COMPLEXITY OF GAMIFICATION

by

Kompalli V M Jwala Seethal Chandra

A Thesis Submitted in

Partial Fulfillment of the

Requirements for the Degree of

Master of Science

in Computer Science

at

The University of Wisconsin-Milwaukee

May 2021

ABSTRACT

COMPLEXITY OF GAMIFICATION

by

Kompalli V M Jwala Seethal Chandra

The University of Wisconsin-Milwaukee, 2021
Under the Supervision of Professor Dr. Amol D Mali

This thesis introduces ideas for determining the Complexity of Gamifying the learning of a task/skill. We have taken three different tasks: Learning of L2 Languages (Non-mother-tongue languages), Learning about Food preparation and Learning of Physical exercises and applied our ideas to identify the complexity of gamifying them. To further supplement our idea, we have taken few existing popular gamified tasks by 3rd party companies and addressed the complexity of making them, using our ideas, and how adding new features to them, will increase the complexity. In summary, our work presented in this thesis is useful in practice for estimating a part of the time needed to design and develop a digital game, estimating the impact of game design on finances, and for revealing some of the gamification factors that can be controlled to meet temporal and financial constraints in the game production.

TABLE OF CONTENTS

LIST OF FIGURES

ACKNOWLEDGEMENTS

I would like to thank my thesis advisor Dr. Amol D Mali for the support and guidance in helping me understand and model this thesis subject.

I would also like to thank the entire faculty and administration of Computer Science Department especially Dr. Mukul Goyal, Dr. Guangwu Xu, Dr. Rohit J Kate, Dr. Christine Cheng, Dr. John Boyland and Dr. Susan Mcroy for making my master's studies fruitful with their insights.

Finally, I would like to thank all my family and friends who supported me throughout the completion of this thesis.

1. Introduction

Gamification is an umbrella term that has gained traction, starting nearly a decade ago. The word stems from the word “Game”. Hence the word Gamification deals with converting of a non-game task into a Game. A game does not necessarily have to be a video game. To understand the word better, we must look at the definition of the word “Game”. As per Merriam Webster dictionary, a “Game” is structured form of intrinsically motivated activities usually undertaken for entertainment or fun and sometimes used as an education tool [1].

To understand the word “Gamification” we should look at the following definition by J Hamari: It is the strategic attempt to enhance systems, services, organizations, and activities to create similar experiences to those experienced when playing games to motivate and engage users [2]. Many corporates are investing resources to effectively gamify various tasks for various purposes. The main reason for gamification would be because of the effect of dopamine, which is a neurotransmitter which activates pleasure centers in our brain. It helps in the regulation of concentration, attention, coordination, learning, and working memory by rewarding us with a good feeling when we accomplish something repeatedly. It basically compensates us for our success. However, this effect can be exploited, particularly in workplace gamification, leading to anxiety [3].

1.1. Motivation

Many researchers did a wonderful job in the field of gamification. And many others discussed the computational complexity of playing the video game. Matthew Stephenson et al. have presented several proofs for the computational complexity of the physics-based video game Angry Birds and

demonstrated that solving levels for different versions of Angry Birds is either NP-hard, PSPACE-hard, PSPACE-complete or EXPTIME-hard, depending on the maximum number of birds available and whether the game engine is deterministic or stochastic [4]. Erik D. Demaine et al. have provided proofs for NP-hardness results for five of Nintendo's largest video game franchises: Mario, Donkey Kong, Legend of Zelda, Metroid, and Pokémon [5]. In addition, they also proved PSPACE-Completeness of the Donkey Kong Country games and several Legend of Zelda games [5]. Erik Demaine, Joshua Lockhart and Jayson Lynch have provided proofs that demonstrates the NP-Hardness of popular video games Portal, Portal 2 and provided a generalized proof which showed many other video games such as Half-Life 2, Halo, Doom, Elder Scrolls, Fallout, Grand Theft Auto, Left 4 Dead, Mass Effect, Deus Ex, Metal Gear Solid, and Resident Evil as NP-Hard [6].

Adele et al. have documented a study, where gamification was used as one of the design tenets to involve and inspire teachers to promote the incorporation of tablets (Computers) in the teaching and learning environment of rural schools [7]. To increase student participation in class, Dimitra et al. investigated students' intrinsic motivation by designing and implementing an eClass using gamification based on the core components of Self Determination Theory (SDT). The use of gamification in learning and instructional design, according to the findings, will increase student motivation [8]. Ahmet et al. noted the positive effects of the gamification, on the employees working in IT Projects [9]. Yaya et al. have presented the empiric results on teaching basic Mandarin as second language (L2) to college students using gamification approach, which outperformed the traditional teaching methods [10]. Similarly, Choiril et al. conducted a research on how "Musou Roman" videogame helped the Indonesian teenagers to learn Japanese alphabet "Kanji" and documented the positive effects of gamification [11].

Despite the amazing work done in the above-mentioned research work, none of them mentions "the amount of the work that needs to be done" in "Gamifying" the task. Hence, this thesis addresses the same by considering the gamification of 3 tasks: Learning of L2 Languages, Learning the Food preparation and Learning the physical exercises. The focus would be on gamification for learning new tasks. Hence these ideas can be utilized in finding the complexity of all gamification tasks for learning.

1.2 Components of successful Gamification of learning tasks.

We believe that the complexity of gamification depends on various components. Complexity in this case means the amount of work done by the designer but not the running time of an algorithm or space/memory required to run it. These dictate the overall complexity of gamifying a task. By finding the complexities of these sub-parts one can find the complexity of gamifying learning tasks. They are as follows:

1. Complexity of creating challenges. For example: Challenges such as quizzes, requiring the player to act in order to cause the desired changes in the states of digital objects with repetitions allowed when needed.
2. Complexity of creating the variations of the challenges. For example: The quizzes can be conducted employing various kinds of input. Instead selecting an appropriate answer on the screen, one might spell or speak the answer. This might give a chance for the user to master the content.
3. Complexity of creating answers to the challenges to make automated in-game checking possible.
4. Complexity of designing rewards.

5. Complexity of designing the game environment.
6. Complexity of designing punishments.
7. Complexity of designing the optional mechanism like A.I that dynamically changes the game to keep the player interested by changing the challenges or the degree of their difficulty.
8. Complexity of designing the optional mechanism like that dynamically changes the reward system, scoring system, punishment system or the gaming world to adjust to how player is playing.
9. Complexity of designing feedback to the player.
10. Complexity of designing the mechanism that detects cheating by the player.
11. Complexity of designing the interactions among the previously mentioned game components.
12. Complexity of checking the correctness of all the above points.

In this thesis, we have primarily used points 1,2 and 3 in the above-mentioned points to identify the complexity of the gamification of learning a certain task.

2. Background

In this section we shall look at types of gamification and address the complexities of previous works done by 3rd party companies in the field of gamification.

2.1. Types of Gamification

Before going further, we must look at the types of Gamification. Although, there are various ideas about the types, the following are widely supported by many researchers. Kapp et al have

proposed that Gamification can be further divided into two types. They are Structural Gamification and Content Gamification [12]

2.1.1. Structural Gamification

Structural gamification is the application of game-elements to propel a learner through content with no alteration or changes to the content [12] Here, the structure surrounding the content, not the content itself, becomes game-like. Taking the scoring elements of video games, such as points, levels, badges, leaderboards, and awards, and applying them to an educational context is a common implementation of this form of gamification. Structural gamification tracks a learner's progress as they complete material, take quizzes to assess their understanding, and progress toward their learning objectives.

2.1.2. Content Gamification

Content gamification is the application of game elements, game mechanics and game thinking to alter content to make it more game-like. [12] Adding plot, challenge, curiosity, suspense, and characters to the content, to engage the learner is a common implementation of this form of gamification. In content gamification, the learner can be stimulated by an appropriate degree of difficulty, mystery, or a well-crafted story. This can be linked to a learner's desire to finish a lesson.

We will discuss about the 3 different tasks which are gamified by using Structural and Content Gamification in conjunction with our ideas. And then we will use our ideas to discuss about the complexity of these gamifications.

2.2. Previous Works on Gamification

As mentioned earlier, there were various research papers, surveys highlighted the importance of gamification, but never addressed its complexity. On the other hand, various 3rd party companies have successfully gamified various learning tasks. We shall look at 3 different gamified tasks and shall address its complexity. The first two are discussed in this section, but the last one will be discussed in section 5.

2.2.1. LeetCode: Gamification of solving Algorithmic problems

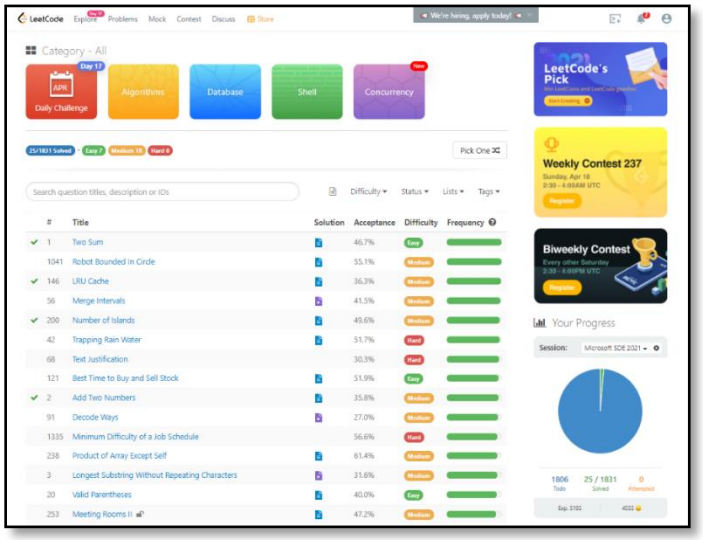

Figure 1: LeetCode's Problem-set Webpage. Source: Myself

LeetCode(https://leetcode.com/) is a popular online judge platform where one can practice their computer programming/coding skills by answering algorithmic questions. It has over 1,100 different problems, supports over 18 programming languages, and has a vibrant community that is always ready to assist the users for coming up with solutions.

This website is an example of Structural Gamification where content itself is not modified but is wrapped with game elements to engage/motivate the users to learn the methods for solving the

algorithmic puzzles. The primary reward system in this website is termed “LeetCoin(s)” which is a form of virtual currency which can be used on the website to redeem various rewards. These LeetCoins can be earned by doing various simple and challenging tasks. Simple tasks are like doing daily check-ins on the website etc. LeetCode conducts various weekly and bi-weekly contests, a kind of competitive programming contests, where users must compete in solving the algorithmic puzzles. The users are ranked, based on time-taken to solve the problems in a contest. There is global leaderboard for users based on their contest history. Each task simple or challenging will reward the user with different amount of LeetCoins. Some of the tasks are as following:

1. Daily Check-in on the website.
2. 30-Day Streak Check-in on the website.
3. Contributing a Valid-Test case, which is a form of checking whether the algorithmic solution is correct or not.
4. Contributing a Question to the website.
5. Identifying the issue with content on the website.
6. Securing 1st, 2nd, or 3rd place in Contest (either weekly or bi-weekly).

These LeetCoins can be used to redeem various benefits such are getting premium subscription for 30 days etc.

The other form of reward system is Badges which are offered to the users who perform well in contests and doing 1 Algorithmic problem every day.

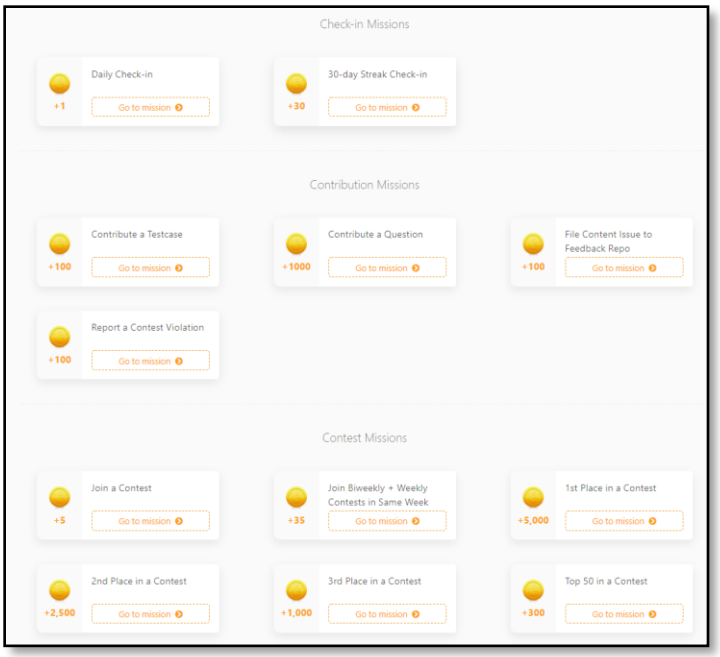

Figure 2: Tasks to earn LeetCoin. Source: Myself

Now let us address the complexity of Gamification. By this we mean what is the amount of work that the designer must do to replicate the website.

1. Primarily, the designer must gather the algorithmic problems. Let us assume that there is $'\mathrm{N}'$ such problems. Here $|N|$ is a positive integer.
2. The designer should come up with Easy-level, Medium-level and Hard-level sets of problems based on the difficulty of the algorithmic problem. Let us assume that there are $'e'$ easy problems, $'m'$ medium problems and $'h'$ hard problems. Therefore, the designer should satisfy the following: $|e| + |m| + |h| = |N|$ and $\mathrm{e} \cap m \cap h = \emptyset$.
3. Each problem should have a $'\mathrm{t}'$ testcases which are used to check the solution. Here $t\ is\ a\ positive\ integer$.
4. The designer must consider the various programming languages that the user will use in answering the given problems. Let us assume that there are $|\mathrm{p}|$ number of programming

languages where every programming language is distinct. The designer must also arrange their respective compliers.

5. The designer should come-up with reward system: by identifying $'r'\ rewards$ which are assigned to the user for completing a certain task. In case of LeetCode, $r = 2$ because there are only 2 types of rewards which are LeetCoins and Badges.
6. The designer should identify the various $'c'\ challenges$ when on completion, shall be rewarded with LeetCoins. The designer should also come-up with the how much LeetCoins does a user will earn on completing a certain challenge that belongs to 'c' challenges set
7. The designer must come-up with various 'redeemables' and their prices in LeetCoins that are redeemed by the user. Let us assume there are $|redeems|$ No. of such reedeemables where $|redeems| > 0$.
8. The designer should come up with 'b' badges to reward the user based on their rating in the competition and completing the monthly challenge of doing a single problem posted every day. In-case of LeetCode, $b = 14$ as the website is offering only 14 badges which are named 'Knight', 'Guardian' and rest are named based on the names of the months in a Year.

Hence, a new designer must do above mentioned work to replicate the LeetCode website. Some of the other popular examples are Hacker-Rank, Codechef etc. which has some of the above-mentioned features. Therefore, the designer must do the above-mentioned work to replicate at-least a part of newly mentioned sites.

2.2.2. Duolingo: Gamification of learning new Languages

Duolingo (https://www.duolingo.com/learn) is a language-learning application offered as both Web and Mobile application. As of March 2021, the language-learning website and app offers 106 different language courses in 38 languages [13]. Duolingo uses a variety of techniques to engage its users, including mimicking the layout of video games. It has a reward system in which users earn "lingots," which is an in-game currency that can be spent on character customizations and bonus levels (both available on the mobile app only). It also has a multiplayer-mode where users all around the world compete to secure top ranks in the leaderboards. The level system that Duolingo uses is XP (experience points), a numerical system that represents a user's skill level. Badges in Duolingo represent achievements that are earned from completing specific objectives or challenges. Let us have a deeper look at the reward system.

- Experience (XP) points: These are earned when the user learns the language by completing certain challenges like learning language by playing the game or securing the top rank in the multiplayer mode.
- Lingots: These are the in-game currency. These used to buy Power-Ups. The user will earn 1 lingot for leveling up by earning XP points, 2 lingots for completing a new skill and 1 lingot for 10-day streaks of learning the language.
- Power-ups: There are 2 powerups. One is “Streak Freeze” that allows the user’s streak to remain in place for one full day of inactivity. The other one is “Double of Nothing” which allows the user to attempt for double their 5 lingot wager by maintaining a seven-day streak.
- Crowns: Crowns are the leveling system. The more the XP points the user earns by playing the game the more crowns they will earn, and this will determine their skill-level. This is

especially useful during the multiplayer mode, where the users with matching (or closer) skill levels are made to compete.

The learning process in Duolingo combines various methods such as:

- listening to the pronunciation,
- reading sentences,
- voice recording,
- forming phrases by ordering words, and
- matching images to words.

But Duolingo does not have a level that teaches the user about the specificities of the language. For example, it does not teach the user about writing letters. Let us look at the complexity of creating such a level, where users are prompted to draw on the screen, the letter of the sound played.

1. Let us assume that users are seeking to learn about writing Japanese Alphabet letters. There are different alphabets in Japanese language: Hiragana, Katakana and Kanji.
2. We assume that the letters should be written in standard computer format. This assumption is important for next points.
3. Let us assume that there are $'n'$ letters in total combining all 3 alphabets.
4. Hence $n = |L_n|$ where $L_n = \{l_1, l_2, \ldots, l_n\}$ and $l_1, l_2, \ldots, l_n$ are unique letters in all 3 alphabets together.
5. Each letter l_k is formed by some set of strokes s_k. Hence $S_n = \{s_1, s_2, \ldots, s_n\}$ where $s_1, s_2, \ldots, s_n$ are set of strokes that form the corresponding letters $l_1, l_2, \ldots, l_n$.

6. Although the letters are unique, they might share some elements from the strokes set. This means that if there some ‘k’ strokes in stroke set s_1 which are used to form letter l_1, then some ‘p’ strokes out ‘k’ strokes might belong to stroke set s_2 which are used to form letter l_2.
7. Hence the designer must consider only $|s_1 \cup s_2 \cup \ldots \cup s_n|$ strokes in total. Let this number be $|\text{Total\_Strokes}|$ where $\text{Total\_Strokes} = s_1 \cup s_2 \cup \ldots \cup s_n$.
8. As for the gameplay, an audio of how the letter will sound will be played, then the user must select from the options (which are strokes used to make the letter) are presented on the screen.
9. We assume that upon selecting the right stroke, it will be placed in the appropriate position of in the letter and upon selecting the wrong stroke it will disappear.
10. Let us assume that a constant number of options $'K'$ will be displayed on the screen each time for the letter, out of which $|s_k|$ strokes are right and form up the letter $l_k \in L_n$.
11. These $'K'$ options can be created from Total_Strokes. But each time for a letter l_k the $'K'$ options should include stokes from stroke set s_k. Hence $K - |s_k|$ strokes are to be selected from the Total_Strokes set. This can be done in various combinations.
12. We assume that there will be no penalty for wrong selection and the user cannot move on to learn the next letter unless they choose all right options.
13. In worst case the user can make $K - |s_k|$ mistakes for the letter l_k. Hence total number of wrong answers that user can make for all $'n'$ letters is $n * K - (|s_1| + |s_2| + \ldots + |s_n|)$. But ‘K’ must be $\max(|s_1|, |s_2|, \ldots, |s_n|)$.

This is the total amount of work that the designer must consider for Japanese language only. For other languages $\text{Total\_Strokes}, |L_n|, K$ will change accordingly.

3. Complexity of Gamification: Learning L2 Languages

A person's second language, or L2, is a language that is not the speaker's first language (L1) and is acquired later (usually as a foreign language, but it may also be a language spoken in the speaker's home country).

3.1. Assumptions

Following are the list of assumptions that we are making before gamifying the task of learning the L2 Languages.

1. We are considering only 1 dialect per language. Since languages like Japanese language has various dialects such as Kansai etc.
2. We are considering the languages that have a writing system.
3. We are considering the languages that only have letters in their alphabet.
4. We are not considering Sign languages.
5. We are not considering the literature of the language.
6. We are not considering the profanity that languages have.
7. We are not considering teaching the users grammar of the language explicitly.
8. We assume that we have a spell checker, sound checker for all Languages that are being considered for gamification.

Now let us look at the complexity of gamifying the learning of the languages after considering the above assumptions.

3.2. Complexity Calculation:

Let us assume that there are N_1 Languages that are being considered for the gamification task. Now, if a user is an English (US) Speaker and wants to learn Japanese we have to consider <English (US), Japanese> a pair that is being considered for gamification.

This means that we must do work for translating English to Japanese and Japanese to English. Now Japanese might be a L1 Language for some users and L2 Language for others. This case would be same for English. Hence, N_1 is the set of all languages that are both L1 Languages for some users and L2 Languages for others.

So total number of pairs such as <English (US), Japanese>, for whom the gamification work must be done can be found using Handshake lemma: which is ${}^{N_{C_2}}/_{2}$Where N is the total number of languages considered for gamification. Hence $N = N_1$

To learn a language, we must learn the Alphabet that a language has, words and usage of the words in the sentences. So, we must gamify the learning of letters of the alphabet, words and finally the sentences in the L2 Language. One more assumption is that the user is familiar with one or more of the languages in the N_1 language set. This is because the user learns the L2 language by correlation of the known L1 language with new L2 language of choice.

3.2.1. Complexity of Gamification: Learning Letters

Let us assume that there are $|L_n|$ letters in the new L2 language. Hence, $L_n = \{l_1, l_2, \ldots, l_n\}$ where $l_1, l_2, \ldots, l_n$ are the letters in the Alphabet of the L2 Language.

Here $|L_n|$ varies with the language that is being considered. Now in-order to gamify the learning of these L_n letters, we need to devise various "methods" or "levels" that follow the gamification methodology. Some of the ways to gamify them are as follows:

1. **Level 1**: Playing the sound of the letters of the L2 Language and ask the user to select the right response (letter) among the number of displayed options on the screen, that corresponds to the played sound.
2. **Level 2**: Asking the user to write or type the letter on the screen for the sound of corresponding L2 language letter that is played.
3. **Level 3:** Asking the user to identify the wrong letter that does not belong to the alphabet set of the chosen L2 Language.

Now, there can be $'\text{letter} - \text{levels}'$ number of such levels where the letters of the chosen L2 Language can undergo gamification. These levels do not necessarily have to be played in a serial fashion. Each level is unique and is not dependent on the other levels. Each level will have certain complexity associated with it. Hence total complexity of gamifying the letters is sum of all the complexities of $'\text{letter} - \text{levels}'$ levels into which the $|L_n|$ letters are gamified. Hence, the equation $C_{L1} + C_{L2} + \cdots + C_{\text{letter}-\text{levels}}$ represents the total complexity of gamifying the letters of the chosen L2 Language. Here $C_{L1}, C_{L2}, \ldots, C_{\text{letter}-\text{levels}}$ represents the individual level complexity.

Let us look at the complexity of one such level. Here, let us consider Level 1 from the above list, where the user has to identify the right response (letter) among the displayed options on the screen that corresponds to the played sound of the letter.

1. We assumed that there are L_n letters in the new L2 language. Hence, $L_n = \{l_1, l_2, \ldots, l_n\}$ where $l_1, l_2, \ldots, l_n$ are the letters in the Alphabet of the L2 Language.
2. Each letter l_k has a particular sound when it is pronounced. Hence, the designer must collect all L_n sounds for that language. This shall be repeated for all N_1 languages.
3. The sound of each letter will be played one by one. The user could play the sound again and again.
4. The user cannot move on to learn sound of the next letter unless he masters the sound of the previous letter. This means that user has to choose the right answer on the screen before moving on the next letter. This is a design decision. The designer can unlock ability for the user to go to all letters in a random fashion.
5. We assume that there is no penalty for choosing the wrong answer and the sound will be played until the corresponding answer is selected.
6. Now, User must choose the corresponding option (square box with text in it) among the $'O'$ options displayed on the screen.
7. $|O|$ is a number that is subjected to change as per the designer's decision.
8. These $'O'$ options have one right answer that is pertaining to the current sound that is being played.
9. We assume that the there is no penalty for the wrong answer and wrong answers shall be removed from options $'O'$ each time the user selects them.
10. But the designer has to come-up with a set of distinct options $'Options'$ from which $'O - 1'$ options are selected and displayed each time for a particular sound. So, $|Options| > |O|$.

11. In the worst case, the user will choose wrong options $|O| - 1$ times until he selects the right option pertaining to the particular sound. Hence $|L_n| * (|O| - 1)$ is total number of times the user selects wrong answer of all L_n letters of the particular L2 Language.
12. Therefore, the complexity for this level: Coming up with content to be gamified, which is number of letters for all N_1 languages and $'Options'$ and combinations of the $'O - 1'$ options that are displayed on the screen for each letter and accounting for the wrong responses of user which has an upper bound $|L_n| * (|O| - 1)$.

The above description was one type of level C_{L1} into which the letters are gamified. Hence $C_{L1} + C_{L2} + \cdots + C_{letter-levels}$ is the total complexity of gamifying the letters.

3.2.2. Complexity of Gamification: Learning Words

Let us assume that there are $|W_n|$ words in the new L2 language. Hence, $W_n = \{W_1, W_2, \ldots, W_n\}$ where $W_1, W_2, \ldots, W_n$ are the words of the L2 Language that are selected for the gamification task of teaching the words.

Here $|W_n|$ remains constant for all languages that are being considered. Now in-order to gamify the learning of these W_n words, we need to devise various "methods" or "levels" that follow the gamification methodology. Each level is unique and is not dependent on the other levels. Some of the ways to gamify them are as follows:

1. **Level 1**: Playing the pronunciation of a word W_k of the L2 Language and ask for the user to select the right response (word) among the number of displayed options on the screen, that corresponds to the played sound.

2. **Level 2**: Asking the user to write or type the word on the screen for the sound of corresponding L2 language word W_k that is played.
3. **Level 3:** Asking the user to identify the synonym of the word that is displayed on the screen. The synonyms chosen here will also belong to the W_n set of words that are considered earlier.

Now, there can be $'word - levels'$ such levels where the words of the chosen L2 Language can undergo gamification. These levels do not necessarily have to be played in a serial fashion. Each level will have certain complexity associated with it. Hence total complexity of gamifying the letters is sum of all the complexities of levels into which the $|\mathrm{W}_n|$ words are gamified. Hence, the equation $\mathrm{C}_{\mathrm{W1}} + \mathrm{C}_{\mathrm{W2}} + \cdots + \mathrm{C}_{\mathrm{word-levels}}$ represents the total complexity of gamifying the letters of the chosen L2 Language. Here $\mathrm{C}_{\mathrm{W1}}, \mathrm{C}_{\mathrm{W2}}, \ldots, \mathrm{C}_{\mathrm{word-levels}}$ represents the individual level complexity.

Let us look at the complexity of one such level. Here, let us consider Level 3 from the above list, where the user has to identify the right responses (synonyms) among the displayed options on the screen that corresponds to the word of the L2 Language displayed on the screen.

1. We assumed that there are $|\mathrm{W}_n|$ words in the new L2 language. Hence, $\mathrm{W}_n = \{W_1, W_2, \ldots, W_n\}$ where $W_1, W_2, \ldots, W_n$ are the words of the L2 Language that are selected for the gamification task.
2. Let us assume that there are $W_1, W_2, \ldots, W_j$ words chosen to be asked as questions for whom $S_1, S_2, \ldots, S_k$ corresponding synonym sets are displayed on the screen along with some other options. Each word W_i is displayed one at a time and each time the user has to

identify the corresponding number of synonyms $|S_i|$ for the word. The user must select all the answers for next word to be displayed.

3. Here $j + \sum_{n=1}^{k} |s_n| = |W_n|$ and all the words along with their synonyms belong to the W_n set of words considered for the gamification task.
4. We assume that there is no penalty for choosing the wrong answer and the word will remain on the screen until all the answers are selected.
5. Now, User must choose the corresponding options (square boxes with text in it) among the $'O'$ options displayed on the screen.
6. We assume that the there is no penalty for the wrong answer and wrong answers shall be removed from options $'O'$ each time the user selects them.
7. $|O|$ is a number that is subjected to change as per the designer's decision.
8. These $'O'$ options have s_k answers that are pertaining to the current word that is being displayed on the screen.
9. But the designer has to come-up with a set of distinct options $|Options|$from which $O - s_k$ options are selected and displayed each time for a word that is being displayed on the screen. So, $|Options| > |O|$.
10. In the worst case, the user will choose all other wrong answer except for the right s_k answers that are displayed. That is, W_1 has $|S_1|$ number of synonyms that are to be selected. So, the user can choose $|O| - |S_1|$ wrong answers before getting the correct answer.
11. In worst case, the user can choose $|O| - |S_1| + |O| - |S_2| + \ldots + |O| - |S_k|$ wrong answers for all the words. The equation simplifies to $j * |O| - (|S_1| + |S_2| + \ldots + |S_k|)$.
12. Therefore, the complexity for this level: Coming up with content to be gamified, which is number of words $|W_n|$ for all N_1 languages, the words that are posed as questions and their

corresponding synonyms, combinations of Options that are displayed on the screen for each word apart from the right answers and accounting for the wrong responses of user which has an upper bound $k * |O| - (|S_1| + |S_2| + \ldots + |S_k|)$.

The above description was one type of level C_{W1} into which the words are gamified. Hence $C_{W1} + C_{W2} + \cdots + C_{word-levels}$ is the total complexity of gamifying the words.

3.2.3. Complexity of Gamification: Learning Sentences

A language can be learned based on various motivations of the user. The right question to ask is "Why people will want to learn the L2 Languages?". For this there are various reasons and few of the important are as following:

1. L2 Languages are taught to the students at various levels of education.
2. The users might want to expand their job opportunities.
3. The users might want to learn to converse with their families.
4. The users might have cultural interest and hence might want to understand more about it through the language.
5. Language learning is found to be a good exercise for Brain.

The number of sentences $|S_n|$ can be gathered by the designer. Since there can be numerous sentences, a finite number of sentences are gathered by the designer based on the above-mentioned assumptions. This is also true for the gamification of the words. Similarly, to the previously mentioned ideas, the complexity of gamification learning of these sentences is summation of all ingenious types of gamifying these sentences into individual levels. Each level is unique and is not dependent on the other levels. Some of the ways to gamify them are as follows:

1. **Level 1**: Rearranging the words in the given sentence such that it makes proper sense.
2. **Level 2**: Filling the given blanks in the given sentence with the proper words that are displayed on the screen.
3. **Level 3:** Selecting the unnecessary parts in the given sentence to make it more succinct.

Let us look at the complexity of one such level. Here, let us consider Level 2 from the above list, where the user has to choose the right response (word) among the displayed options on the screen that correspondingly fills the blank of the given sentence.

1. We assumed that there are $|S_n|$ sentences in the new L2 language. Hence, $S_n = \{S_1, S_2, \ldots, S_n\}$ where $S_1, S_2, \ldots, S_n$ are the sentences in the L2 Language selected for the gamification task.
2. Each sentence S_k has a particular blank that has to be filled with an appropriate word.
3. The user cannot move on to the next sentence unless thy choose the right answer.
4. We assume that there is no penalty for choosing the wrong answer and the sentence will be on the screen until the corresponding answer is selected.
5. Now, User must choose the corresponding option (square box with text in it) among the $'O'$ options displayed on the screen.
6. $|O|$ is a number that is subjected to change as per the designer's decision.
7. These $'O'$ options have one right answer that is fits the blank in the given sentence.
8. We assume that the there is no penalty for the wrong answer and wrong answers shall be removed from options $|O|$ each time the user selects them.
9. But the designer has to come-up with a set of distinct options $'Options'$ from which $|O| - 1$ options are selected and displayed each time for a particular sentence. So, | Options | > | O|.

10. In the worst case, the user will choose wrong options $|O| - 1$ times until he selects the right answer that fits the blank. Hence $|S_n| * (|O| - 1)$ is total number of times the user selects wrong answer for all $|S_n|$ sentences of the particular L2 Language.
11. Therefore, the complexity for this level: Coming up with content to be gamified, which is number of sentences $|S_n|$ for all N_1 languages and 'Options' and combinations of the |O|-1 options that are displayed on the screen for each sentence and accounting for the wrong responses of user which has an upper bound $|S_n| * (|O| - 1)$

The above description was one type of level C_{L1} into which the sentences are gamified. Hence $C_{S1} + C_{S2} + \cdots + C_{sentence-levels}$ is the total complexity of gamifying the sentences where $C_{S1}, C_{S2}, .., C_{sentence-levels}$ are complexities of the individual levels.

4. Complexity of Gamification: Learning Food Preparation

Food preparation is a broad subject that encompasses all the steps involved in getting raw ingredients to eating them as food. Cooking or cookery is the art, science, and craft of using heat to prepare food for consumption. Cooking is a subset of Food preparation. In order to learn the food preparation, one must also understand and learn the various aspects of it. They are as follows:

1. Ingredients used in Food preparation
2. Tools to prep the Ingredients
3. Various food preparation techniques
4. Recipes for making the food

There are other aspects in the food preparation such as Kitchen hygiene etc. But the above 4 are the primary aspects that one should consider before learning the food preparation. So, to gamify food preparation, we should gamify the above steps.

4.1. Assumptions

1. There are various categories of the food such as Adulterated Food, Camping Food, etc. But we will only consider Cuisines. Cuisines are food that are made using a specific set of cooking traditions and practices and are often associated with specific culture or region.
2. We will not consider food ingredients and recipes that are deemed illegal.
3. We will not consider the tools and techniques that are industrial grade.
4. We are not considering recipes of food that are commercially sold a product. Example would be Coca-Cola.

5. We are considering that the gamification of this task is meant for only Single-User/Player. Hence we will not consider the recipes that require multiple users to cook/prep.
6. Our main assumption is that the games do not involve any practical process of the food prep as it would require a human expert as a judge to check the correctness. We will only test the theoretical knowledge of the user.

4.2. Complexity Calculation

As we have discussed earlier, to learn food preparation, the user has to learn about Ingredients involved, Tools to prep those ingredients, various food preparation techniques and recipes to make the food. We assume that the various food preparation techniques are implicitly taught by using recipes. Hence the focus would be on the other 3 categories.

4.2.1. Complexity of Gamification: Learning about Ingredients

Let us assume that there are $|I_n|$ ingredients that are being considered for this task. Hence, the set $I_n = \{I_1, I_2, I_3 \ldots . I_n\}$ where $I_1, I_2, I_3 \ldots . I_n$ are ingredients. There are various ways in which the learning of them can be gamified. These are design dependent. Some of the ways to gamify them are as follows:

1. **Level 1**: Identify the name of the ingredient displayed on the screen
2. **Level 2**: Identify the taste or tastes of the ingredient displayed on the screen

Let us assume that there are Ing_Levels such levels. They do not have to played necessarily in a linear fashion. We assume that the user has the liberty to choose which level to play. Each level is unique and has different complexity. Therefore, if the designer were to make Ing_Levels unique levels the total complexity of the gamification would be $C_1 + C_2 + C_3 + \cdots + C_{Ing\_Levels}$ where

$C_1, C_2, \ldots, C_{Ing\_levels}$ are the complexities of individual levels into which the I_n are being gamified. Let us look at the complexities of Level 1 and Level 2 that are being considered in the above list.

Level 1 deals with identifying the correct name of the ingredient displayed on the screen.

1. We assumed that there are $|\mathrm{I_n}|$ ingredients that are being considered for gamification. Hence, $\mathrm{I_n} = \{\mathrm{I_1}, \mathrm{I_2}, \mathrm{I_3} \ldots . \mathrm{I_n}\}$ where $\mathrm{I_1}, \mathrm{I_2}, \mathrm{I_3} \ldots . \mathrm{I_n}$ are the unique ingredients. Hence the designer should collect pictures for all $\mathrm{I_k} \in \mathrm{I_n}$
2. Each ingredient $\mathrm{I_k}$ has a particular picture used to uniquely identify it.
3. The user cannot move on to the next question unless they choose the right answer, that is choosing the right picture of the ingredient displayed on the screen for the displayed ingredient's name.
4. We assume that there is no penalty for choosing the wrong answer and the picture of the ingredient will be on the screen until the corresponding answer is selected.
5. Now, User must choose the corresponding option (picture of the ingredient) among the $'O'$ options which are pictures displayed on the screen.
6. $|O|$ is a number that is subjected to change as per the designer's decision.
7. These $|O|$ options have one right answer: the picture of the displayed ingredient on the screen.
8. We assume that the there is no penalty for the wrong answer and wrong answers shall be removed from options 'O' each time the user selects them.
9. But the designer has to come-up with a set of distinct 'Options' which are a set of various other pictures including all the pictures of the ingredients considered for the gamification. From these, '$|O| - 1$' options are selected and displayed each time for a particular name

of the ingredient. So, $|\text{Options}| > '|O|$ and pictures of the ingredients are a subset of Options.

10. In the worst case, the user will choose wrong options '$|O| - 1$' times until he selects the right response, that is the right picture of the displayed ingredient name on the screen. Hence $|\mathrm{I_n}| * (|O| - 1)$ is total number of times the user selects wrong answer for $|\mathrm{I_n}|$ ingredients.
11. Therefore, the complexity for this level: Coming up with content to be gamified, which is number of sentences $|\mathrm{I_n}|$ and 'Options and combinations of the $|O| - 1$ options that are displayed on the screen for each ingredient name and accounting for the wrong responses of user which has an upper bound $|\mathrm{I_n}| * (|O| - 1)$

Now, Level 2 deals with identifying the correct taste(s) of the ingredient displayed on the screen.

1. We assumed that there are $|\mathrm{I_n}|$ ingredients that are being considered for gamification. Hence, $\mathrm{I_n} = \{\mathrm{I_1}, \mathrm{I_2}, \mathrm{I_3} \ldots . \mathrm{I_n}\}$ where $\mathrm{I_1}, \mathrm{I_2}, \mathrm{I_3} \ldots . \mathrm{I_n}$ are the unique ingredients. Hence the designer should collect pictures for all $\mathrm{I_K} \in \mathrm{I_n}$
2. Each ingredient $\mathrm{I_K}$ has a particular taste or multiple tastes.
3. There are primarily 5 taste receptors in the tongue: Sweet, Sour, Bitter, Saltiness and Savory. Hotness is not a taste. But since some ingredients like Peppers might cause hot sensation, we will consider it as an extra taste.
4. The user cannot move on to the next question unless they choose the right answer(s), that is choosing the right taste(s) of the ingredient displayed on the screen for the displayed ingredient's name.

5. We assume that there is no penalty for choosing the wrong answer and the picture of the ingredient will be on the screen until the corresponding answer(s) is/are selected and wring answers will be removed from the consideration.
6. Now, User must choose the corresponding option (picture of the ingredient) among the 'O' options which are pictures displayed on the screen. Here $|O| = 6$ since we are only considering 6 tastes.
7. These 6 options have one right answer or multiple right answers. For example: Lime are generally sour in taste. But Oranges/ Mandarins are both sweet and sour.
8. So, among $|I_n|$ ingredients, some $|I_a|$ ingredients have single answers and $|I_b|$ have multiple answers. Therefore $|I_n| = |I_a| + |I_b| \; where \; I_a \cap I_b = \emptyset$
9. In the worst case, the user will choose wrong options 5 times until he selects the right response, that is the right taste of the displayed ingredient name on the screen. Hence $|I_a|$ * 5 is total number of times the user selects wrong answer for $|I_a|$ ingredients with a single taste.
10. Again, $|I_b|$ are further divided into ingredients:
    - a ingredients with 2 tastes
    - b ingredients with 3 tastes
    - c ingredients with 4 tastes
    - d ingredients with 5 tastes
    - e ingredients with 6 tastes
11. Therefore $|I_b| = a + b + c + d + e$

12. In the worst case, the user will make 4 mistakes for choosing right answers for a ingredients, 3 mistakes for b ingredients, 2 mistakes for c ingredients and 1 mistake for d ingredients.
13. So, in worst case the user shall make: $|I_a| * 5 + a * 4 + b * 3 + c * 2 + d$ total mistakes for all $|\mathrm{I_n}|$ ingredients.
14. Therefore, the complexity for this level: Coming up with content to be gamified, which is number of ingredients $|\mathrm{I_n}|$ and identifying the ingredients with single tastes and grouping the ingredients with multiple tastes, and accounting for the wrong responses of user which has an upper bound$|\mathrm{I_a}| * 5 + a * 4 + b * 3 + c * 2 + d$

The above descriptions were for 2 of the levels into which the ingredients might be gamified into. Hence the total complexity of gamifying the ingredients is $\mathrm{C_{L1}} + \mathrm{C_{L2}} \ldots + \mathrm{C_{Ing\_Levels}}$ where $\mathrm{C_{L1}}, \mathrm{C_{L2}} \ldots, \mathrm{C_{Ing\_Levels}}$ are complexities of the individual levels.

4.2.2. Complexity of Gamification: Learning about Tools used for Food Prep

Let us assume that there are $|\mathrm{T_n}|$ tools that are being considered for this gamification. These tools are used for prepping the ingredients and implicitly used in Food preparation. Some of the examples of the tools are Kitchen Knife, Stove etc. The learning about these $|\mathrm{T_n}|$ tools can be done in various ways, which is design decision. Following are 2 ways in which the gamification can be done:

1. **Level 1**: Identify the name of the tool displayed on the screen

2. **Level 2**: Identify the use of the tool displayed on the screen

There can be Tool_Levels number of such levels into which the gamification can be done. Each level is unique and assumed to be independent of each other. Hence total complexity of the gamification is $C_{L1} + C_{L2} \ldots + C_{Tool\_Levels}$ where $C_{L1}, C_{L2} \ldots, C_{Tool\_Levels}$ are complexities of the individual levels. Let us look at the complexities of the above-mentioned levels in detail.

Level 1 deals with identifying the correct name of the tool displayed on the screen.

1. We assumed that there are $|T_n|$ tools that are being considered for gamification. Hence, $T_n = \{T_1, T_2, T_3 \ldots . T_n\}$ where $T_1, T_2, T_3 \ldots . T_n$ are the unique tools that are used for food prep.
2. Each tool T_k has a particular picture used to uniquely identify it.
3. The user cannot move on to the next question unless they choose the right answer, that is choosing the right picture of the tool displayed on the screen for the displayed tool's name.
4. We assume that there is no penalty for choosing the wrong answer and the picture of the tool will be on the screen until the corresponding answer is selected.
5. Now, User must choose the corresponding option (picture of the tool) among the 'O' options which are pictures displayed on the screen.
6. $|O|$ is a number that is subjected to change as per the designer's decision.
7. These $|O|$ options have one right answer: the picture of the displayed tool on the screen.
8. We assume that the there is no penalty for the wrong answer and wrong answers shall be removed from options 'O' each time the user selects them.
9. But the designer has to come-up with a set of distinct 'Options' which are a set of various other pictures including all the pictures of the tools considered for the gamification. From

these, '$|O| - 1$' options are selected and displayed each time for a particular name of the tool. So, $|\text{Options}| > |O|$ and pictures of T_n are a subset of Options.

10. In the worst case, the user will choose wrong options $|O| - 1$ times until he selects the right response, that is the right picture of the displayed tool name on the screen. Hence $|T_n| * (|O| - 1)$ is total number of times the user selects wrong answer for $|I_n|$ ingredients, in worst case.
11. Therefore, the complexity for this level: Coming up with content to be gamified, which is number of tools $|T_n|$ and 'Options' and combinations of the $|O| - 1$ options that are displayed on the screen for each tool name and accounting for the wrong responses of user which has an upper bound $|T_n| * (|O| - 1)$

Now, Level 2 deals with identifying the use of tool displayed on the screen.

1. We assumed that there are $|T_n|$ tools that are being considered for gamification. Hence, $T_n = \{T_1, T_2, T_3 \ldots . T_n\}$ where $T_1, T_2, T_3 \ldots . T_n$ are the unique tools used for food prep. Hence the designer should collect pictures for all tools $T_K \in T_n$
2. Each tool T_K has a particular use. For example, Kitchen Knives are used for Slicing and Dicing the ingredients etc.
3. The user cannot move on to the next question unless they choose the right answer, that is choosing the right use of the tool displayed as text on the screen for the displayed tool's name.
4. We assume that there is no penalty for choosing the wrong answer and the picture of the tool will be on the screen until the corresponding answer is selected.
5. Now, User must choose the corresponding option (use of the tool) among the |O| options which are pictures displayed on the screen.

6. $|O|$ is a number that is subjected to change as per the designer's decision.
7. These $|O|$ options have one right answer: the use of the displayed tool on the screen.
8. But the designer has to come-up with a set of distinct '$Options$' which are a set of various other words or descriptions including all the uses of the tools considered for the gamification. From these, '$|O| - 1$' options are selected and displayed each time for a particular name of the tool. So, $|\ Options\ | > |\ O|$ and uses of the tools in text form T_n are a subset of Options.
9. In the worst case, the user will choose wrong options $|O| - 1$ times until he selects the right response, that is the right use of the displayed tool name on the screen. Hence $|T_n|\ *\ (|O| - 1)$ is total number of times the user selects wrong answer for $|T_n|$ tools, in worst case.
10. Therefore, the complexity for this level: Coming up with content to be gamified, which is number of tools $|T_n|$ and '$Options$' and combinations of the $|O| - 1$ options that are displayed on the screen for each tool name and accounting for the wrong responses of user which has an upper bound $|T_n|\ *\ (|O| - 1)$

The above descriptions were for 2 of the levels into which the ingredients might be gamified into. Hence the total complexity of gamifying the ingredients is $C_{L1} + C_{L2} \ldots + C_{Tool\_Levels}$ where $C_{L1}, C_{L2} \ldots, C_{Tool\_Levels}$ are complexities of the individual levels.

4.2.3. Complexity of Gamification: Learning about Food Recipes

A recipe is set of instructions for preparing something. Food recipes are set of instructions used to make food. Food recipes, in generally assume that the ingredients required for the food prep are already gathered. Our key assumption here is that the user is familiar with all the ingredients and

tools required to follow the recipe. Let us assume that there are $|R_n|$ recipes that are considered for the gamification task. Therefore, $R_n = \{R_1, R_2, R_3 \ldots R_n\}$ is total collection of recipes considered for gamification where $R_1, R_2, \ldots R_n$ are the individual recipes. Now each recipe will have various number of instructions including I_k where $k > 0$. Each instruction is related to prepping of the ingredients (related to recipe) with tools or hands. Now the learning of these R_n recipes can be gamified into various levels. Each level is unique and is independent on the other levels. Some of the ways into which the recipes can be gamified are listed as follows:

1. **Level 1**: Identify the ingredients related to the recipe
2. **Level 2**: Identify the tools related to the recipe
3. **Level 3**: Identify the right order to the instructions for the recipe
4. **Level 4**: Groups the recipes that belong to same cuisine.

These are some of the ways into which the learning of the recipes can be gamified. But there can be "recipe_levels" number of such levels. Therefore, the total complexity of the gamifying the recipes is $C_{L1} + C_{L2} \ldots + C_{recipe\_levels}$ where $C_{L1}, C_{L2} \ldots, C_{recipe\_levels}$ are complexities of the individual levels into which the recipes are gamified, and these levels are unique. Let us look at complexity of Level 1 from the above list.

Level 1 is about identifying the ingredients that are related to the recipe.

1. We assumed that there are $|R_n|$ recipes that are being considered for gamification.
2. Each recipe R_k has some ingredients Ing_k that are used for making the food.
3. Therefore, the recipes $R_1, R_2, \ldots R_n$ will have corresponding sets of ingredients $Ing_1, Ing_2, \ldots Ing_n$ associated with them.
4. The designer must gather pictures for $| Ing_1 \cup Ing_2 \cup \ldots \cup Ing_n | = ingredients$

5. Each time the name of the recipe is displayed on the screen along with the pictures of ingredients associated with and some extra options which might be other items that are not part of the recipe.
6. Let $|\text{Options}|$ be the total number of pictures that are considered for this gamification and ingredients number of pictures are related to all the ingredients that are related all food recipes and other $|\text{Options}| - \text{ingredients}$ are pictures that are other than ingredients.
7. Let $'O'$ be the total number of options that are displayed each time for each recipe's name. For example: If the name of the recipe R_1 is displayed on the screen, then its corresponding pictures of ingredients Ing_1 will also be displayed along with other $|O| - |\text{Ing}_1|$ options.
8. We assume that the there is no penalty for the wrong answer and wrong answers shall be removed from options 'O' each time the user selects them.
9. In the worst case, the user will choose wrong answers the following number of times: $k * |O| - (|\text{Ing}_1| + |\text{Ing}_2| + |\text{Ing}_3| + \ldots + |\text{Ing}_k|)$
10. Hence the complexity of the gamification is: Gathering $|R_n|$ recipes and pictures of all ingredients for the recipes considered. And to mislead the user and to check their understanding $|O| - |I_k|$ number of pictures are to be selected from $\text{options} - |I_k|$ number of pictures for the recipe R_k and this shall be done in any combinations for all the recipes. And finally, the designer has to account to worst-case number of times the user might select the wrong answers which has an upper bound $k * |O| - (|\text{Ing}_1| + |\text{Ing}_2| + |\text{Ing}_3| + \ldots + |\text{Ing}_k|)$

The above description was one of the levels into which the recipes might be gamified into. Hence the total complexity of gamifying the ingredients is $C_{L1} + C_{L2} \ldots + C_{\text{Recipe\_Levels}}$ where $C_{L1}, C_{L2} \ldots, C_{\text{Recipe\_Levels}}$ are complexities of the individual levels.

5. Complexity of Gamification: Learning of Physical Exercises

Exercises are both physical and mental activities that are performed by both humans and some animals. According to Mayo clinic, to aid growth and improve strength, preventing aging, developing muscles and the cardiovascular system, honing athletic skills, weight loss or maintenance, improving health [14] According to National Institutes of Health, National Heart, Lung, and Blood Institute, the physical exercises are classified into 3 categories which are as follows [15]:

1. Aerobic Exercises: These are any physical activities that uses large muscle groups and causes the body to use more oxygen than it would while resting. The goal of aerobic exercise is to increase cardiovascular endurance. Examples of aerobic exercise include running, cycling, swimming, brisk walking, skipping rope, rowing, hiking, dancing, playing tennis, continuous training, and long-distance running [15].
2. Anaerobic Exercises: These are physical activities which includes strength and resistance training, can firm, strengthen, and increase muscle mass, as well as improve bone density, balance, and coordination. Examples of strength exercises are push-ups, pull-ups, lunges, squats, bench press etc. [15].
3. Flexibility Exercises: These stretch and lengthen muscles. Activities such as stretching help to improve joint flexibility and keep muscles limber (supple and agile). The goal is to improve the range of motion which can reduce the chance of injury [15].

5.1. Assumptions

1. For this task, we will only consider body-weight exercises that doesn't require any extra equipment.
2. We assume that the exercises considered are indoor exercises. These will also include exercises that are used in physical therapy.

5.2. Complexity Calculation

Let us assume that there are $|E_n|$ exercises in total that are considered for gamification where $E_n = \{E_1, E_2, E_3 \ldots E_n\}\ such\ that\ E_1, E_2, E_3 \ldots E_n$ are unique exercises. These exercises as considered earlier include only body-weight exercises such as Push-ups, squats etc. Now these exercises can be gamified into various levels, where each level has its own unique complexity. Let us consider one such level. This is an example of content-gamification where we are creating extra content apart from the material that we are considering for the gamification task.

1. We assume that the user is equipped with physical motion sensors which would detect the motion of the user when an exercise is performed.
2. The designer creates a video game in which the main character has to jump over the obstacles as he moves along the screen.
3. The moving of the character will be from left to right and is automatic, but the jumping of the character is determined by the user actions where he/she must move their body.
4. If the user performs the body exercise in a wrong manner the main character in the video game will not jump over the obstacle and the game will be over.

5. So, if there are $|E_n|$ exercises the user will have the option to perform any exercise E_k among the E_n exercises in a random fashion.
6. A tutorial of a chosen exercise will be played on the screen.
7. The user has to perform the exercise E_k some $'n'$ number of times which would prompt the main character in the game to jump over the obstacles $'n'$ number of times as the obstacles approach towards the main character and finally the main character will reach the goal.
8. The game can have various difficulties : Easy, Medium and Hard where the difficulty dictates the number of times the user has to perform the physical exercise in succession. The harder the difficulty the greater number of times the user has to perform the exercise.
9. The difficulty of the game can also be affected based on whether the user has to perform the exercise E_k faster. This means that the main character will move towards the player much faster.
10. Hence the complexity of the gamification for this level is: Considering the exercises $E_n = \{E_1, E_2, E_3 \dots E_n\}$ $where$ $E_1, E_2, E_3 \dots E_n$ are unique exercises plus the complexity of creating the game. The game has 1 main character, some d different types of obstacles, a foreground, a background, and other environmental assets. The designer should consider the various difficulties: Easy Medium and Hard. The designer need not consider complexity of the physical equipment (in this case of motion sensors) that would make this gamification possible.

The above description is for one of the ways into which the gamification of the physical exercises can be done. But there can be $Exercise\_Levels$ number of such ingenious levels. Hence total complexity would be $\mathrm{C_{L1}} + \mathrm{C_{L2}} \dots + \mathrm{C_{Excersie\_Levels}}$ where $\mathrm{C_{L1}}, \mathrm{C_{L2}} \dots, \mathrm{C_{Exercise\_Levels}}$ are

complexities of the individual levels into which the physical exercises are gamified, and these levels are unique.

On the other hand, we can also test the theoretical knowledge of the person playing the game, as it is equally important to know which exercise to perform. An example of this would be in the physical therapy domain, where a particular exercise(s) would only work in the rehabilitation process. Let us consider one more level, where the user has to identify the which major groups are come into action in performing the corresponding exercise. This especially important for athletes.

1. Let us assume that there are $|E_n|$ exercises in total that are considered for gamification where $E_n = \{E_1, E_2, E_3 \dots E_n\}\ such\ that\ E_1, E_2, E_3 \dots E_n$ are unique exercises.
2. The major muscle groups in the body are:
    a. Hamstrings
    b. Quadriceps
    c. Chest
    d. Back
    e. Shoulders
    f. Triceps
    g. Biceps
    h. Forearms
    i. Trapezius
    j. Abs
3. Let $M_n = \{M_1, M_2, M_3 \dots M_n\}\ such\ that\ M_1, M_2, M_3 \dots M_n$ are sets of muscle groups which are activated when exercises $E_1, E_2, E_3 \dots E_n$ are performed correspondingly. And $1 \leq |M_k| \leq 10\ where\ 1 \leq k \leq\ n.$

4. Each time the name of the exercise belonging to set E_n is displayed on the screen along with the 10 muscle groups shown separately as text boxes. The user has to select all the muscle groups activated by corresponding exercise.
5. We assume that there is no penalty for the wrong answer and the user cannot move on to the next exercise unless they answer the current one first.
6. The wrong answers will not be further considered for that question, every time the user selects them.
7. In worst case the user will $10 - |M_k|$ wrong answers for exercise E_k. Hence, in worst case, the user will make $10 * n\ - (|M_1| + |M_2| + \ldots + |M_n|)$ mistakes.
8. The designer can make it more challenging by considering the extra options, that might confuse the users, just like earlier levels for other gamification tasks that we have mentioned.
9. Therefore, the complexity of the gamification is: Considering the total number of exercises for this task, identifying the muscle groups that each exercise will target and finally accounting the worst-case number of times that user might select wrong answers for all the exercises which has an upper bound $10 * n\ - (|M_1| + |M_2| + \ldots + |M_n|)$.

Let us look at a commercial example of gamification of Physical Exercise, particularly, Dance that we had mentioned earlier in the previous work section of this thesis.

5.2.1. Complexity of Gamification : Learning Dance with Just Dance™

The Just Dance series are a series of rhythm-related video games developed and published by Ubisoft. The main gameplay of the franchise is to try to copy what the on-screen dancer is dancing,

with a Nintendo Wii Remote, PS Move Remote, Joy-Con (Nintendo Switch Controller), Smartphone, Microsoft Xbox Kinect Camera or PlayStation Camera judging the player on their performance. With the Wii Remote, PS Move Remote, Joy-Con Controller or a Smartphone, it has to be held in the player's right hand for proper scoring. While gameplay has almost been the same in all games, some new features have been added to the series. (Duets, Trios, Dance Crews, etc.) [16] .This game can be played as a Single Player video game or a player can team up with friends for more fun in Co-op mode. The game offers a multiplayer mode where the user can compete with other players all around the world to secure a best score by dancing for given song.

This is a perfect example of both structural and content gamification. Here the content a set of songs along with their choreographies are gamified using

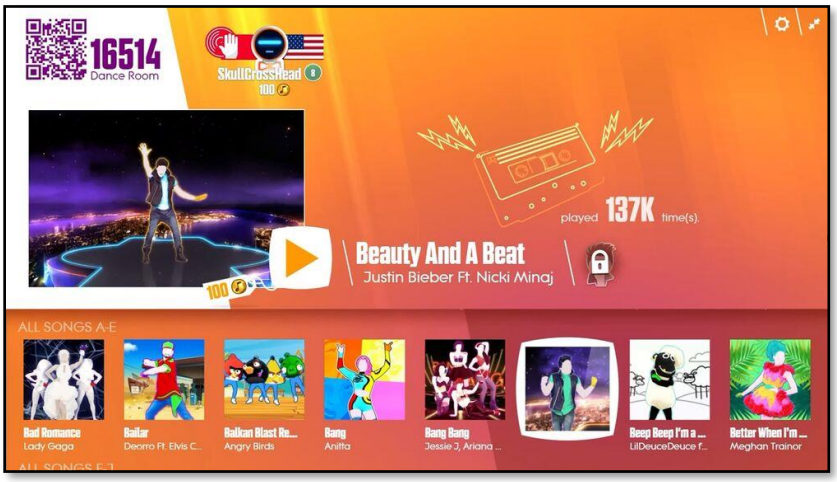

Figure 3: Just Dance Main Screen. Source: https://justdance.fandom.com/wiki/Just_Dance_(series)

- Structural gamification: By adding points, Leaderboard, and other structural gamification elements
- Content Gamification: Where an entire game is created based on the content by laying out clear goals for the user to accomplish.

To understand the complexity of this game we need to identify the core features of the game. They are as follows:

1. There is list of songs that are available on the main screen of the game for the user to choose.

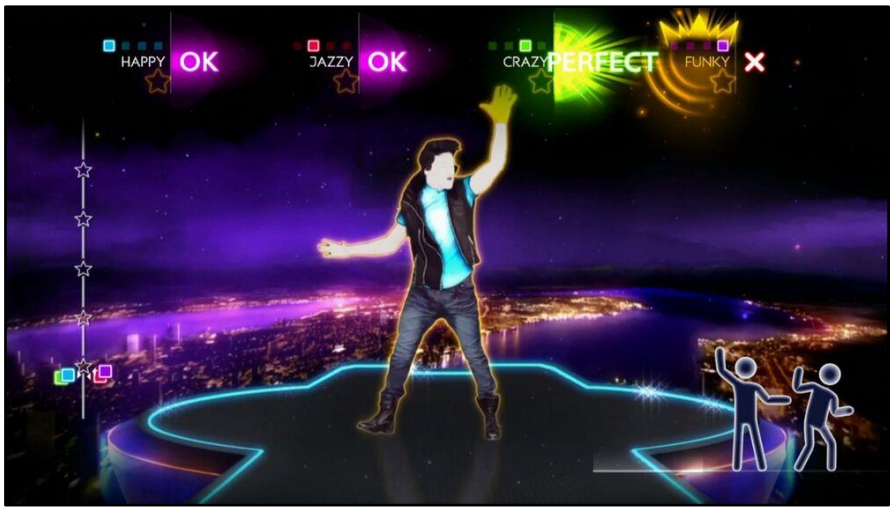

Figure 4: Just Dance Game Screen. Source: https://justdance.fandom.com/wiki/Just_Dance_(series)

2. When the user selects the song, a dancer performs series of dance moves to which the player has to match his/her moves to score points.

Figure 5: Dancer Move Element. Source: https://justdance.fandom.com/wiki/Just_Dance_(series)

3. If we examine, there various elements on the screen in the figure 4. The elements that form the core of gamification are Dancer moves (it's an animation in the game) which are recorded by the developers of the game at the time of development, as seen in figure 5.

4. There are prompts from the game in form of some graphics, which inform the player to perform which dance move next in advance. An example would be as shown in Figure 6.

Figure 6: Dance move prompt element. Source: https://justdance.fandom.com/wiki/Just_Dance_(series)

The precise timing of the dance move played by the important as it is important to score more points.

5. The user must dance to the prompt shown on the screen as seen in figure 6 to score points. There are mainly 5 feedbacks given by the game based on how the player has matched the timing of the move to the prompt shown on the screen. They are Perfect, Super, Good, Ok and Bad. Each of these have certain points and they will accumulate as the player performs the dance moves for all the moves in the song.
6. When all the moves are performed which indicates the end of the song, the score secured by the player will be displayed on the screen.

7. This score is used by the game to unlock other songs or decide positions in the leaderboard in case of Co-op or multiplayer mode.

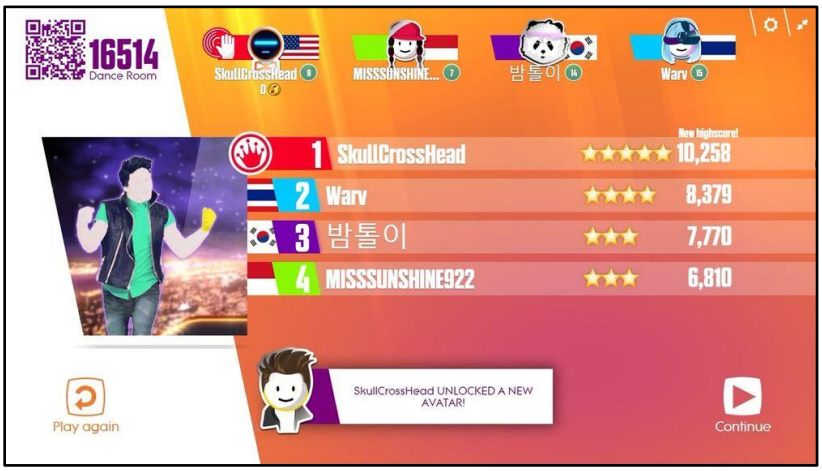

Figure 7: Leaderboard at the end of the song. Source: https://justdance.fandom.com/wiki/Just_Dance_(series)

Now let us look at the complexity of creating such a game.

1. Let us assume that there are $|S_n|$ songs considered for the gamification where $S_n = \{S_1, S_2, S_3 \ldots S_n\}\ such\ that\ S_1, S_2, S_3 \ldots S_n$ are unique songs.
2. Now for each song S_k there is a corresponding dance D_k which must be recorded by the developer to be played along with song in the game. Hence there will be $|D_n|$ dances where $D_n = \{D_1, D_2, D_3 \ldots D_n\}\ such\ that\ D_1, D_2, D_3 \ldots D_n$ are unique dances for corresponding songs.
3. Now each dance will have some set of pictograms which are used are prompts by the game to indicate the user on which dance move to dance.
4. Since dance moves can be shared across dances they might not be unique. But the designer has to come up with unique pictograms like shown in figure 6. Let this be $M_n = \{M_1, M_2, M_3 \ldots M_n\}\ such\ that\ M_1, M_2, M_3 \ldots M_n$ are unique moves used as pictograms in the dances.

5. Now each dance will have a series of moves that have to played by the player, hence will have some $'n'$ number of moves. This number is a combination of moves from pictogram set M_n. Therefore $n = a_1 number\ of\ times\ M_1 + a_2\ number\ of\ times\ M_2 + a_3\ number\ of\ times\ M_3 \ldots + a_n\ number\ of\ times\ M_n\ such\ that\ a_k \geq 0$
6. The designer must consider $'s'$ scoring feedbacks and corresponding number of points awarded. The player will be judged based on the timing of the move performed to match the pictogram prompt and will be given one of the feedbacks from this $'s'$ set and corresponding number of points. In case of Just Dance series $s = 5$.
7. The designer must divide the Dances D_n into various categories based on:
    a. How difficult the song is? In case of Just Dance series they are divided into Easy, Medium and Hard. This is based on how complex the moves are and pace of the prompts displayed on the screen (to which user has to match)
    b. How much effort is required to dance to the song? In case of Just Dance series they are divided into Low, Moderate and Intense.
    c. Total 9 different combinations are possible. For example: <Easy, Moderate> which means the dance moves are easy to perform but this dance would demand moderate amount of effort.
8. Finally, the designer must consider other structural gamification elements such as Leaderboard, points and unlocking of the new dances for user to play based on the score secured in previous levels.

The above points capture the core-complexity of making the Just Dance game which gamifies the dancing, omitting the complexity of creating other aesthetic elements, or gamification elements such as Goals, Daily challenges etc.

6. Physical Gamification of learning tasks

Gamification does not necessarily have to be for the digital world. By this we mean that a learning task can be gamified such that it involves physical elements. For example, let us take the example of identifying the names of the animals, when the pictures are displayed to the user one by one.

1. Let us assume that only one user is playing the gamified task.
2. The user has to identify the name of displayed animal.
3. But this time, instead of displaying the images on screen along with the options to choose from, an instructor/expert will show a picture printed on a paper and will write the options on a blackboard, from which the user has to choose an option.

The complexity of gamifying will be same as we seen in the earlier examples, but it has few limitations. Some of the limitations are as follows:

1. Physical gamification has a limited ability to entertain or educate without using extra resources such as Physical place. For example, the above example would require pictures printed on papers, a black board, duster to erase the chalk and chalk pieces to write on the board. The above method also requires an instructor/expert physically present.
2. Physical gamification has less chances to surprise the user.
3. Physical gamification has less ability to adapt the game based on user's performance. For example, if user is trying to speed through the questions by answering the questions fast, a software can do more efficiently than the physical person.
4. Players cannot switch to various levels in the gamified tasks efficiently and swiftly.
5. The scalability of the physically gamified learning task has a limit for it to work efficiently. For example: Digital gamification of learning languages (Duolingo app) allows millions

of users to use the service simultaneously, which is highly unlikely in physical gamification.

6. Digitally gamified tasks can efficiently store the session state of the user and lets them continue the game from where they had left.
7. Digital gamification offers more freedom to the designers in gamifying the tasks. This would make the game more engaging.

In the lieu of above-mentioned points, we believe that digital gamification of a learning task is better than physical gamification of the same. And we also believe that the complexity of digital gamification is less than physical gamification (under specific conditions) as it is amortized.

7. Conclusion and Future Work

In this thesis, we proposed a way of identifying the complexity of the gamification of learning new tasks, by taking examples of 3 different learning tasks. We also have used the same way to analyze what the complexity might have been for already gamified tasks.

One of the important aspects of the gamification is the reward system for players. The reward system might offer rewards that are both tangible and in-tangible. An example would be the reality TV-Show, “Who wants to be a millionaire?” where the player is offered rewards in money for giving the right answer. This is an example of gamification of learning general knowledge. The other type of rewards might be dependent on the type of gamification that the task is gamified into. The complexity of the gamification will also be affected by the complexity of creating a reward system for the gamified task. We believe that this is especially true for content-gamification of the learning tasks. We also propose that reward system can be designed in two ways:

1. Manual Reward System (Rule-based): Here the designer should come up with all the rules/events/states in the gamified task where the user shall be rewarded for the right action they are taking.
2. Automated Reward System: This is where the A.I would come into play. An example would that the user might exploit the system where a daily login on the game would give the users more experience points for leveling up. This exploit shall be detected, and the user might be punished for doing the same.

One can find the knowledge and skills such as Pictures, Sounds, Sets, lists, tables, mathematical equations, mathematical expressions, diagrams, logical equivalences, facts in forms not captured by other kinds of knowledge, Symbols, Letter, Sequence of steps, Sequence of steps

with constraints, Sequence of steps with exceptions, a decision tree, a table showing mapping of states to actions to teach a policy, state-transition diagrams, correlations and causality among variables, ranking choices, chemical reactions, hierarchy of objects or roles, compositions (diet, molecule, committees etc.), laws of logical inference, inference involving spatial or temporal relationships, motor skills, and cognitive skills (for example, estimating quantities). Then using this knowledge one can investigate the estimation of the effort needed to gamify knowledge-learning and skill-learning in a way independent of the game designer, software and hardware involved in game design and development, considering that the goal of the game may be to teach the player to memorize, apply, analyze, synthesize, evaluate, be creative, improve speed of cognitive or motor activities or improve mental health, sensory skills, physical strength, physical flexibility or cardiovascular health.

Finally, we are confident that designers can get a good-estimation about the amount of work that they have to put-in, considering the temporal and financial constraints, for gamifying the learning tasks using the ideas mentioned in this thesis.

Bibliography

[1] Merriam Webster, "Merriam Webster," [Online]. Available: https://www.merriam-webster.com/dictionary/game.

[2] J. Hamari, "Wiley Online Library," 19 November 2019. [Online]. Available: https://onlinelibrary.wiley.com/doi/abs/10.1002/9781405165518.wbeos1321.

[3] V. Gabrielle, "Fast Company," 1 November 2018. [Online]. Available: https://www.fastcompany.com/90260703/the-dark-side-of-gamifying-work.

[4] J. R. X. G. Matthew Stephenson, "The Computational Complexity of Angry Birds (Extended Abstract)," *International Joint Conferences on Artificial Intelligence Organization*, pp. 5105-5109, 2020.

[5] E. D. D. A. G. G. V. Greg Aloupis, "arXiv.org," 10 February 2015. [Online]. Available: https://arxiv.org/abs/1807.04724.

[6] J. L. J. L. Erik D. Demaine, "arXiv.org," 2016 November 20. [Online]. Available: https://arxiv.org/abs/1611.10319.

[7] A. Botra, M. Rerselman and M. Ford, "Gamification Beyond Badges," in *2014 IST-Africa Conference Proceedings*, 2014.

[8] D. Lamprinou and F. Paraskeva, "Gamification design framework based on SDT for student motivation," in *International Conference on Interactive Mobile Communication Technologies and Learning (IMCL)*, 2015.

[9] A. G. Özdoğan and A. Toprak, "The Effect Of Gamification in Information Technologies Projects," in *3rd International Conference on Computer Science and Engineering (UBMK)*, 2013.

[10] Y. Heryadi and K. Muliamin, "Gamification of M-learning Mandarin as second language," in *1st International Conference on Game, Game Art, and Gamification (ICGGAG)*, 2016.

[11] A. C. A. Fathoni and D. Delima, "Gamification of learning kanji with “Musou Roman” game," in *1st International Conference on Game, Game Art, and Gamification (ICGGAG)*, 2016.

[12] K. M. Kapp, The Gamification of Learning and Instruction Fieldbook: Ideas into Practice, Wiley, 2013.

[13] Duolingo , "Duolingo Language Courses," Duolingo , [Online]. Available: https://www.duolingo.com/courses/all.

[14] Mayo Clinic Staff, "Exercise: 7 benefits of regular physical activity," Mayo Clinic , 11 May 2019. [Online]. Available: https://www.mayoclinic.org/healthy-lifestyle/fitness/in-depth/exercise/art-20048389.

[15] U.S. DEPARTMENT OF HEALTH AND HUMAN SERVICES, "Your Guide to Physcial Activity and Your Heart," NIH Publication, 2006.

[16] Just Dance Wiki, "Just Dance (series)," Fandom, 24 April 2021. [Online]. Available: https://justdance.fandom.com/wiki/Just_Dance_(series).