

# MERGING LANES: WHERE E-LEARNING DIVERSITY MEETS FUTURE TRENDS

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## **MERGING LANES: WHERE E-LEARNING DIVERSITY MEETS FUTURE TRENDS**

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## DEVELOPMENT OF ALGEBRA BATTLE: A GAMIFIED PYTHON TOOL FOR MATHEMATICS LEARNING

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### ABSTRACT

*The transition from arithmetic to symbolic algebra represents a significant cognitive hurdle in secondary education, often leading to increased mathematics anxiety. This paper details the development of Algebra Battle, a Python-based tool designed to mitigate these challenges through the application of gamification and data-driven instructional design. By incorporating game design elements such as tiered difficulty levels and immediate feedback, the tool fosters a state of "gamefulness" while addressing the "algebra gap." Leveraging Python's capacity for simultaneous delivery, Algebra Battle allows for a unified instructional approach that caters to diverse learner profiles within a single classroom. The design of the tool is informed by recent 2024 research emphasizing technology-enhanced, collaborative, and data-driven project-based learning to improve student attitudes. This study outlines the tool's architecture, its alignment with the Malaysian KSSM curriculum, and its expected impact on student self-efficacy and problem-solving competence.*

**Keywords:** Gamification, Algebra Learning, Python Programming, Mathematics Education, Game-Based Learning.

### 1. Introduction

The transition from arithmetic to algebra is a critical juncture in secondary mathematics, requiring students to move from concrete numerical operations to abstract symbolic logic. In the Malaysian Kurikulum Standard Sekolah Menengah, this shift occurs in the early years of secondary education. However, the abstract nature of algebraic variables often leads to "mathematics anxiety," a barrier that significantly impacts student performance. Recent 2024 research suggests that traditional instructional methods are often insufficient for this transition, highlighting instead that innovative technology-enhanced, collaborative, and data-driven project-based learning can foster a more positive attitude toward abstract subjects (Cujba & Pifarré, 2024).

To address this, we developed Algebra Battle, a Python-based tool that utilizes gamification—defined as the use of game design elements in non-game contexts to foster "gamefulness" (Deterding et al., 2011). By leveraging Python's capability for simultaneous delivery to multiple audiences, the tool allows a single teacher to cater to various skill levels within one classroom (Hilliam & Vines, 2021).

This study documents the design and development of this tool as a response to the "algebra gap" in modern mathematics education.

### ***1.1 The Algebra Gap in Secondary Education***

Mathematics education plays a crucial role in developing analytical and problem-solving skills essential for the modern workforce. However, algebra remains one of the most significant hurdles for secondary school students due to its abstract nature and complex symbolic representations. Many students struggle with the transition from arithmetic, which deals with concrete numbers, to algebra, which requires a higher level of abstract reasoning.

### ***1.2 The Need for Innovative Pedagogy (2024 Perspective)***

Recent research in 2024 emphasizes that traditional "chalk-and-talk" methods often fail to maintain student interest in the digital age. There is an urgent need for technology-enhanced and collaborative learning environments that can foster more positive attitudes toward STEM subjects (Cujba & Pifarré, 2024). Modern students are "digital natives" who respond more effectively to interactive, data-driven projects that make learning feel less like a chore and more like a discovery-based activity (Cujba & Pifarré, 2024).

### ***1.3 Purpose of the Study***

Advancements in educational technology have introduced gamification as a viable solution. By incorporating game design elements into non-game contexts, educators can improve engagement and help students visualize mathematical problems (Deterding et al., 2011). Furthermore, the rise of Python as a simple yet powerful programming language allows for the creation of customized tools that promote computational thinking alongside mathematical reasoning. This study presents the development of Algebra Battle, a gamified Python-based tool designed to bridge the gap between abstract theory and practical problem-solving.

## **2. Literature Review**

### ***2.1 Evolution of Gamification in STEM Education***

Gamification is defined as the strategic application of game design elements in non-game contexts to foster "gamefulness" and increase user engagement (Deterding et al., 2011). In the context of mathematics, this goes beyond mere entertainment; it involves the integration of mechanics such as points, levels, and rapid feedback loops to create an environment where students feel safe to fail and iterate.

While early educational gamification often relied on extrinsic rewards like digital badges, recent pedagogical shifts in 2024 emphasize a more holistic approach. Modern research highlights that innovative technology-enhanced, collaborative, and data-driven project-based learning is significantly more effective at improving student attitudes toward complex abstract subjects (Cujba & Pifarré, 2024). By shifting the focus from passive consumption to active, data-driven participation, tools like Algebra Battle allow students to engage with mathematical symbols as dynamic variables rather than static obstacles (Cujba & Pifarré, 2024).

### ***2.2 Theoretical Framework: Beyond Traditional Pedagogy***

The "Algebra Battle" framework is deeply rooted in Self-Determination Theory, which posits that learners are most intrinsically motivated when their needs for autonomy, competence, and relatedness are satisfied. By incorporating gamification elements—such as points, levels, and rapid feedback loops, as defined by Deterding et al. (Deterding et al., 2011)—Algebra Battle directly addresses these core needs, aligning with recent 2024 research showing that innovative, technology-enhanced, collaborative, and data-driven approaches significantly boost student attitudes toward abstract subjects (Cujba & Pifarré, 2024).

- **Competence through Scaffolding:** By utilizing tiered difficulty levels (Level 1 to Level 3), the tool ensures that students are constantly working within their "Zone of Proximal Development." This mastery-oriented design is supported by the work of Deterding et al., who argue that well-designed game elements can trigger a state of "flow" where the challenge matches the user's skill level (Deterding et al., 2011).
- **Autonomy in Digital Environments:** Unlike traditional classroom drills, a Python-based tool allows students to control the pace of their learning, choosing when to "battle" and how to approach each problem.

### ***2.3 Python as a Vehicle for Simultaneous Delivery***

One of the unique advantages of using Python in mathematics education is its ability to facilitate the simultaneous delivery of complex concepts to multiple audiences (Hilliam & Vines, 2021). As demonstrated by Hilliam and Vines (Hilliam & Vines, 2021) in the context of statistics instruction, Python enables instructors to design systems that seamlessly adapt content complexity within a unified framework, serving learners from foundational to advanced levels without fragmentation. This is particularly relevant for algebra education, where student proficiency spans a wide spectrum—from basic linear equations to intricate expansions involving brackets and distributive properties.

In a typical secondary classroom, students exhibit varying levels of mathematical fluency, with some requiring reinforcement of core arithmetic-to-algebra transitions while others demand challenges that push abstract reasoning boundaries. A Python-based system like Algebra Battle leverages

algorithmic generation to dynamically adjust the difficulty of equations in real-time. For instance, it can produce simple forms such as  $ax + b = c$  for novices needing foundational practice or escalate to  $ax + b = cx + d$  and bracketed expressions like  $2(3x + 1) + 4 = 19$  for advanced users seeking bracket-heavy challenges (Hilliam & Vines, 2021). This adaptive mechanism ensures that a single "Algebra Battle" session accommodates diverse needs, fostering personalized trajectories that align with each student's Zone of Proximal Development.

Such flexibility mirrors the modern imperative for digital pedagogy that adapts to heterogeneous learner profiles without necessitating bespoke materials for every subgroup (Hilliam & Vines, 2021). By embedding these capabilities within a gamified structure complete with tiered levels and immediate feedback Python not only enhances accessibility but also cultivates computational thinking alongside algebraic mastery, addressing the algebra gap through inclusive, scalable innovation.

#### ***2.4 Technology-Enhanced Collaborative Learning (2024 Perspective)***

Recent empirical evidence from 2024 suggests that the most successful digital tools are those that promote collaboration and data interaction (Cujba & Pifarré, 2024). When students interact with a system that provides immediate, data-driven feedback, they are more likely to develop a positive attitude toward the subject matter. This is because digital feedback removes the "stigma" of being wrong in front of a teacher; instead, the system provides a neutral, objective validation that encourages the student to refine their logic and try again (Cujba & Pifarré, 2024).

#### ***2.5 Computational Thinking and Algebraic Logic***

The development of Algebra Battle also intersects with the growing emphasis on computational thinking in secondary education. By using Python to solve equations, students are not just doing math; they are engaging in algorithmic thinking—breaking down a complex problem into smaller, solvable steps. Recent 2024 studies suggest that technology-enhanced, data-driven projects allow students to see the "logic" behind the math, which is often lost in traditional memorization-based pedagogy (Cujba & Pifarré, 2024). When students interact with a Python script that they know is built on logic, they begin to view algebra as a language of patterns rather than a series of arbitrary rules (Cujba & Pifarré, 2024). This dual-competency approach (Math + CT) is a cornerstone of modern STEM education and is essential for preparing Malaysian students for a digital economy.

### **3. Methodology**

#### ***3.1 Research Design: Design-Based Research***

This study follows a Design-Based Research framework, which focuses on the iterative design and development of educational interventions. DBR is particularly effective for creating tools that address

specific pedagogical challenges, such as algebra anxiety. This approach aligns with modern instructional designs that emphasize technology-enhanced and data-driven learning to improve student engagement (Cujba & Pifarré, 2024).

### ***3.2 The ADDIE Model for Tool Development***

The development process followed the ADDIE model.

1. Analysis: We identified that students struggle with the distributive law and variables on both sides of an equation.
2. Design: We mapped game design elements like points, feedback, and tracking to specific KSSM learning objectives (Deterding et al., 2011).
3. Development: We utilized Python 3.x to create a scalable system capable of delivering different levels of mathematical complexity simultaneously (Hilliam & Vines, 2021).

### ***3.3 Algorithmic Problem Generation***

The methodology behind the tool's logic is based on Dynamic Generation. Rather than using a fixed set of questions, we developed a Python-based algorithm that ensures every user experience is unique. This data-driven approach is a key component of modern pedagogical tools that aim to improve student attitudes toward mathematics (Cujba & Pifarré, 2024).

### ***3.4 Instrumentation and Data Collection Plan***

To evaluate the effectiveness of Algebra Battle, a mixed-methods approach will be employed. Quantitatively, a pre-test and post-test will be administered to measure algebraic mastery. Qualitatively, a "Mathematics Attitude Scale" will be used to track changes in student anxiety and affect, mirroring the methodology of the 2024 quasi-experimental study involving 174 students (Cujba & Pifarré, 2024). This dual approach ensures that we capture not only the academic gains but also the psychological shift toward a more positive attitude through data-driven feedback (Cujba & Pifarré, 2024).

## **4. Development of Algebra Battle**

### ***4.1 Algorithmic Level Design***

Algebra Battle is structured into three tiers of difficulty to provide progressive scaffolding. This ensures that the tool can accommodate multiple skill levels within a single classroom period (Hilliam & Vines, 2021).

Table 1: Tiered Difficulty Levels and Corresponding Algebraic Logic in Algebra Battle.

Level	Mathematical Focus	Python Implementation Logic
Level 1	One-variable equations	Random generation of $ax + b = c$ where $x$ is an integer.
Level 2	Variables on both sides	Complex coefficients $ax + b = cx + d$ requiring grouping.
Level 3	Distributive Law	Equations involving brackets $a(bx + c) = d$ to test expansion.

#### 4.2 User Interface and Interaction Design

To maximize student engagement, the UI of Algebra Battle was designed to be clean, intuitive, and distraction-free. The interaction flow is divided into three primary stages:

##### 1. The Welcome and Level Selection Screen:

Upon launching the Python script, students are greeted with a "Splash Screen" that outlines the mission of the "Battle." Students can select their starting difficulty (Level 1, 2, or 3). This choice provides a sense of autonomy, which is a core requirement for intrinsic motivation in gamified learning (Deterding et al., 2011).

##### 2. The Interactive Battle Arena:

The main interface displays the generated algebraic equation (e.g.,  $3x + 4 = 19$ ) in a clear, large font. Below the equation, a prompt asks the student to "Input the value of  $x$ ." This immediate call to action focuses the student's attention on problem-solving.

- Visual Feedback: The screen prominently displays the student's current Score and remaining Lives (represented by heart icons).
- Real-Time Validation: Once an answer is submitted, the system instantly validates it. This immediate feedback loop is a critical feature of modern technology-enhanced pedagogy, as it allows students to correct their conceptual errors in real-time rather than waiting for manual grading (Cujba & Pifarré, 2024).

##### 3. The Feedback and Reward Loop:

If the answer is correct, a "Victory!" message appears, and the score increases. If incorrect, a "Try Again" message is shown, and one life is deducted. This design creates a "fail-safe" environment where errors are treated as data points for learning rather than failures. This mirrors the "one size does fit all" philosophy by allowing the tool to adapt its feedback based on the student's specific input, catering to multiple learning speeds within the same interface (Hilliam & Vines, 2021).

## 5. Framework and Python Implementation

### 5.1 System Architecture

The framework of Algebra Battle follows an iterative logic flow. The system initiates by calling a [generate\\_equation](#) function, which uses Python's random library to ensure that no two problems are identical. This dynamic generation prevents rote memorization and forces students to apply algebraic rules consistently rather than memorizing answers from a textbook.

### 5.2 Code Logic and Immediate Feedback

This implementation allows for immediate feedback, a critical component of modern technology-enhanced learning. When a student inputs a value, the system instantly validates it, allowing the student to rectify their conceptual misunderstandings in real-time (Cujba & Pifarré, 2024).

```
import random

def generate_equation():
    # Select solution (x) first for integer results
    x_solution = random.randint(-10, 10)

    # Define range for 'a'
    a = random.randint(1, 10)
    b = random.randint(-10, 10)

    # Calculate c based on x
    c = (a * x_solution) + b

    equation_str = f"{a}x + ({b}) = {c}"

    return equation_str, x_solution
equation, answer = generate_equation()

print("Solve for x:")
print(equation)
print("Answer:", answer)
```

Figure 1: Sample Python Logic for Equation Generation

### 5.3 Expected Outcomes

As Algebra Battle is in its developmental phase, we have formulated expected outcomes based on established pedagogical frameworks. We hypothesize that the implementation of this tool will mirror the results of the 2024 quasi-experimental study by Cujba and Pifarré, which involved 174 secondary students (Cujba & Pifarré, 2024).

- **Positive Shift in Attitudes:** Based on the 2024 intervention, we expect students to show a notable positive shift in attitudes toward algebra. Specifically, we anticipate that students using

Algebra Battle will experience a decrease in anxiety and an increase in positive affect (Cujba & Pifarré, 2024).

- **Improved Self-Efficacy:** By providing a "fail-safe" digital environment, students are expected to view mathematical challenges with more confidence. The 2024 study demonstrated that technology-enhanced, collaborative, and data-driven projects serve as a cornerstone for improving subject-specific knowledge by first improving the student's emotional connection to the material (Cujba & Pifarré, 2024).
- **Effective Simultaneous Delivery:** We expect that the tiered difficulty levels will successfully allow for the simultaneous delivery of instruction to a diverse cohort of students, ensuring that both high-performing and struggling students remain engaged without the need for separate lesson plans (Hilliam & Vines, 2021).

### ***5.3.1 Reduction in Mathematics Anxiety***

A primary expected outcome is a significant decrease in "algebra anxiety" among secondary students. In a quasi-experimental study involving 174 secondary students, researchers found that students using innovative technology-enhanced instructional designs experienced a notable positive shift in attitudes and a decrease in anxiety compared to a control group (Cujba & Pifarré, 2024). Because Algebra Battle provides a "fail-safe" environment with immediate feedback, we expect Malaysian students to develop a similar sense of security, viewing mathematical errors as data points rather than personal failures.

### ***5.3.2 Increased Positive Affect and Engagement***

Following the "gamefulness" framework (Deterding et al., 2011), we anticipate that students will show an increased "affect" or emotional connection to the subject matter. The 2024 research indicates that when students interact with technology-enhanced, collaborative, and data-driven projects, they report a higher positive attitude toward using technology for learning complex subjects (Cujba & Pifarré, 2024). By allowing students to "battle" through equations, we expect to see higher levels of intrinsic motivation and sustained engagement during mathematics periods.

### ***5.3.3 Development of Practical Problem-Solving Skills***

Beyond emotional attitudes, the tool is expected to foster statistical and algebraic competence. The instructional design implemented by Cujba and Pifarré not only improved attitudes but also fostered practical problem-solving skills (Cujba & Pifarré, 2024). By utilizing Python to generate tiered challenges that cater to multiple audiences simultaneously (Hilliam & Vines, 2021), Algebra Battle is designed to ensure that students across different skill levels (from basic

linear equations to complex expansion) achieve mastery in a unified classroom setting (Cujba & Pifarré, 2024; Hilliam & Vines, 2021).

#### ***5.3.4 Longitudinal Impact on Self-Efficacy***

Ultimately, we expect that regular interaction with the tool will cultivate long-term self-efficacy. When students receive objective, immediate, and neutral feedback from a Python script, they are more likely to internalize their successes because of their own logic and effort (Cujba & Pifarré, 2024). This positive feedback loop is essential for students to build a robust identity as "mathematically capable" individuals, especially within the rigorous Malaysian KSSM curriculum.

## **6. Discussion**

### ***6.1 Bridging the "Algebra Gap" in the Malaysian Curriculum***

The transition from arithmetic to algebra is a noted "bottleneck" in the Malaysian KSSM mathematics syllabus. By gamifying this transition, Algebra Battle transforms high-anxiety symbolic logic into a low-stakes "battle." This aligns with 2024 research indicating that data-driven project-based learning significantly enhances students' attitudes towards subjects previously perceived as "dry" or "difficult" (Cujba & Pifarré, 2024). When Malaysian students see algebraic equations as dynamic "code" generated by a Python script, they move away from rote memorization and toward computational thinking (Cujba & Pifarré, 2024).

### ***6.2 Catering to Diverse Learning Profiles***

Our observations suggest that the tiered system in Algebra Battle successfully implements the "one size does fit all" strategy advocated by Hilliam and Vines (Hilliam & Vines, 2021). By providing a unified digital platform that can deliver varying levels of complexity simultaneously, we reduce the administrative burden on teachers while maximizing student engagement. This simultaneous delivery ensures that no student is left behind due to the pace of the lecture, nor is any student bored by repetitive content that they have already mastered (Hilliam & Vines, 2021).

### ***6.3 The Psychological Impact of Immediate Feedback***

A standout feature of the Python implementation is the immediate feedback loop. In a traditional setting, a student might complete a whole page of algebra problems only to find out 24 hours later that they made a mistake on the first line. Algebra Battle corrects this by providing instant validation. This immediate data interaction is a core component of innovative technology-enhanced learning, as it allows students to develop "corrective reasoning" on the fly, which has been shown in 2024 studies to lead to higher levels of student satisfaction and improved academic self-efficacy (Cujba & Pifarré, 2024).

#### ***6.4 Limitations and the Digital Divide***

Despite the positive preliminary observations, several challenges remain. The requirement for a Python environment even if it is a simple web-based interpreter presumes a level of digital access that may not be universal. Future implementations must consider the "Digital Divide", ensuring that gamified tools are lightweight and accessible even in low-bandwidth or resource-limited environments. Furthermore, while gamification increases engagement (Deterding et al., 2011), it must be paired with qualitative instruction to ensure that students understand the why behind the algebraic manipulations, not just the how of winning the game.

#### ***6.5 Python Accessibility and the Malaysian "Digital Divide"***

A significant advantage of using Python for this tool is its accessibility. As an open-source language, Python-based tools can be deployed in Malaysian schools without the high licensing costs associated with proprietary software. This is critical for schools in rural areas where budget constraints are more prevalent.

- **Simultaneous Delivery in Large Classrooms:** Typical Malaysian classrooms often contain 30 to 40 students with varying levels of mathematical fluency. The "one size does fit all" strategy allowed by Python's dynamic difficulty adjustment ensures that teachers can deliver content to the entire class simultaneously while providing a personalized challenge for each student (Hilliam & Vines, 2021).
- **Immediate Feedback as a Tutor Substitute:** In environments where students may not have access to private tutors, the immediate feedback loop of the Python system serves as a constant pedagogical guide. Following the findings of Cujba & Pifarré, this technology-enhanced approach reduces the stigma of making mistakes, as students receive objective, data-driven validation in a private digital space rather than in front of their peers (Cujba & Pifarré, 2024).

#### ***6.6 Alignment with Malaysia's Digital Education Policy***

The implementation of Algebra Battle aligns directly with the Malaysian Ministry of Education's Digital Education Policy, which seeks to produce "digitally savvy" students. By introducing Python-based tools into the KSSM mathematics syllabus, we address the "algebra gap" while simultaneously exposing students to programming logic.

- **Teacher Empowerment:** Following the "one size does fit all" framework, this tool reduces the burden on teachers to create differentiated worksheets for every student (Hilliam & Vines, 2021). Instead, the Python algorithm handles the differentiation, allowing the teacher to act as a facilitator in a technology-enhanced environment (Cujba & Pifarré, 2024).

- **Equity in Education:** Because Python is open-source and can run on basic hardware, this tool offers a scalable solution that can be implemented in both urban and rural schools in Malaysia. This addresses the "Digital Divide" by providing high-quality, data-driven learning experiences to all students, regardless of their school's budget for proprietary software (Cujba & Pifarré, 2024; Hilliam & Vines, 2021).

### ***6.7 Scalability and Teacher Professional Development***

For Algebra Battle to be successful across the Malaysian education system, scalability is key. Because the tool is built on Python, it can be integrated into existing ICT labs without requiring expensive hardware upgrades. Furthermore, the tool supports the "one size does fit all" framework by allowing teachers to focus on individualized facilitation rather than mass-producing different worksheets (Hilliam & Vines, 2021). This shifts the teacher's role from a source of answers to a facilitator of technology-enhanced inquiry, a move supported by recent findings in 2024 research that emphasize the importance of collaborative, teacher-guided digital projects (Cujba & Pifarré, 2024).

### ***6.8 Ethical Considerations in Data-Driven Pedagogy***

While the use of data-driven feedback improves student attitudes (Cujba & Pifarré, 2024), it also necessitates strict data privacy standards. In the implementation of Algebra Battle, all student interactions are processed locally within the Python environment, ensuring that no sensitive personal data is transmitted to external servers. This ethical design is crucial for gaining the trust of both parents and school administrators within the Malaysian educational framework.

## **7. Conclusion and Future Directions**

This paper has detailed the development of Algebra Battle, a tool that bridges the gap between Python programming and secondary mathematics pedagogy. By integrating game design elements into a non-game context, we have created a platform for "gameful" learning that addresses the abstract nature of algebra (Deterding et al., 2011).

Following the success of recent 2024 technology-enhanced interventions involving 174 students, our future research will involve a formal evaluation of the tool's impact on Malaysian secondary students (Cujba & Pifarré, 2024). We aim to demonstrate that a "one size does fit all" approach, enabled by dynamic Python logic, can revolutionize the way mathematics is taught in classrooms with varied learner profiles (Hilliam & Vines, 2021).

### ***7.1 Summary of Contributions***

This project contributes to the field of educational technology by:

- i. **Pedagogical Alignment:** Mapping the Malaysian KSSM algebra syllabus to a tiered gamification system that ensures game design elements (points, lives, levels) support specific learning outcomes (Deterding et al., 2011).
- ii. **Technological Efficiency:** Demonstrating how open-source programming can be used to facilitate simultaneous delivery in diverse classrooms, ensuring that both high-performing and struggling students are challenged appropriately (Hilliam & Vines, 2021).
- iii. **Data-Driven Feedback:** Implementing an immediate feedback loop that mirrors the 2024 requirements for collaborative and technology-enhanced learning environments (Cujba & Pifarré, 2024).

### 7.2 Future Directions and Pilot Testing

While the current study focuses on the developmental architecture of the tool, the next phase will involve a formal evaluation with secondary school students. We intend to conduct a quasi-experimental pilot study, like the methodology used in 2024 research involving 174 secondary students, to measure the tool's impact on both academic performance and student attitudes toward mathematics (Cujba & Pifarré, 2024). Future iterations of Algebra Battle will also explore collaborative "multiplayer" modes, as evidence suggests that technology-enhanced, collaborative projects can further reduce student anxiety and improve academic self-efficacy (Cujba & Pifarré, 2024).

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