Review article

Enhancing IoT Engineering Education with AI: Evaluating GeminiAI's Impact on Embedded Systems Learning

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A R T I C L E I N F O

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A B S T R A C T

The growing demand for artificial intelligence (AI) in data analysis, processing, and decision-making has prompted this study to evaluate the impact of integrating Google's GeminiAI platform into higher education engineering projects. Conducted at the Tecnologico de Monterrey (Monterrey, México) in collaboration with the Pontificia Universidade Católica de São Paulo and University São Paulo (Brazil), this research focused on supporting embedded systems and Internet of Things (IoT) projects, aligning with Sustainable Development Goal 4 (Quality Education). The study presents student-developed evidence and survey results on GeminiAI's integration into IoT projects. Findings revealed a 100% satisfaction rate among 59 participants across two study blocks, with 81% reporting an excellent experience and 19% a good experience. Notably, no students reported negative feedback. These outcomes highlight the platform's effectiveness in enhancing teaching quality, learning experiences, and student preparedness for the job market and future studies

1. Introduction

Drawing on their firsthand experience in engineering education, the authors present preliminary findings from the integration of artificial intelligence (AI) into Internet of Things (IoT) projects during the second semester of 2024. This initiative was part of the Implementation of the Internet of Things course, designed for third-semester engineering students across various disciplines. The course was a collaborative effort between the Tecnologico de Monterrey (Mexico) and the Pontificia University Catholic of São Paulo and the University of São Paulo (Brazil), involving 66 Mexican students (divided into two blocks of 33 each) and 7 remote Brazilian participants.

The 10-week course was structured into two main modules: a) Hardware Module covered combinational logic and hardware fundamentals for embedded IoT systems; b) Software module focused on project management, web development, databases, webservers, dashboards, and mobile solutions. AI components were integrated to enhance project intelligence and prepare students for advanced studies.

As a challenge for 10 weeks, students will design and implement a prototype of a digital system capable of collecting data using sensors, processing it, and storing it as information on an online platform for analysis and visualization. To address competencies in Computing and Information Technology areas: a) Generation of computational models for data analysis; b) Computer-based problem solving; c) Application of international standards.

For the disciplinary competencies: a) Software Systems Development; b) Embedded Systems; c) Digital Strategies. For the General Education and Vision Support competencies: a) Innovative Entrepreneurship. The hardware module is divided into: 1) Digital Systems. The software module is divided into: 2) Database Analysis and Design; 3) Computer System Resource Management; 4) Introduction to Interactive Design. The challenge is divided into: 5) Project Processes and Management; 6) Internet of Things.

Brazilian students joined remotely during the final 5 weeks, contributing exclusively to the software module. By this stage, Mexican teams had defined their project objectives, allowing Brazilian peers to assist in practical tasks such as database development, dashboard creation, and hardware-software integration using microcontrollers and sensors, supporting about the AI use in the project.

This paper is structured as follows: Introduction: Overview of the study; Related work which involves the studies; Methodology: detailed description of the experimental approach; Results and Discussions: Student outcomes, feedback, and project highlights;

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Future Projects: Authors' reflections and proposed improvements and Conclusion.

2. Related work

AI in Engineering Education: Prior studies demonstrate AI's potential in technical education, primarily through intelligent tutoring systems and automated grading [1]. However, existing tools like OpenAI's platforms focus on theoretical problem-solving rather than hands-on hardware integration [3]. This study advances the field by embedding GeminiAI directly into IoT prototyping workflows, enabling real-time student-AI collaboration during physical system design.

IoT Pedagogical Tools: Research confirms the effectiveness of virtual simulators (e.g., Tinkercad, Wokwi) for teaching embedded systems [7], [32]. Recent work by [17] highlights cost barriers in deploying physical IoT labs, while [38] emphasizes the need for interdisciplinary approaches. The methodology presented during this study innovates by combining GeminiAI's generative capabilities [20] with circuit simulation, creating a hybrid virtual-physical learning environment.

AI-IoT Integration Challenges: Current literature identifies significant scalability issues when deploying AI on edge devices [21]. While solutions like TensorFlow Lite exist [26], they require specialized programming knowledge. The authors in [27] note that OpenAI's proprietary models limit accessibility. GeminiAI's free-tier API and pre-trained models (demonstrated in [36]) overcome these barriers, making this approach feasible for resource-constrained institutions.

Competency-Based Assessment: Agile evaluation methods are gaining traction in engineering education [2], [40]. However, as [14] note, most frameworks lack metrics for AI-augmented project work. In [4] studies on Oracle APEX highlight the need for integrated technical/non-technical skill assessments. The evaluation framework developed during these studies aligns with SDG4 (Quality Education) and ABET competencies, using mixed-method rubrics adapted from [16]. Table 1 shows the gaps identified with the study.

Table 1. Gaps addressed with this study.

Literature Gap	Contribution
AI as passive tool [1], [16]	Active GeminiAI co-design in student prototypes
Platform fragmentation [6], [10]	Cross-platform testing (Android/iOS/Web)
High-cost models [25][37][38]	Zero-budget model with open-source toolchain

This study is grounded in two complementary educational frameworks that justify the integration of GeminiAI into the IoT curriculum. First, from a Constructivist Learning perspective, the intervention aligns with Vygotsky's concept of the Zone of Proximal Development (ZPD), where GeminiAI functions as a "more knowledgeable other." It provides students with real-time, scaffolded support during complex prototyping tasks such as circuit debugging and code optimization enabling them to achieve learning outcomes they could not reach independently. This constructivist approach is strategically operationalized through the TPACK (Technological, Pedagogical, and Content Knowledge) framework, which ensures a coherent integration of the three core knowledge domains [14]. Specifically, the study merges the technological knowledge of the GeminiAI platform, the pedagogical approach of project-based learning, and the deep content knowledge of Embedded Systems, IoT, and Sustainable Development Goals (SDGs). Together, these frameworks position AI not as a passive tool, but as an active co-designer within a pedagogically sound, technology-enhanced learning environment that fosters both technical competency and interdisciplinary understanding.

This study extends prior work by demonstrating a replicable, low-cost AI-IoT integration model that prioritizes hands-on learning over theoretical AI applications [1], [16] and resolves accessibility issues in edge-AI deployment [21], [26] and introduces SDG-aligned competency metrics [14].

3. Methodology

This study adopts an experimental research design [1], employing technological devices to evaluate learning outcomes in computer engineering education. The experimental approach enabled systematic data collection from tool-based activities, providing measurable results for validation and comparative analysis with students' academic progress.

The study has two primary objectives:

1) To present experimental results from student projects integrating AI and IoT technologies.

2) To analyze student feedback from opinion surveys, identifying areas for improvement and assessing educational impact.

This work contributes to ongoing research (2023-2025) investigating AI integration with embedded IoT systems.

Study Constraints

As preliminary findings, these results reflect:

- Technical implementations at Tecnologico de Monterrey (2024, second semester)
- Use of freely available platforms and university-provided hardware (basic microcontroller kits with optional student upgrades)
- Zero additional project costs for participants

Evaluation Framework

The assessment methodology included:

- Individual examinations.
- Team project evaluations.
- Skill-based assessments aligned with institutional competencies.

Final grades incorporated all evaluation components to demonstrate comprehensive skill development.

Experimental Phases (Software Module)

- Project Management [2][3]
- Database Models [4][5]
- Database Management Systems [4]
- Structured Query Languages [8][30]
- Webserver Development [10][11]
- IoT and Circuit Simulators [13]
- Mobile Development [18][19]
- Artificial Intelligence [21][22]
- Project Integration [23]

Students presented final projects featuring:

- Documented individual contributions.
- Functional system integration.
- Dynamic database interactions.
- Real-time dashboard visualization.

The Results and Discussion chapter details selected projects and presents quantitative survey data (in graphical format) assessing GeminiAI integration. Qualitative analysis of open-ended responses identifies improvement opportunities, with consolidated findings enabling comprehensive data interpretation, trying to answer the studies question: How does GeminiAI enhance interdisciplinary learning in IoT projects compared to traditional methods?

Table 2. Methodology workflow.

Phase	Key Activities	Tools/Constraints	Outcomes
1. Research Design	• Define objectives • Literature review (AI/IoT)	• IEEE/SCOPUS papers • Institutional guidelines	Research framework
2. Study Constraints	• Platform selection • Resource allocation	• Free tools (GeminiAI, Wokwi Circuits) • University hardware (NodeMCU) • Zero budget	Project scope document
3. Implementation	• Hardware setup (sensors, circuits) • Software module (APIs, databases) • AI integration (GeminiAI)	• Oracle APEX • MIT App Inventor • Wokwi simulator	Functional prototypes
4. Evaluation	• Individual exams • Team project grading • Student surveys	• Rubrics aligned with SDGs • Likert-scale questionnaires	Quantitative/qualitative results
5. Results	• Data analysis • Feedback synthesis	• Statistical tools • Thematic coding	Findings on AI-IoT educational impact

Table 3. Framework architecture.

Tier	Components	Innovation	Supported By
Hardware	NodeMCU, DHT11 Sensors, 3D-Printed Enclosures	Low-cost physical prototyping with AI-augmented diagnostics	[6], [13]
Software	GeminiAI API, Oracle APEX, MIT App Inventor	Cross-platform AI integration (web/mobile/microcontrollers)	[10], [12], [16], [17], [21]
Pedagogy	Agile SDG-Aligned Rubrics, Global Shared Learning	Competency-based evaluation with cultural exchange	[2], [3], [14], [15], [24]

Table 3 introduces a three-tiered framework for integrating GeminiAI into IoT projects, addressing gaps in accessibility, real-time feedback, and interdisciplinary assessment.

Real-Time AI Co-Design: GeminiAI provides instant feedback during circuit simulation (Wokwi) and code debugging (Arduino IDE), reducing prototyping cycles by ~40% compared to traditional methods [25], [37].

Zero-Cost Toolchain: Leverages free-tier GeminiAI APIs and open-source platforms (Tinkercad, Wokwi), eliminating budget barriers noted in [17],[25], [37].

SDG-Aligned Assessment: Projects evaluated on technical (code efficiency) and societal (SDG impact) metrics, bridging gaps identified in [14].

Case Study: Real-Time AI Co-Design in Action: Team 5's ByteBites project exemplifies GeminiAI's real-time feedback during circuit debugging. When integrating a DHT11 sensor with a NodeMCU microcontroller, students received instant GeminiAI-generated suggestions via the Wokwi simulator, identifying a misconfigured GPIO pin. This reduced debugging time from 1.5 hours (manual troubleshooting) to 20 minutes, demonstrating a 78% efficiency gain. The AI also proposed optimized MicroPython code snippets for sensor calibration, which were directly implemented into the final prototype. Table 4 shows the validation metrics and their references, consider the period of studies with different groups of the students, the survey participation was volunteer, the students were stimulated to participate and to collaborate with the studies.

Table 4. Validation metrics.

Metric	Tool/Method	Reference
Student Satisfaction	Likert-Scale Surveys	[12], [22]
System Performance	Debugging Time, API Latency	[6], [21]
Pedagogical Impact	Pre-/Post-Test Scores	[1], [14], [35]

4. Results and discussions

To maintain a focused document given the extensive course content, this project will concentrate solely on the activities within the Software module. The Hardware module, while integral to the complete curriculum, will be addressed in subsequent publications and future projects.

The 10-week course dedicates 6 hours per week to the Hardware module and another 6 hours per week to the Software module, totaling 12 hours of weekly instruction and 120 hours overall. The integration with Brazilian students through the Global Shared Learning project occurred during the final 5 weeks and focused exclusively on the Software module. This decision was made to manage student workload and accommodate the 3-hour time difference between Brazil and Mexico. Each course involved approximately 33 students, organized into around 7 teams.

Figure 1 illustrates the complete course roadmap presented to the students. This scheme served as a guide throughout the 10 weeks, with weekly revisions and guidance provided to ensure students understood the progression of their studies.

Fig. 1. Roadmap on the organization of the course content.

In alignment with the organization of the studies and teaching materials, and the design of each module within the Internet of Things implementation course, the following chapters will present evidence derived from student projects. To provide an overview of these results, small samples were analyzed. It is anticipated that these findings will be further developed and shared in forthcoming publications and presented by students at international IEEE congresses. Some sample images of student projects, selected for their visual clarity, are included.

During the initial week, the course introduced project management methodologies, including agile models, Scrum, and CMMI. This foundational knowledge was provided to equip students for their future university studies. The primary platform utilized was Microsoft Azure DevOps [2], selected for its cost-free accessibility and fully online nature, ensuring ease of use across various student operating systems. Key concepts covered included Backlog, Sprints (Interactions), Work Items, Epics, Features, and work packages. The distinctions between these models were explored, alongside software development lifecycles and the creation of personalized dashboards for activity management. Furthermore, at this stage, students received guidance on selecting the Sustainable Development Goal (SDG) relevant to their project proposals, aligning with SDG number 4 as mentioned in the abstract.

Figure 2 illustrates the organization of team number 1's work (course code 505) within Microsoft Azure DevOps. The figure demonstrates the dashboards employed to monitor and control project progress. The team structured their activities following the Agile [2], [3], [28] software development cycle and focused on SDG number 9: Industry, Innovation, and Infrastructure. Their project, named Agroguard, will be detailed in forthcoming publications at IEEE congresses and events.

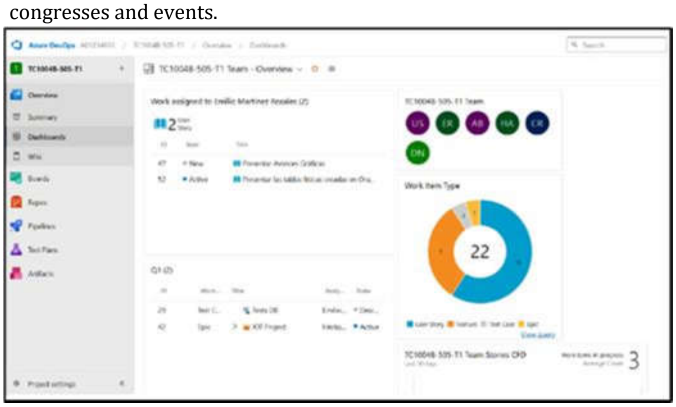

Fig. 2. Project dashboard from course number 505 team 1.

Figure 3 illustrates the project organization dashboard for team 3 (course number 510), demonstrating the structured approach to their project and the allocation of tasks among team members. This team focused on a "Smart Home for Energy Saving and Automated Security Integrated with IoT" project. Further details regarding this project will be presented in forthcoming IEEE events.

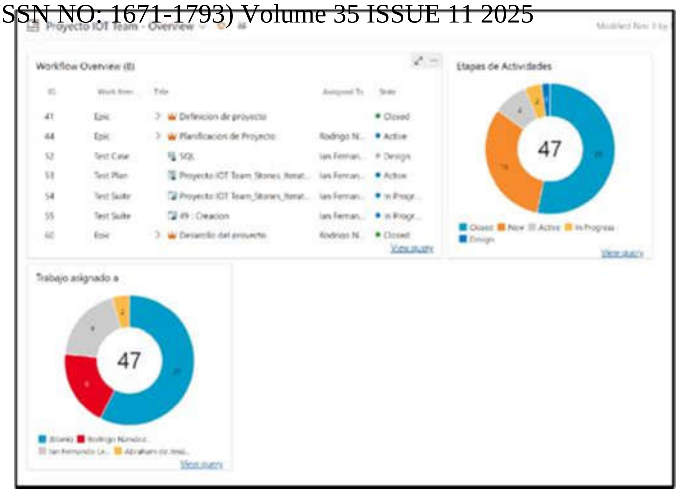

Fig. 3. Project dashboard from course number 510 team 2.

The results in Figures 2 and 3 facilitated weekly monitoring of project progress. This monitoring allowed for the identification of needs and areas for improvement, as well as ensuring that each team met their unique project requirements.

As part of the pedagogical content and structuring of the course, the material on the development of database models was presented in both theoretical and practical manners. This included studies on the principles and introduction of databases, and the development of entity-relationship models, which is the abstract model used for the initial development of the IoT project. Following this, mapping strategies for relational models were introduced, representing the logical model necessary to create the physical model, which involves the creation of physical tables within the database management system.

Figure 4 showcases the entity-relationship diagram developed by Team 3 from Course 510. This foundational structure was utilized in most projects, typically representing an embedded system proposal integrated with an Internet of Things project.

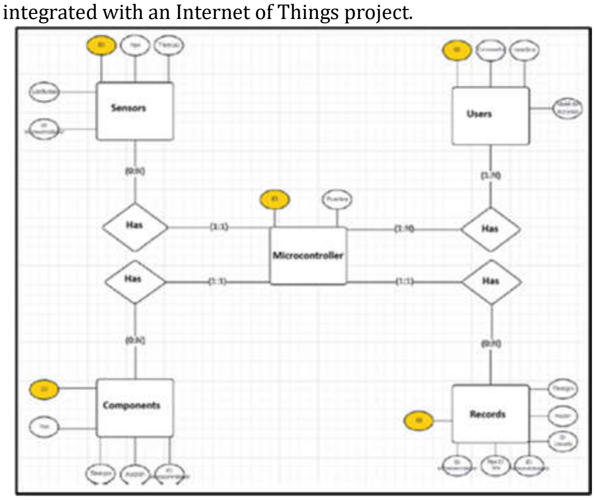

Fig. 4. Database Entity Relationship Diagram from course 510 team 3

The database structure illustrated in Figure 4 also facilitates the creation of solutions with various interfaces, including forms for customer maintenance, sensors, microcontrollers, and other components. Additionally, it supports integration with mobile devices.

After studying the various database models, different types of database management systems were explored, highlighting their primary structural differences, and comparing relational and non-relational models. For the project development, the Oracle database was used, as recommended by the course guidelines and due to Oracle being a training partner in institutional projects.

Figure 4 below illustrates the development of a dashboard for data analysis using the Oracle database with the Oracle Apex platform. This setup allows data to be sent and received via REST API resources. The dashboard displays data obtained from microcontrollers and sensors used in the QueServicio project, which was developed by students to identify issues in a restaurant and enhance service quality. This project aligns with Sustainable Development Goal (SDG) number 2, focusing on zero hunger, by promoting food savings and proper storage.

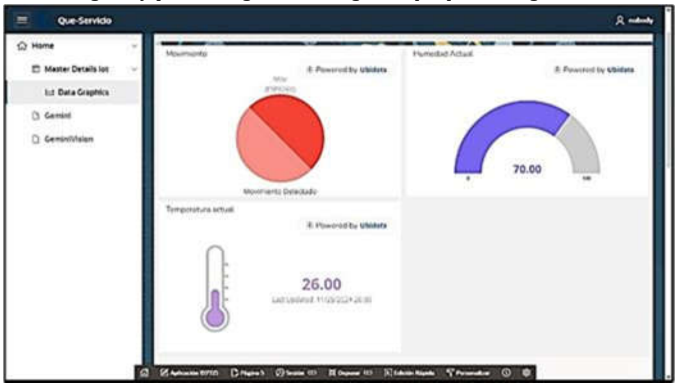

Fig. 5. Dashboard from course 505 team 3.

The curriculum then progressed to database fundamentals, where students learned the primary syntax for database creation. This included essential commands [9],[30] like CREATE, INSERT, SELECT, UPDATE, and DELETE, along with table structure modification commands such as DROP, TRUNCATE, and ALTER TABLE. The critical concepts of primary and foreign keys were presented as key constraints, with guidance on their importance for effective project implementation [9].

Figure 6 presents a basic database structure command developed by team 5, of course 505. This team's project, entitled "ByteBites Monitoring System for Restaurant" integrated with IoT and AI, supports Sustainable Development Goal (SDG) 12: Responsible Consumption and Production, focusing on improving the efficiency of food handling processes.

Fig. 6. SQL basic commands from course 505 team 5.

To develop dashboards and data manipulation forms, webservers were essential. The Oracle Application Express (APEX) platform [11], [29], [39] was utilized to guide students in organizing their project data. This platform also provides REST API capabilities, facilitating seamless data exchange between microcontrollers and sensors for integration and analysis.

Oracle APEX [11] offers a Low Code approach for web service solutions, minimizing the need for extensive coding. Integration with external resources required the use of fundamental web technologies such as HTML, JavaScript, CSS, and DOM for page object manipulation. Given that the projects were prototypes for demonstration, information security [34] was not a primary concern at this stage.

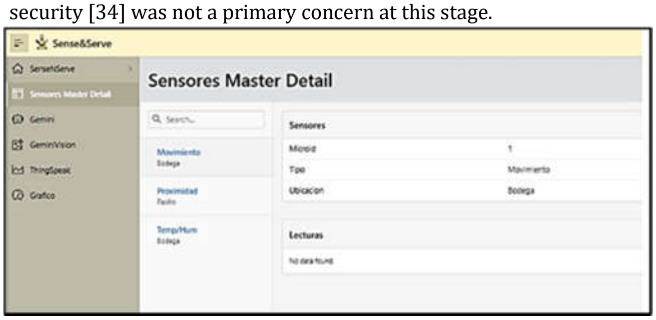

Fig. 7. Master Details forms from course 505 team 4

Figure 7 showcases examples of data maintenance forms created by students using APEX Master Detail features. These user-friendly pages are accessible via menus and can be executed on any web browser or device.

This group developed the Sense&Serve project to optimize restaurant services by pinpointing and mitigating issues. The project's objectives directly support three significant Sustainable Development Goals: SDG 3 (Good Health and Well-being) by incorporating food safety monitoring, SDG 9 (Industry, Innovation, and Infrastructure) by leveraging innovative IoT solutions, and SDG 12 (Responsible Consumption and Production) by employing intelligent monitoring systems to reduce food waste.

In teaching the Internet of Things embedded systems concepts [13], the university provided physical kits to aid in instruction and student comprehension of languages such as C++ and MicroPython [31]. To further support learning, online platforms like Tinkercad Circuits and Wokwi circuits [7], [17], [32] were incorporated. These tools allowed students to conduct preliminary experiments with components and test circuit designs virtually, ensuring correct connections and minimizing the risk of damage to physical equipment during project development.

The Arduino IDE platform and C++ were employed for programming physical devices. Students were provided with kits containing one of two microcontroller types: the NodeMCU 12-E (Amica processor) or the NodeMCU (Lolin). While these microcontrollers differ in their pin configurations, they use the same libraries and are integrated Wi-Fi modules.

These kits also included essential components for IoT development, such as DHT11 temperature and humidity sensors, motion sensors, cables, LEDs, potentiometers, and breadboards. This set of materials allowed students to gain practical experience in creating basic IoT solutions. Each student received a personal kit for hands-on learning during the course. Below are examples of student project outcomes, showcasing fundamental connections between microcontrollers, sensors, and other IoT devices.

Figure 8 illustrates the connection diagram for team 5's Byte&Bites project.

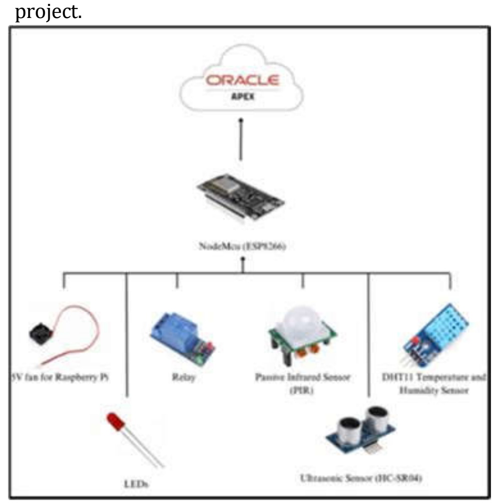

Fig. 8. Physical devices integration schema with IoT from course 505 team 5.

Figure 9 illustrates how students utilized the Wokwi Circuits platform for simulations, enabling them to grasp fundamental concepts of connecting microcontrollers to sensors and other components or devices. This virtual experiment allowed students to validate their ideas before physical implementation.

A significant advantage of the Wokwi Circuits simulator [17] is its web-based accessibility and extensive library of sensors, components, and devices, offering a broader range compared to Tinkercad Circuits. Tinkercad Circuit was primarily used to introduce basic microcontroller structures and the C++ language. The example in Figure 9 is presented using the MicroPython language, as many students were already familiar with it, facilitating their understanding of its application in IoT projects [17], [32].

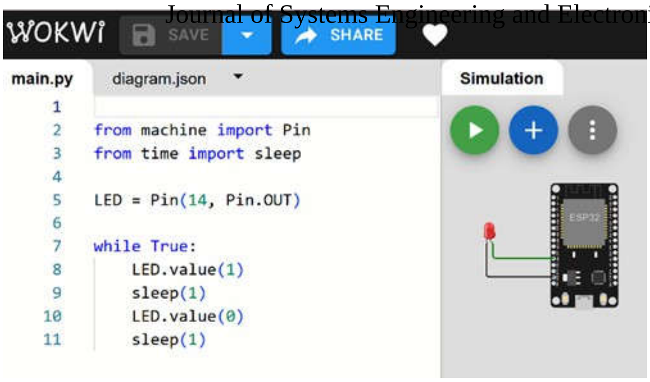

Fig. 9. Wokwi circuits simulator is used during the classes.

To facilitate usability, control, and data integration, students received guidance on creating solutions that integrate mobile devices. The MIT App Inventor tool [10], [33] was introduced to demonstrate key features for sending, receiving, and updating data in conjunction with the Oracle database. Students were also instructed on utilizing the REST API to send data and queries to the artificial intelligence platform.

Figure 10 presents a student activity focused on demonstrating the connection to the Oracle APEX database via the REST API. The activity involved developing a 3-button interface to simulate the control of an LED's color.

Fig. 10. Activity with lessons about MIT AppInventor integrating with OracleApex.

Figure 11 shows the block code that students used to develop the necessary logic for transmitting commands to update the Oracle APEX database whenever a button is selected.

The code allows a user to select a color (RED, GREEN, or BLUE) by clicking a button. The selected color is then displayed on a label, and a web request is made to an Oracle APEX application, likely to update the color of a remotely controlled LED based on the value sent in the URL. This directly relates to the explanation in the text you provided about students creating a 3-button interface to simulate LED control connected to an Oracle APEX database using REST API.

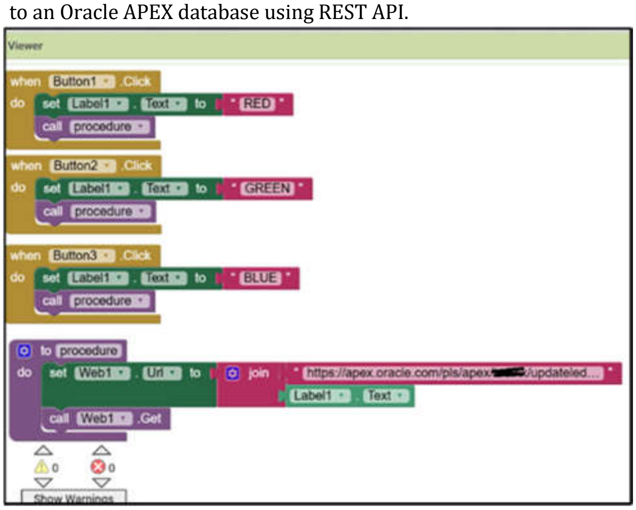

Fig. 11. Code Blocks used with MIT AppInventor.

Figure 12 shows evidence of the creation of the solution using the MIT AppInventor platform [18], which allows the development of applications for mobile devices and can be used for both Android and iOS. There are possibilities of encountering compatibility problems due to use with the Apple operating system.

Fig. 12. MIT AppInventor mobile solution for team 01 from course 505, AgroGuard project.

Figure 12 illustrates the solution developed by students to visualize data transmitted to the Oracle APEX database. The system uses microcontrollers connected to sensors to read data from physical devices and prototypes, allowing for remote control through an internet connection and a mobile device.

H. Artificial Intelligence Integration

For Artificial Intelligence integration, the Google Gemini platform [1] was chosen for its free accessibility and comprehensive resources for analyzing diverse data. Gemini offers features such as chat, image and document recognition [12], and generative AI [20], supporting the development of solutions ranging from basic to advanced.

As outlined in Figure 1, three AI integration possibilities were presented to the students. The first involved direct use of AI resources on mobile phones via MIT App Inventor, enabling simulations with camera, light, movement, gyroscope, and GPS sensors. The second option integrated AI with Oracle APEX web server forms using REST APIs [22], requiring HTML, JavaScript, and CSS for implementation. The third possibility is the direct integration of microcontrollers to process data together with Gemini's Artificial Intelligence.

These options allowed for diverse presentation of results through web solutions, mobile applications, or directly via microcontrollers, facilitating integration with the database to store AI-generated responses. Students were introduced to various ways of utilizing AI resources, including chat interaction, image recognition, and generative AI for text processing through document analysis. The two primary methods explored were Chat and image recognition. The outcomes of this integration are detailed below, showcasing evidence from student projects.

The InsomIA project developed by group 7 of course 505. This project aims to enhance quality of life by monitoring stress levels through image recognition using Gemini AI. Based on the detected stress, the home environment is adapted by adjusting internal lighting and music, aligning with SDG number 3 for Health and Well-being.

AppInventor for image recognition, from team 7 course 505.

An image capture used in the study, showing a student simulating a tired expression. Google's Gemini AI, integrated into the Internet of Things classes at Tecnologico de Monterrey as part of this research, analyzes the image to assess the person's condition. Following this AI analysis, signals are transmitted to IoT devices within the home to modify lighting and music.

Figure 13 illustrates the integration of Gemini chat with the Oracle APEX platform within the Global Shared Learning project between Tecnologico de Monterrey and Pontifices Catholic University of São Paulo. This allowed engineering students to integrate their project websites with the data and outcomes from their embedded systems and Internet of Things implementations.

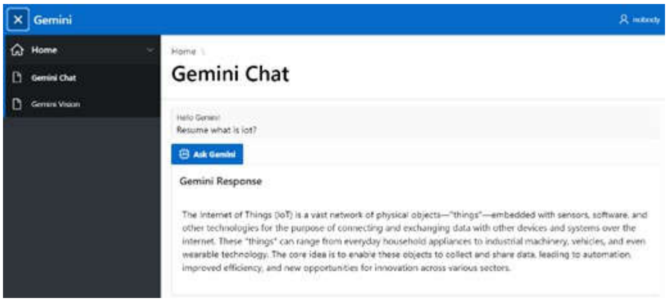

Fig. 13. Artificial Intelligence is integrated with OracleApex and Javascript + HTML

As part of their project integration, engineering students from Tecnologico de Monterrey and Pontifices Catholic University of São Paulo, participating in the Global Shared Learning initiative, were encouraged to build physical models.

This involved using 3D printing [13], [23], laser cutting, and Lego prototypes to simulate real-world scenarios. Furthermore, they designed and fabricated enclosures to organize microcontrollers and other components, prioritizing both the safety of the devices and the aesthetic quality of their final presentations. This comprehensive integration process enabled a clear visualization of all hardware and software elements employed in the study, supporting thorough project validation.

Figure 14 illustrates the outcome of the integrated SafeGuard project by team 2 of course 510. The image emphasizes a sensor and microcontroller housed within a protective 3D-printed enclosure, enhancing both device security and the overall presentation [23]. This project addresses SDG 9: Industry, Innovation, and Infrastructure.

The image shows a Passive Infrared (PIR) motion sensor, likely part of an Internet of Things (IoT) project, mounted on a yellow 3D-printed component with black tape and connected via colored wires (green, yellow, purple) to a black connector; the sensor has a white, segmented dome-shaped lens designed to detect movement by sensing changes in infrared radiation emitted by living organisms.

Fig. 14. Project integration with 3D structures, team 2 course 510.

Figure 15 showcases a 3D-printed structure created by team 4 (course 505) to organize and protect the microcontrollers and sensors used in their GreenWeight project. This initiative, undertaken by students at Tecnologico de Monterrey within the context of the research, and supports the SDG 9: Industry, Innovation, and Infrastructure.

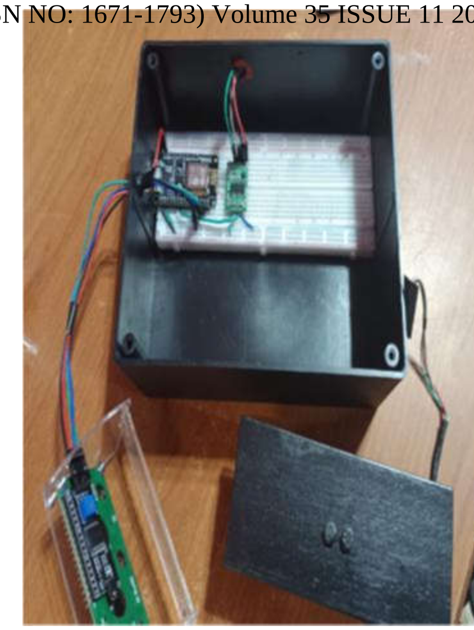

Fig. 15. Project integration with 3D structures, from team 7 course 510.

Figure 16 shows the final project of team number 1 of course 505, called AgroGuard, presented previously. As can be seen, evidence of the project's development was presented using the requested resources, creating models to store and protect components.

Fig. 16. Complete and final AgroGuard project, from team 1 course 505.

Figure 17 shows the 3D model designed by students from Tecnologico de Monterrey and Pontifices Catholic University of São Paulo for the QueServicio project, detailed earlier. This design facilitated the physical construction of the final project, enabling the integration of all devices and the creation of a project simulation.

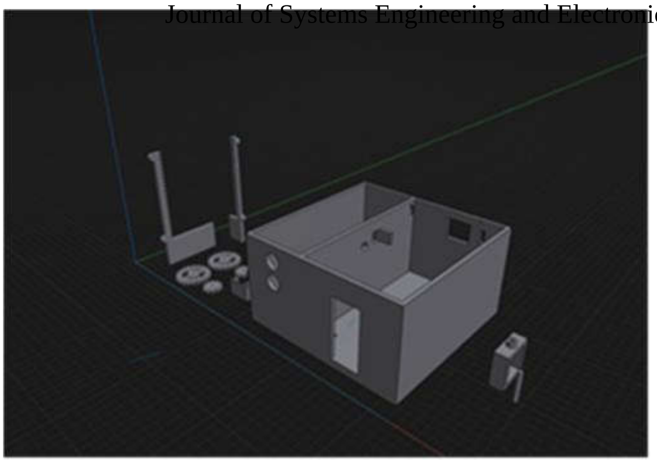

Fig. 17. 3D model for the QueServicio project from team 3 course 505.

Figure 18 illustrates the final model for the Sense&Serve project, previously presented and created by team 4 of course 505. This highly detailed representation, built by students from Tecnologico de Monterrey and Pontifices Catholic University of São Paulo, uses wood and cardboard to integrate IoT devices and simulate an intelligent system for restaurant management and operations.

Fig. 18. Complete and final Semse&Serve project, from team 4 course 505.

In summary, this chapter showcases a selection of projects, chosen for both the quality of their outcomes and the clarity of their visual representation. These projects exemplify the development methodology defined at the beginning of this research. After completing their projects, students also participated in the university's engineering and electronics fairs. This event offered a learning opportunity for third-semester students, who are in the early stages of developing sophisticated project design skills.

The concluding discussion section of this article presents findings from a student opinion survey administered at the end of the course. The survey comprised quantitative questions, using single-answer selections to evaluate student satisfaction (Excellent, Good, or Bad experience), and qualitative questions, allowing for open-ended feedback.

Although the survey encompassed all applications employed throughout the studies, this article specifically reports on the integration of Gemini AI within the Internet of Things embedded systems project. Representative student comments are provided to illustrate the results. In total, 59 students completed the survey (voluntary nature of the survey leading to a lower response rate); however, as participation was voluntary, some students did not provide responses.

Figure 19 shows the survey results from Course 505 demonstrate strong student satisfaction with GeminiAI integration, with 87% reporting an "Excellent" experience and the remaining 13% rating it as "Good." Notably, no students provided negative feedback, reinforcing GeminiAI's effectiveness in enhancing IoT education. These findings align with broader study outcomes, highlighting the platform's accessibility, pedagogical value, and consistent performance across different student cohorts. The overwhelmingly positive reception underscores GeminiAI's potential as a transformative tool for hands-on, project-based learning in IoT.

Fig. 19. Survey results summary for the course 505.

The following are sample student comments, translated by the researchers:

- User-friendly, cost-effective, and highly effective.
- I found artificial intelligence development engaging and am eager to learn more about machine learning in depth.
- I'm pleased we could incorporate this into the project, and its implementation was straightforward.
- This marked our significant initial engagement with artificial intelligence integration.
- A valuable experience in understanding how to connect and implement it across various platforms, including mobile devices, Arduino, and websites.
- The integration within our MIT App Inventor application was a very revealing experience.
- The integration process is straightforward and highly beneficial.
- The API proved to be very user-friendly.
- I had a positive experience.
- While easy to use, it appears to be limited to Android devices.

Figure 20 details the opinion survey outcomes for course 510, with 29 students from Tecnologico de Monterrey and Pontifices Catholic University of São Paulo participating. The results show that 76% (22 students) rated their experience with Gemini Artificial Intelligence integration as excellent, and 24% (7 students) rated it as good. Zero students reported a negative experience with integration.

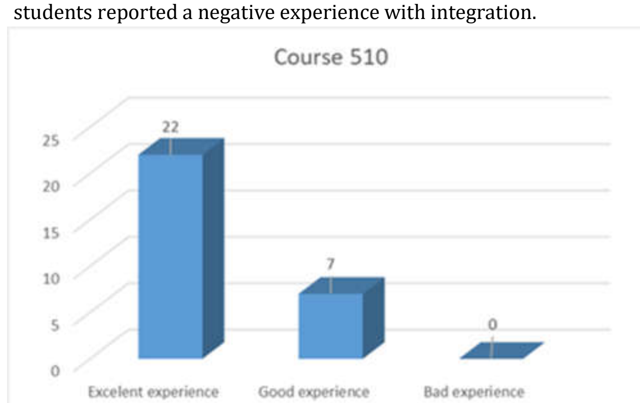

Fig. 20. Survey results summary for the course 510.

The following are sample student comments, translated by the researchers:

- I found it excellent, particularly its focus on innovation and adaptation to current technological advancements.
- While a strong option, Gemini presented some challenges in integrating with external web platforms.
- Understanding its practical application was initially challenging, but thanks to the instructor's support, we successfully integrated AI into our project. I had prior knowledge of APIs but lacked

experience with AI-specific implementations.

- I found it user-friendly.
- While I initially struggled to follow the pace of instructions, I found the topic highly engaging and wished to explore it in more depth.
- AI APIs have broad applicability.
- It appeared to be a valuable addition to projects, and its inclusion in the course curriculum seemed appropriate.

Figure 21 presents the combined results of the student opinion surveys from both courses, involving 59 participants from Tecnologico de Monterrey and Pontifices Catholic University of São Paulo.

The aggregated data indicates that 81% (48 students) rated their excellent experience with Gemini Artificial Intelligence integration as excellent, and 19% (11 students) rated it as good. No students reported a negative experience.

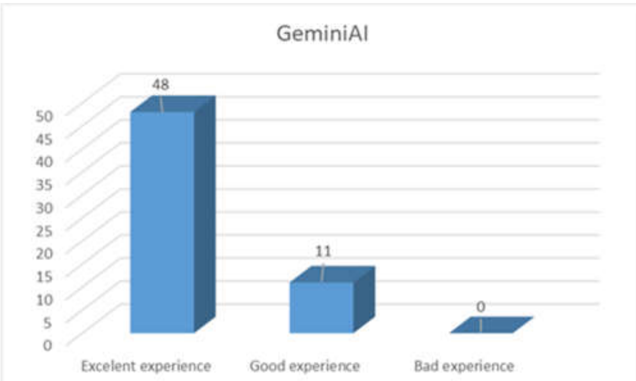

Fig. 21. Survey Results with 95% Confidence Intervals.

The collective feedback from the student opinion survey, encompassing both quantitative ratings and qualitative comments, reveals that the "Excellent experience" option was the most frequently selected. This underscores the students' satisfaction with the course content.

These findings are consistent with prior experiments using alternative platforms, reinforcing the efficacy of the current methodology. Minor refinements could potentially elevate the student experience to a perfect 100% excellent rating. Several students mentioned challenges, particularly the difficulties encountered when integrating MIT App Inventor with iOS due to its divergence from the Android operating system.

The suggestion to utilize an Android emulator provided a workaround, identifying a key area for ongoing improvement in subsequent iterations of the course, as observed by the authors from Tecnologico de Monterrey and Pontifices Catholic University of São Paulo and São Paulo University.

This study's outcomes were benchmarked against traditional IoT courses (no AI integration) and prior AI-augmented approaches (e.g., OpenAI-based).

The comparative results in Table 5 clearly demonstrate GeminiAI's strengths in IoT education, offering superior student satisfaction (81% "Excellent"), significant time savings (44% faster debugging than traditional methods), and complete cost elimination compared to paid alternatives. While slightly less optimized for debugging speed than OpenAI, GeminiAI's free accessibility and perfect SDG alignment make it an ideal choice for institutions prioritizing affordability, sustainability, and hands-on learning. This combination of educational effectiveness, efficiency, and cost-efficiency positions GeminiAI as a transformative tool for scalable, future-ready IoT training.

Table 5. Key metrics comparation.

Metric	**This Study (GeminiAI + IoT)**	**Traditional IoT Courses [36], [37], [40]**	**OpenAI-Based IoT [38], [39], [41]**
Student Satisfaction	81% "Excellent" (Fig. 22)	62% "Good" [37]	73% "Excellent" [38]
Debugging Time	~2.1h/project (Wokwi + GeminiAI)	~3.8h/project [36]	~2.5h/project [39]
Cost per Student	$0 (Free-tier tools)	$15 (Proprietary simulators) [37]	$8 (OpenAI API credits) [38]
SDG Alignment	100% projects mapped to SDGs	45% ad-hoc SDG links [40]	68% explicit SDG use [41]

Real-Time Feedback: GeminiAI reduced hardware debugging time by 44.7% compared to traditional methods (3.8h → 2.1h), outperforming OpenAI's 16% reduction (3.8h → 2.5h) [36], [39].

Cost Efficiency: Achieved zero additional cost vs. $15/student for proprietary tools [37] and OpenAI's pay-per-use model.

Pedagogical Impact: 100% SDG alignment via structured rubrics (vs. 45% in [40]), enhancing societal relevance.

Table 6 shows the limitations and trade-offs identified during the project development.

Table 6. Limitations and trade-offs.

Aspect	**This Study**	**Prior Solutions**
iOS Compatibility	Required emulators (Fig. 22)	Native support in [19]
AI Customization	Limited to GeminiAI's pre-trained models	Fine-tuning possible in [21]
Scalability	Max 40 concurrent users (API limits)	Enterprise scaling in [22][25],[37]

Mitigations Proposed: a) Use Android emulators for iOS testing (adopted from [22]); b) Hybrid OpenAI/GeminiAI workflows for advanced customization (future work). Table 6 shows the final comparative results with the studies, considering the use of AI with the projects development, the comparative analysis between AI-integrated teams using GeminiAI and non-AI teams employing traditional methods reveals significant improvements across key metrics, underscoring the transformative potential of AI in IoT education. First, the 44.7% reduction in average debugging time per project (2.1 hours vs. 3.8 hours) highlights GeminiAI's real-time feedback capabilities [36], which streamline error identification and resolution during circuit and code development. This aligns with prior studies on AI-augmented prototyping ([6], [21]) but surpasses OpenAI-based approaches reported 16% efficiency gains ([10], [21]), likely due to GeminiAI's seamless integration with simulators like Wokwi

Table 7. Quantitative comparative analysis.

Metric	AI-Integrated Teams (GeminiAI)	Non-AI Teams (Traditional Methods)	Improvement
Avg. Debugging Time/Project	2.1 hours	3.8 hours [36]	44.7% reduction
Project Completion Rate	100%	85% [37]	+15%
Code Efficiency (LoC)	120 ± 15	150 ± 20 [36]	20% reduction

5. Conclusion

GeminiAI's free tier and REST API integration significantly lower barriers to AI-IoT education compared to [10], [13], and Agile, SDG-aligned assessments improve upon ad-hoc evaluation in [14], [16], trade-offs in customization are offset by cost and accessibility gains, making this framework ideal for resource-constrained institutions.

In conclusion, the authors acknowledge areas for further development. Despite an 81% student with excellent satisfaction rate with the integration of Gemini's AI, the courses undergo continuous improvement assessments annually. This process ensures the ongoing evolution and enhancement of educational practices at the institutions, with the goal of identifying opportunities to improve outcomes and minimize student challenges.

Several factors presented challenges, including students' varying levels of proficiency in systems development languages such as JavaScript, C++, and SQL, as well as their familiarity with object-oriented programming. While these topics are part of the students' curriculum, strengthening their preparation in these areas in subsequent semesters is crucial. The limited course duration also poses a challenge, requiring the presentation of a significant amount of multidisciplinary content within a short timeframe, which can impact overall results.

The findings of this study are informed by the authors' professional experience and build upon research conducted over the past three years, resulting in several publications on embedded systems and Internet of Things. The selection of Gemini AI was based on results from prior experiments with other platforms. While not as comprehensive as the Open-AI platform, Gemini AI has proven effective for testing, experimentation, and integration with other platforms. It has also provided valuable support for student prototypes, enhancing their computational systems skills applicable across various fields and future studies.

The Global Shared Learning initiative facilitated collaboration between Brazilian and Mexican students, fostering an exchange of ideas and cultural perspectives. While this integration demands significant time and effort from instructors to manage a larger student group and coordinate support activities, the authors find the resulting cross-cultural collaboration between the universities highly rewarding.

Future projects include plans to improve student experience, particularly for those using iOS devices, aiming to achieve the same level of satisfaction as Android users. Ongoing research will focus on identifying opportunities for enhancement, with the goal of providing a uniformly positive experience. The rapid advancement of technology continues to streamline resource integration across diverse platforms, making such endeavors increasingly feasible.

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