
# Puzzle Design Using Iterative Discovery

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# Abstract

*Guac-A-Mole* is a puzzle game that invites players to discover by playful exploration not only the solutions to its challenges, but also the underlying rules. This style of play is encouraged using tacit tutorials, unprompted activity sequences which require players to demonstrate their understanding of controls, rules and mechanics to progress. The puzzles themselves were developed by a similarly playful discovery process of iterative prototyping and playtesting. Evaluation of test data and user survey results suggest opportunities for improvements in mechanics comprehension and difficulty progression.

# Acknowledgements

Without Bailey Sostek, *Guac-A-Mole* would not exist. I would like to extend my deepest gratitude to him for encouraging and humoring me in my earliest days of game development.

I would also like to thank my thesis advisor Brian Moriarty for his vital guidance and advice throughout this project. I am also grateful to Gillian Smith, Yunus Telliel, and Jennifer DeWinter for their aid and council in my pursuit of academia.

Finally, I would like to thank James Boucher and Josh Sostek for their guacamole recipes, the combination of which (as seen in Appendix D) led directly to the creation of *Guac-A-Mole*.

# Contents

Figure 1. Concept art for *Mage Hand*. Source: Charles Baldwin, artist.

# 1. Introduction

This Master's project began with *Mage Hand,* a puzzle game built on a complex 3-dimensional architecture that players could move, shift, and manipulate (Figure 1). This mechanic was intended to challenge the navigation and spatial reasoning skills of players.

Inspiration for *Mage Hand* came from the world design of *Dark Souls* (FromSoftware, 2011) and the dungeon layouts of Nintendo's *Legend of Zelda* series. As a player progresses through *Dark Souls,* each area links to previously visited locations, creating an interconnected 3-dimensional space. Players must form a mental map of the space as they navigate it in order to quickly traverse familiar areas and discover new ones. Similarly, many of the dungeons found in the *Zelda* series involve complex 3-dimensional architectures which players must learn to move through and manipulate to make progress.

The internalization and mastery of complex spaces required by these games provides a distinctive experience in gaming. *Mage Hand* sought to emulate that experience.

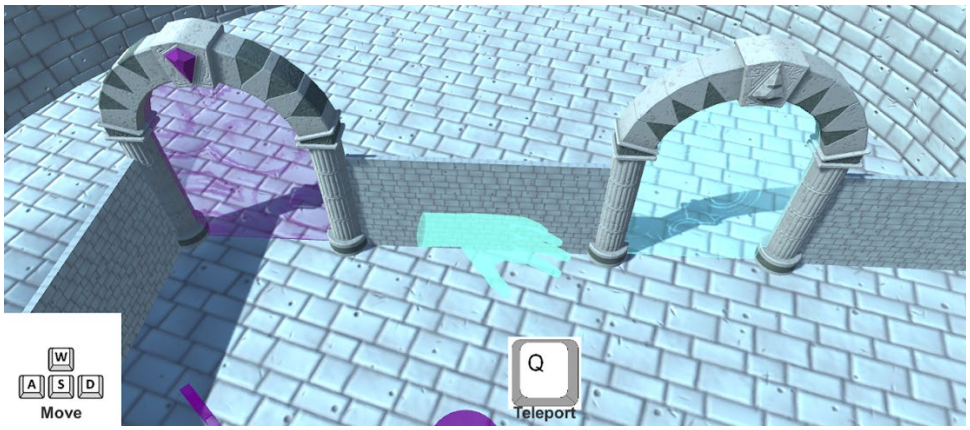


Figure 2. Initial location of *Mage Hand*. Source: Screen capture.


Figure 3. Concept art for puzzle gates in *Mage Hand*. Source: Charles Baldwin, artist.

A preliminary set of rooms was developed that the player could shift around like a slide-puzzle (Figure 2). Navigation required a dynamic visualization of this flexible layout. Gates and keys in each room added local micro-challenges to the play experience (Figure 3).

After initial playtesting, it became clear that the game would require a sustained period of iterative refinement beyond the scope of a Master's project. Although I was gaining expertise in 3D physics working on *Mage Hand,* most of my time and effort were being spent dealing with visual and mechanical glitches rather than puzzle design. I therefore decided to re-focus my effort onto another game I'd been working on in parallel.

Figure 4. An early version of *Guac-A-Mole*. Source: Screen capture.

*Guac-A-Mole* had been in development since I first created it with Bailey Sostek and took it to PAX East 2019 through the WPI booth (Figure 4). The advanced production state of *Guac-A-Mole* made it a better project candidate. Sostek's game engine was set up to support efficient puzzle development. Additionally, many of the basic mechanics were already in place and had been tested by numerous players. This meant that I could focus on what I really wanted to do: develop and sequence excellent puzzles.

This report explains the design methodology for the puzzles of *Guac-A-Mole*. The Critical Context section identifies the games and designers that served as primary inspirations, and reviews the critical context of my design approach to identify its relation to the development practices of those designers. The struggle between narrative- and ludic-focused development is explored, as well as the extent to which a game can be said to "design itself."

The Design section explains how the strategies discussed in the Critical Context section were applied to *Guac-A-Mole*.

The Evaluation section provides playtesting results, including charts and graphics assembled from objective data from recorded play sessions, as well as subjective feedback collected from survey responses. Accompanying this data is an interpretation and analysis of how it might be used to further improve the puzzles of *Guac-A-Mole*.

The Conclusion considers the apparent strengths and weaknesses of *Guac-A-Mole*'s design, and identifies key challenges faced throughout the development process.

## 2. Critical context

*Guac-A-Mole* is a puzzle game, and this report primarily concerns itself with the design of its puzzles. These puzzles are never individual problems presented in isolation. Often, the context in which a puzzle is presented is just as important to the player's ability to solve it as the specific mechanics of the puzzle itself. This contextual influence can take a multitude of forms, including:

- The sequence of puzzles leading up to a puzzle.
- The name of a puzzle.
- The purely aesthetic, non-mechanical features of the environment in which a puzzle appears.
- Any user-interface or textual instructions that may be presented.

All of these factors influence how a player approaches a particular challenge placed in front of them. Tuning this collection of influences to serve a unified experience goal is a difficult task, but immensely satisfying to both players and designers when implemented successfully.

To properly contextualize the approach taken in the development of the puzzles in *Guac-A-Mole*, this section will analyze the practices of the developers of three puzzle games with different focuses. *The Witness* (Thekla, 2016) was created by Jonathan Blow, a highly opinionated designer who places mechanical consistency and logical rigor above all other considerations.

*Portal* (Valve, 2007) takes a more narrative-focused approach. Players must solve its ingenious puzzles in an amusingly contrived and increasingly hostile story context that

eventually offers instruction explicitly intended to make them fail. By contrast, the puzzles in Zachtronics games (such as Exapunks and Opus Magnum) are unusually flexible and open-ended in ways that encourage player creativity and experimentation, with minimal use of narrative scaffolding.

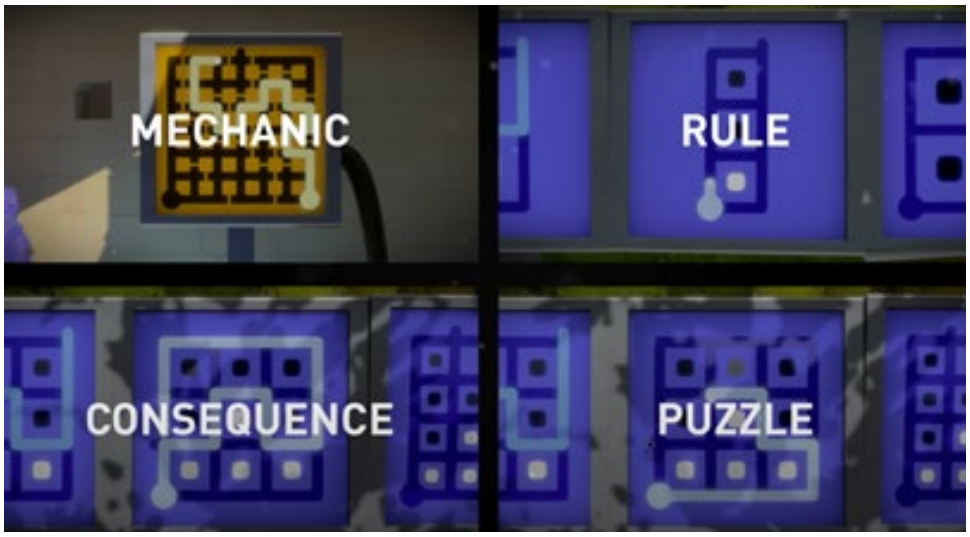


Figure 6. Illustration of Jonathan Blow's puzzle design process.
Source: Brown, Mark. "How Jonathan Blow Designs a Puzzle."(Brown, 2016).

## 2.1. *The Witness*

Jonathan Blow, creator of *Braid* (Number None, 2008) and *The Witness*, practices a design philosophy that cultivates the natural discovery and evolution of game mechanics. He utilizes a four-step process explained by Blow and Marc Ten Bosch in a 2011 IndieCade lecture, illustrated in Figure 6.

> It was very clearly the case that more ideas came out of the development process, and ended up in the final game, than I put into it as a designer. The process of designing the gameplay for this game was more like discovering things that already exist, than it was like creating something new and arbitrary. And another way to say that is that there's an extent to which this game designed itself. (Blow, IndieCade 2011)

Blow's process starts with a basic game mechanic (Step 1). By toying with this mechanic, ideas for variations develop, and potential rule expansions emerge (Step 2) based on those ideas. New rules bring about consequences (Step 3), including the possibility for intriguing interactions between rules. Effective rule composites are then actualized in the creation of new puzzles (Step 4).

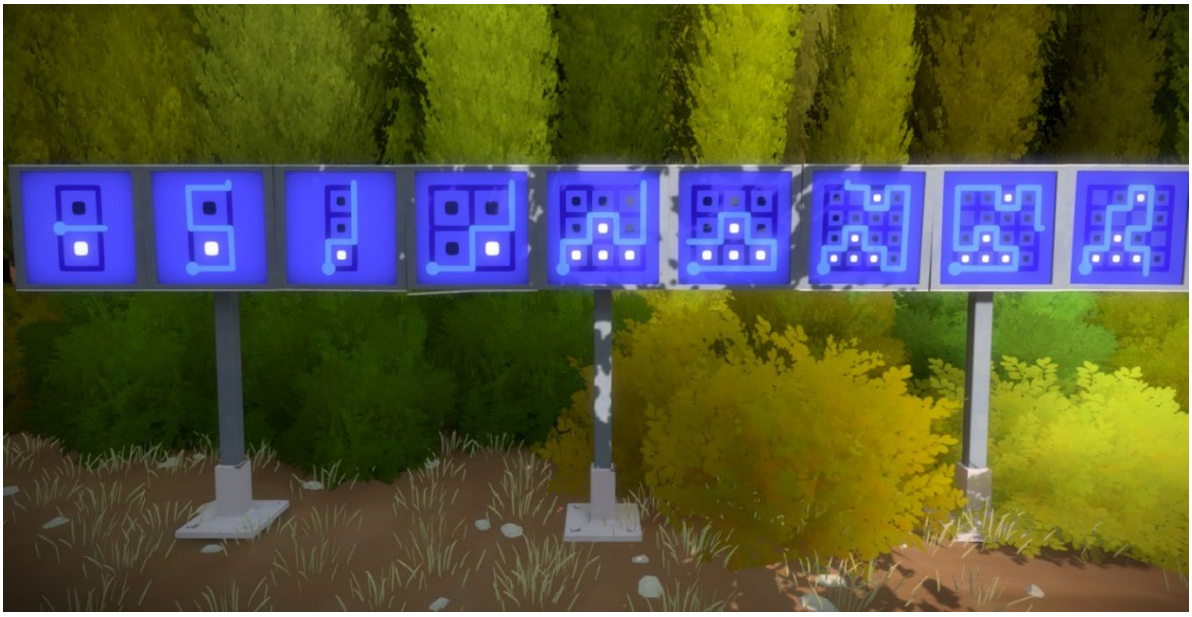

Figure 7. Sequence of Puzzles from *The Witness.* Source: Screen capture.

For Blow, puzzle design is about mining mechanics in search of fresh rules with interesting consequences. He methodically explores the ramifications of each consequence to the fullest. *Every* element of a mechanic is explored and twisted in every way it can, including sequencing, pairing, misdirection, reprisals, and many other techniques (Figure 7). Each puzzle, and each sequence of puzzles, exemplifies an interesting consequence unearthed through this process. His experience goal is to lead the player to share the delight of discovery.

After puzzles have been created, Blow is ruthlessly curatorial, editing out mechanics, rules, and challenges that lack a sense of surprise or novelty, or fail to add anything interesting to the conversation between himself and the player.

> For Jonathan Blow, a puzzle is never just a puzzle. It's a communication of an idea from the designer to the player. Solving the puzzle is the player's way of saying "I understand." And I think "I understand" is a significantly different concept to "I finally figured it out," which is how many puzzle games operate with their arbitrary steps and intricate sequences and red herrings and obtuse mechanisms. But the puzzles in Blow's games feel more fair. And that's why this design philosophy isn't just about letting the design help direct you to the next rule or the next puzzle. It's also about helping you make better and more honest puzzles. *Braid* and *The Witness* introduce all the elements up front and teach their mechanics quickly with introductory puzzles. From there, the harder puzzles are only about understanding the consequences of those known mechanics in different setups, combinations, and layouts. (Brown, 2016)

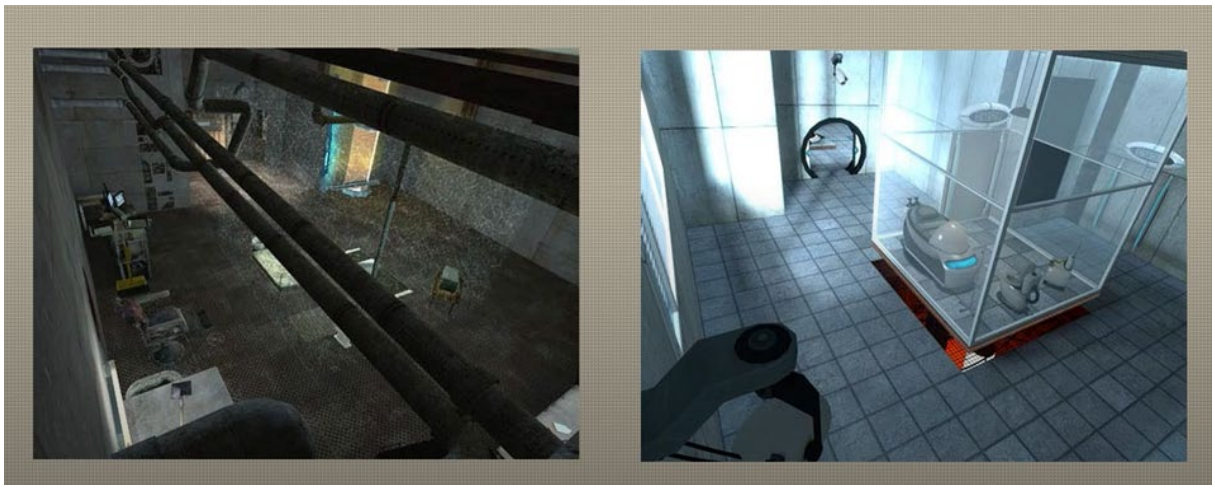

Figure 8. Opening scenes from *Portal*. Source: Screen capture.

## 2.2. *Portal*

Kim Swift and Erik Wolpaw discuss the development of *Portal* (Figure 8) in their Game Developers Conference lecture "Integrating Narrative into Game Design: A *Portal* Post-Mortem" (2020). They claim that the narrative of *Portal* on its own is not particularly compelling, and likewise the gameplay in isolation would feel dry. The tight integration between these two elements, according to Swift and Wolpaw, is what resonates with players of *Portal*.

Wolpaw explains this effect with his "Delta Theory." Games present *two* stories; one *explicitly* related through environment, scripted events, dialogue, cutscenes, etc., and another *implicitly* related by the sequence of actions taken by the player. Wolpaw believes that minimizing the differences between these parallel stories makes the overall play experience more satisfying.

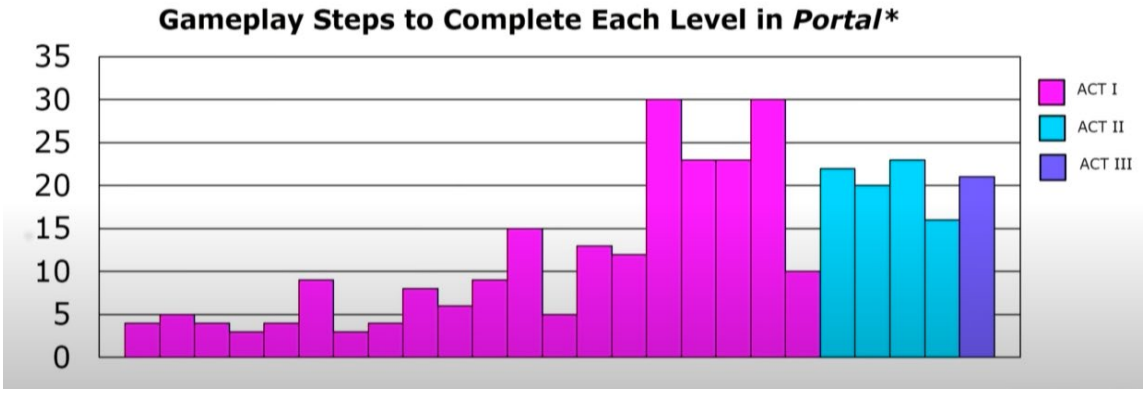


Figure 9. Steps required to solve the levels of Portal.
Source: *Level Design Workshop: Solving Puzzle Design* (Menzel 2017).

In accordance with Wolpaw's Delta Theory, the *Portal* team tried to never allow the narrative story to intrude on the gameplay story. The two were continuously adjusted to complement one another. Like Blow's strict curatorial approach, Wolpaw and his team were ruthless about "trimming narrative fat" from *Portal*. Exposition and dialog were pruned back or excised based on detailed playtest data and user feedback collected throughout the development of the game. Sample data is shown in Figure 9.

Figure 10. Fire pit scene from *Portal*. Source: Screen capture.

Achieving this without losing essential story elements required flexibility. The original game-ending boss battle involved a particularly complex puzzle, but playtesting showed that the finale just wasn't working. Another section that seemed to be working very well, however, was the "fire pit scene" (Figure 10). From the developer's perspective, this scene included one of the easiest puzzles in the game, but testing revealed that players considered it both challenging and rewarding due to its time pressure, high drama and visual impact. Swift and Wolpaw credit *Portal's* thoroughly-crafted narrative for its ability to make an easy puzzle feel difficult and satisfying, and they eventually applied this tactic to the final level as well.


Figure 11. A puzzle from *Opus Magnum* (2017). Source: Screen capture.

## 2.3. Zachtronics

Zach Barth, founder of independent game publisher Zachtronics, takes a different approach to puzzle design. According to Barth, his puzzles are primarily distinguished by their open-endedness (Barth, 2018). In contrast to many games, in which each puzzle has only one solution, Zachtronics titles such as *Opus Magnum* (Figure 11) present the player with a series of tasks, accompanied by a flexible set of rules and tools for solving them.

The approach Barth takes in creating these tasks seems similarly open-ended. “The way we make our puzzles: I just come up with something that looks solvable and interesting” (Barth, 2019). He also questions whether his freestyle challenges even qualify as puzzles. “This is something I’ve been wrestling with a little bit is, like, are these even puzzles? Like, does that even matter? I don’t know, I don’t care, I guess” (Barth, 2019).

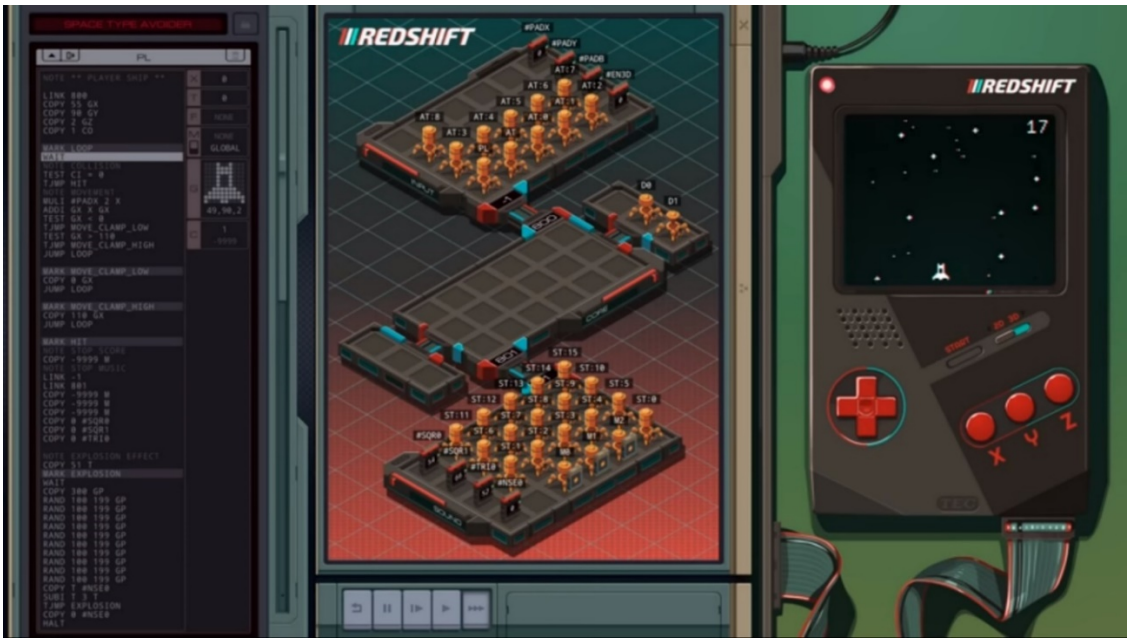


Figure 12: User interface of *Exapunks*. Source: Screen capture.

Barth claims to share Blow's focus on mechanics. "I'm a mechanics person. That's what comes first. Like, truly first" (Barth, 2018). However, background stories clearly play a prominent role in Barth's design process, serving as the initial inspiration and framework for his puzzles. Many Zachtronics titles, such as *TIS-100* (2015) and *Exapunks* (2018, Figure 12), require players to assume the role of a computer programmer, typically in an offbeat retro or futuristic setting. "If we didn't have the story coming before everything I do, I don't know if I would even know what to do" (Barth, 2018).

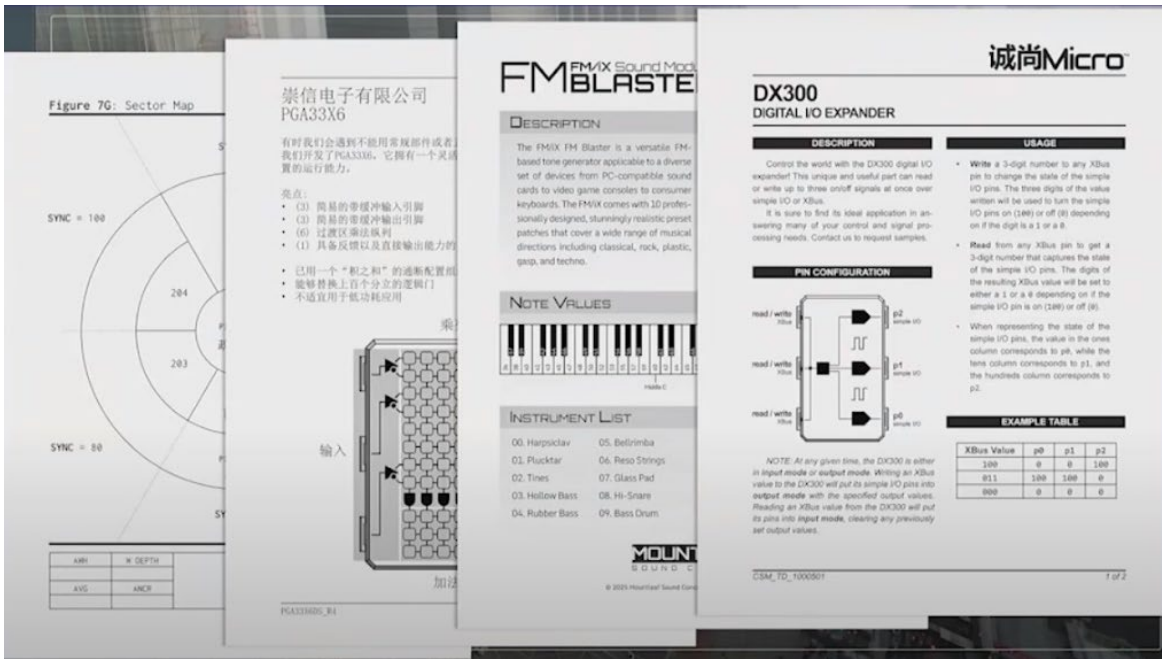


Figure 13. Pages from the user manual for *Shenzhen I/O*. Source: Screen capture.

A key distinction of Zachtronics titles is their unconventional means of tutorialization. Most puzzle games, including *The Witness* and *Portal,* teach new skills/rules/mechanics methodically, one at a time. The improvisational, tool-based nature of Zachtronics puzzles often requires a less structured approach to player education. Some of Barth's titles, such as *Shenzhen I/O* (2016, Figure 13) require the player to consult detailed technical manuals for imaginary computer hardware, controlled by fussy, arcane programming languages which must be mastered to complete the game. Barth says of this process "we sort of end up solving it the bad way, which is that we put someone in the game, we see where they get confused, and then we try to create it so that they either understand it because we've simplified it to the point where it's intuitive enough, or they can learn what's going on" (Barth, 2019).

## 2.4. *Guac-A-Mole*

The goal with *Guac-A-Mole* was to take Jonathan Blow's mechanics-discovery aesthetic and combine it with the situational focus of games like *Portal*. The Zachtronics games provided less direct influence, but offer a perspective on puzzle design that is useful to think about.

Puzzle games force players to place significant trust in the game designer. Every puzzle entails a silent promise: everything needed to solve it is available. This implicit contract between the designer and player facilitates the discovery of the puzzle's solution, and in the long term, keeps players engaged with the game. The challenge, then, is giving the player access to everything they need to know in a way that is more fun than simply telling them.

Blow's mechanics-oriented methodology provides a solid foundation. Every mechanic builds naturally upon the last, and is explored to the fullest. Rules and mechanics can be facilitated without explicit instruction, using environmental and/or narrative context to encourage exploration and discovery. Clear, simple mechanics embedded into a clear, simple situation served as the basis for the development of *Guac-A-Mole*.

Naomi Clark provides a useful way to look at things in *A Game Design Vocabulary:*

> It's compelling to think of a game as a conversation: players make choices and use verbs within a system. In multiplayer games, these choices can communicate with other players … During a play session of a single-player game all the conversation is happening between the creators of the game and the player. It's a tricky kind of conversation to have. As the creator, you have to hope that what you're saying in the conversation — through the rules and shaping of the experience as well as the words, images, or sounds you've added to the mix — gets across and finds a player, somewhere out there, who responses with choices, thoughts, and maybe even interesting strategies and emotional engagement. (Anthropy & Clark, 2014)

When I design a puzzle for *Guac-A-Mole*, it is meant to be a conversation with a player. The techniques used by the designers of the games noted above served as useful guidelines for the journey of creating *Guac-A-Mole*, and the game itself seeks to share that journey with its players. Each puzzle represents a discovery I have made and recreated in the form of an opportunity for the player to experience that same discovery.

# 3. Design

Following the design philosophy practiced by Jonathan Blow usually entails using mechanics as the driving factor behind the game's design. In *Guac-A-Mole,* however, this often was not the case. The game began simply as a pun, combining a tasty avocado-based dip with tiny underground rodents. Bailey and I then attempted to develop a mechanic that would support the silly title.

The first idea was a hip, arcade-style version of the classic carnival game *Whack-a-Mole.* Rather than whacking moles, players would feed moles guacamole when they popped out of holes. Some ideas for making it puzzle-y were thrown around involving placing avocados down next to moles, feeding all the adjacent critters. Eventually, the game would reach hectic and absurd stages where the playing field became a conveyor belt of moles needing to be fed in real time.

Then we had the idea to make it entirely turn-based, and use a unique puzzle mechanic in which placing an avocado lures moles to their position. This mechanic eventually expanded to include everything the game now offers. This expansion was largely situation-driven. We determined what would happen in edge cases of avocado-placement based on what felt natural. *What happens when two moles see the same avocado?* They both move towards it. *What happens when two moles reach an avocado at the same time?* They fight over it and destroy it. *What happens when a mole sees two avocados the same distance away?* It gets confused, doesn't know which one to go to, and ends up staying where it is.

After creating the base mechanics, we looked not to the gameplay elements of the prototype, but to our recipe for guacamole (Appendix C) as a map for where to go next. We added a new ingredient: onions. We knew they needed to work differently from avocados, but we didn't have an idea how exactly that would be accomplished. We found a 3D model for an onion, and it was really big and round, giving us the idea to make the onion "too big to fit into the mole's hole," plugging up the hole when the mole attempts to take it. This onion-stuck-in-a-hole now blocks line of sight for any moles remaining on the field.

The onions led to rocks. Onions blocking line of sight brought about interesting situations, and rocks allowed those to occur without requiring action from the player. This was the first thing that was brought about through a more mechanics-driven decision, but it stemmed from the situational focus of the onion.

For the next ingredient, we added limes. Half a lime, to be specific. Each half-lime leaks lime juice, filling tiles with fluid as moles carry it away.

Our guacamole recipe uses Cajun seasoning, which inspired the addition of peppers. Peppers eventually replaced the lime mechanic, leaving fire instead of lime juice, but fluid remained as a mechanic in the form of water. Ice was brought in as an extension of fire; *what if fire could melt ice and free moles held within?*

Beans were brought in from another joke: *What if moles ate a bean and it made them fart, blowing nearby objects away?* This bit of whimsy turned out to be one of the deepest and most engaging mechanics of the game.

As we gained familiarity with the systems we were creating, mechanical gaps became apparent. We realized that it would be useful to have a tile that you *cannot place an ingredient*

*on*, but moles can walk on and see through just fine. Finding a clean way to implement this proved remarkably difficult. This process we followed for *Guac-A-Mole* has many parallels with the practices of Jonathan Blow; the primary similarity being that every gameplay element stems from a basic core mechanic. But to craft an honest and engaging experience for our puzzles, we looked first to the situational and aesthetic elements of the game, and to the mechanics second.

One thing that remained a consistent design goal since the beginning was providing minimal explicit tutorialization. In *A Game Design* Vocabulary, Anna Anthropy discusses a trend in 21st century game design:

> *Super Mario Bros.* was many people's first video game; there were almost no games similar to it at the time. *New Super Mario Bros.,* in contrast, has almost twenty years of related games as precedent. Despite that, the 1985 game leaves one thing out that's present in the 2009 game: a big sign with an arrow telling the player which direction to go.
>
> What happened between 1985 and 2009 to cause game creators to lose that much trust in the player? The player of *New Super Mario Bros.* Wii gets off easy, in fact, as far as "tutorials" go. Lots of contemporary games feel the need to explain to the player, via game-interrupting exposition and big stupid dumps of instruction text, how they are played. Many games even keep the player from starting the game until she's proven she knows how the buttons work, making her jump in place, in a contextless situation, like a trained pet. (Anthropy & Clark, 2014)

Placing that trust in the player felt important from the start of *Guac-A-Mole*, but it requires the designer of the game to earn that trust through excellent design. Anthropy goes on to say:

> *Super Mario Bros.* didn't need a tutorial. It used design, a communicative visual vocabulary, and an understanding of player psychology — gained from watching players play the game, changing it, and watching them again — to guide the player to understanding the basics of the game. Those first screens teach everything the player needs to know. (Anthropy & Clark, 2014)

The goal, then, was to use design, a communicative visual vocabulary, and an understanding of player psychology to guide the player to understanding the basics of the game. To some extent, this caused the whole game to become a tutorial. Giving the player all of the rules up front and then asking them to solve any given puzzle would not accomplish this; every element of the game needed to work towards communicating to the player how to play, including how the puzzles are presented and the order in which the player encounters them.

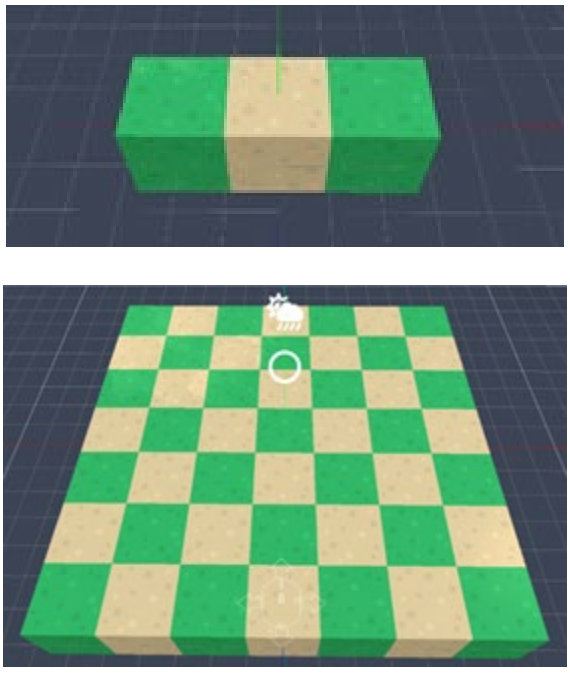

Figure 14. Empty 1x3 and 7x7 *Guac-A-Mole* grids. Source: Screen capture.

## 3.1. Mechanics

*Guac-A-Mole* employs a core set of grid-based puzzle mechanics. Like *Portal* and *The Witness,* additional mechanics that have interesting interactions with the core set appear in various levels. An overworld map, such as those seen in *Snakebird* or *Baba is You,* is used to organize access and progression through levels. Short cutscenes and interactable map elements will provide some light engagement beyond the puzzles to avoid “puzzle fatigue”, but these elements are beyond the project scope.

Figure 15. 3x3 grid populated with puzzle pieces. Source: Screen capture.

### 3.1.1. Levels

A level consists of three components:

1. *The Grid.* This is a 2D grid of any size, though most levels will range between 1x3 and 7x7 (Figure 14). These sizes accommodate a wide range of levels, from simple to complex, while still allowing players to keep the entire puzzle in view and keep track of all elements of the puzzle at once.
2. *Puzzle pieces.* These are the pieces that will be placed on the grid to create a puzzle. These may include moles, ingredients, and obstacles (Figure 15). Moles follow a unique set of rules to obtain ingredients, and obstacles get in their way of doing so. To win a level, all moles must obtain an ingredient.
3. *Inventory.* Each level gives the player a preset selection of ingredients that they can place on the grid (Figure 16). The placement of these ingredients is the players method of solving the puzzles. Players may place an ingredient on any unoccupied square.


Figure 16. A complete level, with the player's inventory displayed on the left.
Source: Screen capture.

### 3.1.2. Rules

The moles have three basic rules that dictate how they move on the grid.

1. *Line of Sight.* If a mole has an unobstructed line of sight (in the 4 cardinal directions) to an ingredient, the mole moves towards that ingredient, picks it up, and returns to its hole.
2. *Equilibrium.* If a mole has line of sight to multiple ingredients that are an equal distance from the mole, the mole becomes confused, not knowing which one to go to. A confused mole remains stationary until the equilibrium is broken.
3. *Fighting.* If multiple moles reach an ingredient at the same time, they fight over it. This destroys the ingredient and leaves the moles unsatisfied.

There are four ingredients in *Guac-A-Mole*, each with unique properties.

1. *Avocados are the* most basic ingredient, with no special properties.
2. *Onions* are rather large. If a mole returns to its hole with an onion, it will be too large to fit into the hole. This plugs the hole, blocking line of sight through that square.
3. *Peppers* are (literally) hot. When a mole picks up a pepper, it leaves a trail of fire in every square it walks through as it returns to its hole.
4. *Beans* make moles flatulent. When a mole picks up a bean, it farts, causing every adjacent ingredient, mole, and obstacle to be ejected away from the mole.

There are also four types of obstacles.

1. *Rocks.* These obstacles block line-of-sight through the square they occupy.
2. *Water.* If a mole steps into a square with water, it drowns, causing a fail state.
3. *Fire.* If a mole steps into a square with fire, it burns, causing a fail state.
4. *Ice.* Moles, ingredients, and obstacles may be frozen in ice at the start of a level. Ice can be melted if it is adjacent to fire.


Figure 17. *Guac-A-Mole* world map, using placeholder background art from *SnakeBird.* Source: Screen capture.

### 3.1.3. World map

The world map displays all the levels of *Guac-A-Mole* (Figure 17). These levels are placed on a grid, and beating a level unlocks all adjacent levels. Locked levels must be unlocked before the player can enter them.

Additionally, the map contains gates. A gate indicates the number of ingredients that must be obtained before it will open. The total number of ingredients used in the player's solutions will be tracked, and count toward the requirements to open a gate. Opening a gate unlocks access to new levels.

## 3.2. Process

### 3.2.1. Methodology

The first thing I did when developing the puzzles of *Guac-A-Mole* was develop a methodology to ensure every mechanic of the game was explored to its fullest extent. I looked at what unique elements went into each puzzle, and identified the following attributes:

- Rules of mole behavior required for the solution
- Ingredients the player could place
- Obstacles present in the level

Things like how the inventory is displayed or moles being present on the grid are consistent across every level, so those factors did not need specific consideration. I wanted to explore each of these unique elements to the fullest, which required looking at how each of them interacts with one another in interesting ways. To make this a simpler task, I decided to enforce a couple of rules to help create a template for level development:

1. The player can be given no more than 2 unique ingredient types in their inventory. This rule kept things simple and elegant, prevented overly complex levels, and kept the scope somewhat reasonable.
2. Obstacles present on the field did not count. This rule ensured that the exploration of mechanics fully explored *the actions the player can take*, as later levels allow players to place obstacles.
3. Any amount of mole behavior rules may be present in any level.

These rules were broken many times throughout the actual development of the levels, but this allowed me to have a clear structure for the entire game. Every combination possible

with these rules and unique elements could be identified before a single level had been created. There are three rules for mole behavior, which can be combined in seven ways. Each of these seven rule combinations would be explored alongside one or two placeable items. This results in over 300 possible levels and provides a base to work from. Figure 18 shows an early sketch with a visual representation of this plan.

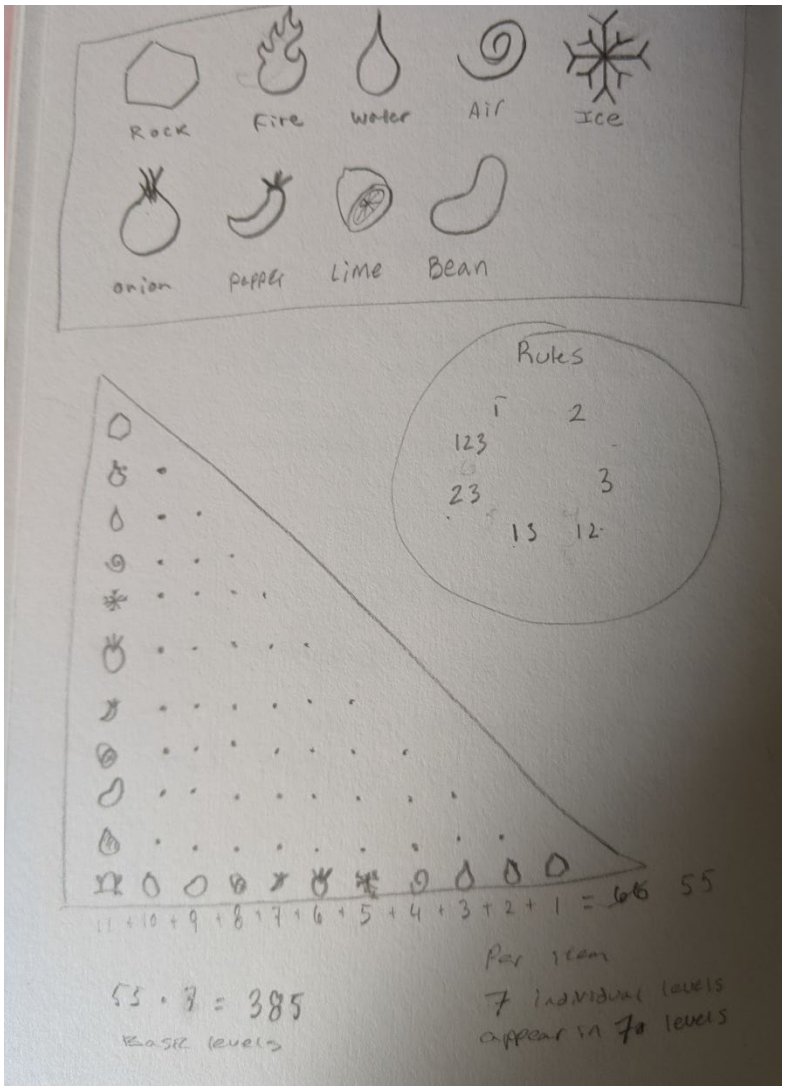


Figure 18. *Guac-A-Mole* Level Plan.
Source: Sketch.

The plan was to use this as a first step in developing puzzles. I created a spreadsheet listing each of the several hundred combinations with a coding system for readability. Avocado

was reduced to the letter A, Pepper became P, Onion became O, and each of the rules for mole behavior became 1, 2, or 3. So a level that explores only the equilibrium mechanic would be identified as “A2”, because the player places avocados and must use equilibrium (rule 2) to solve the level. A level that explores onions alongside peppers and employs the use of every rule would be identified as “OP123”.

To begin working on a level, I would look at what is present in the level, and identify the interesting interactions present there. Theoretically, I could go down the list one by one and eventually make a level for every single combination of elements. This, however, proved impractical. It was difficult to jump around so much, and the sequencing of levels needed to be less linear. I wanted players to be able to explore the ideas of the game in a way that felt natural—something a long, linear list would not provide. I wanted my exploration and development to mirror the exploration the player would experience.

I ended up tackling things one ingredient at a time. I started with avocados, since they are the simplest ingredient, mechanically. The avocado levels, despite being the first developed, differentiated from the coded spreadsheet list more than any other ingredient. This was because they needed to serve as the player’s introduction to the game.

Even though these levels only needed to convey simple ideas, they would be seen by people who had never seen or played the game before. These levels were not only responsible for conveying the rules of avocado placement and how moles would react, but also what the player needed to do to interact with the game and which parts of the screen were portraying relevant information. The player, all at once, needed to become familiar with the inventory, the grid system, the rules of play, what buttons to press, etc.

Exposing the player to more than one new idea at a time went against the fundamental design philosophy and goals of the game. To make this experience less overwhelming for the player, these levels broke completely from the development template. Rather than making one level to explore each of the interesting interactions, several were made. Additionally, these levels used repetition to drill ideas into the player's head.

After the avocado levels were complete (the so-called "tutorial levels"), I moved onto the rest. I started with the single-item levels, so that I could explore each item in isolation before moving to more complex interactions. As I developed these levels, I naturally developed ideas for how items could interact with one another in interesting ways and took note of those for when I developed those levels.

I often broke from the template I had designed. I created levels out of order due to inspiration or a creative block, I included more or less levels for a given ingredient based on the number of interesting interactions I could find, and I took more than the designated number of levels to fully explore some ideas. The shape of the game did not strictly conform to the rigid shape I had initially created and put into a spreadsheet, but creating that template served as an incredibly useful tool for development. It ensured that I *thought* about every possible combination of mechanics and fully explored them. Sometimes this exploration proved fruitful, and sometimes it resulted in throwing away ideas. It also ensured that I always knew what to do next. As soon as I finished a level, I already had the next one waiting for me.

### 3.2.1. Level-Design Walkthrough

Once I had my template in place, I could begin designing levels. This process happened in 4 stages:

1. Interaction Identification.
2. Paper Prototyping.
3. Level Editor.
4. Sequencing.

I never looked at a single level in isolation; every level was considered alongside similar levels. For example, I looked at all of the levels where the player would place only beans at the same time. I would consider the interesting interactions of the ingredient, obstacle, or rule in question for these levels, and write them all down.

After generating a list of interactions, the most important question to ask was "*What does the player need to know in order to be able to make this discovery?"* This question allowed me to sequence the list, putting foundational ideas before more tangential or complex ones. Figure 19 (below) shows an example of one of these lists for the introductory equilibrium levels, alongside the completed paper prototype.

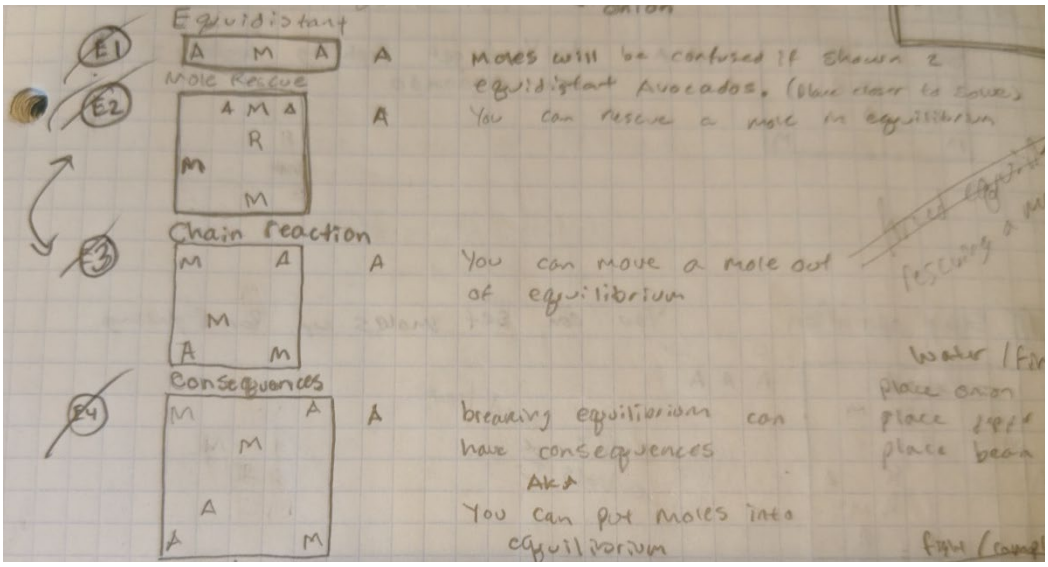


Figure 19. Equilibrium paper prototype alongside interesting interactions.
Source: Personal sketch.

Once I had a sequenced list of ideas, I began developing paper prototypes of levels where the solution would require the player to discover the listed idea. On paper, game entities were represented by the first letter of their name (Moles became “M”, Avocados “A”, Rocks “R”, etc.). This creative process was messy, but typically began with drawing out a grid state that would exhibit the idea. The first level in Figure 19, “Equidistant”, was so simple that this step was enough. I was trying to convey the fundamental idea of the equilibrium rule: “Moles will be confused and remain stationary if they can see 2 equidistant avocados”. I placed a mole on a grid with 2 avocados an equal distance away, and due to visual cues within the game, the idea is immediately clear to the player. Furthermore, if the player does not fully understand the mechanic, they cannot possibly fail the level. Any of the tiles where an ingredient may be placed will solve the level; an ideal state for the first time the player is exposed to a new and essential mechanic.

Not all levels were so simple to create. The second level in Figure 19, “Mole Rescue”, sought to convey a more complex idea: “You can ‘rescue’ a mole from equilibrium.” I began this level in the same way, placing a mole locked in equilibrium. The mole is surrounded by avocados on the right and left, a rock below, and the grid ends above. The only way for the mole to gather an ingredient is for another mole to remove one of the existing avocados. The level cannot start with a mole in line of sight of one of these avocados, or else the level would solve itself automatically. So, I needed to tack on an extra part of the level that leads to this solution. This was a common occurrence and proved quite challenging at times.

After developing the paper prototype, I put the levels into the Reactor game engine created by Bailey Sostek. Reactor is Sostek’s fourth iteration of a custom engine built on Java, specifically created to support development of *Guac-A-Mole*. Figure 20 (below) shows the *Guac-A-Mole* level editor used to create, edit, and test levels for the game.

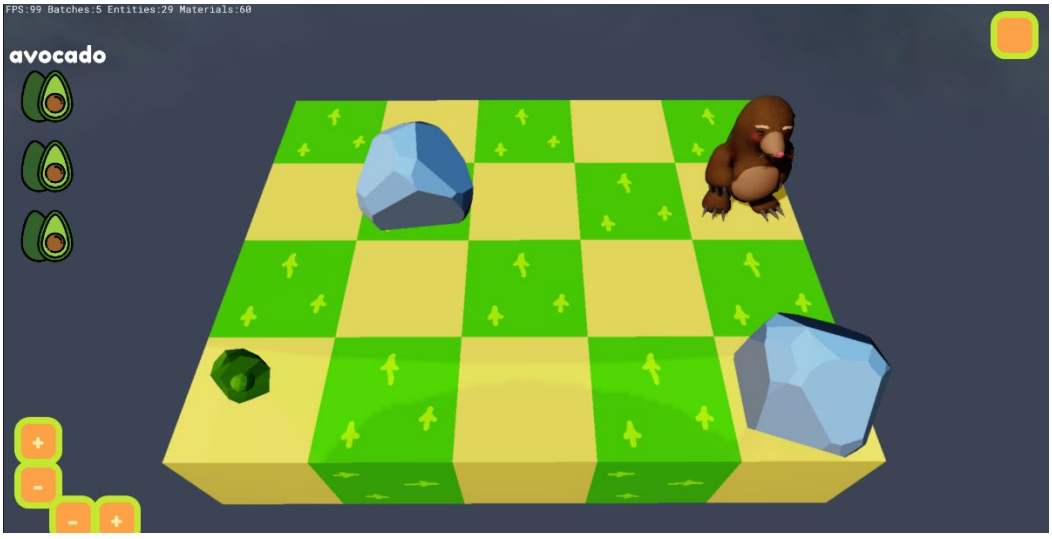


Figure 20. *Guac-A-Mole* level editor.
Source: Screen capture.

The level editor has everything necessary to create a new level without needing to write any code. The +/- buttons in the bottom-left adjust the size of the level, and the user can scroll between all the puzzle pieces, clicking to place or remove a piece from the grid. The inventory can be adjusted from another window, and each level may be saved with a unique level name. I tried to name all the levels when I made the paper prototype, but I would often wait until I had put the level into the engine. The names of each level were intended to give a small hint with a silly or narrative flair.

Once the level is saved, the engine allows you to quickly swap between playing and editing a level for easy testing using the button in the top-right corner. I played every level shortly after creation for multiple reasons:

- A first pass at QA, ensuring the level has a playable solution.
- Identifying design errors or flaws.
- Thinking about the level in the context of the intended discovery, making sure it does what I wanted it to do.

I usually made edits right away, and sometimes I would ask Sostek to play the new level(s) as a preliminary round of playtesting. Once I had several levels saved in the engine, it was time to place them on the map.

Placing levels on the map, naturally, also entailed sequencing the levels. Most of the thinking and work behind this happened on paper, as the engine does not yet support a map-editor. To place levels on the map, I needed to write code for a long list of level nodes with manually identified coordinate-positions. Having a visual aid beforehand helped immensely.

Sequencing of the levels often came naturally, as with the equilibrium levels in Figure 19. These levels built off one another and used similar mechanics. Levels developed separately from one another were more challenging to sequence because there was not a clear connection or reason to put them next to one another. I made these decisions based off what felt right and left it to playtesting to help determine the rest. These guidelines helped in this process:

- The “tutorial levels” should come before any other levels.
- The player should be exposed to simple, single-item levels before exposure to more complex levels with those items.
- Difficulty of levels in sequence should not differ dramatically.
- The player should have multiple paths they can take at any given time, so they can continue even if they get stuck.

These guidelines provided a good starting point, and for the most part sequencing only needed slight adjustment. Once the sequencing of the levels was completed, they were ready for playtesting.

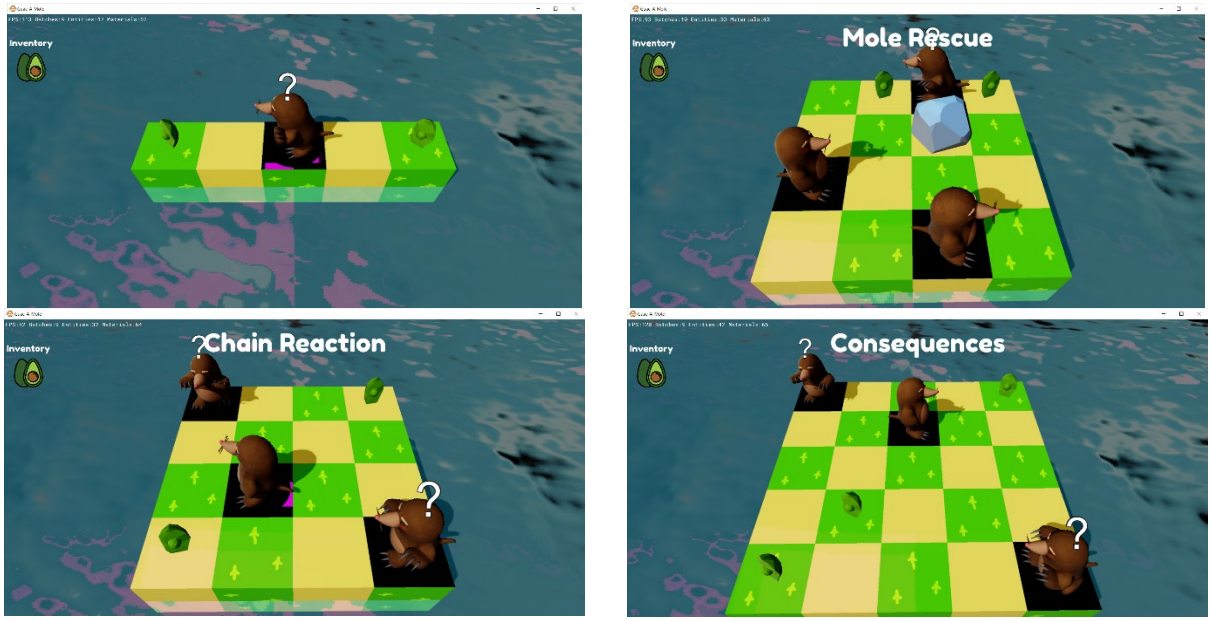


Figure 21. *Guac-A-Mole* equilibrium tutorial levels.
Source: Screen capture.

Figure 21 shows the completed, in-game versions of the equilibrium levels from level 19.

# 4. Evaluation

The purpose of this project was not to create a finished game. *Guac-A-Mole* is a long-term project with ambitious goals. The amount of time and polish required to complete the game exceeds the available time. This project was simply intended to provide most of the puzzle design needed for the game. Taking this into account, the project should be evaluated based on how well it achieves the following goals:

**1. *Guac-A-Mole* will challenge its players with a unique suite of hand-crafted and sequenced puzzles.**

*Guac-A-Mole* will take inspiration from puzzle games like *The Witness*, *A Monster's Expedition* (Draknek, 2020), and *Baba is You* (MP2 Games, 2019). Each puzzle is solved in isolation, and there is some freedom in the order taken to solve them. The sequence of these puzzles will provide a smooth difficulty curve that allows players to gain the knowledge and skills required to solve even the most complex presentations of the game's rules.

**2. *Guac-A-Mole* will use tacit tutorials to instruct players.**

Many games provide explicit tutorialization to ensure the players know exactly how to play, often breaking the flow of gameplay or patronizing players with excessive extradiegetic instruction. Games like *Half-life 2* (Valve Corporation, 2004), *The Witness*, and many *Mario* games provide organic, implicit direction that provide players with all the knowledge they need. *Guac-A-Mole* will take inspiration from these games, providing explicit non-diegetic instruction only to show the controls. Puzzle mechanics and rules in *Guac-A-Mole* will be taught *tacitly,* using puzzles crafted and sequenced to guide players through playful discovery.

### 3. *Guac-A-Mole* will use metrics from playtesters to improve puzzle design.

Using recorded data from play testers, a heat-map will be generated for each level to show the decisions made by players. This will reveal disparities between the designed expectation and the player's actions, as well as identify unexpected puzzle solutions. Additionally, written analysis of recorded data such as time taken to complete each level will be used to improve the difficulty curve and sequence of the levels.

As of May 3rd, 2021, I have received feedback from 29 playtesters. This section provides an analysis of this feedback and how it may be used to improve the design of *Guac-A-Mole* puzzles, along with graphs to show the data. This data, and its analysis, can be used to help evaluate the project goals. The IRB Informed Consent Agreement approved for playtesting is included in Appendix A.

## 4.1. Familiarity with puzzle games

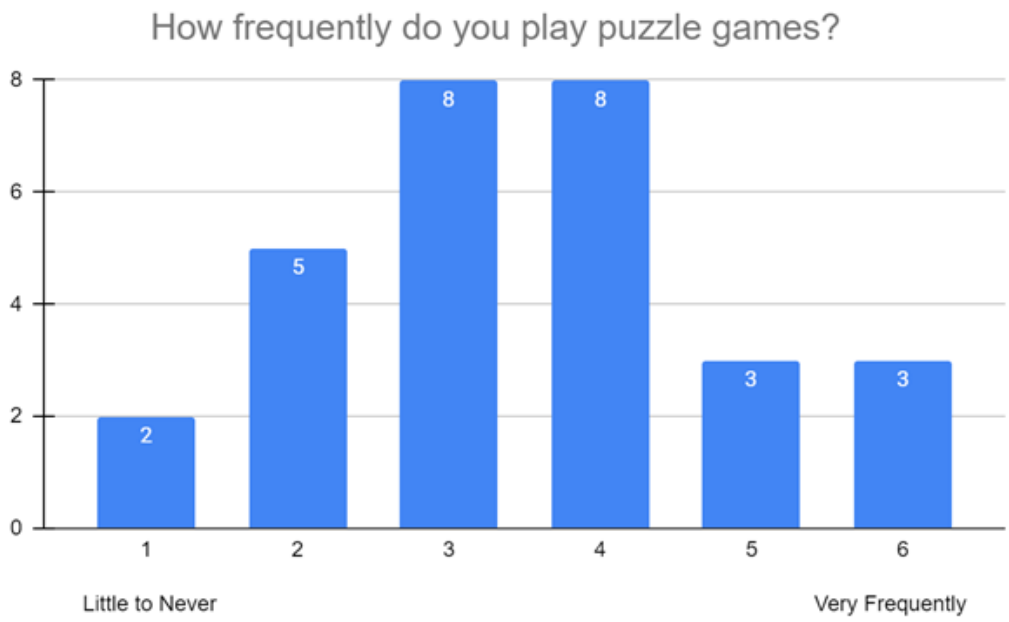


Figure 22. Summary of Question 1 responses.

The group of playtesters had a wide range of experience with puzzle games. The frequency with which they play puzzle games follows a near- bell curve distribution. One goal of designing these puzzles is to make them accessible to anyone, so this distribution should provide representation from all levels of puzzle game familiarity.

## 4.2. Control comprehension

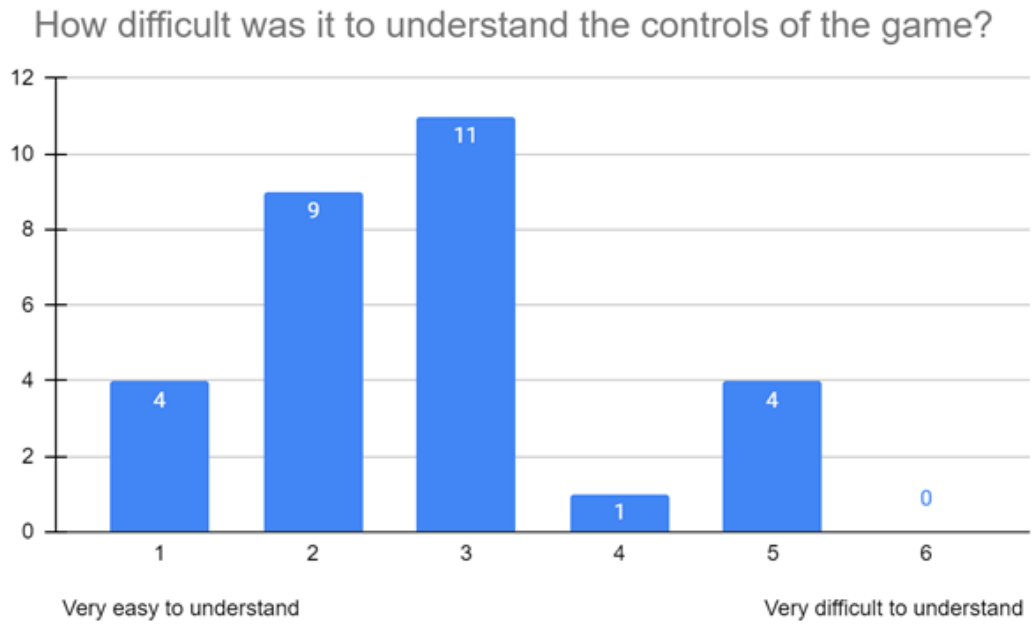


Figure 23. Summary of Question 2 responses.

Most responses indicated the controls were on the easier side to understand, showing that the methods of conveying the controls are off to a good start. However, given that most of these responses were on the border of the halfway point between easy and difficult to understand (3 on the 1-6 scale), there is certainly room for improvement.

Some of the feedback showed that some users experienced bugs that prevented the controls from being displayed as intended; these have been addressed and should not reappear in the future. Additional feedback showed that the correlation between clicking a tile on the grid and an avocado disappearing from the inventory was not clear. As this is the primary interaction the player has with the game, working to make this correlation clearer will be a top priority, as it should provide clarity for the controls, as well as the mechanics, of the game.

## 4.3. Failure condition comprehension


Figure 24. Summary of Question 3 responses.

Most responses indicated the reason for failing a level was on the easier side to understand, showing that the methods of conveying this are off to a good start. However, given that most of these responses were on the border of the halfway point between easy and difficult to understand (3 on the 1-6 scale), there is certainly room for improvement.

Some of the feedback indicated that the victory condition / goal was unclear until the player had beat several levels. In the playtest version, players received a message upon failing a level ("Moles are still hungry"). They received no message or feedback upon *succeeding* a level, other than the game moving on to the next level. Failing a level is not physically possible in the first several levels, so players could not explicitly understand the goal until they fail one of the

later levels. A success message has been added to the game (“All moles have been fed!”), and hopefully this will reduce confusion surrounding failure of levels.

## 4.4. Inventory comprehension

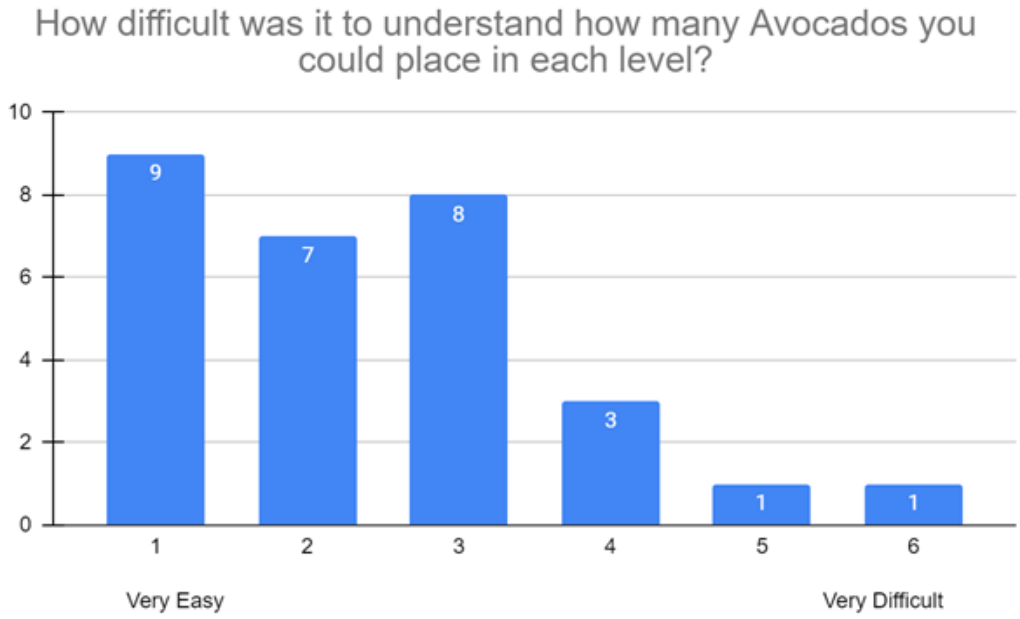


Figure 25. Summary of Question 4 responses.

Most responses indicated the reason for failing a level was on the easier side to understand, showing that the methods of conveying this are off to a good start. However, given that nearly 1/3 of these responses were on the border of the halfway point between easy and difficult to understand (3 on the 1-6 scale), and there was even one play tester who found it very difficult to understand, there is certainly room for improvement.

In the controls section, I mentioned it was not clear to all play testers that clicking on a tile took an avocado out of the inventory to place it in the level. Understanding this is essential to properly understanding and playing the game. This correlation can be improved in several ways, including the use of UI elements or visual effects; perhaps an animation of the avocado in

the inventory leaving the inventory before appearing on screen, or a flash to show it disappearing.

Additionally, the first level provides subtle control indicators to show the players they should move the mouse and click on a tile. Similar indicators could be used to simply notify the players of the inventory's existence, or possibly, with proper iconography, the entire correlation between the inventory and the number of ingredients the player can place.

## 4.4. Average play time per level

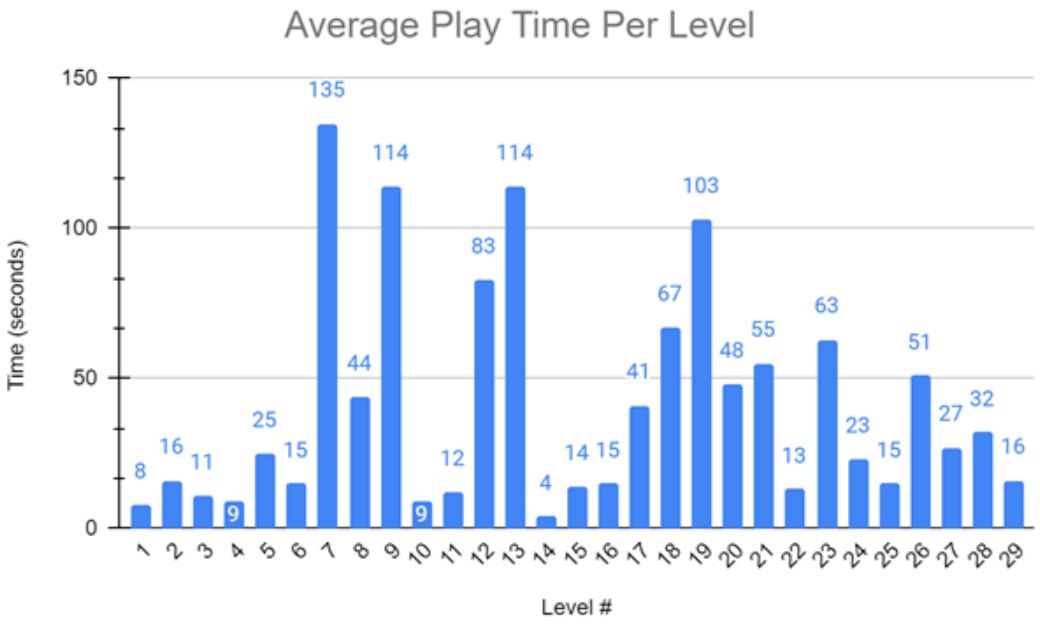


Figure 26. Summary of Question 5 responses.

The average play time per level is incredibly useful. This data reveals there is a lot of work to be done, especially in levels 7-13.

Levels 1-6 all take the average player under 30 seconds to complete. These levels cannot be failed, and simply require the player to understand the basic method of interacting with the

game: clicking on a tile to place an ingredient. I find this time promising, as players do not seem to struggle with that core mechanic.

The time spike from level 6 to level 7 indicates to me that players do not have a strong enough understanding of the mechanics by this point of the game. Level 7 is the first time the player must think ahead and place their first ingredient in a way that sets up successful placement of the second ingredient. This is a big jump for many players. Even though levels 1-6 are easy for players to complete, they do not seem to be prepared for the jump from simply placing avocados next to moles to solving a puzzle.

Similarly, levels 10-13 and levels 14-17 are sequences that teach new mechanics. In levels 10 and 11, players can complete the levels very quickly, but there is a significant spike in difficulty at level 12. Levels 14-17 have a better difficulty curve, but perhaps level 16 could be slightly more difficult to round out the curve.

Levels 18-29 indicate to me that players can gain significant understanding of the mechanics of the game. Despite the levels steadily increasing in complexity, completion time trends downward. This shows that players quickly gain mastery over the game. Changes can certainly be made to make this smoother.

# 5. Conclusion

Throughout the development of *Guac-A-Mole*, I sought to emulate the best practices of excellent puzzle designers. Jonathan Blow's design philosophy served as a foundation; the practice of taking the simplest execution of a mechanic and discovering natural expansions of it. Prototyping these discoveries, cultivating puzzles to lead players to the same discoveries, and curating the puzzles to exclude unnecessary elements became a standard rhythm of development.

The narrative focus of exemplary puzzle games like Portal was just as important. Narrative and aesthetic tools allowed contextualization within the world of the game. The effects of this are far reaching, easing the player into an understanding they don't even realize they have attained.

Unlike the open-ended problems found in Zachtronics games, the design practices followed for *Guac-A-Mole* sought to communicate a specific discovery from the designer to the player. Rather than presenting a problem and telling the player to read a manual to understand how to solve it, the goal of *Guac-A-Mole* was to present players with a problem and silently tell them "You already know how to solve this". This was accomplished with carefully cultivated tacit tutorials.

There were two great challenges faced in the development of the puzzles of *Guac-A-Mole*. Discovering interesting and new interactions based on the core mechanic was a great source of joy, and this was the part of the game that felt like it almost designed itself. This process mostly entailed asking questions about specific cases and looking to the narrative of

the game for an answer. The first challenge was identifying the best way to reverse-engineer these interactions to lead the player to make the same discovery; the best individual puzzle to wordlessly convey a new idea. The second, and perhaps greater, challenge was identifying the best way to present these puzzles, tying in the narrative, aesthetic, and gameplay elements into a unified experience.

Using these design philosophies gave a purpose to every puzzle. The goal of creating new puzzles was never simply to pad a list of levels with more content, but rather to communicate an idea. This resulted in a personal, artistic connection to the work being done, and avoided anything arbitrary.

The final measure of success for the puzzles of *Guac-A-Mole* is that players understood how to play and showed their ability to solve even the most complex puzzles given to them. This was accomplished without providing them any words or explicit instructions, and only giving minimal aesthetic or narrative context. The process of presenting the player with new ideas one at a time, and slowly building on them and combining them worked for *Guac-A-Mole*.

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# Appendix A: IRB Informed Consent Agreement

**Informed Consent Agreement for Participation in a Research Study**

**Investigator: Brian Moriarty**

**Contact Information: bmoriarty@wpi.edu**

**Title of Research Study: Puzzle Game Design**

**Sponsor: None**

**Introduction**
You are being asked to participate in a research study. Before you agree, however, you must be fully informed about the purpose of the study, the procedures to be followed, and any benefits, risks or discomfort that you may experience as a result of your participation. This form presents information about the study so that you may make a fully informed decision regarding your participation.

**Purpose of the study:** The purpose of this study is to obtain feedback on the project in order to facilitate design improvements and find/address operational bugs.

**Procedures to be followed:** You will be asked to play a brief game lasting less than thirty minutes. Instrumentation in the game software will anonymously record your activity during play. After completing the game, you will be asked to complete a brief, anonymous survey describing your subjective experience.

**Risks to study participants:** You will have an opportunity to enjoy and comment on a new game under active development. Your feedback will help improve the game experience for future players.

**Benefits to research participants and others:** The researcher will obtain playtest feedback that will improve the design of the project and the quality of the evaluation portion of the project report.

**Record keeping and confidentiality:** Records of your participation in this study will be held confidential so far as permitted by law. However, the study investigators, the sponsor or its designee and, under certain circumstances, the Worcester Polytechnic Institute Institutional Review Board (WPI IRB) will be able to inspect and have access to confidential data that identify you by name. Any publication or presentation of the data will not identify you.

**Compensation or treatment in the event of injury:** There is no foreseeable risk of injury associated with this research study. Nevertheless, you do not give up any of your legal rights by signing this statement.

**For more information about this research or about the rights of research participants, or in case of research-related injury,** contact Brian Moriarty at bmoriarty@wpi.edu. You may also contact the WPI IRB Manager (Ruth McKeogh, Tel. 508 831-6699, Email: irb@wpi.edu ) and the Human Protection Administrator (Gabriel Johnson, Tel. 508-831-4989, Email: gjohnson@wpi.edu).

**Your participation in this research is voluntary.** Your refusal to participate will not result in any penalty to you or any loss of benefits to which you may otherwise be entitled. You may decide to stop participating in the research at any time without penalty or loss of other benefits. The project investigators retain the right to cancel or postpone the experimental procedures at any time they see fit.

**By signing below,** you acknowledge that you have been informed about and consent to be a participant in the study described above. Make sure that your questions are answered to your satisfaction before signing. You are entitled to retain a copy of this consent agreement.

_____ Date: _____

Study Participant Signature

_____

Study Participant Name (Please print)

_____ Date: 3/5/2021

Signature of Person who explained this study

# Appendix B: Playtest Survey (Round 1)

## Guac-A-Mole Playtest Survey

* Required

1. How frequently do you play puzzle games? *

*Mark only one oval.*

| | 1 | 2 | 3 | 4 | 5 | 6 | |
|---|---|---|---|---|---|---|---|
| Little to Never | ◯ | ◯ | ◯ | ◯ | ◯ | ◯ | Very Frequently |

2. (Optional) Please list some puzzle games you have played recently.

3. What control scheme did you use when playing the game? *

*Mark only one oval.*

- ◯ Mouse & Keyboard
- ◯ Controller
- ◯ Other: _____

4. (Optional) If you used a controller, what type of controller did you use? (XBOX 360, PS4, etc.)

5. (Optional) Is there a type of control scheme you would like to have used to play this game, but were unable to?

6. How difficult was it to understand the controls of the game? *

*Mark only one oval.*

| | 1 | 2 | 3 | 4 | 5 | 6 | |
|---|---|---|---|---|---|---|---|
| Very easy to understand | ◯ | ◯ | ◯ | ◯ | ◯ | ◯ | Very difficult to understand |

7. (Optional) Do you have any additional comments about the game controls?

8. Were you ever confused about why you failed a level? *

*Mark only one oval.*

| | 1 | 2 | 3 | 4 | 5 | 6 | |
|---|---|---|---|---|---|---|---|
| I was never confused about why I failed a level | ◯ | ◯ | ◯ | ◯ | ◯ | ◯ | I was frequently confused about why I failed a level |

9. (Optional) Do you have any additional comments about failing levels?

10. How difficult was it to understand how many Avocados you could place in each level? *

*Mark only one oval.*

| | 1 | 2 | 3 | 4 | 5 | 6 | |
|---|---|---|---|---|---|---|---|
| Very easy to understand | ◯ | ◯ | ◯ | ◯ | ◯ | ◯ | Very difficult to understand |

11. (Optional) Do you have any additional comments or suggestions about displaying how many Avocados can be placed in each level?

12. How would you describe the goal of the game to others? *

13. (Optional) Do you have any additional comments about the goal of the game?

14. (Optional) Do you have any final comments or feedback about Guac-A-Mole?

# Appendix C: The Recipe That Started It All

**Ingredients**

*2 ripe avocados*

*¼ of a small, fresh white onion*

*¼ juice of a lime*

*Cajun seasoning to taste*

*Tortilla Chips*

**Instructions**

*Thinly slice and dice the onion and set aside.*

*Cut the lime and set aside.*

*Slice the avocados in half lengthwise with a sharp knife and pull the halves apart. Set aside the half without the pit.*

*In one motion, swiftly but carefully chop the knife into the pit of the avocado, embedding it into the pit. With one hand holding the handle of the knife, and the other holding the avocado, twist to dislodge the pit from the avocado. Discard the pit.*

*Slice the avocado flesh with a knife horizontally, then vertically, careful not to pierce the skin. Using a spoon, knife, or simply squeezing the avocado, scoop as much flesh as possible into a bowl. Discard any grey or dark flesh.*

*Mash the avocado in the bowl with a fork, breaking up any chunks.*

*Add the onion, lime juice, and Cajun seasoning to the mashed avocado, and mix until well blended.*

*Scoop guacamole with tortilla chips and enjoy!*