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Project-Based Learning in Smart House Development: Artificial Intelligence and IoT Technologies for Efficient Living

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Abstract: This paper examines the application of project-based learning in the development of smart houses, emphasizing the integration of artificial intelligence (AI) and Internet of Things (IoT) technologies to enhance efficiency and comfort in daily life. Through project-based activities, students acquired technical skills such as programming, working with sensors, and implementing machine learning algorithms, alongside soft skills like teamwork and problem-solving. The evaluation of the results revealed significant improvements in students' understanding of STEM (science, technology, engineering, and mathematics) concepts, as well as increased motivation and engagement throughout all stages of the project. The use of the Multi-Role Project (MRP) model facilitated the combination of practical engineering tasks with reflective learning processes. The findings indicate that such projects not only enhance students' competencies in STEM fields but also prepare them to contribute to the advancement of smart cities and sustainable technologies.

Keywords: Project-based learning; smart house; artificial intelligence; IoT; STEM education; sustainable development; smart cities;

1 INTRODUCTION

Smart cities represent a vision of the future where technology is used to improve the quality of life, increase energy efficiency, and reduce the negative impact on the environment. They integrate advanced technologies such as the Internet of Things (IoT), machine learning, and sustainable urban practices, creating an environment that is not only technologically advanced but also environmentally sustainable. A key challenge lies in educating new generations to acquire the competencies needed to contribute to the development of such communities.

In this context, project-based learning stands out as an innovative and effective educational approach, enabling students to integrate theoretical knowledge with practical skills by working on real-world problems. Through this method, students not only solve technical tasks but also develop critical thinking, collaborative skills, and creativity — all key attributes needed for the future.

As research shows [1], [2], project-based learning contributes to increasing student motivation and developing multidisciplinary skills. Its application in STEM education allows students to confront real challenges, using technology and innovation to develop solutions [3]. Additionally, integrating the concept of smart cities into educational projects, as analysed in [4], further highlights the potential of this approach in the context of sustainable development.

This paper explores the potential of project-based learning through the analysis of the "Smart House" project, conducted in collaboration with students. The aim is to demonstrate how this approach not only fosters individual and team competencies but also prepares students for active participation in creating sustainable and technologically advanced urban communities.

2 THEORETICAL FRAMEWORKS

2.1 Fundamentals of Project-Based Learning

Project-based learning is based on the principles of learning through real-world projects, where students actively explore, ask questions, and solve problems. This approach enables the integration of theoretical and practical knowledge, developing critical thinking and collaboration skills [1]. Dewey emphasized that education should be centered on the child, fostering experiences that are connected to their interests, needs, and real-world applications. This perspective forms the foundation for experiential and project-based learning, where students engage actively in solving practical problems [5]. The benefits of project-based learning include increased student motivation, better understanding of complex topics, and the development of 21st-century skills such as communication and creativity [2].

2.2 Project-Based Learning and STEM Education

Integrating project-based learning into STEM education provides students with the opportunity to apply knowledge from multiple fields through interdisciplinary projects. According to [3], this approach allows students to understand the connection between science and technology and everyday life while simultaneously developing practical skills.

The MRP model, developed by [2], offers an additional framework for implementing project-based learning in STEM education. This model relies on the concept of learning through real projects and includes two parallel processes: an engineering project, where students create tangible products, and learning through the project, which encompasses reflection and the development of professional skills. The MRP method has proven particularly effective in developing teamwork, communication, and technical competencies, as well as in preparing students for real challenges they will encounter in professional environments.

2.3 Smart Cities as an Educational Context

Smart cities use technologies such as the Internet of Things (IoT) and machine learning to enhance infrastructure and sustainable development [4]. The integration of machine learning allows for the optimization of urban resources, such as energy grids, transportation systems, and waste management. These technologies not only improve efficiency but also contribute to reducing the carbon footprint, making them key elements in sustainable development.

In education, projects related to smart cities provide students with the opportunity to apply knowledge in creating innovative solutions to urban challenges. For instance, the "Smart House" project involves designing systems for household automation, which not only develops technical skills but also raises awareness about the importance of energy efficiency and sustainability. By applying methods such as project-based learning and interdisciplinary education, students acquire competencies that are crucial for contributing to the development of such cities in the future.

It has been emphasized that the use of machine learning in smart cities not only enhances infrastructure but also enables students to explore the potential of new technologies through practical applications in real situations [4]. Such projects allow young people to understand how theoretical knowledge can be used to address global challenges, such as urbanization and climate change.

3 METHODOLOGIES

3.1 Educational Context

The "Smart House" project was implemented within the course *Applied Information Technologies* at the Technical School in Čačak. The project involved fourth-year students from the *Information Technology Electrotechnician* program. The course covers topics such as programming, web programming, an introduction to artificial intelligence, databases, and technical documentation. The project was carried out as a collaborative effort, with multiple teachers contributing based on their areas of expertise, ensuring students received comprehensive guidance across various disciplines.

When selecting the project topic, care was taken to cover as many of these topics as possible, allowing students to integrate theoretical knowledge with practical skills.

The project encompassed the following areas:

- Programming: Developing technical solutions using Arduino microcontrollers, sensors, and programming tools,
- Web Programming: Creating applications for remote control of smart house functions,
- Artificial Intelligence: Applying AI algorithms for license plate recognition and security control,
- Databases: Managing and storing data collected through sensors,
- Technical Documentation: Documenting all project phases, including planning, implementation, and evaluation.

Through project implementation, students acquired various skills, including:

- Technical skills: Development of hardware and software solutions, working with tools like the Arduino platform and MIT App Inventor,
- Communication skills: Presentation of results and team coordination during different project phases,
- Problem-solving: Addressing technical challenges through an iterative process of testing and evaluation.

3.2 Project Plan: "Smart House"

The theme "Smart House" was chosen due to its relevance to the concept of smart cities, which are essential for the sustainable development of urban environments. According to [4], smart cities integrate technologies such as machine learning and the Internet of Things (IoT) to optimize resources and increase efficiency. The "Smart House" project provides students with an opportunity to explore and apply these concepts in everyday life, thereby developing technical and analytical skills.

The research question was:

“How can we design and implement a smart House system using artificial intelligence and IoT technologies to enhance functionality, safety, and user comfort, in line with the principles of sustainable development?”

The project plan and implementation were structured into multiple phases, integrating various topics from the course Applied Information Technologies. The phases included:

- Initial Design: Students explored available technologies, such as light and temperature sensors, considered technical feasibility and costs, and created initial sketches and ideas,
- Prototype Development: Using the Arduino platform and sensors, basic modules for light and temperature control were developed,
- AI System Integration: Algorithms for facial recognition and security features were implemented, along with integration with cameras for enhanced safety,
- Mobile Application Development: Using MIT App Inventor, students created an application for remote control of smart house functions, including lighting and temperature,
- Testing and Iteration: Functional testing was conducted, sensor calibration issues were resolved, and system stability was improved,
- Presentation of Results: The final phase included prototype presentations, functionality demonstrations, and the creation of technical documentation.

3.3 Roles of Students and Teachers

Students: According to the MRP model [2], students had clearly defined roles within the team, such as leader, programmer, analyst, and designer. This division of tasks allowed each student to contribute to the project based on their interests and skills. During the implementation of the "Smart House" project, students actively participated in researching, designing, and testing the prototype, developing both technical and communication skills.

Teachers: Teachers played a key role as mentors and facilitators of the process. According to [1], the role of teachers in project-based learning is not only to provide technical support but also to guide students through the process of reflection and problem-solving. In this project, teachers ensured that students understood the theoretical concepts necessary for practical application while motivating them to take responsibility for their own learning.

Table 1 Roles and Responsibilities in Project-Based Learning for Smart House Development

Role	Description of Tasks
Students	Research, design, and implementation of technical solutions (e.g., programming, sensor integration).
Team Leader	Coordination of team activities, task distribution, and project progress monitoring.
Programmer	Writing code to control smart house functionality, integrating the mobile application with hardware.
Prototype Designer	Sketching concepts, creating physical components, and implementing hardware solutions.
Analyst	Evaluating system performance, identifying problems, and proposing improvements.
Teachers	Mentorship support: explaining theoretical foundations, providing technical assistance, and facilitating reflection on learning.
Facilitator	Organizing ideation sessions, ensuring resources, and guiding students through different project phases.

The combination of clearly defined roles and teacher support, as in Table 1, contributed to the successful implementation of the project, as well as the development of key competencies among students, including independence, teamwork, and creative problem-solving.

4 RESULTS: THE "SMART HOUSE" PROJECT

4.1 Initial Design Phase

The project began with a preparatory phase during which students studied various types of smart technologies, innovations in automation, energy consumption, and user interfaces. They participated in brainstorming sessions where they collaboratively developed unique concepts for prototypes and created detailed sketches. During this process, students considered costs, technical complexity, and feasibility. This phase was crucial for laying a solid foundation for further project development.

4.2 Construction of the Prototype

During the construction phase, students combined physical system components using Arduino microcontrollers and various sensors. They connected motion sensors, temperature control units, and lighting controls to a central control board, Arduino Mega. Initial functional testing was conducted to ensure that all system components operated correctly. This phase was essential for understanding hardware integration and system compatibility.

4.3 Integration of AI and Webcam

One of the main features of the project was the integration of AI technology with a webcam to enhance security. Students trained the AI system to recognize license plates of authorized users and automatically open garage doors, as illustrated in Figure 1. To improve recognition accuracy, they implemented machine learning techniques and optimized the system for operation in various environments. This phase required advanced programming skills and an understanding of AI applications in real-world scenarios.

Figure 1 The webcam recognizes the license plate and opens the garage door

4.4 Mobile Application Development

Students designed a mobile application to interact with the smart systems using MIT App Inventor, as shown in Figure 2. They created an interface that allows users to manage smart house functions, such as lighting, temperature, and energy consumption. The application also enabled Bluetooth connectivity with the Arduino Mega board, providing remote control. Added functionalities included real-time alerts, such as motion detected by sensors or temperature changes. Management begins with selecting a room, as demonstrated in Figure 3.

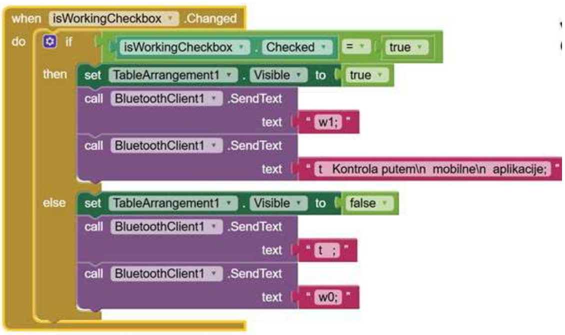

Figure 2 A section of the code for Bluetooth connection

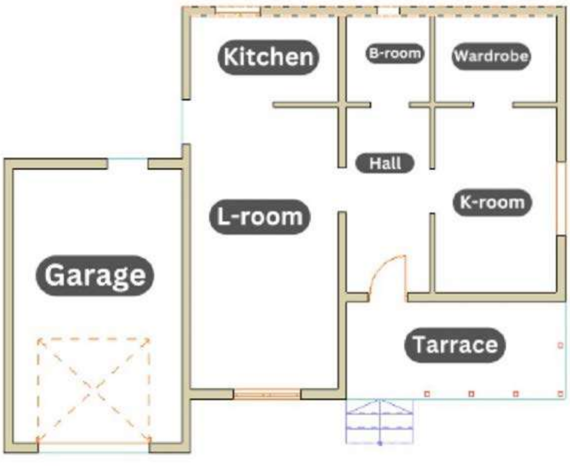

Figure 3 The initial screen of the application

4.5 Testing and Iteration

Throughout the project, testing and improvement occurred through a cyclical process involving continuous evaluation and enhancement of the system. Students faced technical challenges, such as sensor malfunctions, incorrect calibration, and programming errors. Through an iterative approach, errors were identified and corrected, while system functionalities were progressively improved.

In the testing and iteration phase, students followed a cyclic process of evaluating and improving their prototype. This aligns with the methodology described in [6], where students used MATLAB as a tool to simulate and optimize bioprocess systems.

The iterative nature of the "Smart House" project aligns with the principles discussed in [7], where project-based learning emphasizes continuous evaluation and refinement. Similar to the challenges faced in interdisciplinary projects like CAD/CAM in mechatronics [7], students in this project engaged in iterative testing to identify and resolve issues related to sensor calibration, hardware integration, and software functionality. This process not only improved the reliability of the prototype but also reinforced the importance of applying theoretical knowledge in practical settings.

Active participation from team members and feedback from teachers played a crucial role in this process. Their suggestions and recommendations allowed for prototype enhancements and increased system efficiency. This phase provided students with valuable experience in solving engineering problems and highlighted the importance of re-evaluating results for the success of complex projects.

4.6 Presentation and Demonstration

At the end of the project, students presented their results through detailed PowerPoint presentations and practical demonstrations of the prototype's operation. Presentations covered key aspects of the project, including descriptions of technical solutions, challenges encountered during development, and strategies implemented to overcome these challenges. The focus was on explaining the design and implementation process, as well as learning through problem-solving.

Practical demonstrations showcased the prototype’s functionalities, including automatic light regulation, temperature control, and soil moisture monitoring, as well as advanced security measures such as license plate recognition for access control and fire protection using fire sensors. These demonstrations allowed the audience to understand the technical complexity of the project and the innovative solutions students devised and implemented.

4.7 Evaluation

Feedback from teachers and other students regarding the presentations was essential for evaluating the project's success. Teachers emphasized the technical aspects and professionalism of students during the presentations, while students shared their experiences and suggestions for improving future projects, as shown in Table 2. This exchange of opinions helped identify the project’s strengths and weaknesses, further enhancing the learning process.

Table 2 Feedback on Key Aspects of the Smart House Project

Category	Teacher Comments	Student Comments
Prototype Design	"Well-designed functionalities, but sensor connectivity could be more stable."	"It was our first time working with sensors, and it was challenging, but we learned a lot."
Programming	"The code is functional, but there is room for optimization and better documentation."	"Working on Bluetooth connectivity was interesting, although it was difficult at first."
AI Technology	"Ambitious AI system integration; more examples could be added in the future."	"It was great working on image recognition, but optimizing accuracy was tough."
Mobile Application	"The app interface is intuitive, but additional functionalities could be implemented."	"We’re proud we managed to connect the app with all house functions."
Teamwork	"Teams collaborated well and showed a high level of responsibility."	"Teamwork was key, and we all contributed our knowledge."
Presentation of Results	"Presentations were clear and professional, but demonstrations could have been more detailed."	"It was exciting to showcase our results to the audience."

5 CONCLUSIONS

The "Smart House" project demonstrated how project-based learning can be a powerful tool for enhancing the educational process, particularly in STEM fields. Through this project, students not only acquired technical skills and practical knowledge but also developed essential soft skills such as teamwork, communication, and critical thinking. These competencies are vital for success in the modern world, especially in the context of the development of smart cities and future technologies. Students in the "Smart House" project reported heightened motivation and a deeper understanding of concepts such as IoT, AI integration, and system optimization.

The application of models like the MRP further enriched the teaching process, enabling students to combine engineering work with reflection on their own learning.

Smart cities, as a concept, offer broad opportunities for integrating technology and sustainability into educational projects. Education plays a central role in preparing young people for global challenges such as urbanization and climate change.

The outcomes of the "Smart House" project underscore the benefits of project-based learning in developing interdisciplinary skills. PBL fosters teamwork, problem-solving, and the ability to integrate knowledge from multiple fields, such as electronics, programming, and hardware design. Similarly, students in this project demonstrated improved collaboration and technical expertise while working on complex, real-world challenges. These findings support the conclusion that PBL is an effective pedagogical strategy for preparing students to meet the demands of modern technology-driven industries.

The "Smart House" project serves as an example of how educational initiatives can contribute to the development of critical skills and competencies essential for the future. The integration of theoretical knowledge and practical application through this project demonstrated that project-based learning is not only useful but also a necessary approach in modern education.

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