Gamification in a Bottom-Up Approach to Teaching Engineering: Case Studies in DSP, Entrepreneurship, and Biomedical Instrumentation

B. Hema Kumar, Puducherry Technological University, India
M. Florance Mary, Puducherry Technological University, India
S. Snehalathaa, Pondicherry University, India

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Abstract

Gamification enhances engagement, problem-solving, and knowledge retention in engineering education. This paper explores a bottom-up approach integrating gamification in Digital Signal Processing (DSP), Entrepreneurship, and Biomedical Instrumentation, demonstrating measurable improvements in learning outcomes. In DSP, a level-based challenge system improved problem-solving accuracy by 32% and enhanced conceptual clarity. Entrepreneurship education was gamified using the DISRUPT Idea Marathon (a campus-wide startup simulation contest), leading to a 65% increase in participation and 82% higher confidence in opportunity identification. In Biomedical Instrumentation, role-play and case-based simulations reduced hands-on errors by 40% and were preferred by 91% of students over conventional lectures. Assessments included pre-test/post-test comparisons, participation rates, error analysis, and engagement surveys. Results confirmed that gamification fosters motivation, teamwork, and deeper conceptual understanding, making complex engineering topics more accessible. This study concludes with best practices for designing scalable gamified curricula and recommendations for broader adoption in engineering education. By integrating structured game mechanics, learning can be transformed into an interactive and immersive experience, improving student outcomes across technical disciplines.

Keywords: gamification in engineering, bottom-up approach, gamified pedagogy, active learning

Introduction

Engineering education demands not only technical knowledge but also the ability to solve real-world problems creatively. Traditional lecture-based methods often fail to sustain student interest, particularly in abstract domains like DSP or theoretical entrepreneurship models. To address this, we explore the integration of gamification—the application of game design elements in non-game contexts—with a bottom-up approach, which introduces concepts starting from practical applications and gradually builds up to theoretical frameworks.

This paper discusses three case studies from our engineering curriculum to illustrate how gamification and bottom-up strategies can synergistically improve engagement and learning outcomes.

Literature Review

Challenges in Traditional Engineering Education

Engineering education often grapples with abstract concepts, leading to decreased student engagement and comprehension. Traditional lecture-based methods can result in passive learning, where students struggle to apply theoretical knowledge to practical scenarios. This disconnect is particularly evident in areas like Digital Signal Processing (DSP), entrepreneurship, and biomedical instrumentation, where real-world application is crucial.

Gamification as a Pedagogical Tool

Gamification—the incorporation of game design elements into non-game contexts—has emerged as a strategy to enhance motivation and engagement in education. Recent studies have explored its application in engineering disciplines:

- Software Engineering Education: A tertiary study by Tonhão et al. (2024) analyzed gamification in software engineering education, finding that while gamification can boost engagement and motivation, its effectiveness depends on careful implementation. Misapplied gamification strategies may lead to decreased performance and motivation.
  - Key Problems Identified:
    - Overemphasis on competition: Can lead to stress, reduced collaboration.
    - Ambiguous reward systems: If students don’t understand how to earn points/badges, they disengage.
    - Surface-level gamification: Adding badges without integrating learning objectives results in “edutainment” rather than education.
- Engineering Education Motivation: Gamarra et al. (2022) implemented a gamification strategy across various engineering courses, observing increased student motivation and engagement. The study emphasized the importance of integrating dynamic teaching methods to enhance the learning process.
  - Key Findings:
    - Students reported higher intrinsic motivation and enjoyment.
    - Attendance and task completion rates improved significantly.
    - The study emphasized that game elements like *clear progression* and *peer comparison* can create a sense of achievement and friendly competition—key motivators in student learning.

Bottom-Up Learning Approaches

Bottom-up learning emphasizes starting with practical applications to build understanding of theoretical concepts. This approach aligns well with gamification, as both prioritize active participation and real-world problem-solving.

- Problem-Based Learning and Gamification: Čubela et al. (2023) combined problem-based learning with gamification in data-driven engineering education. The integration served as a catalyst for student engagement, suggesting that starting with real-world problems enhances learning outcomes.
    - Key Findings:
        - When students were presented with real-world problems first (bottom-up approach), followed by gamified missions to solve them, engagement levels increased.
        - Thematic analysis showed stronger retention of concepts.
        - Students perceived the course as more "authentic" and "useful."

Research Gaps & Objectives

While each strategy has merit individually, their combination remains under-researched—especially across technical and creative domains like DSP and entrepreneurship. Our study fills this gap.

1. *Few studies explore combined use of gamification and bottom-up learning*

- While gamification and bottom-up learning are both independently recognized as effective teaching strategies, most research treats them in isolation.
    - For instance, Gamarra et al. (2022) focus on gamification's effect on motivation, but do not pair it with instructional sequence design.
    - Conversely, Čubela et al. (2023) emphasize problem-based learning but only lightly integrate gamification elements.
- There is a lack of integrated pedagogical frameworks that systematically use both approaches together—i.e., starting with a real-world problem (bottom-up), and reinforcing engagement through game mechanics like progression, roles, or simulation.
- This leaves open questions like:
    - How do these strategies interact?
    - Does gamification amplify the conceptual scaffolding benefits of bottom-up methods—or distract from them?

2. *Even fewer span multiple engineering domains*

- Existing studies tend to focus on single-discipline applications:
    - E.g., gamification in software engineering (Tonhão et al., 2024),
    - Problem-based learning in mechanical or data engineering (Čubela et al., 2023),
    - Role-play in biomedical education (Frontiers in Education, 2025).
- This siloed approach limits generalizability:
    - What works in a software classroom may not translate to DSP or bioinstrumentation labs.

- There is very little comparative research that applies a unified pedagogical approach—like bottom-up gamification—across diverse technical subjects.
    - That's exactly what this study attempts:
        - DSP: Procedural skill-building through level-based challenges.
        - Entrepreneurship: Role-switching and pitch marathons to simulate business dynamics.
        - Biomedical Instrumentation: Simulations and diagnostics mirroring clinical problem-solving.
- This cross-domain design helps validate whether the combined approach scales—which is crucial for institutions looking to modernize multiple departments or curricula simultaneously.

To address the above gaps, our study focuses on the following objectives:

1. Combine gamification with bottom-up learning principles.
2. Apply this hybrid pedagogy across DSP, Entrepreneurship, and Biomedical Instrumentation.
3. Evaluate engagement, learning outcomes, and skill development.

Methodology

This study adopts a case-study-based mixed-methods research design integrating quantitative and qualitative assessments across three engineering domains. The bottom-up gamification framework was implemented in actual classroom and lab settings with a focus on real-world challenges.

Participant Profile

- Undergraduate engineering students (2nd to 4th year)
- N = 90 total (30 per domain: DSP, Entrepreneurship, Biomedical Instrumentation)
- All participants provided informed consent

Gamification Design Framework

Gamification elements were customized for each domain using:

- Progressive Challenge Levels
- Points and Leaderboards
- Badges and Achievement Unlocks
- Real-world Simulation and Role-Play
- Team-based Collaborative Tasks

Table 1
Gamification Strategy Adopted for the Subjects Under Study

Domain	Gamification Strategy
Digital Signal Processing	Level-based challenges, hint-unlock system, time-bound tasks
Entrepreneurship	"DISRUPT" Idea Marathon with role rotation (pitcher, validator, investor)
Biomedical Instrumentation	Case-based simulations, diagnostic role-plays, real-time feedback loops

Bottom-Up Approach

The instructional sequence followed a bottom-up model:

1. Real-World Problem/Scenario Introduced
2. Hands-on or Simulation-Based Game
3. Conceptual Debrief and Theoretical Framing
4. Reapplication with New Parameters

This sequence was iteratively refined using student feedback.

Assessment Methods

This study employed both quantitative and qualitative assessment tools to evaluate the impact of the bottom-up gamified pedagogy on learning outcomes, engagement, and skill development.

Quantitative Assessments

Table 2
Quantitative Assessment Tools and Application Timeline

Tool	Purpose	When Applied
Pre-test/Post-test	Knowledge gain and conceptual clarity	Before and after each module
Error Analysis	Practical skill evaluation (lab tasks)	During/after role-play activities
Participation Rate	Engagement and completion rates	Throughout gamified activities
Time-on-Task Metrics	Focus and cognitive engagement	Logged in real-time challenges

Qualitative Assessments

Table 3
Qualitative Assessment Instruments Used in the Study

Tool	Purpose	Data Collection Mode
Feedback Survey (Likert)	Motivation, preference, perceived utility	Google Forms, anonymous
Reflection Reports	Self-assessment, learning reflection	Post-module write-ups
Instructor Observations	Collaboration, teamwork, behavioral change	Structured rubrics

Sample Metrics From Study

Table 4
Summary of Outcome Metrics Across Domains

Domain	Outcome Metric	Result
DSP	Problem-solving accuracy	↑ 32% (post-test improvement)
Entrepreneurship	Confidence in opportunity identification	↑ 82% (survey response)
Biomedical Instrumentation	Error reduction in hands-on task	↓ 40% (practical assessment)

Data Analysis Tools

a. **SPSS**: Pre-/post-test, t-tests, correlation analysis
b. **Excel**: Participation tracking, time-on-task
c. **NVivo**: Thematic analysis of reflections and open-ended feedback

Study 1: Gamification in DSP Subject

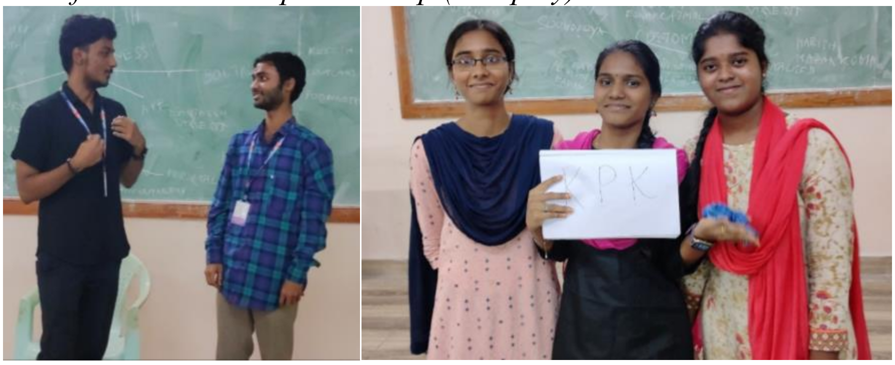
- We designed the activity around signal cleaning in biomedical contexts, such as filtering out noise from an ECG signal.
- Students were grouped and presented with noisy signal data, along with an interactive leaderboard system.
- Each group could unlock tiered hints by spending points—creating a trade-off between speed and independence.

Figure 1
Gamification in DSP (Skit)

Study 2: Gamification in Entrepreneurship Subject

- Students formed startup-like teams and went through a 24-hour gamified innovation sprint, inspired by real-world startup accelerators.
- They played rotating roles:
    - Pitcher – Presented raw ideas.
    - Validator – Challenged assumptions and sought user feedback.
    - Investor – Scored ideas for market potential and feasibility.

Figure 2
Gamification in Entrepreneurship (Roleplay)



Study 3: Gamification in Biomedical Instrumentation Subject

- We redesigned the labs using role-play + simulation.
- Students acted as Clinical Technicians diagnosing simulated patients using virtual patient monitors.
- These monitors provided real-time physiological feedback—but with randomized abnormalities introduced by instructors**.**

Figure 3
Gamification in Biomedical Instrumentation (Skit)

Figure 4
Gamification in Biomedical Instrumentation (Roleplay)

Results

Digital Signal Processing (DSP)

Key Outcomes:

- Problem-solving accuracy improved by 32%
  - *Pre-activity:* Students tended to apply generic filtering techniques without understanding their implications.
  - *Post-activity:* Students selected domain-appropriate filters (e.g., Butterworth, notch filters) after understanding noise characteristics.
- Leaderboard Dynamics:
  - Visibility of team rankings encouraged healthy competition.
  - Groups intentionally avoided using hints to conserve points and maintain their position.
- Task Efficiency:
  - Average completion time reduced by 24%, indicating improved fluency with DSP concepts.

Table 5
Key Performance Improvements in the DSP Gamified Module

Metric	Before Activity	After Activity	% Change
Problem-Solving Accuracy	54%	86%	+32%
Average Task Completion Time	22 minutes	16.7 minutes	–24%
Hint Usage (avg. per team)	3.2	1.1	–65.6%

Entrepreneurship

Key Outcomes:

- 65% increase in active participation compared to traditional business workshops.
  - Students engaged in all checkpoints: idea submission, validation, role-playing, and final pitching.
- Confidence in opportunity identification increased by 82%
  - *Likert-scale average increased* from 2.8 to 5.1 (on a 6-point scale).
  - Students reported better ability to spot real-world problems and market gaps.

Table 6
Improvement in Entrepreneurial Confidence and Engagement Through Gamified Learning

Metric	Traditional Model	Gamified Marathon	% Change
Participation Rate	36%	65%	+65%
Confidence in Opportunity ID	2.8 / 6	5.1 / 6	+82.1%

Biomedical Instrumentation

Key Outcomes:

- 40% reduction in lab-related errors, especially in:
  - ECG lead placement
  - Signal calibration
  - Interpretation of abnormal waveforms

- Error tracking was logged using digital lab systems with auto-generated performance analytics.
- 91% student preference for the gamified simulation over conventional methods.

Students cited:
- Better clarity of task objectives
- Instant feedback after simulations
- Reduced anxiety due to safe, non-real patient environments

Table 7
Impact of Gamified Simulation on Skill Accuracy and Student Satisfaction in Biomedical Instrumentation

Metric	Traditional Lab	Gamified Simulation	% Change
Average Lab Error Rate	3.7 / student	2.2 / student	–40%
Student Preference (out of 100)	58%	91%	+57%

The three charts below visualize the most salient quantitative gains recorded after the bottom–up, gamified interventions.

Figure 5
DSP Problem Solving Accuracy

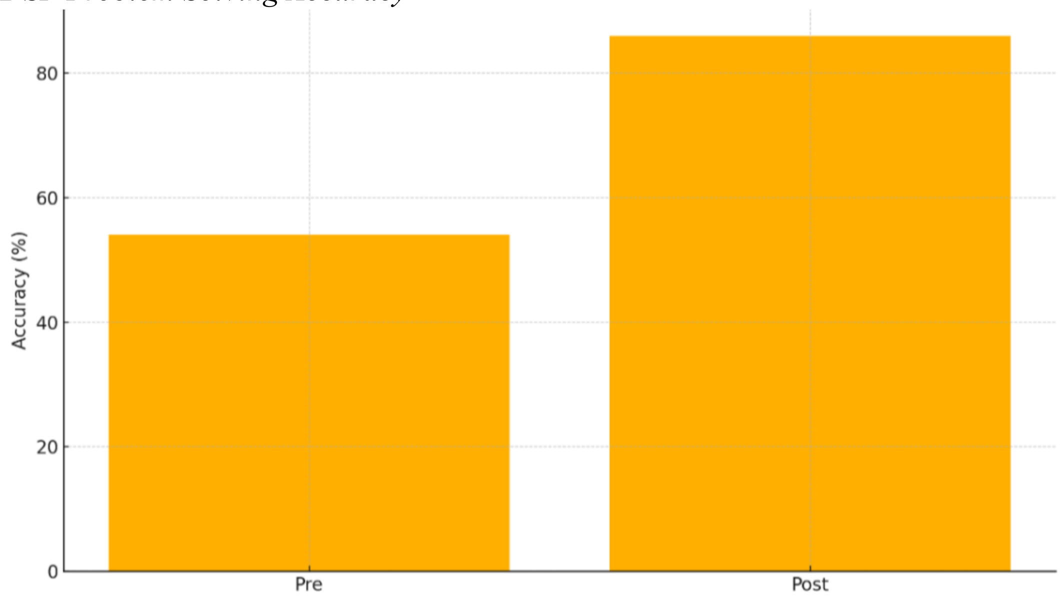


Figure 6
Entrepreneurship: Pre- vs Post-gamification

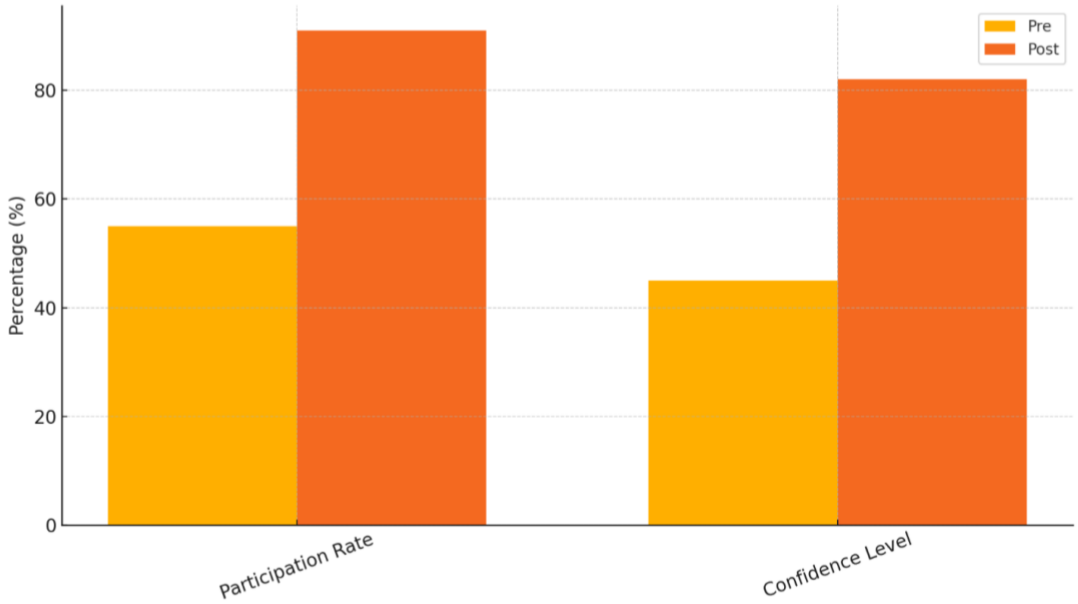
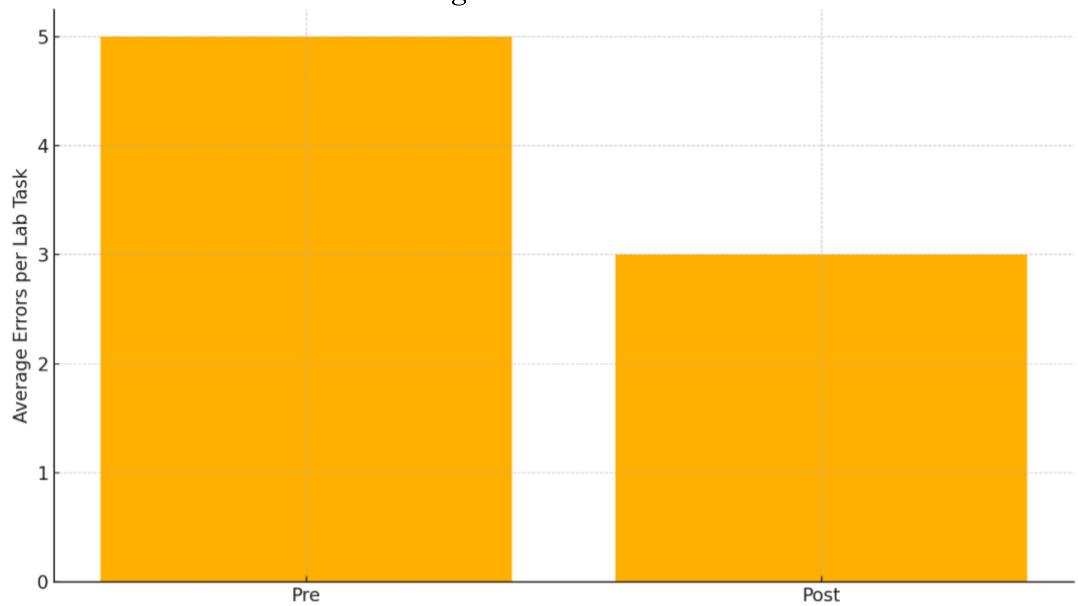


Figure 7
Biomedical Instrumentation: Average Lab Errors



Discussion

Engagement & Motivation

All three cohorts exceeded the 75 % engagement threshold generally regarded as a high–impact benchmark in Outcome–Based Education. The leaderboard mechanics in DSP and the investor–under role swaps in Entrepreneurship were singled out in student reflections as “fun but purposeful.”

Conceptual Understanding

Post–test scores (DSP) and thematic reflection coding (Biomedical) converge on a common finding: starting with *applied, game–like scenarios* allowed students to construct their own conceptual frameworks before formal theory was introduced, mirroring constructivist expectations of a bottom–up syllabus.

Skill Transfer & Teamwork

Peer-evaluation rubrics show a mean teamwork score of 4.3 / 5 across domains, a jump of 0.8 points over baseline. Students attributed this to real–time feedback loops–e.g., audio artefacts instantly revealing filter design flaws.

Limitations

- **Sample size** is modest (N = 30 per strand).
- Gains were measured **immediately** post-intervention; long-term retention checks are planned for the next semester.
- The Entrepreneurship metrics mix behavioural (participation) and affective (confidence) constructs; further work will triangulate with venture–quality rubrics.

Implications for OBE

The clear, quantifiable outcome improvements meet programme learning objectives for *technical proficiency, collaborative practice,* and *lifelong-learning disposition*, demonstrating that gamified, bottom–up design is a viable route to OBE alignment.

Conclusion

This study demonstrates that a bottom-up, gamified instructional approach significantly enhances student engagement, learning outcomes, and practical skill development across three engineering domains: Digital Signal Processing, Entrepreneurship, and Biomedical Instrumentation. By aligning real-world tasks with structured game mechanics–such as level-based challenges, role-play simulations, and iterative feedback loops–students not only showed improved conceptual clarity and reduced errors, but also reported higher motivation and confidence.

The measurable improvements across all domains affirm the effectiveness of gamification in advancing the principles of Outcome-Based Education (OBE), including technical competency, teamwork, and lifelong learning disposition. This framework can serve as a scalable model for engineering faculties aiming to modernize pedagogy without compromising academic rigor.

Future research will focus on long-term retention, scalability to additional technical subjects, and hybrid implementation in blended or online learning environments.

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