Implementation Of Gamification-Based Digital Learning Through Arduino Project Development Using The ADDIE Instructional Model

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Abstract

Digital systems courses can be constrained by from low student engagement and limited opportunities hands-on hardware practice. This study contributes a replicable implementation model where ADDIE is operationalized as a student project management cycle (not merely an instructor design model) integrated with PjBL gamification, and evaluated using multi source learning analytics and rubric based prototype assessment. A total of 124 first term students at Universitas Muhammadiyah Metro completed a term long sequence in which they followed ADDIE phases analysis, design, development, implementation and evaluation to create working prototypes addressing real world issues (e.g., Smart Guidance Stick, Flood-Warning System, AquaFeed). Quantitative descriptive analysis drew on learning management-system logs, assignment and quiz scores, rubric-based project evaluations, and mid and end term exam results. Mean participatory-activity scores were high (M = 88, Coeficient Variation (CV) = 6 %), indicating uniformly strong engagement fostered by point, badges and leaderboards. Project quality was likewise strong (M = 87, CV = 10 %), and showed a positive correlation with participation. Quiz performance was very high (M = 92, CV = 11 %), while midterm and final exam means were 85 (CV = 18 %) and 88 (CV = 10 %), respectively, demonstrating improved cognitive attainment after targeted feed-forward interventions. Outliers students scoring ≤ 60 on tasks or exams, or producing incomplete projects were identified for diagnostic mentoring. Overall, the approach produced consistently high participation (M=88; CV=6%) and prototype quality (M=87; CV=10%), alongside strong cognitive attainment (midterm M=85; final M=88). The findings describe strong observed performance and identify low-scoring students for diagnostic mentoring; they do not establish causal effectiveness because the study had no control group, pretest, or inferential analysis. The implementation provides a structured model for integrating gamification, ADDIE, and Arduino projects in digital systems instruction.

Keywords: Gamification; ADDIE; Arduino project; Project based learning; digital learning

INTRODUCTION

The Industrial Era 4.0 and the shift towards Society 5.0 have changed the global education landscape, including in Indonesia. Education is no longer just a process of delivering material, but has developed into a means to form digital skills, critical thinking skills, and technology-based innovation. In this context, universities are required to build a learning ecosystem that is interactive, flexible, and adaptive to the development of the times (Dinata, 2021; Tasya et al., 2023). Based on the latest data from the Indonesian Internet Service Providers Association, by 2024, internet users in Indonesia will have reached 221.6 million people or around 79.5% of the total population, a significant increase compared to the previous year (APJII, 2024). This fact shows that digital infrastructure is increasingly evenly distributed and online learning has great potential to reach students widely.

However, behind these numbers, However, behind these numbers, Challenges arise in the form of low student involvement, lack of interactivity in digital learning, and limitations of real practice-based learning (Kaatrakoski et al., 2017) In the midst of increasing technology penetration in the world of education, online learning also faces a number of serious challenges. (Dunlosky et al., 2013; Ioannou et al., 2016; Kaatrakoski et al., 2017). In addition, online learning often does not allow for in-person practicums, even though practicum is very important in the field of engineering and computers to form psychomotor skills and problem-solving. This has an impact on the weak practical skills of students, especially in terms of device assembly, coding, and drafting hardware-based logic systems(Tehranipoor et al., 2023). To answer these challenges, a more active and contextual approach to learning is needed. One effective approach is Project-Based Learning (PjBL), which is a learning strategy that places students as active subjects through direct involvement in planning, designing, and completing real projects. PjBL encourages collaboration, creativity, and mastery of concepts through hands-on practice, bridging the gap between theory and application (Fitri et al., 2024) . In this context, the use of Arduino as an open microcontroller platform has become particularly relevant. Arduino allows students to build simple intelligent systems that are directly connected to sensors and actuators, such as gas detection devices, temperature sensors, disability aids, and more so that learning experiences become more applicative, contextual, and meaningful (Bedoya-Cano et al., 2025; Pino et al., 2022; Ziemann, 2023).

One of the strategic innovations in digital learning that has received widespread attention is the application of gamification. Gamification refers to the use of game elements such as points, levels, leaderboards, challenges, and rewards into non-gaming contexts, including education. In the context of (Moeniralam & Wit, 2024; Schreiber, 2021). When applied in technology project activities such as the development of Arduino-based systems, gamification can provide an immersive and problem-solving experience oriented to real-world problems (Kulkarni et al., 2022; Tran et al., 2023; Zainuddin, 2024).

When PjBL is combined with gamification elements, for example, the awarding of levels, challenges, and a point system in a learning experience project becomes more interesting and competitive (Riswanto et al., 2024; Riswanto et al., 2025). However, to implement this combination systematically, a strong instructional design framework is needed. The ADDIE (Analysis–Design–Development–Implementation–Evaluation) model has been proven to be able to provide structure in designing and evaluating digital learning media that is responsive to the needs of 21st-century students (Crompton et al., 2024; Nor et al., 2022). This is where the role of the ADDIE model becomes central, as it provides structured guidance ranging from student needs analysis, content and activity design, learning media development, project implementation, to evaluation of learning outcomes and processes. The application of the ADDIE model in the context of Arduino project-based learning equipped with gamification elements is a potential combination to improve the overall quality of digital learning. With ADDIE, the learning process not only focuses on the final results, but also on the process of skill development, collaboration, and reflection on learning experiences, thereby supporting the achievement of students' cognitive, psychomotor, and social attitude competencies in an integrated manner (Crompton et al., 2024; Spatioti et al., 2023).

Prior research emphasizes that effective digital learning especially in online or technology enhanced settings requires systematic instructional design models to ensure alignment between learning objectives, learning activities, and evaluation. In addition, project-based learning (PjBL) in higher education has been consistently associated with improvements in a range of student outcomes and provides established approaches for evaluating project quality and learning outcomes (Özkan et al., 2025). Evidence syntheses also indicate that gamification can yield positive effects on motivational or behavioral outcomes and academic achievement when implemented with appropriate design and mechanics (Sailer & Homner, 2020a). Empirical work integrating Arduino-based activities with digital learning materials has reported measurable learning gains, supporting the relevance of Arduino projects as authentic, hands-on learning interventions (Papadimitropoulos et al., 2021).

Based on this evidence, it is important to conduct an in-depth study of how digital learning that combines Arduino-based projects and gamification elements can be designed and implemented systematically. In this context, several questions to be answered to understand the effectiveness of the approach as a whole. First, how can the stages of applying the ADDIE model in the development of gamification-based Arduino projects be carried out systematically? Second, what is the quality of student project results developed through ADDIE? Third, to what extent can the effectiveness of gamification-based digital learning increase student learning outcomes?

This study aims to provide a comprehensive understanding of implementing the ADDIE model in gamification-based digital learning by documenting systematic design decisions and their links to learner outcomes, in line with calls for more structured evidence connecting online instructional design and outcome measurement (Martin et al., 2020; Özkan et al., 2025). In addition, this study assesses the quality of students' Arduino project products using artifact-focused criteria, which is consistent with how project-based learning research commonly evaluates learning through the quality of produced work and performance rubrics (Guo et al., 2020). The study examines the effectiveness of gamification based digital learning on student outcomes across cognitive and skill related dimensions, considering meta-analytic evidence that gamification can improve learning outcomes depending on design features and implementation context (Huang et al., 2020; Sailer & Homner, 2020b), and that practical experimentation with Arduino-supported activities can yield measurable learning gains (Papadimitropoulos et al., 2021). In addition, this study is expected to analyze the effectiveness of gamification-based digital learning on student learning outcomes, both in the cognitive, psychomotor, and social attitudes domains.

The project-based digital learning implemented in this course required students to develop Arduino microcontroller-based prototypes through a complete engineering workflow, from project planning and circuit or sensor testing in a simulation environment to real-world implementation. This approach is consistent with evidence that project-based learning in embedded systems helps students connect theory and practice, improve mastery of core concepts, and develop system-level design skills under realistic constraints (Rodriguez-Sanchez et al., 2016). Students produced prototypes such as a smart guidance stick, household gas sensor, smart feeder, flood warning system, and smart agriculture or aquafeed projects. Similar Arduino or sensor-based assistive technologies (e.g., smart canes using ultrasonic or IR sensing) have been widely reported for disability support, demonstrating how microcontroller projects can directly address inclusion and mobility challenges (Sahoo et al., 2019). Moreover, low-cost sensing and IoT systems are commonly used for safety monitoring (e.g., combustible gas leakage detection and monitoring reliability) and for disaster risk reduction (e.g., real-time flood monitoring and early warning), supporting the relevance of student projects in security and environmental resilience contexts (Landi et al., 2025). In the domain of smart agriculture, IoT-based monitoring and data-driven decision support are well-established directions, aligning with student applications toward smart farming and resource efficiency (Rai et al., 2024). Students design projects ranging from planning, simulation at Proteus, to real-world implementation of tools, such as Smart Guidance Stick, Household Gas Sensor, SmartFeeder, Flood Warning System, and AquaFeed projects. The projects show that students not only learn programming concepts and sensors, but also apply their solutions in the areas of security, disability inclusion, energy efficiency, and smart agriculture.

Although the Project-Based Learning (PjBL) approach, gamification, and ADDIE's instructional design model have been widely studied separately, it is still very rare to find research that integrates all three in the context of real project-based digital learning such as the development of the Arduino system (Riswanto et al., 2025). Most studies have not clearly explained how the ADDIE model can be used as a systematic stage carried out by students in developing projects, starting from needs analysis, design, development, implementation, to evaluation of works. In fact, the use of ADDIE is not only relevant for lecturers as learning designers, but also effective as a guide for students in developing projects in a gradual, structured, and reflective manner (Wang et al., 2025; Zhang et al., 2024). On the other hand, the existing literature generally only emphasizes cognitive outcomes or learning motivation, without fully evaluating students' psychomotor skills and collaborative attitudes, as well as the technical quality of the prototypes produced. Additionally, the application of gamification in project-based learning has often not been directly linked to contextual and real-world problem-solving (Himmi et al., 2025). Therefore, this research is important to fill this gap by presenting a digital learning model that combines PjBL, gamification elements, and ADDIE stages as a direct approach carried out by students in the development process of the Arduino project, in order to improve the quality of the process and overall learning outcomes.

METHODS

This study used a quantitative descriptive classroom implementation design. The analyzed cohort comprised 124 first-semester students enrolled in a digital systems course at a private university in Lampung, Indonesia. The study examined learning records generated during one semester of gamification-based Arduino PjBL. Because the design used one cohort without a control group or pretest, the analysis was intended to describe implementation and performance patterns rather than estimate causal effects.

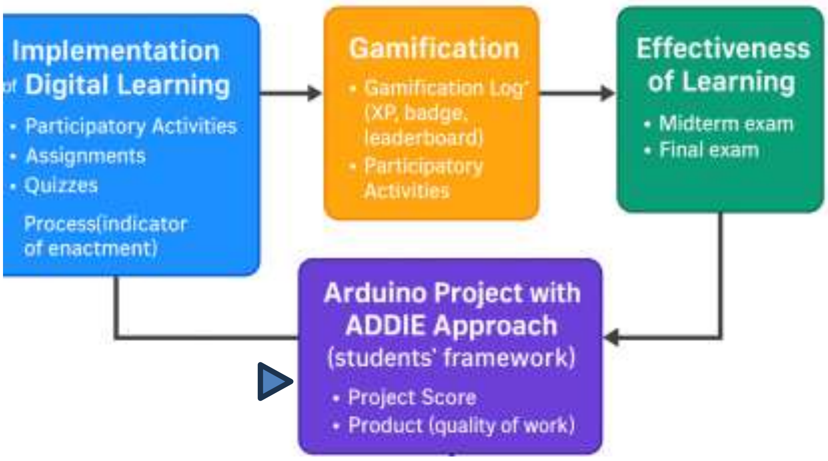

Figure 1. Data sources and analytical framework

The implementation combined four components. Digital learning activities were delivered through the institutional learning management system (LMS); gamification used cumulative experience points (XP), badges, leaderboards, and rewards; students developed Arduino prototypes through the ADDIE phases; and learning outcomes were summarized from project and academic scores. Figure 1 presents the relationships among these data sources.

Table 1. Data sources, operational definitions, and analytical roles

Construct	Data source	Operational definition and score	Analytical role
Gamification log	LMS records	Cumulative XP, badges, leaderboard positions, and rewards recorded across scheduled course activities and extracted at the end of the semester; session-by-session frequency was not analyzed.	Documents implementation context; not treated as an independent inferential variable.
Participatory activity	LMS activity record	Composite score on a 0-100 scale representing participation in scheduled activities, assignments, quizzes, and online forums.	Descriptive indicator of engagement.

Assignments	LMS assignment scores	Scores on a 0-100 scale; non-submission remained recorded as 0.	Descriptive indicator of routine task performance.
Quizzes	Quizizz/LMS records	Scores on a 0-100 scale; incomplete or missed attempts were retained as recorded.	Descriptive indicator of short-term conceptual performance.
Arduino project	Course project rubric	Score on a 0-100 scale based on prototype quality and functionality and the student presentation/technical explanation.	Descriptive indicator of product and practical performance.
Midterm examination	Course examination record	Score on a 0-100 scale.	Descriptive indicator of cognitive attainment during the semester.
Final examination	Course examination record	Score on a 0-100 scale.	Descriptive indicator of end-of-semester cognitive attainment.

The project rubric was the course assessment rubric in the semester learning plan and was applied by the course lecturer. Independent rubric validation and inter-rater agreement were not examined, which is acknowledged as a limitation. All scores were analyzed on their original 0-100 scales. Non-submissions and examination absences recorded in the course system as zero were treated as observed values, not missing values, and were retained in the calculation of means, standard deviations, and coefficients of variation. No imputation or case deletion was performed. Boxplots were used to identify unusual values and describe score concentration and dispersion. The coefficient of variation was calculated as CV = (standard deviation/mean) × 100%. No inferential test or correlation analysis was conducted.

RESULTS AND DISCUSSION

Gamification-based digital learning is applied by utilizing the quiziz application, where students are given stimulus in the form of comprehension tester questions before the project is carried out by students (Riswanto, Alarifin, et al., 2025). The gamification elements applied in this study include XP (experience points), badges, and rewards. The stages of learning that are carried out. The application of learning in this course explicitly directs students to compile and develop Arduino-based projects with the ADDIE approach. The ADDIE (Analysis, Design, Development, Implementation, Evaluation) model is used not only as an instructional design framework by lecturers, but also as a stage of student work in designing digital technology projects systematically (Riswanto, Hidayat, et al., 2025). The implementation of the ADDIE Stages as seen in figure 2 shows the stages of project development by students in learning.

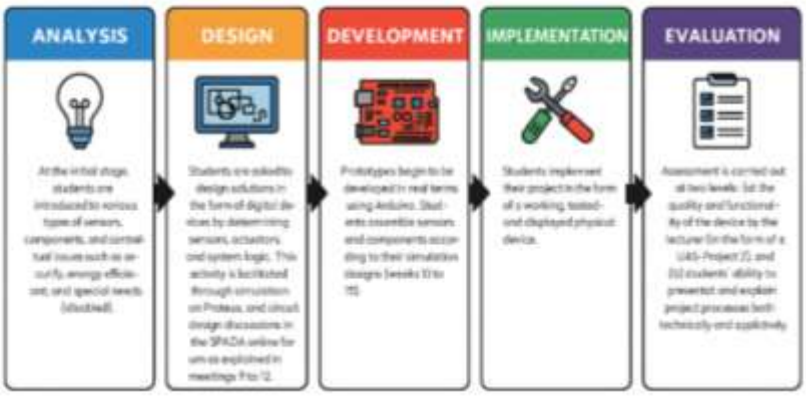

Figure 2. ADDIE phases used as the students' Arduino project workflow

1. Analysis

In the initial stage, students are introduced to different types of sensors, components, and contextual issues such as safety, energy efficiency, and special needs (difabel). This aligns with physical computing approaches that engage learners in designing systems with sensors/microcontrollers to address real world contexts (Vergara et al., 2025). The variety of project titles (e.g., Smart Guidance Stick, Household Gas Sensor, Smart Plant Sprinkler) also reflects the authenticity and artifact-oriented nature of project-based learning, where students develop concrete products grounded in real problems (Guo et al., 2020), including assistive solutions for visual impairment (Panazan & Dulf, 2024) and energy-efficiency oriented engineering design challenges (Purzer et al., 2015).

2. Design
Students are asked to design solutions in the form of digital tools by determining sensors, actuators, and system logic. This activity was facilitated through simulations on Proteus and series design discussions in the SPADA online forum, as described in the 4th to 9th week meetings.

3. Development
Prototypes began to be developed in real life using Arduino. Students assemble sensors and components according to their simulation design (weeks 10 to 14). This process includes programming, testing, and documentation of digital device development. In the development of projects based on the ADDIE approach, students from various classes design a variety of technological solutions that are contextual and applicable according to the needs of the community. The analysis stage is carried out by identifying actual issues such as security, energy efficiency, disability assistance, and smart agriculture. As a result, students designed innovative projects such as the Smart Guidance Stick and Difability Distance Sensor Hat to help the visually impaired, Fire Sensor and Gas Leak Detection to mitigate the risk of fire and explosion, and Smart Room Climate for automatic room temperature and humidity management. In the field of agriculture and livestock, projects such as AquaFeed, SmartFeeder, Automatic Crop Watering and AgriShield were developed, which utilize moisture sensors, RTC, and ultrasonics to improve efficiency and sustainability. On the other hand, projects such as Smart Clap Switches, Automatic Door Sensors, Motor Anti-Theft Systems, and Smart Security Systems show students' creativity in designing household automation and property protection systems. Seen in figure 3, several examples of student project development results are presented. Through the stages of design, development, implementation, and project evaluation, all students are actively involved in applying the principles of digital system design integrated with Arduino-based programming and sensor technology, as a form of direct application of contextual and meaningful learning.


Smart Guide Stick Prototype Project


Project Fire Alarm in a House

Automatic plant watering project Project automatic lights with proximity sensor
Figure 3. Examples of student projects

4. Implementation

Students implement their projects in the form of physical tools that can be used, tested, and displayed. Products such as AquaFeed, SmartFeeder, and CountSmart are the result of the real-world implementation of field needs-based solutions.

5. Evaluation

The assessment is carried out at two levels: (a) the quality and functionality of the tool by the lecturer (in the form of Project), and (b) the ability of students to present and explain how the project works technically and applicatively. This evaluation also covers the cognitive, psychomotor, and affective domains according to the value rubric in the term learning plan.

The application of the ADDIE model in courses not only provides a directed learning structure, but also becomes a systematic thinking tool for students in completing technology projects (Mudjisusatyo et al., 2024; Wahyudin et al., 2022). With project-based and the integration of gamification elements on the SPADA platform (such as participatory activities and collaborative forums), students are directed to become active, reflective, and solution-oriented learners in facing real problems through technological approaches. The model provided checkpoints for problem definition, design justification, prototype testing, implementation, and reflection.

Table 2. Descriptive summary of learning indicators and outlier treatment

Indicator	Mean	CV	Main distribution and identified outliers
Participatory activity	88	6%	Most scores 85-95; one score of 0.
Project score	87	10%	Most scores 85-95; one score of 0 and three scores 55-65.
Assignment score	78	18%	Most scores 75-85; outliers at 0, 38-45, and 60.
Quiz score	92	11%	Most scores 85-100; outliers at 20, 47-50, 63-65, and 70.
Midterm examination	85	18%	Most scores 80-95; about 12 students below 60, including 12.
Final examination	88	10%	Most scores 80-95; outliers at 0 and 64-68.

Table 2 summarizes the main indicators and clarifies that all outlying and zero scores were retained. Figures 3 and 4 display the participatory-activity and project-score distributions.

Data analysis based on the two presented boxplots shows the distribution and tendency of student values in the two main aspects of project-based digital learning: participatory activities and final project outcomes. Figure 3 shows the Boxplot of Participatory Activity which represents variations in student participatory activity scores, including engagement in assignments, quizzes, and online learning forums. Meanwhile, figure 4 shows the Boxplot of Project Outcome which reflects the quality of the results of the Arduino project developed by students using the ADDIE approach. These two visualizations provide a quantitative overview of the distribution of values and identify outliers that require special attention in improving the learning process.

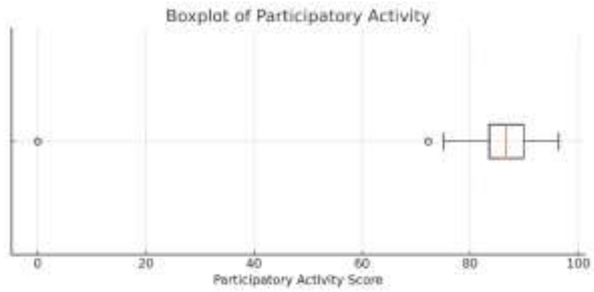

Figure 3. Boxplot of Participatory Activity

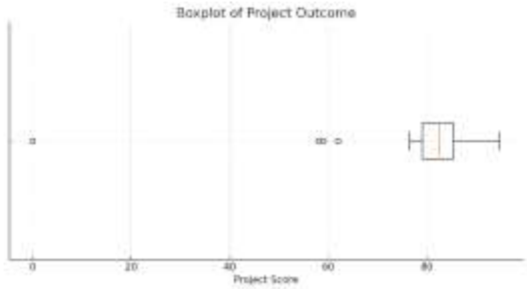

Figure 4. Boxplot of Project Outcome

Descriptive statistical analysis of student participatory activities on figure 3 showed an average participation score of 88 points with a deviation of around ±6 points. The coefficient of variation of 6% indicates that the level of student activity is relatively uniform. The distribution of the data shows a slight negative skewed, indicating that most students show high participation, with one outlier recording an extremely low score (0 points). The visualization showed a concentration of scores in the range of 85–95 points, corroborating the finding that most students showed active engagement during learning. This finding is strengthened by a box-plot that reveals the existence of one outlier, namely students with a score of 0 points, which is an anomaly in the context of general class participation.

Pedagogically, these results provide some important implications. First, the low coefficient of variation shows the success of gamification strategies in encouraging equitable participation among students. The XP (experience points), badges, and reward-based mechanisms applied seem to have succeeded in creating an effective and inclusive motivation system (Smiderle et al., 2020). Second, the existence of outliers needs to be followed up through an individual approach. This can include clarifications regarding attendance, technical barriers to the Learning Management System (LMS), or other motivational issues. Counseling-based interventions or learning assistance can be a strategic step (Henríquez et al., 2024). Third, the high median score (≈90) strengthens the suspicion that digital learning integrated with gamification elements not only increases engagement, but also has the potential to create a competitive and collaborative learning environment. The gamification approach in the context of digital learning shows high effectiveness in forming active and equitable student participation patterns (Park & Kim, 2021; Puig et al., 2023; Tomé Klock et al., 2024). This strategy is worth maintaining and refining in future digital project-based learning schemes.

The analysis of the results of the rubric-based project in Figure 4 shows an average high score, which is 87 points, which indicates that the majority of students are able to meet the set criteria. The coefficient of variation of 10% reflects moderate variation in yield quality, although the relative distribution is still uniform. Negative skew scores and high kurtosis indicate a stacked distribution of scores at high scores, but there are a small number of students with low scores, including one student who did not collect any projects at all (score 0). Data visualization through the boxplot revealed the peak score in the range of 85–95 points, showing the dominance of quality project results. However, one cluster of extreme scores was identified at 0 and three low scores in the range of 55–65 points. The box-plot visually confirms these four outliers, making it clear the existence of students who need special attention. These findings have significant pedagogical implications. About 85% of students scored ≥ 80 points, indicating that the integration of the ADDIE model and the gamification approach is effectively able to encourage students to produce good projects. However, four outliers required diagnostic mentoring-based interventions to identify potential barriers such as technical difficulties with Arduino, time management constraints, or low learning motivation. In addition, the moderate variation in scores indicates that the assessment rubric is quite clear and can be maintained. If a higher level of differentiation is required, adjustments to the weight of innovation criteria in the rubric can be an alternative to reinforcement.

Interestingly, these findings are consistent with previous analyses related to student participatory activities, which recorded an average participation of 88 points with a CV of 6%. The alignment between digital participation and the quality of the final product confirms that active engagement in digital learning supported by gamification elements has a positive correlation with student project performance. This means that activeness during the learning process is not only procedural, but contributes directly to success in completing project-based tasks.

Data visualization in the form of a boxplot used to analyze the distribution of assignment scores in Figure 5 and student quizzes in project-based digital learning in Figure 6. This analysis aims to identify general trends in student performance, detect outliers, and evaluate the extent to which score variations reflect engagement, concept understanding, and consistency of academic achievement during the learning process. This boxplot is also an important basis in formulating more responsive and targeted learning interventions.

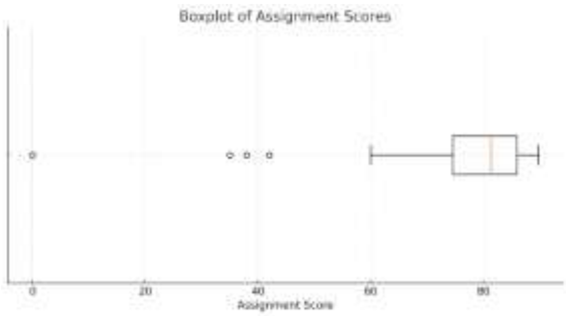

Figure 5. Boxplot of Assignment Scores

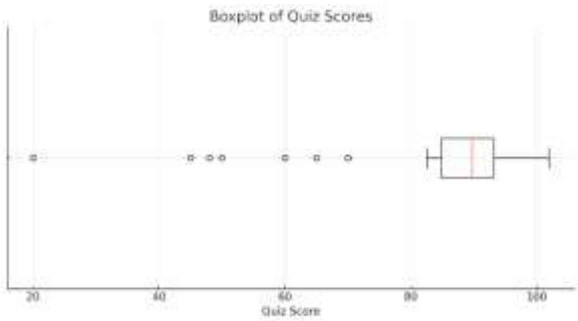

Figure 6. Boxplot of Quiz Scores

The results of the analysis of the task score in Figure 5 showed an average of 78 points, exceeding the threshold of the Minimum Completeness Criterion of 70, but still below the achievement in participatory activities (mean 88) and final projects (mean 87). The coefficient of variation of 18% indicates a wider distribution of values than other variables, showing significant variation in performance between individuals. Distributions showing negative skew reinforce that most college students have high scores, with the tail of the distribution leading to several low scores, including one extreme score of zero.
The histogram visualization revealed a distribution pattern of three clusters: the majority of scores were concentrated in the range of 75–85, small clusters in the range of 38–45, and one student who did not collect any assignments at all (score 0). This data is reinforced through a box-plot that displays outliers at three key points: a score of 0, a range of 38–45, and a score of 60 each indicating possible motivation issues, delays, or low quality of task completion.

Compared to activity and project variables, tasks have the highest coefficient of variation, indicating low individual consistency. This can stem from time management factors, clarity of instructions, or a higher cognitive load in regular tasks. These findings provide some important pedagogical recommendations. First, it is necessary to redesign assignments by breaking them down into smaller and gradual deliverable units, as well as providing quick feedback so that students can monitor and improve their performance on an ongoing basis (Allred, 2025). Second, an initial monitoring system needs to be implemented to detect scores below 60 at the beginning of the term so that targeted interventions can be provided early (Cabezas et al., 2024; Hall et al., 2021). Third, strengthening specific gamification elements for tasks such as giving a "Task Streak" badge or bonus XP for timely collection can be used to increase motivation in completing routine tasks (Khan et al., 2020; Schöbel et al., 2020; Wiley et al., 2020; Yang et al., 2021). Variations in performance on assignments reflect the need for instructional strategies that are more adaptive and responsive to differences in students' learning styles and time management. Strengthening the task mechanism can support the success of gamification-based digital learning as a whole.

The analysis of the quiz score in figure 6 shows a very high average, which is 92 points, which indicates that most students are able to complete the quiz well. This high score hints at two main possibilities: the quiz material is relatively easy or the questions given have matched the practice patterns previously available in gamification-based LMS platforms. With a coefficient of variation of 11%, the variation in performance is in the medium category, with a score distribution that skews towards high but still contains some low scores. Histogram visualization shows the dominance of scores in the range of 85–100 points, with small clusters at 45–50 and one extreme outlier at 20. The box-plot identifies four outliers, namely scores of 20, 47–50, 63–65, and 70. Outliers at very low scores (20 and < 50) are most likely due to incompleteness in taking quizzes, network glitches, or poor understanding of the material. Scores between 63–70 while not extreme, still need attention for learning interventions or remedy sessions.

When compared to the other components activities (mean 88, CV 6%), project (mean 87, CV 10%), and assignment (mean 78, CV 18%) quizzes have the highest average. This shows that the integration of quiz questions with gamification approaches and the use of LMS has succeeded in improving academic performance in the short-term evaluative aspect. However, the existence of significant outliers on the quiz is also an indication that not all students are able to maintain optimal performance in exam conditions. The pedagogical implications of these findings include the need to revalidate the quiz questions to ensure a balanced and even level of difficulty. Analysis-based questions can be added to avoid dominating memorization questions or just structured exercises (Ormerod et al., 2023; Zamanifar & Hartmann, 2020). Students with scores below 70 are advised to get an offer in the form of a quiz retake or video-based discussion session so that they can understand the mistakes that occur. In addition, the integration of the automatic feedback feature in the LMS is important so that students can immediately reflect on mistakes and improve their study strategies independently (Rauf et al., 2023; Winstone et al., 2021). The high performance of quizzes reflects the success of gamification-based digital learning designs in improving cognitive achievement, although it still requires adaptive strategies to support students who show low performance.
The visualization of the boxplot that describes the distribution of student scores in the Midterm Exam is seen in figure 7 and the Final Exam is seen in figure 8 as an indicator of cognitive achievement in project-based digital learning. This picture provides a comprehensive picture of student academic performance, showing the distribution of dominant scores, the existence of outliers, and potential inequality in learning outcomes that need to be further analyzed to support more effective evaluation strategies and learning interventions.

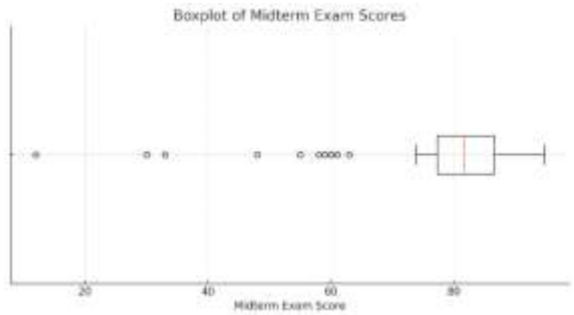

Figure 7. Boxplot of Midterm Exam Scores

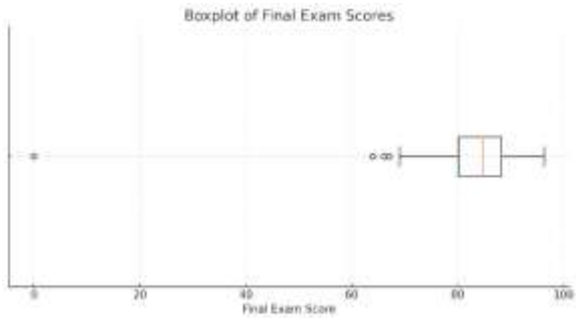

Figure 8. Boxplot of Final Exam Scores

The results of the Middle Exam in figure 7 show an average score of 85 points, above the Minimum Completeness Criterion of 70. However, a variation coefficient (CV) of 18% indicates a fairly high level of variation equivalent to the value of an assignment and greater than that of activities, projects, or quizzes. The value distribution shows a negative slope, indicating a concentration of scores in the high range, but with a long left tail covering a number of low scores. The visual distribution shows that the main mound of values is in the range of 80–95, with additional clusters between 55–70, as well as extreme points in the range of 12–35. The box-plot shows a significant number of outliers, including a score of 12 (likely due to absenteeism or incomplete exams), as well as low scores in the range of 30–60. There were about 12 students (about 10% of the population) who scored below 60, indicating a vulnerable group that needed special attention. When compared to other learning components, mid-exams and assignments occupy the position with the highest CV (18%), while activities, projects, and quizzes show much lower variation. This indicates that students' conceptual and theoretical understanding is not as homogeneous as participatory involvement and applicative ability in the project.

The pedagogical implications of these findings include several important points. First, an analysis of question items is needed to evaluate the validity, difficulty, and discriminating power of intermediate exam questions, considering the potential incompatibility between the exam content and the practical approaches and digital activities that have been implemented. Second, it is necessary to prepare a structured remedial program for students with scores below 70, as an intervention before the Final Exam. Third, the results of the middle exam can be used as a basis for learning differentiation. By implementing adaptive gamification strategies, lecturers can group students based on cognitive achievement and provide supporting materials or different challenges according to the level of needs of each group (Carvalho et al., 2023; Daghestani et al., 2020; Nieto-Escamez & Roldán-Tapia, 2021; Saleem et al., 2022). The results of the middle exam provide insight that the integration between theoretical aspects and practice-based activities needs to be harmonized in order to produce a comprehensive and equitable understanding among students.

The Final Exam results in figure 8 show excellent performance, with an average score of 88 points, far exceeding the Minimum Completeness Criterion of 70. The coefficient of variation of 10% indicates a relatively close and similar distribution of grades to the results of the project, reflecting the consistency of students' academic performance. The score distribution shows a negative slope and high kurtosis, indicating the accumulation of high scores with little extreme values at the bottom. The histogram visualization shows the concentration of values in the range of 80–95, with one small cluster around 65–70, and one extreme outlier at a score of 0. The box-plot confirmed the existence of outliers in the score of 0 and in the vulnerable group with a score of 64–68. Students with a score of 0 are most likely not taking the exam, while the other four students who score below the graduation criteria require remediation. Comparison with the results of the Middle Exam shows a positive trend. The average score increased from 85 to 88 points, while the coefficient of variation narrowed from 18% to 10%, indicating an increase in performance as well as a narrowing of the distribution of scores. The absence of extreme outliers such as a score of 12 in the middle exam is an indication that post-exam learning interventions through feed-forward strategies that combine formative feedback with gamification elements have succeeded in improving students' academic understanding and achievement equally.

The pedagogical implications of these findings are clear. First, the format of evaluation and remedial sessions between the middle and final exams proved to be effective and worth maintaining. Second, good practices such as the use of game-based review question banks need to be documented as a continuous evaluation model for the next term. Third, individual focus is still required for students with a < score of 70, which is recommended to gain access to remedial programs or alternative assessments based on a differentiated approach (Fyfe et al., 2022; Peters et al., 2022; Pourdana & Tavassoli, 2022; Puzio et al., 2020). The final exam not only serves as a final cognitive measuring tool, but also as a testament to the success of proactive feedback-based instructional design and gamification designed to improve performance in a systematic and inclusive manner (Koseda et al., 2024).

CONCLUSION

This classroom implementation showed that ADDIE can be used as a student project workflow within gamified Arduino PjBL. Descriptive results indicated high and relatively homogeneous participation (M = 88, CV = 6%), strong project scores (M = 87, CV = 10%), high quiz and final-examination means, and greater dispersion in assignment and midterm scores. The ADDIE model, which is applied systematically through the stages of analysis, design, development, implementation, and evaluation, has guided students in designing and realizing technology projects that are contextual, applicative, and relevant to real needs, such as assistive devices, security systems, and energy efficiency. The distributions identify practical priorities: early monitoring of non-submission, diagnostic mentoring for low project scores, staged assignments, item review, and remedial support. The study is limited by its one-cohort descriptive design, absence of a control group and pretest, use of a single instructor and single project rater, lack of independently validated rubric evidence, and absence of inferential or correlation analysis. Future studies should compare groups or repeated cohorts, use validated instruments and multiple raters, and test associations among participation, project quality, and learning outcomes. The present findings therefore support the feasibility and pedagogical utility of the implementation model, not a causal claim of effectiveness. Overall, the synergy between ADDIE's approach, gamification strategy, and Arduino project has succeeded in creating an interactive, collaborative, and supportive digital learning ecosystem that supports the development of 21st-century competencies as a whole.

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