start by building the structure following the structure assembly manual. The iEDU system is contained within a transparent 20 cm x 20 cm x 20 cm volume structure to allow for easy assembly, understanding, and visualization. Next, the students connect the Raspberry Pi Pico's RP2040 to the payload support board. The Raspberry Pi is then connected via USB to a laptop computer that serves as the iEDU's ground control. A software development environment is installed for the coding portion of each experiment. Thonny is used by default as a MicroPython-compatible integrated development environment. Once everything is set up, students can walk through the lesson plans. Background documents should be covered first as they provide a brief understanding of the system they are replicating and its importance to CubeSats.

Students follow the how-to-code procedures guiding them through coding their experiments. The four procedures include Thermocouple and Heater, GPS and Gyroscope, Compass, and UV and Solar Power lesson plans. With these four procedures, the iEDU kit educates on the major subsystems of a CubeSat system (**Figure 3**).

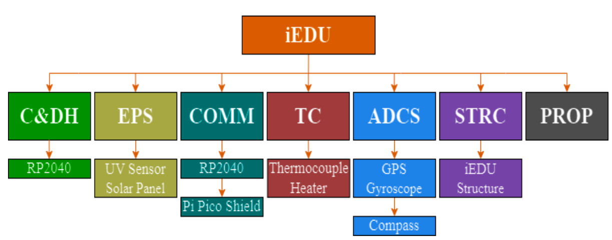

Figure 3: iEDU Subsystems and Assemblies Diagram

Structure

The external structure is comprised of 3D-printed frames holding laser-cut polycarbonate walls that transparently encapsulate the avionics (**Figure 4**). This protects the avionics and the other components within a CubeSat. The frames and walls are held together with hex nuts and bolts (**Figure 5**). The nuts and bolts can be hand-tightened so there is no need for tools, but all the fasteners may be tightened with a 3 mm allen wrench.

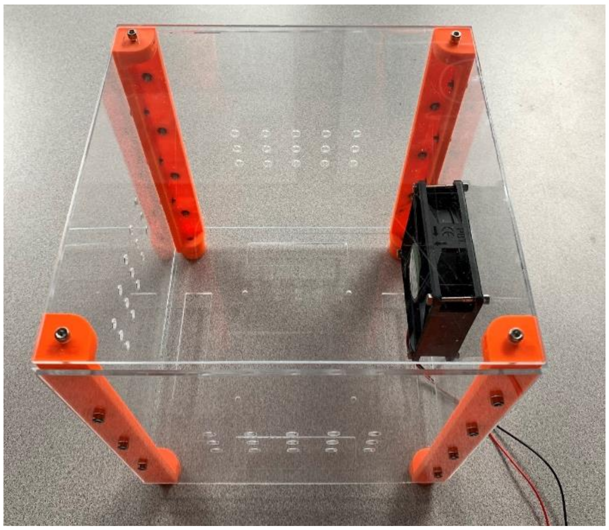

Figure 4: iEDU Bus Structure

Figure 5: iEDU 3D Printed Frame

These materials were chosen due to their readily accessible nature by schools or other organizations. The frames and walls may be 3D-printed and the walls can also be made from 3D-printed material if a laser cutter is unavailable. The kit includes computer-aided design (CAD) files for the structure so the build can be recreated or modified as needed (**Figure 6**).

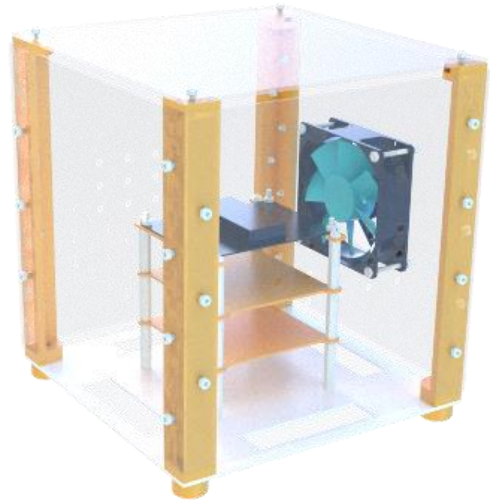

Figure 6: iEDU CAD

Avionics

The iEDU kit comes with a Raspberry Pi Pico RP2040 microcontroller (**Figure 7**) and a payload interface Click Shield for Pi Pico (**Figure 8**) to control the various Click Boards™. The Raspberry Pi Pico and Click Shield are connected to the ground computer via USB. The ground computer also provides the Thonny code development environment.

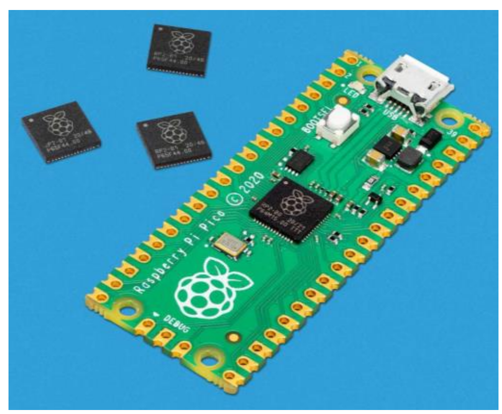

Figure 7: Raspberry Pi Pico RP2040 Microcontroller[2]

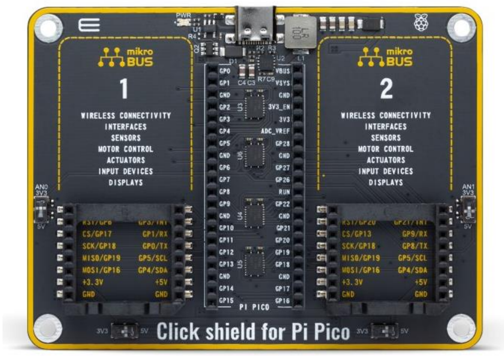

Figure 8: Click Shield for Pi Pico[3]

With over 1000 Click Boards™ options, seven were selected (Thermocouple, Heater, Gyroscope, GPS, Compass, UV, and Solar Power) to match sensor functionality present on spacecraft. Once these Click Boards™ were identified, lessons were developed around how they are used on the spacecraft.

Coding

The iEDU kit is compatible with MicroPython, Rust, and C. Using MicroPython as the primary programming language for the iEDU kit is a strategic choice due to its popularity, simplicity, and widespread use in educational settings. The kits also provide a complete MicroPython solution for each lesson plan. This safety net allows students to explore and experiment with confidence, knowing that they have access to comprehensive resources if they encounter a challenge they cannot solve on their own.

Lesson 1: Thermocouple and Heater

The first lesson introduces the Thermo K Click board with a thermocouple attachment and the Heater Click, offering students a hands-on opportunity to explore concepts related to the thermal management subsystem of a CubeSat. The experiment simulates a heated (Heater Click) battery pack (simulated by a block of aluminum) while sensing the temperature of the battery pack (Thermo K Click) (**Figure 9**). The objective of this experiment is to provide an understanding of why a thermal management system is important for CubeSats and how it can be implemented.

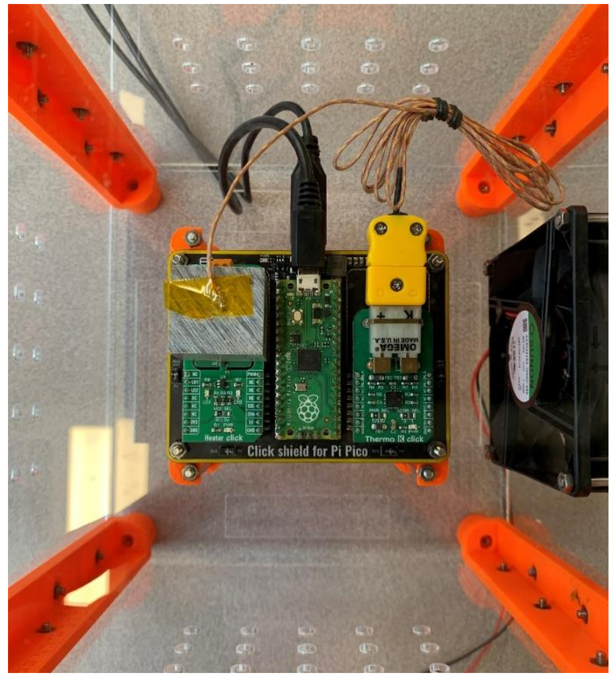

Figure 9: Thermal Management System Setup

The Thermo K Click utilizes an MCP9600 thermocouple with a -200 C to +1372 C range. A 2-wire communication protocol Inter-Integrated Circuit (I2C) is used to write to and read from the Thermo K Click. The Heater Click implements a TMP235 heater that can heat the aluminum “battery pack.” Pulse-Width Modulation (PWM) regulates the heater.

At the end of the lesson, students understand the basics of I2C protocol, how the Raspberry Pi Pico RP2040 communicates with the various Click Boards™, how PWM works, and an understanding of how a thermal management system on a CubeSat works.

Lesson 2: Gyroscope and GPS

A Gyro 6 Click and a GPS3 Click in this lesson plan offer students a hands-on opportunity to explore concepts related to the attitude determination and control system (ADCS). The experiment measures the orientation and position of the iEDU structure (**Figure 10**). Students obtain background on GPS tracking and how a gyroscope works.

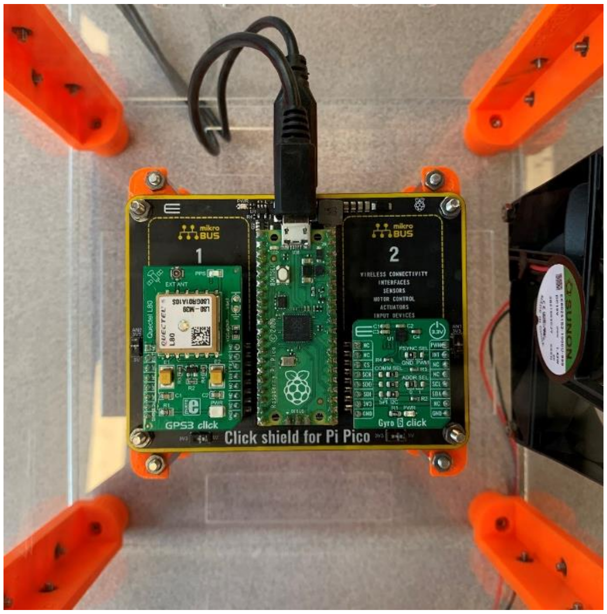

Figure 10: Attitude Determination and Control System Setup

The Gyro 6 Click utilizes an IAM-20380 electronic gyroscope that communicates through I2C protocol. This electronic gyroscope provides an output of $\phi,\ \theta,\ \psi$ axis angular rates. Where ϕ is the angle rate about the x-axis (roll rate), θ about the y-axis (pitch rate), and ψ about the z-axis (yaw rate). Utilizing this data, the students will implement a Forward Euler integration algorithm to obtain the orientation in degrees.

The GPS3 Click utilizes an L80 GPS receiver module with a patch antenna. Unlike the other Click Boards™, the GPS3 Click communicates through a universal asynchronous receiver/transmitter (UART). UART communicates through a transmitter and receiver on both devices allowing for both receiving and sending data. The students utilize the GPS3 Click to obtain longitude and latitude in degrees and altitude with respect to sea level in meters, all with a precision of less than 2.5 meters circular error probability (CEP).

At the end of the lesson, the students will understand the basics of I2C and UART protocols, how the Raspberry Pi Pico RP2040 communicates with the various Click Boards™, how GPS and Gyroscopes work, and an understanding of how portions of the ADCS within a CubeSat work.

Lesson 3: Compass

Introducing the electronic Compass 5 Click in this lesson offers students a hands-on opportunity to explore additional concepts related to the attitude determination and control system (ADCS). The experiment measures the magnetic field flux near the iEDU structure. An external magnet is used to change the magnetic field flux sensed by the compass (**Figure 11**).

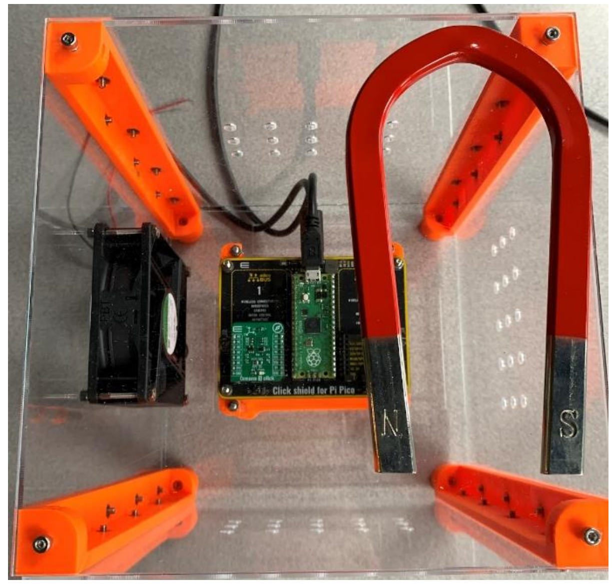

Figure 11: Compass Setup

The Compass 5 Click utilizes the AK09918C, a 3-axis electronic compass with high sensitivity. Utilizing the I2C protocol, the Compass 5 Click measures the generated magnetic field and outputs a value proportional to the field strength.

At the end of the lesson, the students understand the basics of I2C protocols, how the Raspberry Pi Pico RP2040 communicates with the various Click Boards™, how an electric compass works, and they get more of an understanding of how portions of the ADCS within a CubeSat works.

Lesson 4: UV and Solar Power

Introducing the UV 4 Click and Solar Energy Click in this lesson offers students a hands-on opportunity to explore CubeSat electrical power system concepts. This experiment includes a MIKROE solar panel to generate power from the Sun and a Pkcell LP785060 3.7V lithium polymer rechargeable battery to store the energy (**Figure 12**).

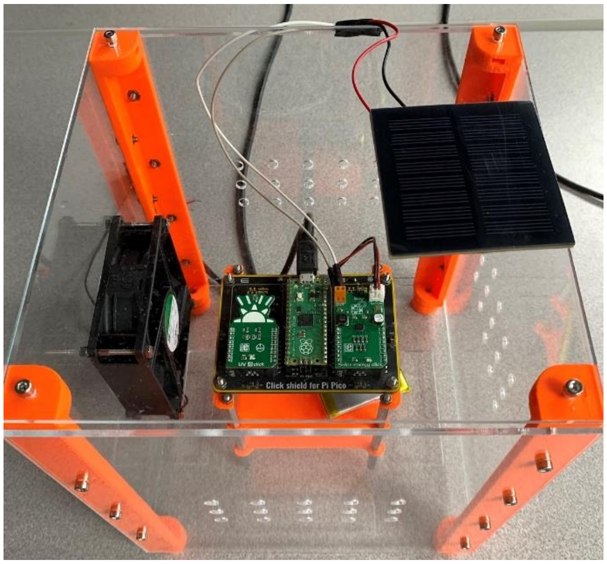

Figure 12: Power Management System Setup

The UV 4 Click incorporates a Si1133 ultra-violet (UV) and ambient light sensor, enabling detection across a spectrum of wavelengths including UV-A, UV-B, infrared radiation (IR), and visible light. This versatile sensor serves as a valuable tool for monitoring lighting conditions and radiation levels in various applications. The Solar Energy Click utilizes the BQ25570 chip attached to a solar panel to capture energy and charge a Pkcell LP785060 3.7V lithium polymer rechargeable battery.

At the end of this lesson, the students will understand the need for a power management system, how to utilize both I2C and UART protocols, and how the Raspberry Pi Pico RP2040 interacts with various Click Boards™.

Post Experimentation

Once all lessons are completed, students are free to explore over 1000 off-the-shelf sensors available for taking measurements (e.g., attitude determination, temperature, magnetic field, lux, etc.) and generating various outputs (e.g., data, servo control, etc.). The students can take what the iEDU has taught them to formulate and develop these new experiments they brainstorm. When students understand how to read from and write to the different Click Boards™ they can further their education by completing more challenging experiments without the guidance of the tutorial documentation. The end goal is to have all students interacting with the iEDU go beyond the produced material and create their own payloads from the Click Boards™ implementation.

Weekend-Long Camp

The iEDU was introduced to a select group of students within the Illinois 4-H Extension program. LASSI offered a weekend-long camp to teach the students about the iEDU and served as a pilot to understand the successes and challenges associated with the iEDU assembly and related documentation. The camp was broken up into the assembly of the structure of the iEDU and the development of experiments.

Before the assembly portion, the students were given a presentation on the importance of the structure for CubeSat designs. The students had no problems following the structure documentation provided to them in the time allocated for assembly.

Before each experiment following, the students were given background information through interactive presentations. After each presentation, the students followed the how-to-code document for each lesson that explored the various coding functions that would be required to retrieve and analyze the data from that experiment. If the students had any questions the LASSI team provided support. Questions and responses were recorded to allow for future modifications to the presentations and the how-to-code documentation.

Distribution

Of the students who attended the initial weekend-long camp, eleven were selected to participate further on a "Mission Command Team." Team members returned to their home counties to guide other students through the iEDU program. By spring 2024, 211 students have been reached through these efforts. Using the evaluation results and feedback from the Mission Command Team, the current activities provided by LASSI will be expanded to include elements of 4-H Positive Youth Development (PYD). These expanded activities will be delivered statewide by Illinois 4-H during the 2024/25 program year. It is expected to reach over 1,000 students during this period, with the potential to expand the program to other states, in the future.

Results

After the iEDU experience, students were given a survey to complete. This survey consisted of questions relating to their experiences with the iEDU and lesson plans. The students answered via agreement scales to best represent the iEDU experience. The data received from the 211 students indicated the experience was well-received overall (**Table 1**).

Table 1: Results of Evaluation Post iEDU Experience

Percentage of Students Evaluated	Responses by Students
93%	This program gave me the opportunity to explore something I really care about.
100%	Because of this program, I learned how to do something new.
86%	Because of this program, I improved my problem-solving skills.
93%	Because of this program, I improved my ability to work with others.
71%	Because of this program, I am more excited about exploring a career in aerospace/STEM.
57%	Because of this program, I plan on using these skills in another setting.
14%	I have participated in activities or programs like this in the past.
100%	My school does not offer opportunities to explore STEM like I did in this activity/program.

This data indicates that the provided hands-on learning experiences sparked interest in STEM fields and equipped students with practical skills and knowledge. The feedback from all students mentioned their school does not explore STEM opportunities like the iEDU further proves iEDU's success.

Post iEDU Competition

With the successful demonstration of the iEDU, LASSI intends to host a scientific payload competition. Utilizing LASSI's Payload Support Board for CubeSats, students who participated in 4-H will submit payload designs for an upcoming CubeSat mission.[4] The winning payload will be launched on its own 1U CubeSat and flown in low Earth orbit for a set duration. The purpose of this competition is to continue promoting STEM education, with a particular focus on CubeSats, and to highlight the educational opportunities provided by LASSI. This initiative aims to inspire and engage students in space science and technology, fostering a deeper interest in these fields and showcasing the practical applications of their learning.

CONCLUSION

The iEDU was designed to provide STEM education to students with limited access to STEM-related activities within their schools. It has successfully taught over 200 students about space systems, with the number of participants expected to grow as the distribution of the iEDU expands. The program includes four initial comprehensive lessons, offering students an in-depth understanding of the CubeSat subsystem's roles and significance.

Through the iEDU, students learn to program and obtain real-time results from their experiments, allowing them to gain practical STEM education outside of traditional classroom settings. With over 1000 off-the-shelf Click Boards™ available, the iEDU offers more potential than the initial four lessons provided by LASSI. It is designed to be versatile and extendable, enabling students to create and develop their own experiments as they advance in their education.

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