Assessing Parallel and Distributed Computing Knowledge Through a Card Game

[1st] Srishti Srivastava
Computer Science
University of Southern Indiana
Evansville, IN, USA
fsrishti@usi.edu

[2nd] Mary L. Smith
Computer Science
Hawaii Pacific University
Honolulu, HI, USA
mlsmith@hpu.edu

***Abstract*—This research introduces a card game designed to enhance the understanding of parallel and distributed computing (PDC) concepts among junior and senior undergraduate computer science students. The game is an interactive assessment tool that enables instructors to evaluate student knowledge and simultaneously identify which PDC concepts are inherently covered within undergraduate curricula. The game reinforces core PDC concepts by employing active learning strategies, such as collaborative group activities, while engaging students in a dynamic and interactive learning experience. The game's design is guided by the NSF/IEEE-TCPP Curriculum Initiative, ensuring it aligns with industry-relevant knowledge and best practices in parallel and distributed computing education.**

***Index Terms*—Parallel and Distributed Computing, Student Engagement, Active Learning, Early Computer Science Undergraduate Curriculum, Cards Game, Unplugged CS Activity**

I. Introduction

Recognizing the critical role of parallel and distributed computing (PDC) in modern computing, the National Science Foundation (NSF), in collaboration with the Institute of Electrical and Electronics Engineers Technical Committee on Parallel Processing (IEEE-TCPP), has initiated efforts to integrate PDC concepts into undergraduate computer science curricula [26]. However, effectively conveying the breadth and complexity of PDC to students can be challenging. Traditional instructional methods, which often rely heavily on lectures and textbooks, can present students with an overwhelming amount of information, potentially hindering their grasp of fundamental concepts.

To address this challenge, we have previously investigated the use of "unplugged" activities, which involve hands-on, physical activities that simulate or model computing concepts without the use of computers. Our preliminary research demonstrated the effectiveness of these unplugged activities in increasing student participation and improving their understanding of key PDC topics [30]. To further adopt the pedagogical benefits of active learning and collaborative group work, we developed a card game called *PDC Quest* that introduced topics from the concepts categories of PDC recommended in the NSF/IEEE-TCPP Curriculum Initiative on Parallel and Distributed Computing [31] [35]. The card game is specifically designed to foster collaborative learning by encouraging students to work together in groups, discuss concepts, and solve problems together. By combining the engaging nature of a card game with the pedagogical benefits of active learning and collaborative group work, our goal is to establish a stimulating and effective learning environment that enables students to comprehend complex parallel and distributed computing principles better.

This research aims to evaluate the depth of experience *junior and senior* computer science students have gained with PDC concepts throughout their undergraduate education. It also explores students' perceptions of the game after playing, specifically regarding engagement and enjoyment, critical thinking skills, collaboration, and motivation and self-efficacy. To achieve this, we propose a modified version of a previously developed card game. In order to understand students' preexisting familiarity with essential PDC concepts relevant to their curriculum, we employed this interactive assessment method in junior/senior level courses at our respective universities at the start of the Spring 2025 semester. The assessment also evaluates the impact of the card game on student learning of PDC concepts through a post-activity survey. The survey adapts elements (questions and frameworks) from the Student Assessment of Learning Gains (SALG) survey [36] and the Motivated Strategies for Learning Questionnaire (MSLQ) [37] [38]. The remaining sections of this paper will delve into the details of our proposed instructional activity and its potential implications. Section II provides a synthesis of relevant literature, identifying research gaps addressed by this study. Section III outlines the experimental design, data collection procedures, and analytical methods. The benefits of integrating gamified PDC instruction are discussed in Section IV. Finally, the Section V summarizes the findings and outlines the directions for future research.

II. Background and Related Work

Parallel and distributed computing (PDC) has emerged as a critical area in research and education in STEM disciplines, particularly in computational science and engineering.

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Although the importance of "parallel thinking" has been emphasized [5], many recent computer science graduates lack a foundational understanding of PDC. Despite efforts to integrate PDC into the undergraduate curriculum through modular approaches [8]- [13], elective courses, and dedicated teaching materials [14]- [16], challenges remain. Bogaerts [17]- [20] has explored integrating parallelism concepts into introductory CS courses (CS0 and CS1). This approach involves incorporating supplementary lectures on parallel computing and hands-on programming activities within the existing curriculum to provide students with foundational knowledge and practical experience in parallelism. Traditional teaching methods, such as lectures and programming exercises, may not effectively convey the complex concepts of PDC to students [19]- [25]. This highlights the need for innovative pedagogical approaches to enhance student understanding of both the theoretical and practical aspects of parallel and distributed computing.

Research has shown that a fun and low-stress learning environment enhances student motivation and learning outcomes [32] [33]. Educational games, including those using flashcards, have shown significant potential in achieving these goals. Flashcards promote active recall, engage metacognition, and facilitate confidence-based repetition – all proven effective learning strategies [1]- [4]. In previous research, we explored using a card game to introduce PDC concepts to undergraduate students but did not fully develop it or have students play it [31] [35]. Building upon this foundation, this research proposes a modified version of the card game to assess the level of experience junior and senior computer science students have gained with PDC concepts during their undergraduate studies.

III. Methodology

To assess the degree of PDC knowledge among junior and senior CS students, we modified the flashcards developed in our previous study [31]. This involved carefully identifying and categorizing the specific PDC concepts to be assessed, adhering to the guidelines outlined in the NSF/IEEE-TCPP Curriculum Initiative on Parallel and Distributed Computing [26]. The resulting eight categories and their associated questions are detailed in Table I. Based on our analysis of the ACM Computer Science Curricula 2023 [34], we hypothesize that a significant proportion of the PDC categories and related topics included in our assessment are likely to be implicitly addressed within the core curriculum of most undergraduate computer science programs, both within the United States and internationally.

A. Game Design and Description

To assess student knowledge, we developed a card game called PDC Quest based on the eight PDC categories in Table I. The game includes 80 cards (questions), each illustrated with the PDC category on one side the category question, answer, and a unique QR code on the other. PDC Quest is designed for groups of three players. However, it can be adapted for more than three players if needed. A deck of 80 cards serves as the *Deal* stack. Each card features the game name, category number, and code on the front. The question, answer, and a QR code linking to further explanation are on the back (Figure 1). We created a dedicated website (a Github repository) with detailed game rules and descriptions of each question, including links to relevant sources. This additional resource will assist evaluators in assessing student answers and facilitate further discussion.

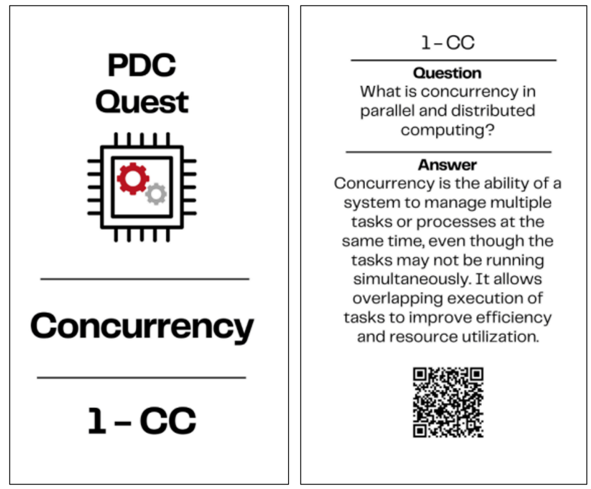

Fig. 1: PDC Quest Sample Card

(a) Note: Each card includes a QR code. Scanning the code will direct the players to a website offering additional details and links to resources related to the specific question.

Before gameplay, the game moderator can select and shuffle the desired category cards into the Deal stack. Player 1 draws a card and passes it to Player 2. Player 2 reads the question aloud, and Player 1 has 60 seconds to answer. Players 2 and 3 evaluate the answer, assigning scores of 0 (incorrect), 1 (partially correct), and 2 (correct). The QR code can be used for further discussion and evaluation. Player 1's score (category and score) is recorded, and Player 2 places the card in the Played stack. Play continues rotationally, with each player drawing a card, answering the question, and having their answer evaluated by the other two players. Scores are recorded on the score sheet as illustrated in Figure 2, indicating player names, categories, and scores. Once all cards are played, players calculate their average score for each category. This analysis can help identify areas where further study is needed.

B. Data Collection and Analysis

The PDC Quest card game was played with groups of junior and senior computer science students to enhance student engagement and understanding of PDC concepts at Hawaii Pacific University (HPU) and the University of Southern Indiana (USI) at the start of the 2025 spring semester. The game's duration was limited to 45 minutes due to the time constraints imposed by our course schedule. After the game, a survey was administered to assess knowledge and understanding of parallel and distributed computing concepts

TABLE I: PDC concept categories with sample questions

PDC Concept Category	Related Questions
1-Concurrency (CC)	What is concurrency in PDC? How does concurrency differ from parallelism? What is a race condition in concurrent systems?
2-Mutual exclusion (ME)	Why is mutual exclusion important in PDC? What is a critical section, and how does mutual exclusion relate to it? What is the difference between mutual exclusion and deadlock?
3-Consistency in state/memory manipulation (CM)	What is consistency in PDC? What is the difference between strong and eventual consistency? What is the CAP theorem and how does it relate to consistency?
4-Message passing (MP)	What is message-passing in parallel and distributed computing? What are the key differences between message-passing and shared memory approaches? What are point-to-point and collective communication in message-passing?
5-Shared-memory models (SM)	What is a shared-memory model in PDC? What synchronization mechanisms are commonly used in shared-memory models? How does the concept of a critical section relate to shared-memory programming?
6-Scalability (SC)	What is scalability in the context of PDC? What are the two main types of scalability? What role does the architecture of a system play in its scalability?
7-Scheduling and load balancing (SL)	What is scheduling and load balancing in the context of PDC? What are the common types of scheduling algorithms used in parallel computing? How do static and dynamic scheduling differ?
8-Speedup/Amdahl's law (SA)	What is speedup in the context of PDC? What is Amdahl's Law? Can you provide an example of Amdahl's Law in practice?

PDC Quest Scoresheet

Score (0–no or incorrect answer, 1–partially correct answer, 2–complete & correct answer)

Average score for each category (total score for each category/number of cards played in that category)

Average Score:

Mastered Understanding: 1.8 and above

Good understanding:1.6-1.78,

Average understanding: 1.4-1.58

Category	Player's Name 1	Player's Name 2	Player's Name 3
CC	C1 (1), C3(0), C5(2)		
ME			
CM			
MP			
SM			
SC			
SL			
SA			
Avg 1-CC	(1+0+2)/3 = 1		
Avg 2-ME			
Avg 3-CM			
Avg 4-MP			
Avg 5-SM			
Avg 6-SC			
Avg 7-SL			
Avg 8-SA			

Note: Sample data for player score recording includes C# indicates the card played (#) indicates the score and Average score for each category (total score for each category/number of cards played in that category)

Fig. 2: Sample PDC Quest Score Sheet

and to assess engagement, enjoyment, critical thinking, collaboration, motivation, and self-efficacy related to the card game. The survey, adapted from the Student Assessment of Learning Gains (SALG) [36] and the Motivated Strategies for Learning Questionnaire (MSLQ) [37] [38], collected quantitative and qualitative feedback from participants. The survey included Likert scale questions that assessed students' perceived knowledge in eight PDC categories, along with two questions each on engagement, enjoyment, critical thinking, collaboration, motivation, and self-efficacy. In addition, the survey contained two open-ended questions. One question asked students to identify previous courses that had contributed to their understanding of parallel and distributed computing. The other asked for suggestions how to improve the card game to enhance the learning experience. As mentioned, the researchers implemented the PDC Quest card game in two upper-level undergraduate CS courses with junior and senior students. These courses had relatively small enrollments, with 18 students at USI and 10 at HPU. Due to the limited sample size, the responses were combined for analysis, resulting in 28 participants. Given this sample size, the analysis remains descriptive. Given the small sample size and the Likert scale data, descriptive statistics are presented using the median, not the mean. In addition, a summary of the responses to open questions has been included.

As shown in Figure 3, the median score of 3 suggests that most respondents provided a neutral response, indicating that the card game neither significantly enhanced nor failed to enhance their understanding of the concepts in the categories of Speedup/Amdahl's Law, Scheduling and Load Balancing, Scalability, Consistency in State/Memory, and Mutual Exclusion. In contrast, a median score of 2 for the Shared Memory Models and Message Passing categories suggests that most respondents felt the card game did not help them understand these concepts. The mixed effectiveness, particularly the neutral or negative learning impacts observed for certain PDC concepts, necessitates a deeper analysis. We plan to directly address the areas yielding neutral/negative responses by revising and enhancing the supplementary learning materials associated with those specific topics. Our aim is to provide more effective support and ensure a better understanding of these concepts through improved instructional resources. Furthermore, we plan to initiate departmental discussions regarding the PDC topics that received neutral/negative feedback to explore ways to enhance PDC instruction within the existing curriculum.

As shown in Figure 4, the majority of respondents agreed or strongly agreed that PDC Quest was engaging, enjoyable, and promoted active participation, with median scores of 4 and 5, respectively.

As illustrated in Figure 5, the median response of 3.5 suggests that participants generally agreed that the PDC Quest game encouraged critical thinking in their decision-making. However, some respondents remained neutral, indicating a moderately positive but mixed perception. In contrast, the median score of 2.5 suggests a slight tendency toward disagreement regarding the game's effectiveness in fostering new learning strategies. Responses were relatively balanced between neutral and negative perceptions, indicating a somewhat negative, though not strongly opposed, view.

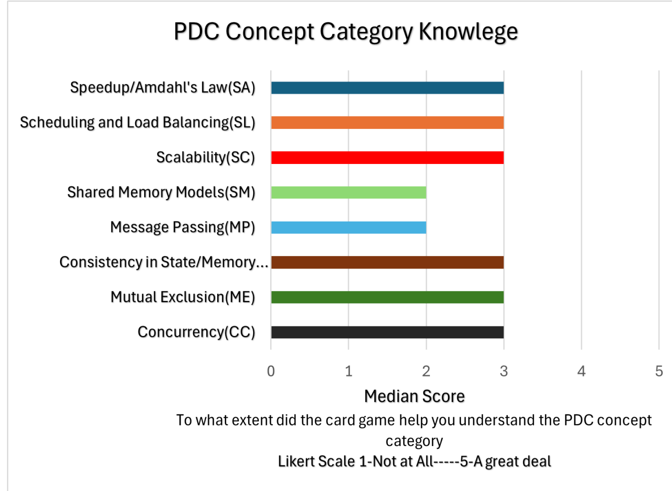

Fig. 3: PDC Quest Response Knowledge

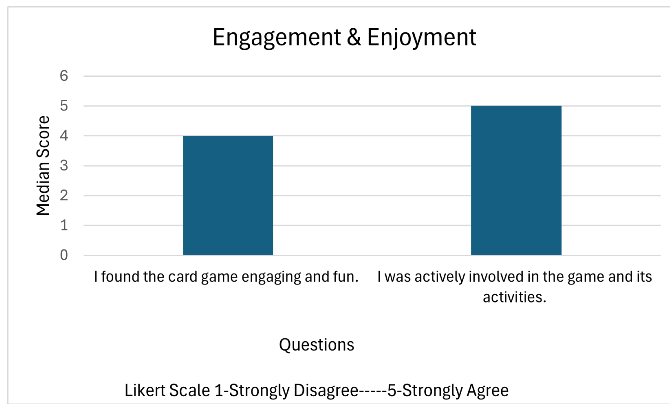

Fig. 4: PDC Quest Engagement

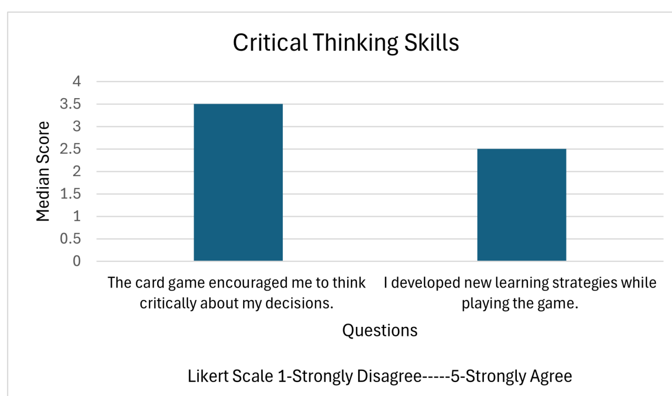

Fig. 5: PDC Quest Critical Thinking

As presented in Figure 6, the median score of 4 for the statement regarding effective communication with peers during the PDC Quest game suggests that most respondents agreed.

In contrast, the median score of 3 for the statement on the game's impact on teamwork skills indicates that a substantial portion of respondents selected "Neutral," suggesting either a balanced distribution of opinions or an absence of strong sentiment.

Fig. 6: PDC Quest Collaboration

As shown in Figure 7, the median score of 4 for the statement about the card game motivated them to learn more about parallel and distributed computing suggests that most respondents agreed. In contrast, the median score of 3 for the statement about respondents' confidence in applying what they learned in the game to real-world scenarios indicates that a substantial portion selected "Neutral," reflecting either a balanced distribution of opinions or an absence of strong perspectives.

Fig. 7: PDC Quest Motivation and Self Efficacy

Participant Feedback: Feedback from participants on how to improve PDC Quest to improve a better learning experience. Several suggestions were provided in response to the open-ended question about improving the card game to enhance the learning experience. These suggestions were grouped into the following categories.

Clarity and Specificity: Many respondents suggested rewording vague or open-ended questions to make them more specific, helping players better understand them and improving response quality. Additionally, they recommended allowing more time for questions and providing clearer grading instructions to enhance the learning experience. The 45-minute gameplay limitation revealed that some categories were not covered, indicating a need to extend the time or reduce the number of categories per game.

Learning Aids and Resources: Suggestions included adding hints, definitions, or analogies to the cards to assist players, particularly first-time players. Linking videos to QR codes was also recommended to provide more detailed explanations and help players better understand the concepts.

Difficulty Levels and Coverage: Participants suggested incorporating varying difficulty levels for each question, assigning different point values accordingly. Including more questions from earlier coursework was also recommended to provide a more comprehensive learning experience.

Gameplay Mechanics and Scoring: Enhancements to scoring clarity were proposed, such as adding individual card numbers and refining the instructions for score recording. Additionally, adjusting how cards are shuffled could increase the challenge by avoiding consecutive cards from the same category.

Curriculum Contributions: Feedback from participants on which CS courses at USI or HPU contributed to their understanding of parallel and distributed computing is shown in the word cloud in Figure 8. In descending order of PDC concept coverage, students most frequently cited computer architecture, operating systems, data structures, software engineering, and database technologies.

Fig. 8: Courses taken that have taught PDC concepts

(a) Note: A word cloud visually represents text data, where the size of each word indicates its frequency or importance in the dataset. The larger the word, the more frequently it appears in the text.

PDC Quest Score Sheet: The PDC Quest score sheet aims to help students identify which categories of PDC concepts they need to study further while also providing instructors with a measure of student understanding. In this implementation of the PDC Quest card game, students were given a 45-minute class period to play. We observed that most of the groups were unable to progress through many categories of questions in the allotted time, making it challenging to analyze the results of the scorecard in this initial test. However, the results provided valuable insights into potential modifications for future implementations of the game. For example, extending the game beyond the classroom, perhaps as part of a student ACM meeting, would provide more time for in-depth gameplay. Alternatively, the game could be adapted for shorter class sessions by limiting the number of PDC categories used, focusing only on specific topics such as Consistency, Scalability, Message Passing, or other selected combinations.

IV. Observations and Benefits of the Proposed Approach

1) Instructors as Participant Observers: During the implementation of the card game in two junior- and senior-level undergraduate computer science classes at USI and HPU, instructors served as facilitators and participant observers, moving between groups to monitor interactions and provide guidance as needed. Their observations were documented through note-taking, which included tracking the time spent on each stage of the game, recording direct quotes from student discussions on PDC questions, scoring answers using the score sheet, and noting student suggestions for improving the information on the GitHub page. Based on these observations, instructors will revise the game to address the challenges the students encountered, incorporating additional scaffolding where necessary. Further analysis of these observations will explore the game's effectiveness in enhancing student engagement and problem-solving skills.

2) Benefits of the Card Game: The PDC Quest card game offers a dynamic and engaging approach to assessing student knowledge. By providing immediate feedback and encouraging collaborative problem solving, it fosters critical thinking and application. As a low-stakes assessment, it creates a relaxed and supportive learning environment that promotes communication and caters to students' diverse learning styles. Here we outline a few of the key benefits of our proposed approach:

Increased Engagement and Motivation: Gamified assessments can enhance student motivation and engagement compared to traditional tests.

Immediate Feedback: The game's interactive nature provides immediate feedback on student understanding, allowing for real-time adjustments and reinforcing learning.

Critical Thinking and Application: The game encourages critical thinking and problem-solving skills as students apply their knowledge to answer questions.

Informal and Low-Stakes Assessment: The game creates a low-pressure environment, reducing anxiety and encouraging students to demonstrate their knowledge more freely.

Collaboration and Communication: Teamwork and peer interaction within the game foster collaboration and communication skills.

Differentiated Learning: The game can cater to diverse learning styles, making it a more inclusive assessment method.

V. Conclusions and Future Work

This work presents the development and implementation of a card game, using the flashcards that were introduced in [31]. Th proposed approach is designed to foster a more engaging and enjoyable learning experience for students learning complex foundational PDC concepts. Acknowledging the challenges of learning PDC, we believe gamification is key in enhancing instruction in undergraduate CS programs. While traditional teaching methods remains essential, this card game is being proposed to provide a valuable supplementary learning experience. During the Spring 2025 semester, we conducted a pilot study of the game in junior- and senior-level computer science courses. To assess student knowledge gaps, we utilized the score sheet as shown in Figure 2 alongside a post-activity survey to gather student feedback on the game. In addition, using two open ended questions on the survey, the students were asked to provide suggestions for improving the game, and to reflect on coursework that introduced them to the PDC concepts covered in the game. Moreover, instructors observed and facilitated gameplay, circulating among student groups to monitor interactions and provide assistance. The instructor observations were recorded using notes capturing gameplay time, student discussions (including quotes), answer scoring, and suggestions on improving additional resources provided through the GitHub page.

Based on the feedback, planned future improvements include rewording vague questions, streamlining the score sheet for better clarity, and adding learning resources such as instructional videos and supplementary links to the PDC Quest website. Furthermore, we aim to allocate more time for responses and discussions to enhance the overall learning experience. To address this, we plan to implement one of two strategies in future iterations: either utilize the full class session to allow for more comprehensive gameplay, or conduct the activity during extended after-hours sessions, such as ACM club meetings, to provide students with ample time to engage with the game and its concepts. Given the small sample size, we were limited to analyzing survey responses using descriptive statistics. In the future, we plan to implement the game with a larger cohort to enable statistical analysis while gaining deeper insights into the effectiveness of the game. To achieve a larger sample size and more comprehensive data analysis, we plan to collaborate with instructors at other universities to implement our PDC Quest game in their senior/junior-level CS classes and collect additional data. We also plan to incorporate more open-ended questions to the post-activity survey in future iterations of the game. This will be further assessed using sentiment analysis to extract actionable insights into student perceptions. This approach will help us continue to identify areas for improvement in the design of the card game and its implementation, ultimately guiding the development of more effective and engaging learning experiences for future cohorts.

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