Evaluating Cognitive Skill Development in CS Students Through Gamified Car Racing: A pilot study involving Active Learning in India

Dr. Divya Mohan, Department of Computing Technologies, School of Computing, SRM Institute of Science and Technology, Kattankulathur, Chengalpattu, India-603203

Divya Mohan is an Assistant Professor in the Department of Computing Technologies at SRM Institute of Science and Technology, India. She completed her Ph.D. in Computer Science and Engineering from Vellore Institute of Technology. Her research interests span wireless network scheduling, soft computing, machine learning, and active learning strategies in computing education. She has authored multiple peer-reviewed journal and conference publications and actively integrates research-driven and student-centered pedagogies into her teaching practice. Dr. Mohan is particularly interested in applying artificial intelligence and data-driven approaches to enhance engineering education outcomes and learner engagement. She has participated in several faculty development programs and workshops focused on innovative teaching, curriculum design, and experiential learning. Her work aims to bridge the gap between emerging technologies and effective engineering education practices

Dr. Bhuvana Gopal, University of Nebraska - Lincoln

Dr. Bhuvaneswari (Bhuvana) Gopal is an Assistant Professor of Practice in the School of Computing at the University of Nebraska-Lincoln where she teaches Software Engineering, Software Security in Practice, the industry internship course, and leads the Learning Assistant Program that serves several computing courses at the School of Computing. Dr. Gopal is a College of Engineering Teaching Fellow at UNL. Dr. Gopal has extensive experience in the software industry, where she spent 14 years in various roles, including Software Architect and Lead software engineer positions before switching to full time academia. She is also a Microsoft certified professional, with an MCPD certification. Her research work is focused on evidence-based, active learning pedagogies to improve software engineering education. She has published papers specifically on Peer Instruction and Process Oriented Guided Inquiry-based Learning-like pedagogical approaches in the undergraduate software engineering classroom, both in person and virtual. She holds a Bachelors degree in Physics from the University of Madras, Chennai, India. She holds two Masters degrees - one in Computer Science from the University of Nebraska-Lincoln, and one in Medical Physics from Anna University, Chennai, India. She holds a Ph.D. in Computer Science from the University of Nebraska-Lincoln.

WIP: Evaluating Cognitive Skill Development in CS Students Through Gamified Car Racing: A Pilot Study Involving Active Learning in India

Introduction

Active learning in computer science education is growing globally but remains limited in India, where traditional lecture-based methods dominate, often resulting in passive learning. This creates a gap between theory and practical understanding, particularly in complex subjects like Computer Organization and Architecture (COA). Gamification addresses this by enhancing student participation, engagement, and problem-solving skills. Integrating game mechanics into COA instruction makes learning more interactive and immersive, leading to better understanding and retention.

Studies have shown that active learning methods—such as collaborative learning, peer Instruction, and project-based assignments enhance student comprehension and teamwork in Indian CS classrooms [1]. Gamification, an active learning technique that integrates game elements into educational activities, enhances motivation and improves academic outcomes [2]. Flipped classrooms, which deliver lecture content online while reserving classroom time for interactive problem-solving, have also demonstrated effectiveness in boosting student engagement and knowledge retention [3]. Despite positive evidence, there is limited structured implementation and empirical validation of gamified approaches in Indian engineering education [4].

This paper presents a pilot study utilizing Gamification pedagogy in lecture-based content delivery in Computer Organization and Architecture (COA) paper by using Blooket Platform. This paper begins with an overview of relevant literature and outlines the research questions guiding the study. The subsequent section describes the gamification methodology and presents the student feedback questions. This is followed by the results and analysis, and finally, the paper concludes with key insights and implications.

Related Architecture

Theoretical Foundations

Gamification has come as an effective pedagogical strategy to enhance student motivational, engagement and learning outcome. It engages in use of game mechanics in educational environments in a form of interactive learning. The theoretical framework observed in [5] shows how game elements build up learning behaviours via mediating and moderating mechanisms. Secondly, these mechanisms are related to how gamification components are linked to educational performance and relate to individual differences (e.g., goal orientation and self-efficacy) [6].

Most of the theories upon which gamified learning is based are classical conditioning, expectancy theory, goal-setting theory, and self-determination theory [7]. These motivational techniques were already established in psychology before the rise of gamification. Gamified Project-Based Learning (GPBL) combines project-based learning with gamification elements like challenges, rewards, and interactive games to boost student engagement. Studies [8] show that GPBL improves motivation and knowledge retention, especially when supported by technology and theoretical insights. Gamified learning is additionally supported by embodied cognition theory, which asserts that physical interaction and sensory experiences play significant roles in cognition. [9] Gamified learning strategies integrating virtual reality simulations and kinesthetic learning exercises are learning strategies that leads to a more immersive and engaging educational experience. Points, badges, and leaderboards are considered the most popular game elements in a gamified flipped classroom [10] for the purpose of engaging and motivating students.

A systematic review of 74 empirical studies (2010–2019) on gamified flipped classrooms identified key game elements that improve learning, grounded in self-determination theory, flow theory, and the technology acceptance model. Findings consistently showed enhanced motivation, engagement, and academic performance. One study found that competitive gamification led to higher intrinsic motivation and performance compared to noncompetitive and control groups [11]. According to the researchers, these benefits were due to the fact that competition enhances a sense of competition and social connection.

Gamified Learning in Engineering

Gamification has recently been adopted in engineering education to boost participation, understanding, and motivation. Researchers from India and the USA find it effective in addressing traditional teaching limitations, creating engaging environments that enhance academic performance. [12]. Kahoot is one of the tools that has shown to be effective in online learning by increasing active participation and reinforcing key concepts [13].

Gamification is now taken into account even in engineering disciplines and has proven to be successful in teaching engineering topics like sustainability and programming. Gamified learning strategies have been effective in India in improving conceptual understanding and students' engagement in the subjects [18]. Gamification is already part of STEM curricula in the USA, aiding the learning of complex topics like environmental sustainability. Despite its benefits, challenges remain in selecting suitable game mechanics, managing costs, and ensuring proper validation [14]. Moreover, barriers to the communication and technical aspects must be tackled in order to achieve the best use of gamification [16]. Future work should focus on validating gamification's effectiveness and the impact of specific game elements on student performance. Integrating gamification into mobile and digital platforms can make learning more engaging and immersive [15].

Gamification elements that have been structured properly by using the Octalysis Framework in social sciences and training programs have shown to be successful [17]. Future research and implementation of gamification in engineering education appear promising. It has also been integrated into flipped learning, especially post-COVID-19, with studies highlighting its potential to enhance the effectiveness of this approach [22]. Combining gamification with traditional methods can simplify and modernize complex engineering subjects, making them more accessible and engaging. Untapped areas include applying gamification in software engineering education within LMS environments, where course scope and size significantly impact success [19]. Additionally, personalized gamified interventions show promise for supporting students with ADHD, with broader implications for engineering education [20].

Gamified Learning in Computer Science

In computer science education, gamification has been widely applied in attempts to deal with problems like students' low involvement and high difficulty of the technical topics. It has been suggested that gamified learning environment brings more motivation and engagement and better academic performance [25]. For instance, applying gamification in UML modelling courses has motivated the students and improved the grades of students [22].

Studies on C-programming education show that gamification boosts learning outcomes, with long-term effectiveness sustained throughout semesters. However, its impact may vary with classroom size, highlighting the need to optimize group dynamics [21]. While gamification generally improves student performance regardless of gender, its effect on self-efficacy and identity development remains unclear [25]. Platforms like Kahoot, ClassDojo, and ClassBadges help enhance participation and collaboration in schools and universities [24]. In online learning, gamification increases student contributions and task engagement, showing a medium to large effect [23]. Challenges associated with gamified learning in computer science include communication barriers, technical skill gaps, and the sustainability of engagement over extended periods. Table 1 emphasizes the key challenges while implementing Gamified Learning. Studies emphasize that while gamification initially increases motivation, there is a risk of diminishing effectiveness due to the novelty effect [26].

Recent studies also explore adaptive gamification using AI-driven personalization, such as reinforcement learning-based learning paths [30]. Additionally, cross-cultural implementations in gamification design have highlighted the importance of local context in student response [31]. These methods were not explored in the current study and represent future directions.

Research Questions

In this Study, we describe a study conducted with undergraduate students using a gamified learning approach in a Computer Organization and Architecture course through an interactive car racing platform. Our Research Questions (RQ) for this study were:

RQ1: Does gamified learning approach enhance conceptual understanding, engagement and problem-solving abilities of undergraduate students in a Computer Organization and Architecture course compared to those taught using traditional methods?

RQ2: Does gamified learning influence students' learning behaviours and increase their likelihood to recommend the approach, as reflected in feedback surveys, and explore how students respond to gamified learning environments, particularly in terms of conceptual understanding, engagement, and problem-solving abilities?

Research to Practice Implementation and Methodology

This section outlines the implementation of gamification in an educational context aimed at enhancing student engagement, improving problem-solving skills, and reinforcing theoretical knowledge through peer learning for sophomore computer science students.

In this study, a gamified car racing quiz was implemented using the Blooket platform, featuring multiple-choice questions categorized by cognitive level Recall (R), Conceptual (C), or Procedural (P), as shown in Table 1. Students progressed along a virtual race track by answering questions correctly, with streaks of three correct answers unlocking power-ups for faster advancement. This interactive format encouraged sustained engagement, critical thinking, and spatial reasoning [27]. The quiz included three categories of questions:

- **Recall Questions** – to test memory and foundational knowledge,
- **Conceptual Questions** – to evaluate understanding of core principles,
- **Procedural Questions** – to assess the ability to apply concepts in practical scenarios.

These questions were developed based on the peer instruction learning[28] model, encouraging collaborative reasoning and active participation among students.

Table 1. Multiple Choice Questions in Gamified Learning

Q. No	Questions asked in gamified Learning	Question Category
1.	The instruction cycle is the procedure a microprocessor goes through to process an _______.	R
2.	A component which stores this value in an internal register, usually called the ___________.	R
3.	It is called as Non-Volatile because of its Retaining Property.	C
4.	What is the BCD of 13?	P
5.	What is the Excess-3 code for 9?	P
6.	Convert binary to decimal number (11101)2	P
7.	Convert octal number 540 into binary number.	P
8.	What is the correct order?	C
9.	Computers represent information in a specific __________ form.	R
10.	A personal computer; designed to meet the computer needs of an individual.	R
11.	Control unit works with a reference signal called _________	C
12.	Which bus is Unidirectional?	C
13.	Which one belongs to Data Transfer Instruction?	R
14.	Which type of address does it belongs to?	C
15.	What Addressing mode is this?	C

Table 2. Feedback Questions on Effectiveness

Questions	Description	Expected Answers
On a scale of 1 to 5, how engaging did you find the car racing game for learning?	Engagement	Rating scale from 1 to 5 (1 = Not Engaging, 5 = Highly Engaging)
How helpful was the game in improving your problem-solving skills?	Helpfulness	Rating scale from 1 to 5 (1 = Not Engaging, 5 = Highly Engaging)
Did the game help you better understand the learning objectives?	Understanding	Yes/Somewhat/No
How challenging did you find the game levels? (3 = Balanced)	Challenge	Rating scale from 1 to 5 (1 = Too Easy, 3 = Balanced, 5 = Too Difficult)
Would you recommend this game-based method to other students? Why or why not?	Recommendation	Yes / No (Provide reasons for your choice)

At the conclusion of the gamified learning session, a feedback survey was administered to students. The survey consisted of two sections: the first assessed the effectiveness of the gamified learning method, with results being summarized in Table 2; Second captured student preferences and recommendations regarding the use of gamified learning, presented in Table

3. The questionnaire used in the survey was custom-designed by the authors specifically for this study, comprising a mix of free-form response questions and rating-based. Although questions were categorized into recall, conceptual, and procedural types, the study did not employ validated instruments to measure specific cognitive or spatial reasoning skills. Future work will use tools such as the Purdue Spatial Visualization Test or problem-solving rubrics to assess these learning dimensions more rigorously.

Ethical Considerations

To ensure ethical compliance, students participated voluntarily with full awareness of the study's purpose and methods. Anonymity and confidentiality were maintained by aggregating responses, and all data were handled in line with the university's ethical guidelines. These measures upheld ethical standards while supporting a comprehensive analysis of gamified active learning.

Result and Analysis

In our study, sentiment analysis of student feedback on gamified learning was conducted using Google Colab for computational analysis. This approach enabled a deeper exploration of both the cognitive and emotional responses of students. By leveraging this methodology, key trends related to student engagement, motivation, and learning effectiveness were identified. Student responses were further analyzed using the VADER sentiment analyzer to evaluate the sentiment distribution across different aspects of the game-based learning experience [29]. To gain a comprehensive understanding from the students' perspective.

Table 3. Feedback Questions on Preferences

Mapped Label in Figure 2	Questions	Description	Expected Answers
Col_4	What part of the game did you enjoy the most?	Favourite aspect of the game	Open-ended response based on personal experience
Col_5	Did you feel frustrated at any point in the game? If so, why?	Frustration level and reasons	Yes / No (If yes, explain briefly)
Col_6	What feature or aspect of the game would you like to see improved?	Suggested improvements	Open-ended response with specific suggestions
Col_7	Did you feel motivated to complete more levels or challenges? Why or why not?	Motivation for progression	Yes / No (Provide reasons)
Col_8	How often did you collaborate or discuss strategies with your peers during the game?	Peer interaction and collaboration	Sometimes / Often / Always

Effectiveness of Gamified Approach

Sentiment analysis of student feedback indicated a highly positive response toward the gamified learning approach, with students expressing increased enthusiasm and motivation. Approximately 96% of the respondents considered gamification to be an effective tool for promoting active learning. The feedback frequently included descriptors such as "interactive," "engaging," and "fun," reflecting a high level of student involvement and enjoyment. However, around 4% of the responses were neutral, acknowledging the novelty of the approach but expressing concerns regarding the alignment of gamified activities with core content and the overall structure of the gamification framework.
A set of survey questions given in Table 2 was structured and developed to evaluate the students with respect to focusing on their engagement, understanding concepts, problem solving skills and in terms of the overall learning experience.

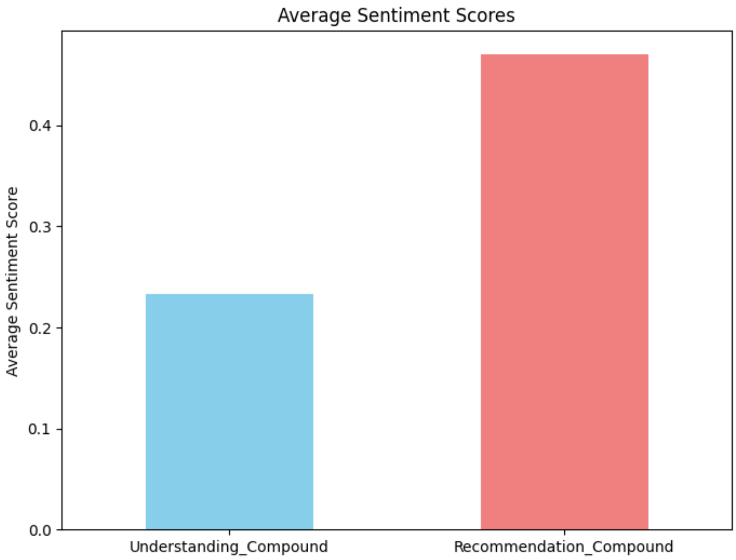

Figure 1. Average Sentiment Score for Gamified Learning

Figure 1 illustrates the aggregated sentiment polarity for gamified learning, based on the compound scores derived from open-ended student feedback using the VADER sentiment analyzer in Google Colab. These compound scores range from -1 (most negative) to +1 (most positive). These sentiment scores capture the emotional tone of responses, such as enthusiasm or frustration, but do not directly measure cognitive improvement. While positive sentiment may support engagement and motivation, it is not a substitute for objective assessment of learning or skills gained shown in Table 2. While 96% of students endorsed the gamified approach, 45% reported difficulties in fully grasping the material, primarily due to technical constraints and initial adaptation to the digital platform. Some feedback highlighted the need for refinement in game mechanics such as level progression and feedback delivery to improve instructional effectiveness. While the original aim was to compare gamified learning with traditional methods, this study does not include a control group or pre-intervention data. Thus, claims about comparative effectiveness are exploratory and not definitive. Future work will implement a control group and a pre-post testing design to rigorously assess the impact of gamification.

Limitations

The current sample size (n=25) limits generalizability and precludes the use of inferential statistics. Findings should be viewed as indicative rather than conclusive. Future iterations will include larger samples and statistical methods such as t-tests or ANOVA to validate observed trends.

- While the original aim was to compare gamified learning with traditional methods, this study does not include a control group or pre-intervention data. Thus, claims about comparative effectiveness are exploratory and not definitive. Future work will implement a control group and a pre-post testing design to rigorously assess the impact of gamification.
- Subsequent phases of this research will implement a control group and validated pre/post instruments to test the hypothesis of gamification's effectiveness over traditional methods.

Behaviour and Preferences

Student responses were analyzed using the VADER sentiment analyzer to assess sentiment distribution in the game-based learning experience. As shown in Figure 2 and detailed in Table 4, sentiment distribution across feedback questions reveals that 17 students expressed positive sentiment, 7 were neutral, and 1 was negative, indicating an overall positive attitude toward gamified learning.To explore behavioral aspects and preferences, questions listed in Table 3 captured insights on engagement, sources of frustration, motivation, and collaboration.

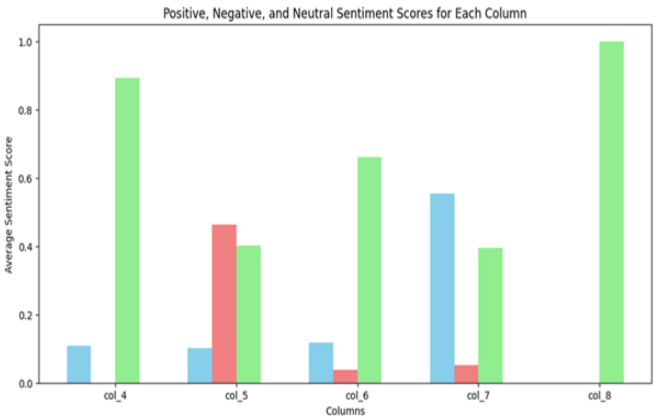

Figure 2. Sentiment Scores of Feedback Questions in Table 3

Table 4. Sentiment Distribution with Corresponding Color Codes Used in Figure 2

Sentiment Category	Description	No. of Students	Percentage (%)	Color in Figure 2
Positive	Green Bar	17	68	Green
Neutral	Blue Bar	7	28	Blue
Negative	Red Bar	1	4	Red

From the analysis, it is evident that approximately 68% of the students exhibited positive behavior and a clear preference for the gamified learning approach. This indicates that a majority found the method engaging, enjoyable, and beneficial for understanding software engineering concepts. Table 4 presents the detailed distribution of student sentiment, with 28%

showing a neutral stance likely due to unfamiliarity with the format or concerns about alignment with course content and only 4% expressing a negative perception.

It's important to note that this conclusion is based on a small sample of 25 students. To gain more generalizable and statistically significant insights, larger studies across multiple cohorts and course settings are needed. Incorporating qualitative feedback from instructors would offer deeper insight into practical challenges, instructional alignment, and the overall impact of gamified learning. Adopting a dual approach combining both quantitative and qualitative methods would enable a more comprehensive evaluation of gamification as an effective pedagogical strategy in computer science education.

Conclusion

While the results indicate increased engagement and positive sentiment among students using the gamified model, the lack of a control group limits direct comparison with traditional methods. Nonetheless, this pilot study in a sophomore-level engineering course highlights the potential of structured, sentiment-informed gamified learning to boost motivation and interaction. The findings support further research with controlled designs to evaluate long-term outcomes and scalability in culturally specific contexts.

In response to RQ1: Gamified learning helped undergraduate students in a Software Engineering class understand key concepts such as software development practices, testing, and integration workflows more effectively. Students reported improved engagement and clarity, although some faced initial adaptation challenges due to the novelty of the gamified approach and the digital platform.
In response to RQ2: Gamification led to increased student enthusiasm and motivation in learning computer science, with feedback highlighting the experience as "fun," "interactive," and "engaging.".
The study supports gamification as a promising instructional strategy, particularly in Indian higher education. Future work should focus on curriculum integration, accessibility, and scalability, supported by empirical validation through larger, controlled studies. This pilot study indicates that gamified learning can enhance engagement and perceived understanding, particularly in culturally specific contexts like Indian engineering education. However, limitations such as the lack of a control group, small sample size, and absence of validated cognitive assessments limit the strength of the conclusions. Future work will address these through controlled comparative studies, integration of standardized skill assessments, and larger participant pools.

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