CONTEXTUAL GAME-BASED FRAMEWORK TO SOLVE MAPPING CHALLENGES IN ELECTRICAL ENGINEERING

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ABSTRACT

This paper explores how a contextual game-based framework helps to solve complex problems in the field of electrical engineering. To support this study, UNTANGLED, scientific puzzle game is used. The game is developed to solve mapping problems in the field of electrical engineering by using human intuitions. Data Flow Graphs (DFGs) are disclosed to participants in the form of puzzles and players must arrange these puzzles based on rules and regulations provided to reach feasible solutions. In this study, telemetry data for feasible solutions are considered and analysis is performed on different levels of complexity, which are arranged as easy, medium, and hard in the game. Scores obtained and type of moves used by participants to solve these puzzles determine their performance. Findings revealed that participants showed a statistically significant difference in their performance based on level complexity. This paper suggests that developing context-based frameworks like games or interactive applications can help learners to assimilate difficult concepts or enhance problem-solving skills.

KEYWORDS

Contextual Game-Based Framework, Electrical Engineering, UNTANGLED, Human Intuitions, and Problem-Solving Skills

1. INTRODUCTION

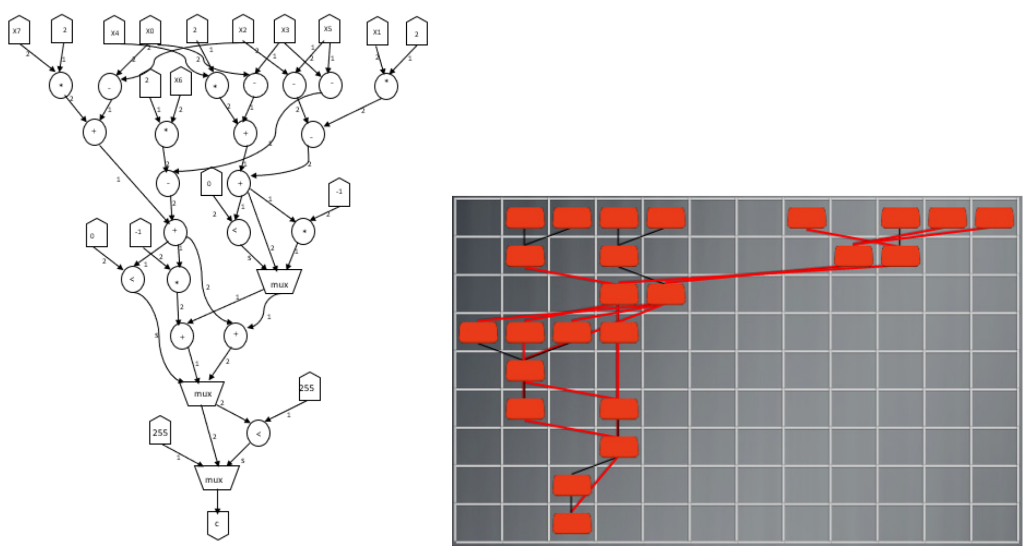
Science and Engineering requires transferable and decision-making skills in addition to technical skills. These skills are essential to the ability to obtain solutions for real-life problems. These skills can be learned by students in different contexts and they are termed as formal and informal contexts. Instances for formal context are classrooms, laboratories, and so on, whereas examples of informal contexts are games, simulations, and so on [6]. Informal contexts have characteristics such as increasing students' interest in learning new concepts, nurturing students' abilities to apply skills to reality, and providing more flexibility in time and freedom for solving problems [3]. Among all informal contexts, games are accounted to have the potential to make learning a more intriguing process.

Types of games also show impact on the outcome. Educators need to develop games that suits their learning outcome. Squire in [5], [7] defined context based on the kind of games. For exogenous games, he defined context as "a motivation wrapper", and for endogenous games, it is "the content of the experience". His study mentioned that games are becoming a powerful medium for military, business, and non-profit organizations. However, he suggests to educators to consider games as a potential medium, which is a different perspective for learning. In [16], authors study is focused on contextualized gaming frameworks that can engages students' interest for the long term and use this knowledge for solving complex or advanced problems. In addition, these gaming frameworks enhance self-motivation, encourage learning and shared knowledge in groups, provide flexibility in diverse thinking, and offer good learning experience [2].

To examine this study, a scientific puzzle game, UNTANGLED is used. This is designed to develop efficient algorithms to produce low power portable electronic devices. Each puzzle in this game is a benchmark that represents real time digital and signal processing application. The rest of this paper is organized in seven sections. Section 2 presents an introduction on framework used in this study, section 3 describes how the framework looks and how the data is distilled to perform analysis, section 4 illustrates the analytical results obtained after performing few statistical tests which suit the sample data, section 5 delineates the analytical results obtained and provides the recommendations for educators, and finally the last section summarizes this study with a conclusion.

2. RELATED WORK

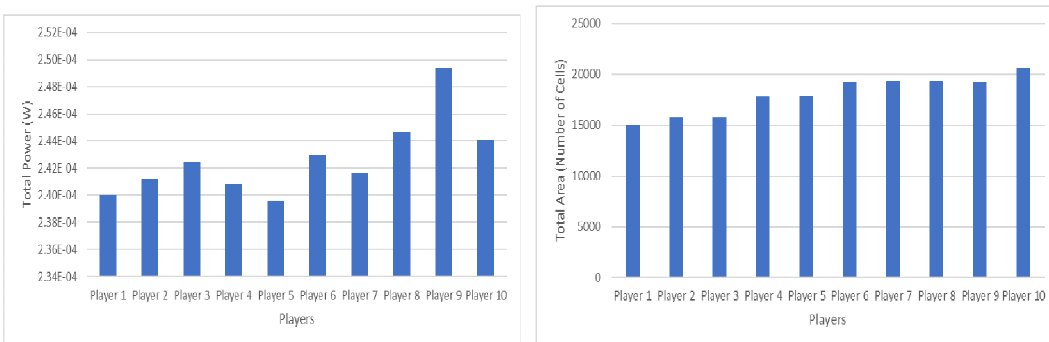
Demand for low power portable devices in the modern era requires compatible hardware like Coarse Grained Reconfigurable Architectures (CGRAs). Though these architectures fulfil the needs of emerging technology, mapping an application to these architectures is considered a main hindrance for the wide usage of these architectures. Dr. Mehta and our team designed a gaming framework called UNTANGLED to uncover the mapping challenges with human intuition [13], [14], [15]. In the year 2012, the National Science Foundation (NSF) has conducted the International Science Engineering Visualization Challenge, in which UNTANGLED has received the *People's Choice Award* in the category of games & apps [11],[12]. To conduct our study, a protocol determined by the Institutional Review Board (IRB) of the University is followed. Participants from all over the world can play this open source game after a one-time registration [10]. In this gaming framework computational data flow graphs are provided to players in the form of puzzles by hiding computational details.



(a) (b)

Figure 1. Example of a real time application presented in a gaming framework (a) Sobel DFG (b) representation in the game

Figure 1(a) shows a Data Flow Graph (DFG) which is considered as one puzzle in the game. This graph has 29 computational nodes and 29 connections. Figure 1(b) shows the representation of DFG in the gaming framework. Players are provided with coloured blocks in a two-dimensional grid and need to arrange these blocks in a compact form based on the constraints provided. Developing an efficient mapping algorithm is a challenging task for designing low power reconfigurable architectures. Our gaming framework allow player arrange nodes in more compact way which help in power and area reduction. There are variety of ways puzzles can be solved, hence we have multiple solutions for each puzzle. Figure 2 illustrates the sample of ten players' solutions, which shows the impact on the power and area parameters. We have considered the players' mapped solutions and synthesized using 28nm standard cell library in Synopsis tool. We have used Synopsis Design Compiler and Synopsys Prime Time-PX tools to measure the areas and power characteristics of players' solutions. Figure 2 shows area and power consumption for different players' solutions chosen randomly for the puzzle shown in figure 1.



(a) (b)

Figure 2: Power and area of ten players' solutions (a) Power, and (b) Area

For instance, from figure 2, we can observe that player 1 solution consumes less power and area compared to player 2 solution. Likewise, each player's solution has different area and power characteristics. These graphs show how players' solutions have impact on solving mapping challenges of reconfigurable architectures. Based on the constraints in connectivity and variety of nodes, there are 13 subgames (G1-G13) in this gaming environment. Each subgame is different based on constraints in placing blocks, connectivity between the nodes, and type of nodes. Subgames G1-G11 have red rectangular nodes and circular blue nodes. Players have freedom in placing rectangular nodes anywhere on the grid, whereas the blue nodes need to be placed around the periphery of a grid. However, G12-G13 have green nodes where players have to place them in green cells in a grid. Four different patterns are developed in each subgame (G12-G13). These subgames can be considered as constrained compared to remaining subgames (G1-G11) in this game.

2.1. Proposition

The primary impetus of this study is to observe the performance of participants in solving complex electrical engineering puzzles, when the problem is presented in the context of a game.

In this game, seven puzzles are available to solve in four different constraints called patterns.

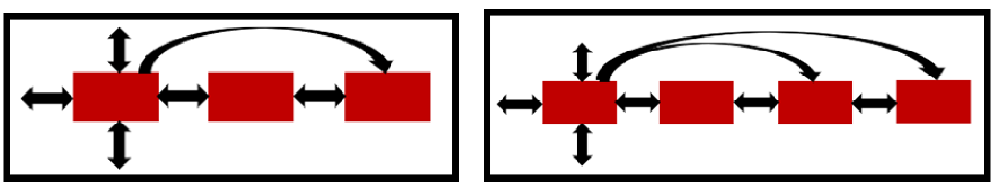
This is reinforced by the following research questions:

(i) How many participants solved puzzles provided in this game?
(ii) Is there any difference in the strategies used by participants between different puzzles?
(iii) Are there any differences in the performance of players over a period of game play?

The next section provides details on different features available in the gaming framework, representations of the four patterns, and data distillation of extracted participant data from the game database.

3. EXPLORATORY MODEL

The UNTANGLED game is used in this study to examine the performance of participants in a contextualized framework to solve complex problems. For this analysis, the telemetry data extracted from the game database is considered for the subgames G12 and G13. Figure 3 shows the connectivity of subgames G12 and G13. These subgames are different in terms of connectivity between the blocks. Figure 3(a) illustrates connectivity in G12, in which nodes corresponding to each node can be placed vertically, horizontally, and by hopping one node. In G13 (fig. 3(b)), in addition to vertical and horizontal, corresponding nodes can be placed by hoping one or two nodes. Figure 4 shows a window that appears for a player to select any pattern of interest and figure 5 is the window which appears immediately after selecting a pattern. Each pattern has seven levels (P1-P7) and are arranged as easy (P1 and P2), medium (P3-P5) and hard (P6 and P7) levels based on complexity. All these seven levels represent real-life applications. Apart from these, there are a variety of features available to participants to help improve their performance. Tutorials shown in figure 4 help players to know the rules and regulations of game play. If we need to keep track of top scorers and want to beat their scores, a leader board ranks players based on scores, violations, and time taken to complete a puzzle. In order to view this leader board, players have to click on the "Leaders" option which is seen in figures 4.



(a) (b)

Figure 3. Connectivity between the blocks in subgames (a) G12, and (b) G13

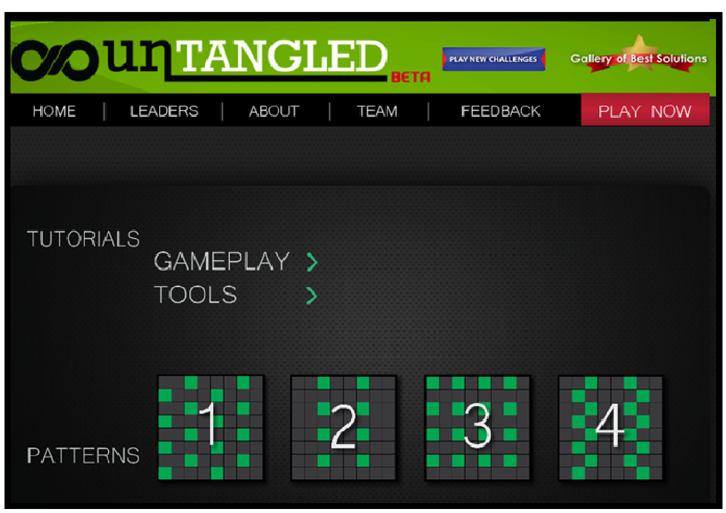


Figure 4. Game window which shows the options for pattern [10]

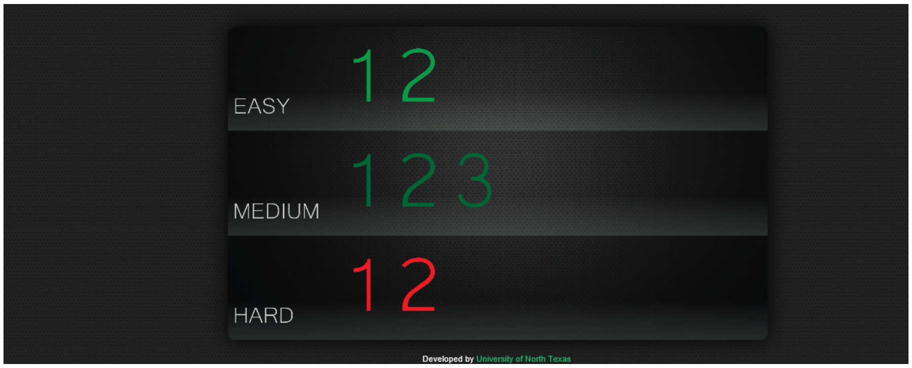


Figure 5. Game window which shows the options for selecting level to play [10]

Table 1 provides information on the number of nodes and connections in each level. In table 1, columns represent the levels P1-P7, and rows indicate the number of nodes and number of connections between the nodes. For consecutive levels the number of nodes increases and in turn the connections also increase. Hence, complexity of level is defined by an increase in the number of nodes and connections.

Table 1. Number of nodes and connection information of P1-P7 levels

Levels	**P1**	**P2**	**P3**	**P4**	**P5**	**P6**	**P7**
Number of nodes	21	23	28	42	41	52	61
Number of Connections	20	22	30	52	50	61	66

Figure 6 shows unsolved graphs/puzzles which appears to players at the start of game with zero score, number of violations, and timer which starts counting immediately when the window is loaded. To move nodes and arrange them in compressed form, different features are provided in the gaming environment. Players can use a variety of options available in the gaming framework and obtain feasible solutions. There are multiple solutions for each puzzle, whereas a solution which is arranged in compact form without violations is considered as one of the feasible solutions. Hence, each puzzle has multiple feasible solutions which are arranged in multiple ways.

In two subgames, there are red and green rectangular nodes arranged in a grid, in which green nodes need to be placed in green cells, and red nodes in grey cells. The green cells in a grid are provided in four different ways and these are considered as four patterns in this game. Figure 6 (a-d) shows a sample of an initial graph in four patterns for level and these four patterns are explained as below:

Pattern 1: In horizontal spacing, green cells in a grid are placed after every three grey cells, whereas in vertical spacing green cells are place in alternating cells.

Pattern 2: Green cells are placed in alternating cells vertically, and after every two grey cells horizontally

Pattern 3: Green cells are observed in an alternating pattern, both in vertical and horizontal directions

Pattern 4: In one horizontal lines, green cells is placed after every two grey cells, whereas in another line green cell is placed after every four grey cells. These two horizontal patterns are repeated as rows in a grid. In vertical spacing, a green cell is placed diagonally to another green cell in a zig-zag pattern.

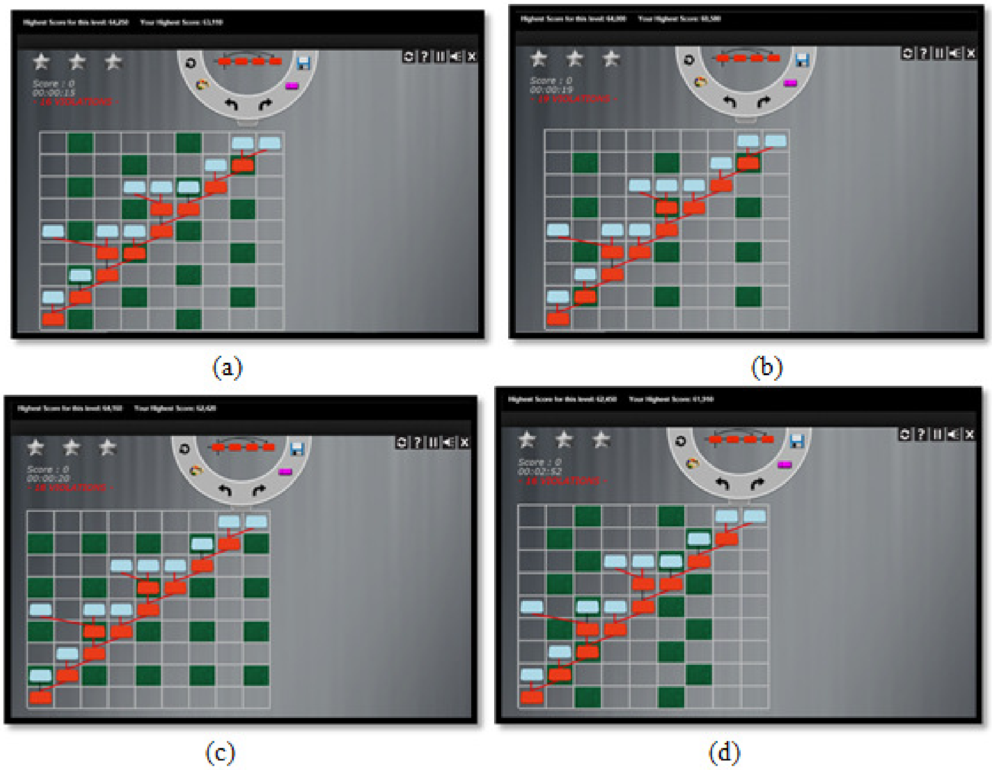


Figure 6. Example of initial graphs for four patterns of level appears in the game window (a) Pattern 1, (b) Pattern 2, (c) Pattern 3, and (d) Pattern 4 [10]

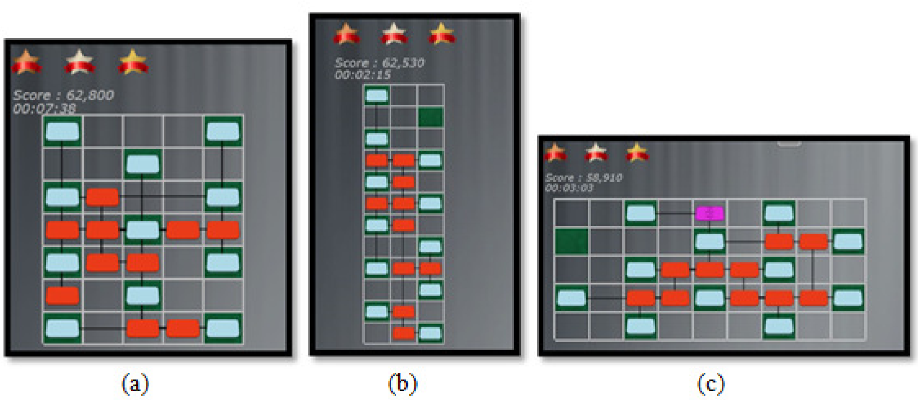


Figure 7. Example of solved graphs for level of pattern 1 (a) Solution 1, (b) Solution 2, and (c) Solution 3 [10]

In addition to red and green nodes, there are pink nodes which player can add or remove based on requirements. These nodes can be used to make a connection between the two nodes and overcome violations. There are a variety of moves that players can use to move these nodes. Different type of moves in this game are single, multi, swap, add pass, remove pass, and rotate. The top left corner of figure 6 shows score, violations and time taken by players to solve the puzzle. In addition, there are pause, save, and reload options in the right corner. The centre panel offers other options like paint, flip/rotate, add pass gate, and remove pass gate. Figure 7 depicts three feasible solutions of the level. In this puzzle there are 11 green nodes which have to be placed in green cells and red nodes which have freedom to be placed anywhere on the grid except in green cells. In figure 7(a), solution 1 has the highest score compared to the other feasible solutions given in figure 7(b) and (c). This can be considered as one of the optimized solutions as there are no empty green cells, whereas this is not true in solution 2 and solution 3. In solution 3, there is a pink node which is used by the player to connect the two nodes. Also, there are three stars (bronze, silver, and gold) which are considered as incentives to players. These are awarded to player during the game session based on their performance. The next sections explain the results obtained from the extracted data.

3.1. Data Distillation

Telemetry data for feasible solutions of G12 and G13 subgames is extracted from the UNTANGLED database. There are total 56 puzzles in these two subgames, in which each subgame has four patterns with seven levels in each.

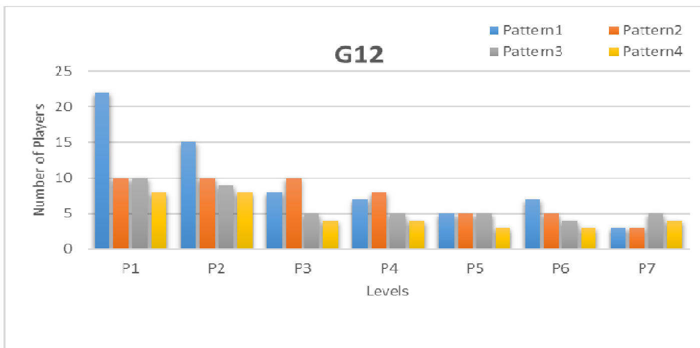


Figure 8. Number of players in G12 subgame

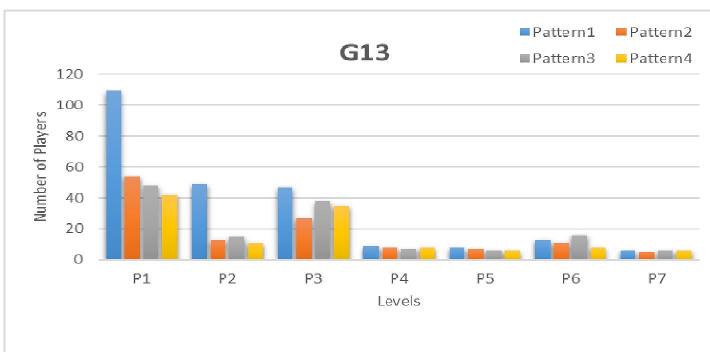


Figure 9. Number of players in G13 subgame

Figures 8 and 9 clearly answer the first research question mentioned in proposition. Figure 8 shows total number of participants in the G12 and figure 9 illustrates total participants in G13. Figures 8 and 9 show that the number of participants in G13 is larger compared to the number of participants in G12. There are total 195 participants in G12 and 615 participants in G13. These two figures make explicit that the number of participants in G12 and G13 subgames decreased as the complexity of level increased. In order to examine how the contextual-game based framework affects the performance of players in solving complex engineering problems, we have considered the pattern 1 of G13 data, which has a plausible sample size. Moreover, from the descriptive statistics performed, we have observed that the data extracted from the database is not satisfying the conditions of normal distribution. Hence, suitable statistical tests for such data are non-parametric tests. The next sections explain the results of inferential statistics which helped to answer the research questions.

4. INFERENTIAL STATISTICS

In this section, we discuss statistical results obtained from non-parametric data. The performance of players is analysed based on score, violations, type of moves, and number of moves used to solve puzzles. The analysis is performed in order to answer two research questions mentioned in section 2. First, we observed the performance of participants based on complexity of puzzle. Second, we compared the performance of player on solving easy and hard puzzles. The Kruskal-Wallis test can be considered as one of the suitable tests based on the characteristics of the data. This test is used to find whether there is any significant difference among different groups. If the p-value or asymptotic significance (represented as Asymp.Sig in the following tables) is ≤ 0.05, this indicates there is statistically significant difference in the mean value obtained by the groups.

4. 1. Performance difference within different levels

To perform this analysis, type of moves and score are considered as dependent variables, and level (levels P1-P7 within the game) as independent variable. Tables 2 and 3 show the p-values and mean ranks obtained after performing the Kruskal-Wallis test. Table 2 shows the p-values (Asymp. Sig) obtained for all dependent variables (except for rotate move) are ≤ 0.05, which shows there is statistically significant difference in the mean number of moves used by participants in each level. The p-value (0.06) for the rotate move determines that there is a slight significant difference in the mean number of moves used among the different levels. Finally, from p-values in table 2, we can conclude that that there is statistically significant difference among different levels in the scores obtained and type of moves used.

Table 2. Significance value of levels for type of moves (G13-Pattern 1)

	Single	**Swap**	**Multi**	**Add**	**Remove**	**Rotate**	**Score**
Chi-Square	82.689	43.74	46.51	93.03	60.122	17.946	120.94
Df	6	6	6	6	6	6	6
Asymp. Sig.	.000	.000	.000	.000	.000	.006	.000

In table 3, each level mean rank depicts in which level participants are using a greater number of moves. For instance, in single move, there are different mean ranks obtained for different levels.

This depicts that the mean number of single moves used by participants varies based on complexity of puzzle. Also, we can see mean rank for level P3 (single) is 228, which has the highest mean rank among all levels. This determines that a greater number of single moves are used by players in the P3 level compared to all other levels.

Table 3. Mean ranks of levels for type of moves and score (G13-Pattern 1)

Dependent Variables	Level	Mean Ranks
Single	P1	94.22
	P2	98.28
	P3	214.62
	P4	228.08
	P5	139.60
	P6	195.11
	P7	200.00
Swap	P1	95.91
	P2	114.89
	P3	180.31
	P4	178.17
	P5	141.74
	P6	183.61
	P7	168.75
Multi	P1	107.29
	P2	113.92
	P3	182.85
	P4	161.83
	P5	122.71
	P6	177.78
	P7	146.06
Add	P1	93.18
	P2	109.30
	P3	192.62
	P4	180.75
	P5	131.95
	P6	226.17
	P7	227.88
Remove	P1	103.52
	P2	118.33
	P3	178.42
	P4	175.25
	P5	118.51
	P6	177.56
	P7	192.50
Rotate	P1	119.50
	P2	119.50
	P3	119.50
	P4	119.50
	P5	122.04
	P6	133.00
	P7	134.56
Score	P1	93.93
	P2	166.49
	P3	192.62
	P4	48.50
	P5	166.21
	P6	11.44
	P7	6.88

For most of the cases, we can see that mean ranks for medium levels are high compared to easy and hard. That is, players used a greater number of moves in medium levels than in easy and hard levels. Mean ranks for score show that different levels have different mean ranks. As score function is different for different levels, we cannot compare which level score is highest and lowest based on mean ranks. Similar assumptions can be obtained by observing the mean ranks of all levels for other dependent variables.

4. 2. Performance difference within game period

In this analysis, the overall time taken by players to solve a puzzle is divided into four quarters (Q1, Q2, Q3, and Q4). However, the variable which groups these four quarters is represented as *Game Period.* Here, we have observed whether participants showed reasonable difference in their performance during the game session. To analyse the performance, we have considered score obtained in each quarter. These results are explored only for P1 and P7 levels in pattern 1 of the G13 subgame. This explains whether participants showed any difference in solving simple and complex puzzles. Further, to perform the Kruskal-Wallis test, score is considered as dependent variables and *Game Period* as an independent variable.

Table 4. Mean ranks for the score obtained in each quarter (G13-Pattern 1)

Dependent Variable	Level	Game Period	Mean Rank
Score	P1	Q1	231.87
		Q2	246.07
		Q3	213.18
		Q4	182.88
	P7	Q1	5.33
		Q2	12.67
		Q3	17.67
		Q4	14.33

Table 5. Significance value of game period (G13-Pattern1)

Levels	Chi-Square	df	Asymp. Sig.
P1	15.351	3	.002
P7	9.773	3	.021

Table 4 shows the mean ranks of each quarter for levels P1 and P7. Different mean ranks show there is difference in the mean score obtained after each quarter. The p-values (0.02 and 0.21) in table 5 determine that mean score obtained in each quarter is statistically different in both easy and hard levels. Tables 4 and 5 conclude that there is a statistically significant difference in the mean scores obtained among four quarters.

5. DISCUSSION AND IMPLICATIONS

STEM students need to be prepared to solve real problems immediately after their graduation. These problems are complex, unpredictable, and subtle. Hence, researchers [1], [4], [18] suggest developing problem solving environments or contextualized gaming frameworks which help students to transfer knowledge and have a hands-on experience. Honey & Hilton (2011) explained the importance of informal context (games, simulation tools and so on) over formal context (classrooms, laboratories and so on) in science education. Their research concludes that learning in a gaming context is used to motivate individual learning, help reach a variety of learning goals, and develop decision-making skills. However, other studies [8], [17] explain how a bird's eye view on games has changed over a period of time. Recently, games are treated as an essential medium to enhance students' abilities and engage their interest for a long period.

In our approach, we used a framework in which an electrical engineering problem is presented in a gaming context. We observed how participants can develop or use problem-solving strategies to obtain feasible solutions. Score function and type of moves are considered as strategies used by players to solve a given puzzle. By examining these parameters, we analysed the performance of players. Statistically significant difference among the levels (P1-P7) explains that players are changing their strategies based on the complexity of the game. We also observed how the players are changing their strategies within a play session. To perform this analysis, the total game period is divided in to four quarters. During the game period, players showed significant difference in the mean scores obtained in both easy and hard levels. This explains that players changed their strategies for both simple and complex puzzles. Finally, results conclude that there is a difference in type of moves and scores obtained in different levels, and players contribute equally to solve either easy or hard puzzles.

Games have abilities such as: applying concepts to reality, increasing learning time, relating to the subject in a novel form, and exploring advanced methodologies gained from the experience [9]. In addition, our findings suggest to educators that presenting a topic/problem in a gaming context can lead to better results. Especially for self-learning courses, this kind of gaming frameworks can motivate students and enhance their interest in learning complex problems without instructor aid. In our game, we have observed how players used different type of moves and improved their score over a period of time in the game session. Statistically significant difference between first and fourth quarters determines that players used different strategies to solve the given problem. Similarly, our study suggests to game designers or researchers who are designing gaming frameworks to include parameters that can enhance players' interest to solve complex problems. Games should precipitate the problem-solving skills and enact them while facing real-world problems. Results in this paper shows that participants showed considerable difference in the number of moves used in each level. However, there are a smaller number of participates who showed interest to solve complex puzzles. Hence, we suggest that a framework should motivate players' interest not only in solving simple puzzles but also to solve more complex puzzles

6. CONCLUSIONS

Thus, from this study we observed how a contextual-based framework can solve complex problems. In this paper a scientific puzzle game UNTANGLED, which is designed to solve complex mapping challenges, is used. This gaming framework offers variety of subgames where player can solve a variety of reconfigurable architectures. In the future, additional subgames can be added for further exploration of customized architectures. Results illustrate that participants showed statistically significant difference in type of moves used and scores obtained in each level. Also, we observed that players showed plausible difference in the score obtained in every quarter of their game period. Finally, from our study we inferred that players changed their strategies based on level complexity, and they showed the same effort to solve both easy and hard puzzles. Hence, we provide suggestions to educators and researchers to develop context-based frameworks such as games and interactive applications that includes tools to motivate self-learners and increase their learning time.

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