Jungle Maze: Explore Risks and Merits Behind the Adaptive Procedural-Content-Generation Game Mechanic

by

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Abstract

Procedural content generation (PCG) has been a beloved game design element since *Rogue* (1980). Recent titles like *Minecraft* (2011) and *Terraria* (2011) also presented the charm behind this game mechanic. Yet, most PCG games implement content generation independently from players' in-game behaviors. On the contrary, *adaptive PCG*, which generates content on-the-fly that actively evolves the random generator according to players' real-time actions, has high potential yet rare presence. This study explores this issue by developing and investigating an adaptive PCG digital game - *Jungle Maze*. By analyzing participants' feedback through the perspectives of Nicole Lazzaro's *Four Fun Keys* (2015) and Mihaly Csikszentmihalyi's *Flow Theory* (1990), this paper aims to explore the merits and risks behind this game mechanic. At last, this study answered the question of when and how designers should use the adaptive PCG mechanic. The analysis proposes insights for future adaptive PCG research and game designs.

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1. Introduction

As a game design element, *procedural content generation* (PCG) can create unique player experiences by its unpredictability and replayability. It encourages players to explore the underlying game system, game the generators and even predict the generation patterns instead of interacting with the game world itself, which further inspires players to practice such understanding during the repeated gameplay and gain fulfillment through mastery (Short & Adams, 2017, p. 10-12). However, in most PCG games, players interact exclusively with the generated result, and the generation process is hardly involved in players' decision-making. Most content generators in games only consider their own sets of rules and do not take players' real-time activities into account (Smith, 2014). Shaker et al. (2016, p. 8) also concluded that *generic content generation*, which does not take players' actions into account, is the mainstream in modern game designs, whilst its counterpart, *adaptive content generation*, is only partially used in some games.

Though adaptive generation is not a prevailing game mechanic compared to its generic counterpart, it is gaining increasing and positive attention among academics. Yannakakis and Togelius (2011) investigated this game mechanic with the Player Experience Model (PAM) and concluded that adaptive generation could positively contribute to player engagement. From a design perspective, as adaptive generation creates additional interaction with generators, it expands *meaningful decision-making*, which was regarded by Sid Meier as the key element of video game design (Rollings & Morris, 2000). Jesse Schell also described in his book *The Art of Game Design* that in-game meaningful decisions are essential and should "have a real impact on what happens next, and how the game turns out," which coincides with the adaptive generation mechanic (2014, p. 179).

Therefore, a conflict appears between adaptive generation's great potential and its rare use in practice. This research study aims to explore this issue by investigating the risks and merits behind adaptive generation from both practical and theoretical approaches. As such, an adaptive PCG game, *Jungle Maze*, was developed as the research subject for this paper. To better identify adaptive PCG's design risks through this game, this study adopted a mixed methods approach, combining a survey with an interview, in order to cover both the general impressions about the game and the

detailed experience during the play. By analyzing *Jungle Maze*'s performance in adaptive PCG implementation, this paper provides solutions for when and how designers should use the adaptive PCG game mechanic, proposing tips for future game designs and insights for related studies.

2. Background

Aside from the researcher's personal preference in PCG games, PCG game design itself is worth exploring due to its challenging but rewarding nature. The book *Procedural Generation in Game Design* points out that though PCG game development poses difficulties in stabilizing quality, anticipating development scale, and producing ideal designer-driven experiences, PCG games have distinctive advantages in both objective utilitarian and subjective player experience. In short, PCG increased code extensibility and reusability and can create exclusive experiences from its "abundant playable content, living systems and inhuman creativity" (Short & Adams, 2017, p. 11).

Extensibility and reusability grant modern PCG games potential for ongoing updates, and the unique experience that PCG reproduces convinces continuous development. Titles like *Minecraft* (Mojang, 2011) and *Terraria* (Re-Logic, 2011) have even kept releasing updates for over ten years. Meanwhile, unlike non-PCG games, in which updates and downloadable contents (DLC) usually have independent add-ons like new characters, stories and maps, PCG games can replenish playability by simply integrating new rules and items into existing systems. As one of the top rated games on Steam (Steam DB, 2022), *Terraria* pursued such a style and gained sustained success. Its major updates usually come with new biomes and events, which keep intriguing players to return to the familiar world and experience the excitingly new challenges.

Such update strategy not only comes from the development conveniences, but the innate advantages in keeping the game fun. As Raph Koster summarized in his A *Theory of Fun* for Game Design, successful games should incorporate the following elements (Koster, 2005, p. 120):

> **Preparation**: Before taking on a given challenge, the player gets to make some choices that affect their odds of success.

In a generated game world, randomness assures challenges remain unknown before encounters. This exclusive nature of PCG inspires players to make preparations according to the random surroundings in every play through.

A sense of space: This refers to spaces like a chessboard or a map.

As all generated sub-regions, like biomes, are spatially unknown to players, PCG games can greatly enhance the experience of exploring the games' spaces.

A solid core mechanic: This is a puzzle to solve, an intrinsically interesting rule set into which content can be poured.

A range of challenges: This is basically content. It does not change the rules, it operates within the rules and brings slightly different parameters to the table.

PCG games usually update by adding new elements to existing core systems. In this case, challenges can be enhanced to a great extent - novel trials in a familiar world allow players to pick up challenges more easily, compared to experiencing an independent world in a DLC, while still keeping the challenge experience surprising. As such, the dynamic challenges in a core system endow PCG experience with greater immersion and fulfillment.

A range of abilities required to solve the encounter: Players should have various choices to deal with the encounters in a game.

Skill required in using the abilities: Players skills should be useful during an encounter. This includes any sort of experience, like timing and resource management.

In PCG games, the diversity in strategies is intrinsic - random maps produce unpredictable resource positions and event times, which test players' skills in dealing with challenges of any combinations and under any circumstances. In *Terraria*, thousands of unique items grant players variety in personalized experiences. Due to the different chest and mines players can find, their equipment and battle styles vary greatly. Therefore, adding new rules and items to the game can easily magnify the scale of such ramifications and further diversify the gameplay.

Contemporary PCG games, including the beloved *Minecraft* and *Terraria*, implement generic content generation in most cases. The map generation results are settled before players enter games, and the random generator works independently from

players' interference. However, though the adaptive PCG mechanic is rare in the market, a few adaptive-PCG-like implementations have already shown the mechanic's great potential. In *Left 4 Dead* (Valve, 2008), various game settings, including enemy types, equipment and spawn rates, will be set adaptively according to players' measured emotional intensities. In this case, adaptive PCG is used as dynamic difficulty adjustment to keep players engaged. In *Galactic Arms* (Evolutionary Games, 2010), adaptive PCG is applied to a weapon evolution system, which customizes future weapons according to players' current equipment sets and use preferences.

Moderate adaptive PCG implementations, like the application in difficulty adjustment, can serve players' preferences and hence smooth the experience (Shaker et al., 2016, p. 9). Therefore, expanded adaptive PCG, which produces solid playable content according to players' inclinations, could potentially affect game experiences more profoundly.

Expanded adaptive PCG can be inspired from the adaptive mechanics of some generic PCG games, where triggerable events have crucial impact to players' journeys. In *Terraria*, several important resource generations and biome changes can be triggered by players' behaviors. For example, a meteorite lands a few days after a player destroyed a dark orb in the corruption biome. Though players remain unaware about such mechanics in the first playthrough, the game reminds players about such correlations later on, including immediate notifications after certain boss fights. For example, after the "Wall of Flesh" falls, the game tells players that the game world has drastically changed, and many new enemies are unleashed. In such way, the game inspires players to explore the mechanics behind various events:

Stage 1: Players do not know the correlation, and are surprised by events.
Stage 2: Players get noticed about some of the correlations directly.
Stage 3: Players realize some events always happen at a regular time, and start to learn the rules behind them.
Stage 4: Players comprehend the correlations and start to make informed decisions for preparations.

Eventually, such a process of unraveling a mystery allows players to prepare well before triggering events. Compared to the surprising and curious experience in early playthroughs, the gameplay becomes more and more strategic through repetition.

Though *Terraria*'s map generation is still dominated by generic PCG, adaptive mechanics play decisive roles in enemy invasions, biome changes and boss fights. Players' decisions during these moments can drastically shape the play experience later on. Therefore, it is worth exploring how adaptive PCG could perform on a larger scale. From *Terraria* case study, we noticed that the strategic experience gets enhanced after players know the correlation between their actions and future events. In a real adaptive PCG game, the awareness of such correlations should be increased. In this case, a question arises - if the player knows the adaptive nature and mechanics underlying the complete generation system, how does it affect the overall experience, including excitement, curiosity and strategy?

In consideration of adaptive PCG's rare practices in commercial games and research projects, this study developed an adaptive PCG game, the Jungle Maze, to robustly investigate the impact of the adaptive PCG game mechanic on players.

3. Design Methodology

After a preliminary research-directed game design, a tile-based, 2D, top-down-view shooting game was created. All design decisions are discussed in this section.

3.1 Why designing a tile-based, 2D, top-down shooter game?

Most PCG games embrace tile-based designs, and one of the obvious reasons is the convenience in building effective algorithms. However, this doesn't imply that non-tile-based games are harder to build but better in creating PCG experiences.

Tiles can create not only visual but logical alignments. Aligned objects can organize various information more clearly, therefore can easily grab attention and create evident objectives. Gestalt perception theory points out that organisms perceive parts of the perceived areas as hanging together more tightly than the others due to perceptual grouping, and one of the principles of the Gestalt is *proximity* - when individuals perceive a assortment of objects, they perceive objects that are close to each other as a group (Wagemans et al., 2012). Figure 1 shows an example of the Gestalt proximity rule.

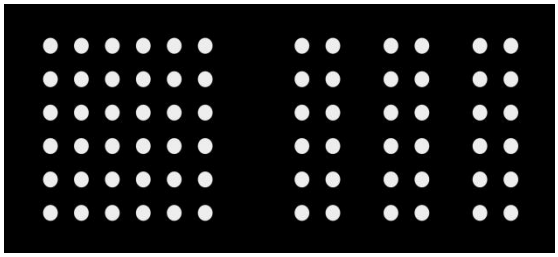


Figure 1: Gestalt proximity

Figure 2: Tiles in *Terraria*

The tile-based design is capable of utilizing Gestalt theory in two directions. On the one hand, similar, aligned tiles can form diverse aggregation of shapes while keeping its elementary properties organized, mitigating the visual distraction from randomness - the two gold ore areas in the Figure 2 are different in shapes and distant in positions, while seem very uniform visually due to the use of the same tile elements. This is not very obvious in non-tile-based games like *ARK: Survival Evolved* (Studio Wildcard, 2017) in Figure 3 and *Don't Starve* (Klei Entertainment, 2013) in Figure 4.

Figure 3: Resources in *ARK: Survival Evolved*

Figure 4: Resources in *Don't Starve*

On the other hand, when something breaks the proximity, like the mushroom and chest in Figure 2, it also becomes a captivating target for exploration. This feature can also help generation algorithms to create meaningful decision-making by simply placing stuff.

Aside from the perception benefit, tile-based design also provokes strategies, as it tests players' understandings of the tile system, including tiles' various properties and movement patterns on tiles. For example, in tile-based games like *Minecraft* and *Terraria*, players can have positive awareness about whether enemies, projectiles, liquids or lights could travel through tiles and touch them. Figure 5 shows an example of players building very simple yet effective fortresses to tackle difficulties.

Figure 5: A simple fortress in *Terraria*, allowing players to shoot without getting harmed

The decision to make a 2D top-down game was also based on careful consideration. 2D games can avoid navigation complexity due to the additional z-axis and can provide meaningful information more effectively - every time players move, a new row or column of complete tiles appear on the screen. Meanwhile, as top-down-view games do not have gravity, characters have equal costs moving either horizontally or vertically. This property grants *Jungle Maze* easier PCG algorithm designs - games with elevations like sky, ground and under-ground usually need different generators. Implementing games with gravity and elevations might aggravate the noise of unwanted variables like diverging algorithms.

At last, a game in the familiar top-down shooter genre was implemented on top of all the research-directed designs. The use of projectiles could again add meaningfulness and strategy to the tile system..

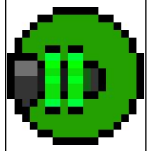
3.2 The game design of *Jungle Maze*

The game *Jungle Maze* was designed to emphasize on players' controls over the map generation. In this game, players are asked to fight through several levels and reach the destination. Players need to collect and use items properly, including generating appropriate maps, in order to win the game. To better explore adaptive PCG's advantages and disadvantages compared to non adaptive PCG games, *Jungle Maze* was designed to have two parts - pre-made levels and adaptive PCG levels. Note that both parts are the same shooter game, except players did not have map generation control in the first part. Figure 6 and 7 show the screenshots of two parts respectively.

Figure 6: Player fighting in designed levels. All items are kept as cards in the top-middle inventory.

Figure 7: Player browsing items in the PCG levels. Next level's terrains and enemies can be set to top-left slots

Table 1 shows a complete list of available items and the designs behind them. It covers both normal shooter game items and adaptive PCG items.

Item Icon	Item Name	Item Category	Description	Designer's Thoughts
	Sword	Weapon	A sword that players can always equip by pressing [E].	Give players something to use when out of ammo.
	Coin	Pick-able	Dropped by enemies. Evenly generate a health or a random weapon to the deck when collected.	Random supplies **create fragments in inventory and stimulate players to sort the messy inventory bar, hence training the players to use items**. This is a necessary preparation for the second part's adaptive PCG.
	Gun	Weapon/ Collectable/ Card	1. When using a weapon card, the corresponding weapon will be equipped. 2. When collecting weapon items or coins on the map, a specific or random weapon card will be generated.	Bullet will bounce on walls. This makes it **especially powerful in maps with walls and small rooms**.
	Shot gun			Scatter 3 bullets, but every shot has 0.5 seconds to cool down. It is both **good at around-the-corner surprise attacks or dealing with groups of enemies in open areas**.
	Plasma			Scatter 5 bullets, but the first shot always needs 0.3 seconds preparation. This is **dominating when dealing with a group of enemies in an open area**. It is the **most powerful weapon**, but the bullet cost is huge.
	Rifle			Bullets split a bit, and shoot speed is fast. This is a weapon **useful under all circumstances**, but the bullets run out fast.

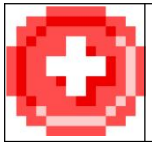
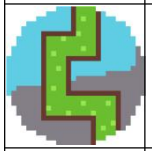
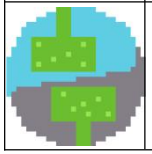
	Health	Collectable/ Card	Similar to Weapon Cards.	There are many health items in the map, but none-of them heals a huge amount. This again **stimulates players browsing and using items frequently**.
	Enemy	Character/ Card	1. Enemy card with random weapon spawns for every 15 seconds. 2. When in the inventory, enemy cards changes enemy types every 20 seconds 3. In the designed map, using an enemy card spawns target enemies in the current level immediately. 4. In the PCG part, they affect the enemy proportions in the next level.	1. The auto-spawned enemy card is yet **another stimulus to push players sorting the inventory bar**. 2. Players can swap unwanted enemy cards by waiting. This **provides the trade-off** that if players do not want to fight with a certain type of enemy, they must wait and let that card occupy an inventory slot for a while. 3. The enemies holding different weapons also inherit the weapon's properties, **giving players strategic choices about whether or not to spawn the enemy in the given map**.
	Water Card	Card	1. Dropped by enemies in PCG levels. The probability is 30% for terrain cards and 70% for supplies. 2. Terrain cards have the same swap mechanic as the enemy cards. 3. Different combinations of terrain cards determine the style of the next level. All combinations are shown in the next page.	1. Water card determines the obstacle tile type - use it to generate water area around walk-able tiles, else walls will be generated. 2. The essential difference is that **bullets can pass through water area but not walls, making water levels more dangerous while rewarding for range attack**.
	Path Card	Card		These two cards determine the size of the rooms. Using any of them individually creates relatively large rooms (islands), while combining them will produce small rooms (islands). This also **provokes decision-making** like generating small rooms for the bouncing gun bullets.
	Room Card	Card		

Table 1: All item designs in *Jungle Maze*

All combinations of terrain cards can be found in Figure 8. These examples represent all possible map styles players can generate through combining various terrain items.

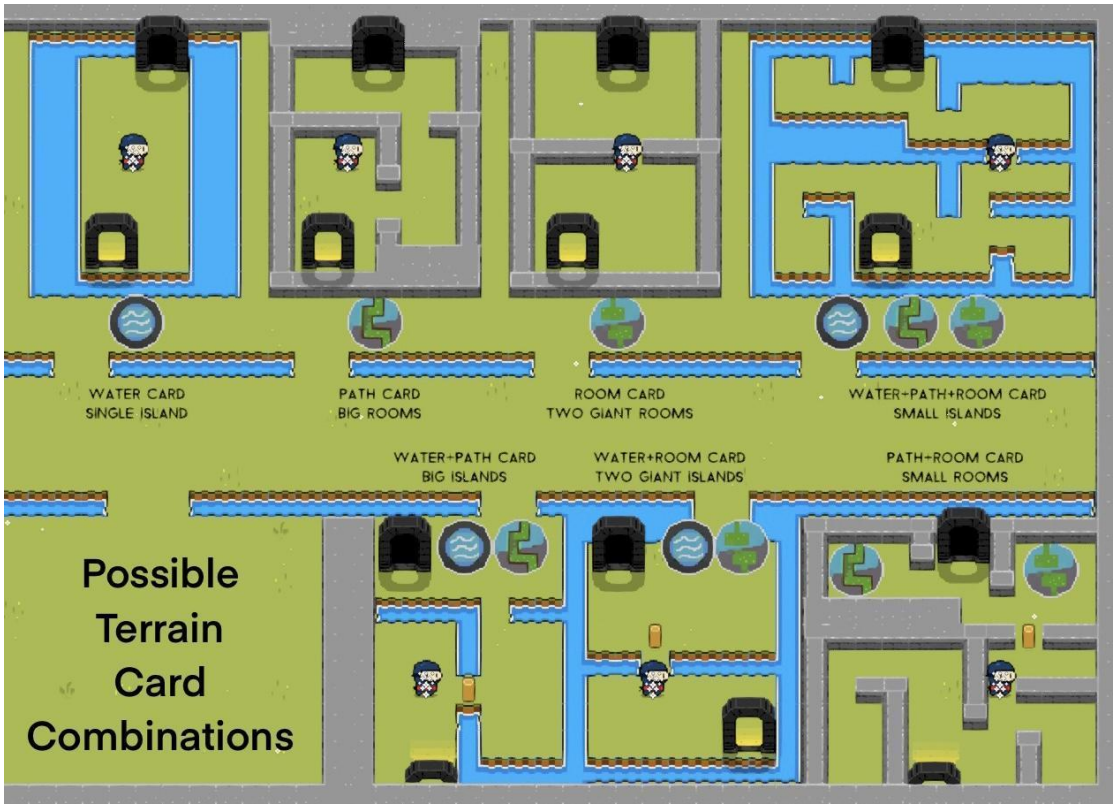


Figure 8: All possible combinations of terrain cards

In summary, the terrain system in *Jungle Maze* was designed to encourage players to select easier-to-handle terrains according to their weapon and health situations. The play experience during such decision-making is a key measurement of this study.

4. Research Methodology

Seeking for more comprehensive measurements in player experience, this study conducted mixed method analysis with a two-stage data collection approach. A survey and an interview were designed as data collectors. Based on Nicole Lazzaro's *Four Fun Keys* (2015) and Csikszentmihalyi's *Flow Theory* (1990), players were asked to reflect on their overall fun experience after the play session and the flow experience during the playthrough.

The survey answers the question of "when to use adaptive PCG" from a player's perspective. It examined adaptive PCG's different potentials in creating different fun experiences, which led to conclusions about the types of fun for which adaptive PCG works best. Meanwhile, the interview answered the question of "how to design better adaptive PCG". It scrutinized the detailed merits and risks in *Jungle Maze*' s adaptive PCG system, which helped us to summarize tips for similar future designs.

4.1 The *Four Fun Keys*

The ultimate goal of the *Jungle Maze*'s adaptive PCG design is to create a fun experience. Accordingly, the preeminent objective of this methodology is to inspect how well the mechanic performs in creating different kinds of fun. However, as a subjective experience composed of various emotions, fun is hard to analyze (Vieira & da Silva, 2017). For easier deconstruction and analysis, this study adopted the methodology from Nicole Lazzaro's *Four Fun Keys* (Lazzaro, 2015). This theory decomposes the fun experience into four major types and many sub-categories, which assists us in organizing playtesters' reflections and doing effective comparisons. An overall demonstrations of the *Four Fun Keys* can be found in Figure 9. In light of Nicole Lazzaro's fun types, a survey was created to collect players' different fun experiences after playing through respective game stages (pre-made or PCG levels).

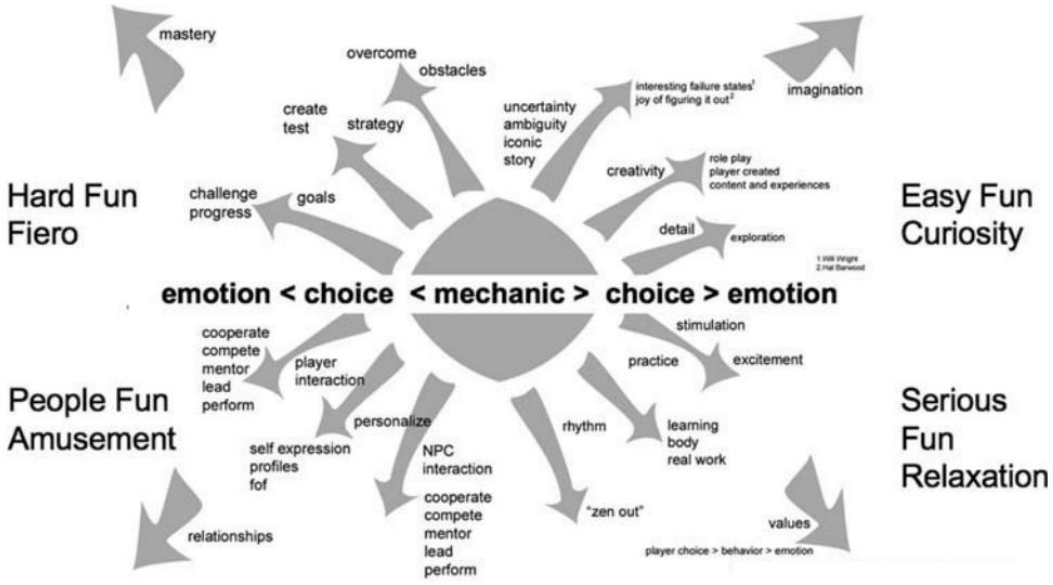


Figure 9: The *Four Fun Keys* by Nicole Lazzaro

Here is a list of the major fun types in the *Four Funs Keys*. In this study, *hard*, *easy* and *serious fun* are selected. *People fun* is omitted due to the absence of multiplayer elements and NPCs in *Jungle Maze*. The ones used as criteria for this study are in bold.

1. Hard Fun - mastery
    a) Overcome obstacles
    b) **Strategy** (short term or long term strategies)
    c) **Challenge** to achieve goal
2. Easy Fun - imagination
    a) **Uncertainty**
    b) **Creativity**
    c) **Exploration**
    d) **Role-play**
3. Serious Fun - practice
    a) **Practice real-life skills** (like time management)
    b) Physical improvement (fitness game)
4. People Fun - Social interaction with NPCs and other players
    a) Self-expressions, personalization
    b) Cooperation
    c) Competition

After playing the game, playtesters were asked to grade their different fun experiences for each part respectively. A copy of the survey can be found in the appendix section, and the collected results can be found in the result section.

4.2 The *Flow Theory*

Besides evaluating players' overall fun experience after the complete play session, this study also focuses on the dynamic engagement during the playthrough. Mihaly Csikszentmihalyi's *Flow Theory* has long been adopted in game design as a measurement for player engagement (Schell, 2014, p. 118). In short, *flow* is an optimal experience in which the level of challenge in any complex ability is just above the level of ability of the person attempting the task (Csikszentmihalyi, 1990, p. 74). Figure 10 and 11 show the original *flow theory* and the evolved model for evaluating *flow experience* as related to challenge and ability.

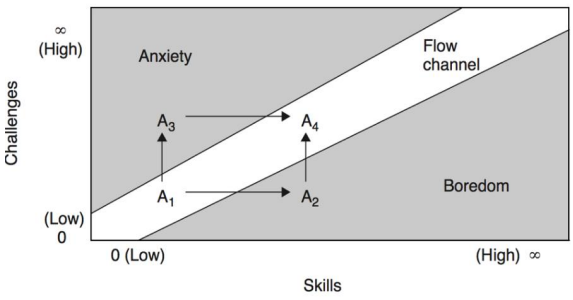


Figure 10: The Flow. After Mihaly Csikszentmihalyi, *The Flow* (1990), p. 74

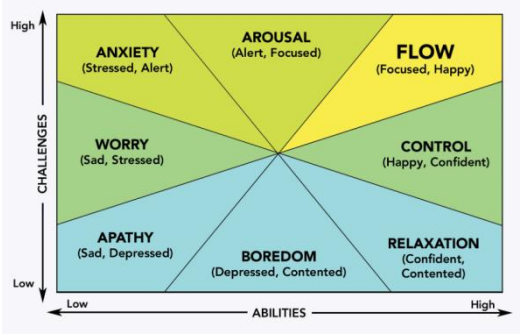


Figure 11: The model of flow as related to challenge and ability

To evaluate how adaptive PCG succeeded or failed in *Jungle Maze*, players were asked to recall the engaging and unpleasant (anxious or bored) moments during interviews. The interview questions were organized according to the fun types in the survey. For example, players were asked when the game prompted strategic options, how engaged did they feel. At last, players' feedback was categorized by respective fun types. The interview reflections were later combined with survey results to better evaluate Jungle Maze's performances in implementing adaptive PCG.

4.3 Research Procedure

Participants were asked to follow 3 steps:

1. Playing the game *Jungle Maze*, making sure to pass all levels.

2. Filling out the survey, comparing between the fun experiences in pre-made and adaptive PCG levels.

3. Talking about the choices in the survey, reflecting on *Jungle Maze*'s successes and failures in creating the mentioned fun types.

The 8 sub-fun types used in the survey are listed below. Every type of fun is followed by two 5-scale scalar questions, asking about two parts' performances respectively.

1. Hard Fun challenge - overcoming obstacles and achieving the goal.

2. Hard Fun short term strategy - strategic decision within a single level

3. Hard Fun long term strategy - strategic decision across different levels

4. Easy Fun creativity - attempting different in-game actions and testing the results

5. Easy Fun uncertainty - unpredictable in-game objects or events

6. Easy Fun exploration - spatial exploration in maps or logical exploration in systems

7. Easy Fun role-play - substituting into the game and remembering your own journey

8. Serious Fun practicing real-life skills - time/resource management

After the survey, participants were asked to reflect on their detailed experiences in interviews. It is worth noting that the fun-experience-grade in the survey does not necessarily correlate with the positive or negative reflections in the interview. When players engaged in certain fun experiences more than other types, the corresponding game designs also attracted more attention. Therefore, a praised fun experience from the survey could receive more critiques during the interview. The involved game design modules hence should be more robust and need more careful designs.

5. Results

This study consisted of 25 valid survey replies and 8 online interviews. Survey participants include 18 males and 7 females, and the gender ratio in the interview sessions is 5 males to 3 females.

5.1 Quantitative Result

To evaluate *Jungle Maze*'s performance in creating fun, the survey questions were organized by respective fun types. Every question consists of two 5-scale-questions, asking about the amount of fun experience players felt in every part (per-made and adaptive PCG). For example, in the challenge fun question, scale 1 to 5 means:

1. No challenging experience at all
2. Few challenging experiences
3. Some challenging experiences
4. Many challenging experiences
5. A Lot of challenging experiences

There are 8 questions in a survey, standing for 8 types of fun that players can grade. The following figures and descriptions cover the statistical result by fun types. A summary about the overall comparison between pre-made and adaptive PCG levels can be found at the end of this section.

	1	2	3	4	5
Adaptive PCG	0	2	12	10	1
Designed	3	9	11	1	1

Figure 12: Survey feedback - grades on challenge fun

Challenge fun derives from the feeling of overcoming obstacles and achieving the goal. Most of the challenge experiences happened during the combat. From the survey results, adaptive PCG levels received grades with the mean of 3.4, and the designed levels received grades with the mean of 2.52. The paired t-test returned a p-value of $4.85*10^{-10}$ (<0.05), showing that adaptive PCG produces more short term strategic

experiences. The differences in means and the p-values from all data groups will be summarized later.

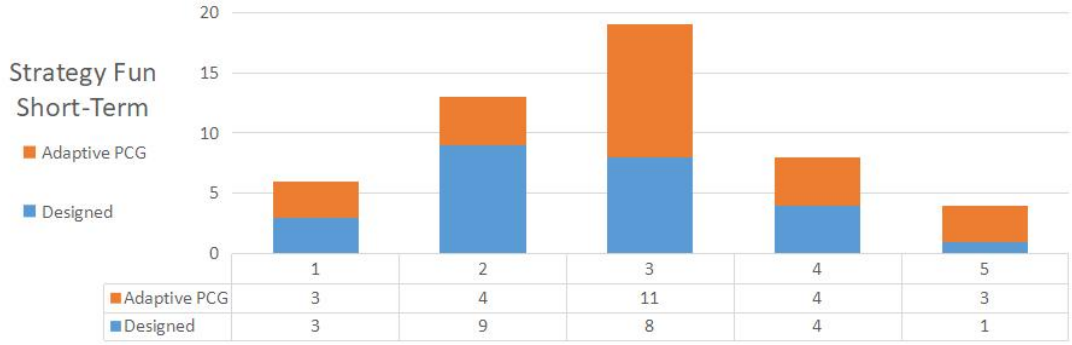


Figure 13: Survey feedback - grades on short-term strategy fun

Short term strategic fun derives from the strategic decision within a single level. This includes strategies like movement strategy, inventory sorting and attacking priorities. From the survey results, adaptive PCG levels are graded with a mean of 3, and the designed levels received grades with the mean of 2.64. The paired t-test returned a p-value of 0.001195 (<0.05), showing that adaptive PCG produces more short term strategic experiences.

Figure 14: Survey feedback - grades on long-term strategy fun

Long term strategic fun derives from the strategic decisions across levels. This includes strategies like reserving weapons and health supplies for future levels. From the survey results, adaptive PCG levels are graded with a mean of 3.4, and the designed levels received grades with the mean of 2.36. The paired t-test returned a p-value of $1.439*10^{-13}$ (<0.05), showing that adaptive PCG produces more long term strategic experiences.

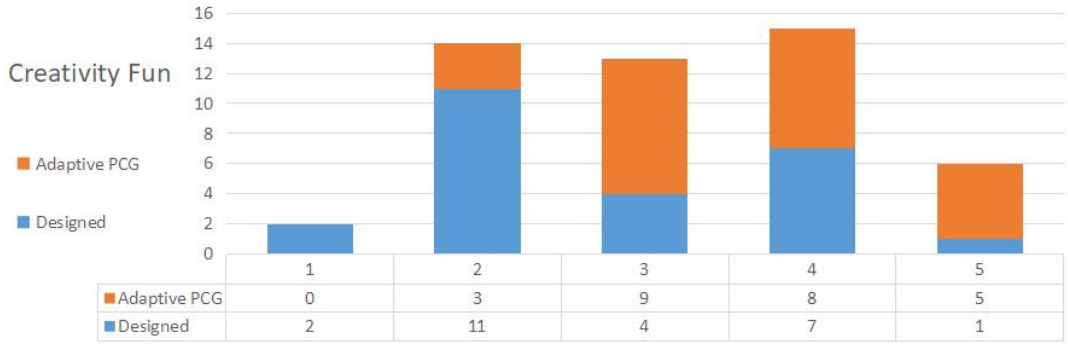


Figure 15: Survey feedback - grades on creativity fun

Creativity fun derives from attempting different in-game actions and testing the results. From the survey results, adaptive PCG levels are graded with a mean of 3.6, and the designed levels received grades with the mean of 2.76. The paired t-test returned a p-value of $4.669*10^{-9}$ (<0.05), showing that adaptive PCG produces more creative experiences.

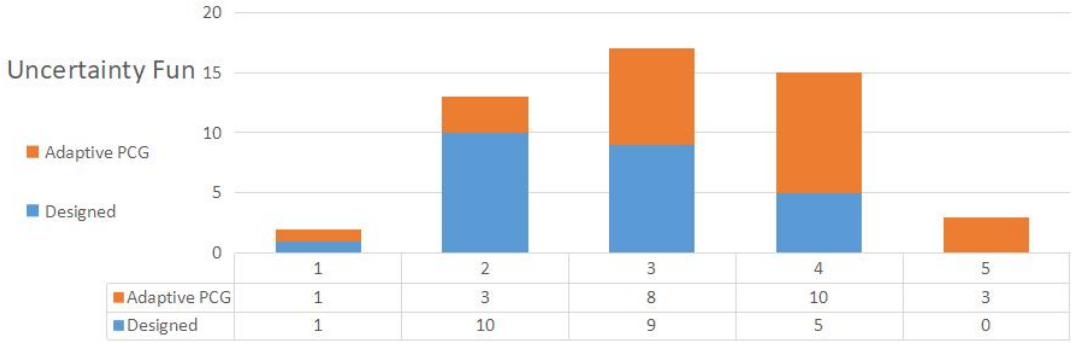


Figure 16: Survey feedback - grades on uncertainty fun

Uncertainty fun derives from encountering unpredictable in-game objects or events. From the survey results, adaptive PCG levels are graded with a mean of 3.44, and the designed levels received grades with the mean of 2.72. The paired t-test returned a p-value of $4.34*10^{-8}$ (<0.05), showing that adaptive PCG produces more uncertain experiences.

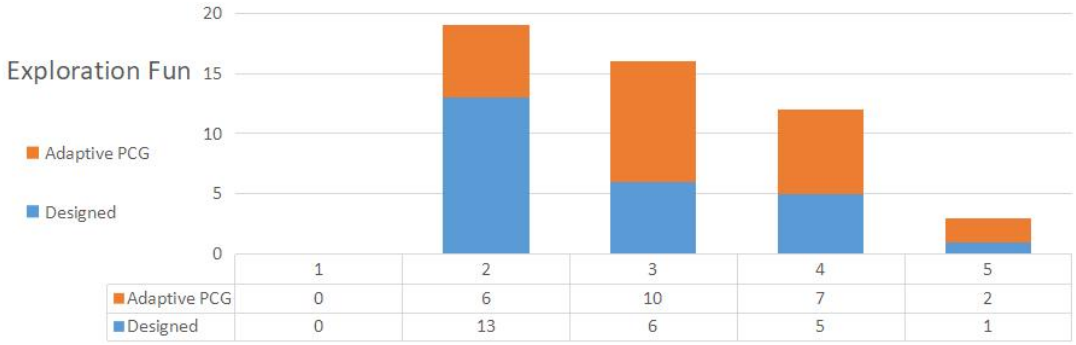


Figure 17: Survey feedback - grades on exploration fun

Exploration fun derives from either spatial exploration in maps or logical exploration in systems and rules. From the survey results, adaptive PCG levels are graded with a mean of 3.2, and the designed levels received grades with the mean of 2.76. The paired t-test returned a p-value of 0.0002211 (<0.05), showing that adaptive PCG produces more exploration experiences.

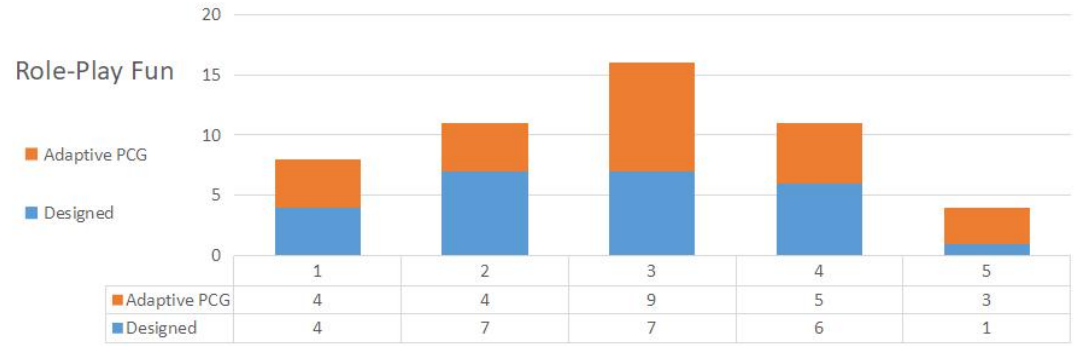


Figure 18: Survey feedback - grades on role-play fun

Role-play fun happens when players substitute themselves into the game and remember their own journeys. From the survey results, adaptive PCG levels are graded with a mean of 2.96, and the designed levels received grades with the mean of 2.72. The paired t-test returned a p-value of 0.01107 (<0.05), showing that adaptive PCG produces more role-play experiences.

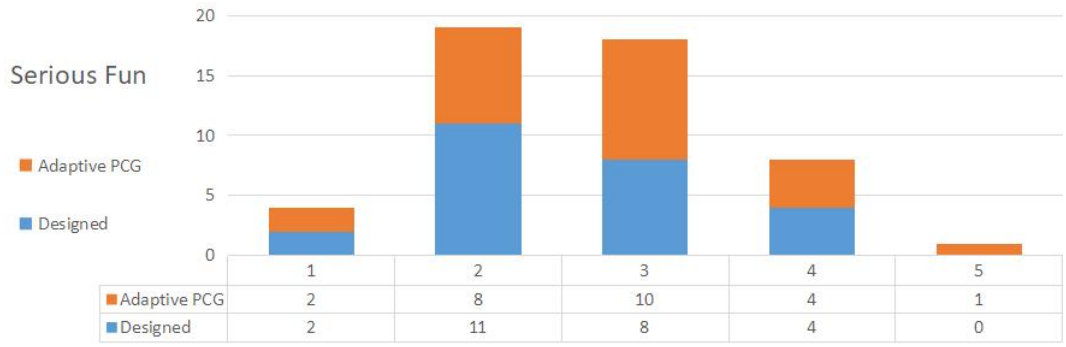


Figure 19: Survey feedback - grades on serious fun

Serious fun happens when players feel the growth of their innate skills. From the survey results, adaptive PCG levels are graded with a mean of 2.76, and the designed levels received grades with the mean of 2.56. The paired t-test returned a p-value of 0.02198 (<0.05), showing that adaptive PCG produces more personal-growth experiences.

The results indicate that adaptive PCG received positive feedback in all 8 fun types. This accords with former studies' conclusion about adaptive PCG's prospect as a successful game design element (Yannakakis & Togelius, 2011). To better demonstrate the grade differences and figure out nuances between different fun-creation potential, results are sorted in the Table 2. The mean difference in this table represents how much better adaptive PCG levels performed compared to pre-made levels.

Fun Type	P-value in ascending order	Mean		
		Pre-made	Adaptive PCG	Difference
Long term strategy	$1.44*10^{-13}$	2.36	**3.4**	**+1.04**
Challenge	$4.85*10^{-10}$	2.52	**3.4**	**+0.88**
Creativity	$4.67*10^{-09}$	2.76	**3.6**	**+0.84**
Uncertainty	$4.35*10^{-08}$	2.72	**3.44**	**+0.72**
Exploration	$2.211*10^{-4}$	2.76	**3.2**	**+0.44**
Short term strategy	$1.195*10^{-3}$	2.64	3	+0.36
Role play	$1.107*10^{-2}$	2.72	2.96	+0.24
Serious	$2.198*10^{-2}$	2.56	2.76	+0.20

Table 2: Side-by-side comparison between pre-made and adaptive PCG

We used the midpoint in the scalars, number 3, to divide the result. Mean values larger than 3 means that adaptive PCG has evident advantages in creating the matching fun experiences.

To further explore the decisive factors behind the most experienced (mean > 3) fun types and analyzing the possible risks in the corresponding game designs, interviews were conducted.

5.2 Qualitative Result

Due to the impact of the global pandemic, all 8 interviews were conducted online. Though the participants who eventually took the full interview were a subset of all playtesters, the researcher conducted several rounds of return visits to avoid missing any of the valuable viewpoints. During the interviews, the most important criteria is to compare between the designer's initial expectations in creating respective fun and the players' actual experience (positive and negative) during the playtests. By identifying participants' responses in relation to the fun types, we organized their reflections into the Table 3.

Fun Type	Levels		Participants Feedback	Mismatches with Designer's Expectation
Challenge	Designed Levels	Positive	The challenge mainly came from combat.	No mismatch
		Negative	Game seemed **easy**.	The game design aimed to create challenges.
	Adaptive PCG levels	Positive	The challenge **mainly came from combat.**	The adaptive levels aimed to challenge players by abundant strategic choices. If players do not shift their play styles in the adaptive PCG, the game design is not effective in this part.
		Negative	The generated map was not "surprising", **map elements are not abundant** for playing.	
Short term Strategy	Designed Levels	Positive	Collectable weapons in the designed map made up of my short-term strategy.	No mismatch
		Negative	The game **didn't produce enough pressure** under which decisions must be made.	The game should always provoke meaningful decisions.
			All bullets can defeat an enemy in 3 shots, which makes all **weapons** kind of **identical**.	The weapons were designed to be more useful under certain circumstances.
	Adaptive PCG levels	Positive	Increased item types made me use items more frequently, in case cards blocking the way.	No mismatch
		Negative	The new terrain cards **block the inventory** space, producing an annoying experience.	The terrain cards are designed to provide choices. But, in this case, players think such decision-making is unnecessary.
Long term Strategy	Designed Levels	Positive	Mainly from saving supplies for the next level.	No mismatch
		Negative	No related feedback.	/
	Adaptive PCG levels	Positive	I **later understood** the meaningfulness of choosing and matching terrain and enemy cards. This created strategic fun.	It is worth noting that many players had a hard time realizing the necessity of using terrain cards during the early playthroughs.
		Negative	The **information** in this game **got overwhelming** when all kinds of cards jammed in the inventory.	Again, the information in the game should become the soil for meaningful decisions. It gets overwhelming because they do not matter that much to players, hence negatively interfering players' natural decision-making in their minds.
		Negative	I mostly just used whatever I had. I **didn't even notice the "adaptive"** PCG. I thought all maps are totally random, until you told me just now.	

Fun Type	Levels		Participants Feedback	Mismatches with Designer's Expectation
Creativity	Designed Levels	Positive	The various surroundings inspired me to be creative during combat in different places	No mismatch
		Negative	No related feedback.	/
	Adaptive PCG levels	Positive	I was motivated to explore different terrain and enemy combinations.	No mismatch
		Negative	Most of the **PCG choices did not matter**. I wouldn't lose or have a hard time if the wrong cards were used.	Same issue covered in short and long term strategy section
Uncertainty	Designed Levels	Positive	I was curious about the maps in front.	No mismatch
		Negative	Most of the map was **visible at first glance**, which **weakened the uncertainty**.	This issue also exists in PCG maps, as the generated maps are even less diverse.
	Adaptive PCG levels	Positive	I was very **uncertain about what will happen after the random generation**.	Players shouldn't be so uncertain about the generation result, because the adaptive PCG allows previewing and interfering with the random generation process. This is because players do not realize the meaningfulness of the terrain card.
		Negative	No related feedback.	
Exploration	Designed Levels	Positive	The designed level had many detours leading to rewards, making it worth exploring.	No mismatch
		Negative	Game was **easy**, and sometimes I did not want to explore because I can easily pass the level.	Same issue covered in short term strategy section
	Adaptive PCG levels	Positive	It was refreshing to me seeing the results of different generations.	These seem conflicting with each other, but they actually say the same thing. Because one factor is playing the key here - playing time. Players who do not repeat much might not grasp the "adaptive" nature of the generation, while the experienced players get bored because the generation is no longer random to them.
		Negative	The randomly **generated maps are very similar**. When using the same card combinations, the map looked almost identical. Therefore, I didn't explore after the first time.	

Fun Type	Levels		Participants Feedback	Mismatches with Designer's Expectation
Role play	Designed Levels	Positive	The exploration was immersing.	No mismatch
		Negative	No related feedback.	/
	Adaptive PCG levels	Positive	I can feel the role-play from controlling my own journey.	No mismatch
		Negative	The **map diversity is not abundant** enough for me to have more controls. This makes the game a bit boring.	Same issue covered in exploration section
Skill practicing	Designed Levels	Positive	No related feedback.	/
		Negative	I learned some divide-and-conquer skills from fighting through the maps.	No mismatch
	Adaptive PCG levels	Positive	I gradually grasped the rules, and started to use strategies. Because I **cannot ignore those new cards in the inventory**.	This is the similar issue as explained in long term strategy - the adaptive PCG rules do not provoke strategies immediately. Skills practicing was not self-motivated, instead, many players use terrain cards for offloading the burdens.
		Negative	Resource management seemed weak in this game. The overall difficulty is **easy**.	

Table 3: Organized interview feedback

In summary, the major mismatch between players' experiences and designer's expectations is that though the adaptive PCG enhanced some fun experiences, the meaningful decision-making in these fun types was still insufficient or made in wrong places. According to player feedback, there are 3 major reasons.

1. **Adaptive PCG options were not meaningful.** Players' improved experience was from the superficial impression of increased complexity, instead of from in-depth interactions with the adaptive system. Moreover, the combat and exploration were not deeply affected by terrain generation choices, thus players did not feel the necessity of using terrain cards carefully.

2. **Adaptive PCG choices were overwhelming to novice players**. Though in the current easy version, experienced players could still escape from making adaptive PCG decisions, to novice players, the massive map generation questions could burden them with dense and daunting tasks.

3. **Random generation results became way too predictable**. When the players realized how to use the terrain cards and have total control over the upcoming game contents, the map generation agency shifted from game to players, which violated the game's PCG nature.

6. Discussions

In this section, adaptive PCG's merits and risks exposed in results will be discussed.

6.1 What can adaptive PCG give to designers

6.1.1 Adaptive PCG can enhance experience by long-term strategy

According to survey results, the adaptive PCG system in *Jungle Maze* successfully enhanced following fun experiences.

Fun types	Adaptive PCG Grade Mean	Mean Difference
Long term strategy	3.4	**+1.04**
Challenge	3.4	**+0.88**
Creativity	3.6	**+0.84**
Uncertainty	3.44	**+0.72**
Exploration	3.2	**+0.44**

Table 4: The fun types that adaptive PCG showed obvious advantages

In short, *Jungle Maze*'s adaptive PCG system prompted *strategic* options and *challenged* players by requiring them to be *creative* in *exploring uncertainties* lying within and coming out of the adaptive PCG system. Though *challenge*, *creativity*, *uncertainty* and *exploration* are common target experiences in most PCG game designs (Short & Adams, 2017, p. 10-12), the *long-term strategy* changed the tune of the game. For example, by handling map generation controls to players, the interactions with the game world expands from only reacting to unknown *challenges* to also being well prepared before possible *challenges*. Therefore, appending adaptive PCG to a game can expand the original *creativity*, *uncertainty* and *exploration* experiences.

However, adaptive PCG cannot guarantee immediate success in creating these fun experiences. In *Jungle Maze*, the adaptive system was directly attached to the map generator, and this experimental combination could have hidden risks.

6.1.2 Adaptive system can also create risks

Direct introduction of new game mechanics is a risky move, as it could create overcomplicated rule sets and make the game hard to learn. In *The Art of Game Design*, this is recognized as *innate complexity* (Schell, 2014, p. 195). According to Jesse Schell's advice, choices in games should derive from simple but expandable rules (*emergent complexity*) and always provide clear first-step instructions (*accessibility*). According to interview feedback, the adaptive PCG in *Jungle Maze* was overwhelming players with choices, which restrained its advantages in creating fun. Therefore, to avert adaptive PCG's risks and maximize its potential in enhancing fun, the current hotchpotch approach should be optimized.

6.2 How to design better adaptive PCG game

6.2.1 Be aware of the interchangeable options in decision-making

As a player-driven mechanic, adaptive PCG especially counts on meaningful decision-making. However, from *Jungle Maze* playtest feedback, many players ignored expected decision-makings even towards the end of the game. Players choosing cards randomly was a common phenomenon during playtests. To identify

the problems more clearly, we need to first decompose Jesse Schell's definition a little bit and see how our implementation went wrong.

"*Meaningful choice* . . . will have a real impact on what happens next, and how the game turns out" (Schell, 2014, p. 179). Apparently, players' in-game actions should carry out game-state changes (impact what happens next) and affect the players' progress on achieving objectives (impact how the game turns out). In *Jungle Maze*, the meaningful choices are built around two assets - weapons and levels (consist of terrain and enemies). The design aimed to inform players that every weapon has advantages and disadvantages when dealing with different enemies and terrains. For example, the gun with bouncing bullets works better in narrow spaces like small rooms. Meanwhile, the small rooms help block the damage from range-attacking enemies. Ideally, players should think carefully before confirming PCG settings, in case adverse situations are created. However, such experience was not strong.

According to player feedback, the strategic decision-making was weak because the game wasn't hard (stats balance) and weapons were not diverse (item design). In other words, players thought they could handle all situations with any weapons (options are interchangeable), thus they stopped making decisions strategically.

While we can always tune and patch the game with harder stats settings like higher enemy damages, forcing players to find the right choice among nuanced items, it is better to provide more diverse options. One approach could be designing items with more distinctive mechanics. For example, we can design a grenade, which is especially powerful in wall levels (you can attack gunmen when they cannot touch you) while dangerous in enemies' hands behind the obstacles.

Therefore, in adaptive PCG games, creating strong strategic correlations between game objects, like weapon and level environment, is an effective way to provoke meaningful decisions. Such designs can also produce a series of trade-offs in resource management. For example, players sometimes need to choose between using an unmatched item to relieve emergencies or keeping it for better values in the future.

Strong correlations enrich players' autonomy, encouraging players to control more and think more in games. However, emphasizing strategic correlations exhaustively can also be dangerous, especially in adaptive PCG games.

6.2.2 Adaptive choices should not control too much in PCG games

Player autonomy is regarded as a key factor to build value and sustain engagement in games (Rigby & Skinner, 2014). However, this usually refers to the abundant available interactions in a crafted or generated game world. In an adaptive PCG game, when players have too much autonomy over the generator, we might cross the critical line where players design the game more than designers do, causing damage to the *flow* experience.

Jenova Chen presented a dynamic adjustment model to maintain *flow* experiences for different kinds of players. This model aims to adjust *flow channels* for both hardcore and novice players dynamically by "pulling" them out of their own frustration or boredom zone when bad experiences are detected (Chen, 2007). A demonstration of this model can be found in Figure 20.

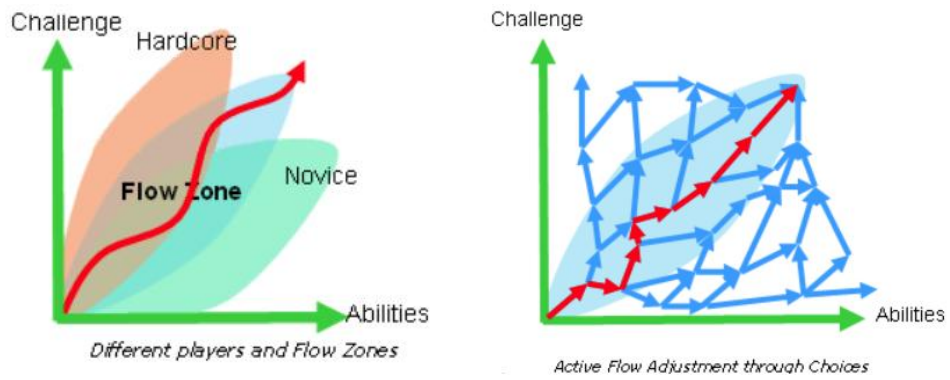


Figure 20: Dynamic flow adjustment. After Jenova Chen, *Flow in games* (and everything else) (2007).

Flow is an ideal experience that designers work hard to achieve. But, in adaptive PCG games that allow players to fully determine future game content, the traditional game design model gets reversed - whether players can or cannot reach the flow experience now depends on players' own decisions. Even if players do not always make biased decisions, like always picking the same, easy level, they can hardly make designer-like decisions and create fun levels by themselves.

6.2.3 Adaptive and PCG should be placed side-by-side, not be mixed up

To this point, the discussion seemingly steps into a dilemma - when we enhance adaptive decision-making, we also abuse the PCG's uncertainty. On the one hand, the adaptive nature informs players about the certain consequences behind their actions and encourages them to control the future, while on the other hand, the PCG mechanic aims to produce uncertain fun with an unpredictable future.

However, this does not mean that adaptive design and PCG are irreconcilable components. From a discrete math point of view, the negation of *all* is *some*, instead of *none* (Pace, 2012, p.67). For example, the opposite of "all students" is "some students", instead of "no student". Accordingly, the fix for player-having-total-control over map generation is not player-having-no-control, but player-having-some-control. Therefore, we can reach coexistence by allowing adaptive choices and the PCG system both control a portion of the game and then assemble the results together. If we only allow players to determine small sub-areas on the map and randomize the rest, we can reach the balance where players feel the autonomy of controlling some risks while still having an uncertain adventure affected by randomness. In short, we need *partially adaptive PCG* designs.

In *Jungle Maze*, the complete autonomy misled the PCG's uncertainty and exploration experiences, especially after repeated gameplay. According to the previous discussion, we can separate players' controls from the random generator. Figure 21 shows one possible improvement.

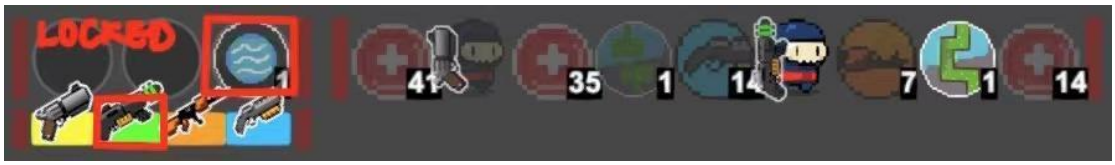


Figure 21: Improved design in *Jungle Maze* - limited adaptive control

For example, when level begins, we can randomly specify map or enemy settings, instead leaving everything blank to players. When players know that 60% of the next level will be covered with water and high damage enemies will walk around, a clearer objective emerges - players need to use cards more wisely in order to reduce the risks caused by the current setting. More specifically, they need to either reserve wide-range weapon ammos or use terrain and enemy cards in order to reduce water area or the proportion of high damage enemies.

Another benefit of partially adaptive PCG is providing optimizations for algorithm complexity. As mentioned in design methodology, when players are responsible for generating the whole map, 3 terrain cards already need 7 different full-map generation algorithms. However, if we only allow players to add sub-areas into a machine generated world, we can use independent mini algorithms instead of monolithic algorithms for any combinations. For example, we can inform players that a sub-region generated by their terrain card combination will be injected into a machine generated map. When players are told about the base style of the next level, they can evaluate the risks and use appropriate cards to generate preferred sub-regions. Figure 22 shows a possible map generated from this design.

Figure 22: Improved design - injecting adaptive result

Meanwhile, in future updates, if we want to add possibly conflicting cards like a dessert card, we do not need to worry about how to combine dessert with water. Instead, we can just spawn water and desert in different locations and allow each of them to interact with compatible terrain8cards, like path and room.

7. Conclusion

Though many researches and commercial games have endorsed adaptive designs' capability in PCG games, complete adaptive PCG games do not appear, seemingly doubting the feasibility of such practices. The result of this study indicates that this conflict actually stems from an underlying competition between players' adaptive controls and machines' PCG system - while PCG is defined as content generations without direct human interference (Togelius et al., 2011), adaptive design encourages active human autonomy.

By developing and analyzing the digital game *Jungle Maze*, this paper presented adaptive PCG's potential in enhancing *long-term strategy*, *challenge*, *creativity* and *uncertainty*. Since long-term strategy was recognized as the key experience, PCG designers should consider using adaptive PCG mechanic when they need more long-term decision-making in the game.

Through the players' feedback, this study disclosed adaptive PCG's design risks and proved the feasibility of combining player autonomy (adaptive) with machine generation (PCG). In conclusion, to make the coexistence happen, designers must not directly mix these two mechanics together, causing one to expel another. Instead, player control and machine control should work separately and only merge at the finishing stage.

Although this study only implemented one game for analysis, the design iterations were concrete and intensive. As the result of exhaustive data collection and discussion, the straightforward conclusion again proved the difficulty of spotting a fundamental design risk. That said, the study's scrutinous process and the outcome can still become valid references for any game-related analysis or design practices. In particular, the introduction of analytical tools including the *Four Fun Keys* (Lazzaro, 2015), the adaptive *flow* model (Chen, 2007) and discrete math can inspire future adaptive PCG or any other game design studies.

Aside from in the adaptive PCG practice, this study also opens up a more general question in game design, which is how to keep players in an *flow channel* while giving players distinct control over game contents. Though this research paper thoroughly experimented such coexistence in an adaptive PCG game, the decisive factors can be different in other designs or game genres. Conceivably, practices in

reconciling seemingly opposite design factors can inspire more innovations in game designs.

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10. Appendix

10.1. Survey

Introduction:

Dear respondent, my name is Yang Hu, also a final year graduate student from Northeastern University. This survey serves as the data collector for my graduate thesis in the Game Science and Design program. There are 3 multiple choice questions and 16 scalar choice questions. The survey might not take more than 10 minutes.

Your participation is entirely voluntary, and all information collected in this survey will be kept anonymous and strictly confidential. The information gathered will only be used for the following study purposes. You have the right to refuse to answer any questions/items or to avoid participating at any time for any reason.

This study uses survey-interview combinations for player analysis. It will be much appreciated if you can also schedule an interview with me to discuss your survey choices in detail. The interview will not take more than 15 minutes, but I will be glad to talk more with you if you wish to.

If you have any queries regarding the survey questions, please contact me. Thank you for giving your valuable time to complete the following survey questionnaires.

1. Please leave your name or nickname. This information is only used for identifying between different responses during interviews.

2. What is your current gender identity?

- Female
- Male
- Other
- Not sure
- Rather not to say

Mini questions

Warm-up: this game consists of two parts:

a. The first 3 levels are designer-made levels

b. The last 3 levels are randomly generated under players' instructions.

In the following questions, please grade your experience of these two parts . The question layouts of the mini questions are all identical, hence only the first question is fully expanded here.

3. Hard Fun challenge - overcoming obstacles and achieving the goal.
   - No challenging experience at all
   - Few challenging experiences
   - Some challenging experiences
   - Many challenging experiences
   - A Lot of challenging experiences
     - ___ Challenge experience in pre-made levels
     - ___ Challenge experience in adaptive PCG levels

4. Hard Fun short term strategy - strategic decision within a single level
5. Hard Fun long term strategy - strategic decision across different levels
6. Easy Fun creativity - attempting different in-game actions and testing the results
7. Easy Fun uncertainty - unpredictable in-game objects or events
8. Easy Fun exploration - spatial exploration in map or logical exploration in system
9. Easy Fun role-play - substituting into the game and remembering your own journey
10. Serious Fun practicing real-life skills - time/resource management

10.2 The original survey link

https://forms.gle/VDN6yWiVFUWcqNzZ9

10.2 Game link (itch.io)

https://mfdarenz.itch.io/jungle-maze