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AquaFarm Ace: A Game on the Intensive Aquaculture Process of *Oreochromis niloticus*

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Abstract: As Aquaculture accounts for 52.4% of the fishing industry in the Philippines, it boasts potential in providing a stable source of food and livelihood. AquaFarm Ace is a 2D Time-Management simulation game on the intensive aquaculture process. The player takes the role of an aquaculturist as they go through the various stages of aquaculture. The game showcases hatchery, transportation, grow-out, and brood stock stages in the aquaculture stages of *Oreochromis noliticus*. This study aims to contribute to the scholarly community of aquaculture and serious game design. The game was developed using the following tools: Aseprite, beepbox.co and Unity 2020.3.181f and is made available through Unity Play. The researchers selected volunteer participants to play test the game and answer pretest, post-test, and game experiences questionnaires to gather data in relation to the effectiveness of the game. The results show that AquaFarm Ace contributes to raising awareness of aquaculture and can play a key role in highlighting its increasing demand in the aquatic scene in the Philippines to alleviate the socioeconomic problems such as food and job security. To note, play testers retained information about the aquaculture process of *O. niloticus* after playing the game. As shown on the Game Experience survey, the testers see the game as an enjoyable experience and a potential tool to teach aquaculture.

Keywords: Serious game design, aquaculture, time management games

1. Introduction

The Philippines, being an archipelagic state, has an abundance of water resources that spans about 2,000,000km^2 of its territorial area while its land area only covers about 301,000km2 and a coastline of 17,460km^2. With this, the Philippines is considered one of the leading producers of fishery products, ranking 7th in the world. Much of its production is consumed locally (Rivera et al., 2002; Romana-Eguia et al., 2022).

As of 2010, the country has been experiencing a decline in fish production due to the exploitation of its water resources by capture fisheries and other fishing grounds (Romana-Eguia et al., 2020). Concurrently, the Philippine aquaculture scene has significantly increased during the last decade and is expected to address the shortfall in fish production as well as issues pertaining to poverty and food insecurity. Due to its dynamic production system, aquaculture has steadily contributed to the fishing industry (Lieberman, 2001; SEAFDEC , 1993).

With the richness of the Philippines' marine resources, aquaculture is the raising of aquatic flora and fauna in areas where they can be harvested (SEAFDEC, 1993). Ayson claims that aquaculture is the fastest-growing food production sector as of 2015. Ayson further expounds that the impacts of aquaculture provide a vital role in providing food sources and income. Aquaculture provides 3.5% of the national GDP of the Philippines. This industry provides about 28.7% of the GDP production to the agriculture GDP (Ayson, 2015; Lieberman, 2001). In 1947, the Bureau of Fisheries and Aquatic Resources (BFAR) was established to facilitate the growth of the aquaculture industry of the Philippines. As of 1997, BFAR ranks the

Philippines as the 3rd biggest producer of seaweed that contributes to 9.3% of the world's seaweed production (Romana-Eguia et al., 2020).

As discussed by Teves and Ragaza, aquaculture contributes to the fish supply that alleviates the problems of overfishing, habitat degradation, and diminishing fish stocks (Teves & Ragaza, 2014). As fish is part of the daily diet of poorer countries in Asia, fish is one of the more widely used sources of animal protein, the demand for aquaculture products provides opportunities for profit (Brummett, 2003).

The research covers Philippine aquaculture with a particular focus on the production process of cultivating aquatic plants and animals as a medium to spread awareness, expand understanding, and encourage positive actions toward Philippine aquaculture. The game encompasses the following: (1) how these processes occur, (2) corresponding challenges to these processes, and (3) the overall production of aquatic resources through aquaculture.

The research focuses on tilapia species, particularly the Nile tilapia *Oreochromis niloticus*. Additionally, tilapia is readily available and relatively easier to market due to its inexpensiveness, international demand, and flexibility to be sold as a product (Teves & Ragaza, 2014; SEAFDEC, 1993). This showcases aquaculture practices and processes of the Philippines in hopes to spotlight the difficulties, challenges, and potential of aquaculture which, in turn, provide a deeper understanding, appreciation, and awareness to aquaculture. This is done by creating a game that presents the aquaculture process and highlights the challenges of fulfilling the demand for fish resources.

This paper will answer the following questions: (1) What aspects of aquaculture in the Philippines should be translated into the game? What game mechanics can be of use? How will these aspects be depicted in the game? (2) How can the game highlight the demand for aquatic resources and raise awareness of the aquaculture processes in the Philippines? (3) How can the game be engaging and fun while providing insights into the state of aquaculture? (4) How effective is the game in teaching players about aquaculture in the Philippines?

2. The Aquaculture Process

To supplement the world food production process, animal husbandry and capture fisheries thrive as the main sources of animal protein. However, as the world population increases, these methods become increasingly inadequate for the actual food demand. With this, world aquaculture production rapidly develops to gain recognition as the main source of seafood production. By Food and Agriculture Organization (FAO, n.d.-a) definition, aquaculture is the farming of aquatic organisms such as fish, mollusks, crustaceans, and aquatic plants (Lucas & Southgate, 2012). Unlike capture fisheries, where the seafood is caught in the wild, aquaculture intervenes with the rearing process; dealing with the practice of artificial breeding, raising, and stocking of aquatic animals to enhance seafood production.

In this paper, the researchers identified the general domestication process for intensive finfish aquaculture, specifically the aquaculture of *O. niloticus* tilapia. Intensive farming refers to the type of culture system where it maximizes the stocking rate by fully engineering the growth process of the fish by feeding them with optimal feeds and controlling water nutrients and organic matter within small tanks (Oddsson, 2020). General aquaculture with market objectives follows specific phases such as hatcheries, transporting, grow-out systems, and brood stock management (Funge-Smith & Phillips, 2001).

2.1 Oreochromis niloticus Aquaculture Process

Tilapia is one of the most important fish produced in the Philippines. It is a major component of the Philippines' subsistence fisheries and aquaculture due to its prolific nature. Compared to other culture fishes, domesticating tilapia is a simple and efficient job as it is naturally fast-growing and adaptable, requiring low investment for fish farmers (Gabbadon, 2008).

2.1.1 Hatchery

Hatchery systems are farm laboratories where eggs are kept in a conditioned environment similar to their natural breeding process. As the basic unit of fish husbandry, the fish egg quality is a critical step for successful fish production. Upon arrival from the broodstock unit, a quality control check is performed to ensure the absence of contaminated stocks. The eggs are classified into stages using egg graders, and healthy eggs are weighed and disinfected before incubation (Primavera, 1995).

Incubation tanks are set up with a gentle flow, as Tilapia are mouthbrooders, which means that natural incubation occurs orally. (Morretti et al., 1999). In the rearing tanks, fry undergo sex reversal through administration of male hormonal steroid to prevent uncontrolled reproduction. Proper grading is done to discard abnormal or female fry, and healthy male fish are fed larger powdered feed for 3 weeks before transport to the nursery and grow-out systems (Ali et al., 2020; SEAFDEC, 1993)

2.1.2 Transportation

When fish are being transported from one environment to another, it is important to imitate the previous water conditions the fish were exposed to. This is because fish are susceptible to becoming hyperactive, increasing their respiration rate and metabolic excretion when being transferred (Primavera, 1995). Additionally, aside from physical injuries and shock from handling and packaging, transportation of live fish may also result in progressive changes in the quality of water and fluctuating concentration of chemicals. Any means of transportation can be used when transporting live fish, but special container vehicles are often used by established companies. In most cases, polyethylene (PE) bags, which are filled with water and pure oxygen, placed in insulated polystyrene cardboard boxes act as the specialized containers in special vehicles (FAO, n.d.-b; Morretti et al., 1999). No matter how short or long-distance travels are, it is always required to provide special care and attention to the fish.

2.1.3 Grow-out Systems

High-quality seed stock necessitates rigorous quality control throughout the grow-out process, involving constant monitoring of juveniles in concrete tanks after being conditioned for optimal growth. Fingerlings are regularly fed and sorted by size, with aquaculturists choosing total or partial harvesting based on market demand. Harvesting involves using seines to capitalize on fish migratory instincts while minimizing stress through cooler conditions. The harvested fish are transported to processing facilities or holding cages before reaching marketplaces. After each harvest, tank cleaning and draining are vital to prevent contamination and cannibalism in subsequent spawns (Gabbadon, 2008; Romana-Eguia et al., 2020).

2.1.4 Broodstock Management

A properly managed broodstock unit is necessary to ensure quality seed stock for any aquaculture system. Broodstock refers to the matured fish used for breeding to enhance fish egg quality and quantity. It is important for spawning units to be kept separated from the hatcheries to avoid disturbance and contamination. After carefully selecting the best fish in a group, it is important to check the sex of each fish since there is a prescribed stocking ratio in spawning tanks. For tilapia, the best stocking ratio is 2-3 females for every male. To identify the sex of the fish, gently hold the fish and flip them to their stomach to examine their genitals near the anus. Males have pointed genitals, while females have rounded ones (Eguia, 2007; Romana-Eguia et al., 2020).

Males are often placed inside the tank to aid them to establish their territory prior to defending and attracting the females. Subsequently, female fish lay eggs inside the pot before leaving them to the male fish to be fertilized. After this, the female will pick up the fertilized eggs in her mouth. After spawning, eggs are collected from the female's mouth carefully by hand, opening up the female's mouth and gently dipping her mouth into transport containers,

releasing the eggs. These eggs are then transported to the hatchery units for artificial breeding. After the eggs are harvested, the female broodfish is transferred to a different tank for rest and recuperation. This broodfish can be used in future spawning sessions after 2-3 months and must be cared for regularly (FAO, n.d.-a).

2.2 Games on Aquaculture

Among games that feature aquaculture, two games stand out. Both games show promise on the resource management of aquaculture, but lack in showing each step of the process of aquaculture. These games are more focused on the management of the farm than showing the realism of the process of the aquaculture.

First, AquaKultor, dubbed as the first-ever published aquaculture simulation game, has inspirations of resource management games such as Theme Park, Theme Hospital, and Sid Meier's Civilization. The gameplay features fast-paced farming once the fish eggs are placed. The game shows realistic elements of managing the environmental impact as an effect of the process. Additionally, there are minigames inside the main game itself, such as cleaning the nets under a time limit (Evans, 2018).

Aquaculture Land immerses players in a pond management simulation where they begin with a plot of land, a worker, and some initial funds. The game involves regulating various pond components to optimize fish growth and quality. Players can also introduce machines to aid in fish care, and the gameplay includes intricate tasks like employee management, breeding, harvesting, and selling fish, complete with a quest system for selling or fulfilling customer requests. However, it's worth noting that the game is still in early access and lacks certain features, primarily in post-processing, offering extensive and semi-intensive fish farming for specific species (Lopez, 2020).

3. Design and Development

3.1 Game Mechanics

The game mechanics were designed to provide players with a simplified and engaging experience that mimics real-life aquaculture practices. The developers opted for a time management simulation game style that would allow players to complete tasks quickly and efficiently. It was developed using Unity game engine version 202.3.181f and is made available through Unity Play.

General aspects of aquaculture such as waiting for the fish to grow, regularly feeding the fish, monitoring the fish, and moving the fish around the laboratory are present in all stages of the game. The developers chose to incorporate these to commonly known game mechanics to ensure that players could quickly understand and engage with the game. This approach allowed the developers to focus on integrating educational elements seamlessly into the gameplay, without the added burden of complicated controls or mechanics hindering the player's ability to learn.

To simulate the waiting time involved in real-life aquaculture, the average waiting time in the game has been narrowed down to five to fifteen seconds, allowing players to engage in other tasks. Additionally, repetitive actions such as harvesting, feeding, and monitoring fish are simplified by merely interacting with the game object

Actions are translated into a "hold button" game mechanic to signify the energy expenditure required. Furthermore, complex aspects of aquaculture are simplified using pop-up windows with a drag-and-drop feature to represent the aquaculturist's movement. Overall, these design choices ensure that players can easily understand and engage with the game, while still incorporating the necessary educational elements.

3.2 Translation of Game Mechanics

The game aims to teach players that aquaculture is a meticulous and time-consuming process, but one that is ultimately efficient and sustainable. Through engaging gameplay mechanics, players will learn about the different stages of aquaculture, the importance of attention to detail, and gain an appreciation for this industry. The incorporation of different aspects of aquaculture to the game are as follows:

At the start of the game, the player must input their name and choose between a male or a female character. This element advocates for gender inclusivity in the world of aquaculture. Upon receiving the message from a quality control officer, the player sees a map of the aquaculture farm and proceeds to start the actual gameplay. There are 5 stages in the game which correspond to the 4 phases of aquaculture, mainly the hatchery, transportation, grow-out systems, and broodstock selection. Different phases have different tasks and stations around the map. The player is provided with a starter item and must carry out a series of tasks on it through aquaculture processing techniques to create a new item. The goal is to complete as many items to move onto the next phase of aquaculture. At the end of the stage, the final score received will award the player points. Figure 1 shows a visualization of the workflow of the game mechanics for each stage.

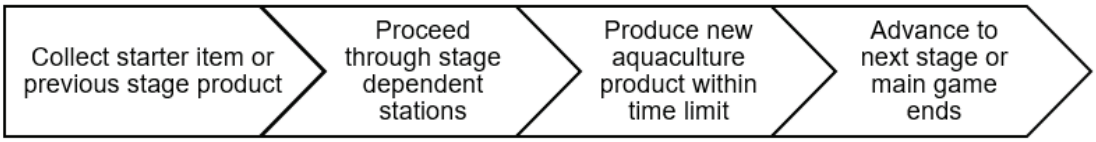

Figure 1. Game Mechanics Flowchart

In the Hatchery stage, the player receives a collection of fish eggs from the receiving station. The player must place the eggs in the quality control station where he will be grading the fish eggs for any possible infested batch. A mini-game screen will pop up at this point where the player must quickly identify the contaminated samples to be discarded. The player then disinfects the seedstock. The player then transfers the seedstock to the incubation period for hatching. At this point, the player must wait until the eggs hatch. While managing this, more seedstock arrives for grading and collecting newly-hatched fry. Players then move the fry to the sex reversal station, where they must feed them when a "feed" notification appears. By this period of the stage, the player must be managing multiple seedstock at once. After the sex reversal station, the player transfers the collected fry in the final grading station ready for transport.

In the Transportation phase, the map and stage are divided into two. During the first map, the player must collect the fry in the receiving station and transfer it to the filling station where a meter appears to indicate the water levels. Next, the player must go to the oxygen station and hold the interact button, making sure that the oxygen fills up to only the PE bag. After filling multiple bags, they move to the vehicle. While the player keeps in check with the driver, the player must also monitor several bags at once. A notification pops up indicating problems have risen. When a notification pops up, the player must attend to the bag by pressing the interact button. The player constantly monitors both the driver and the bags until the stage ends.

The Grow-out Systems and Market Selection stage are primarily like the Hatchery stage with some modifications. The player initially takes the PE bags from the receiving station. The player places the fish bags in tanks as it is important to only let the fish out once after conditioning them. Upon conditioning, the player places the fish in their respective grow-out tanks. Different tanks represent different methods of harvesting. In total harvest, the fish will be collected in one single order. In partial harvest, the fish will be harvested one at a time until all have been gathered. There are different containers depending on the tanks that the fish will be stored at, and it is the player's responsibility to match the correct container to its respective tank. After each order, the harvest collection data is logged in the computer system.

In the brood stock unit, the player receives healthy quarantined fish from the receiving station. The player then separates female fish to male fish by playing a mini-game that lets him identify the fish through their genitals. Pointed "V" openings for male, and “U” openings for females. The player places fish in separate spawning tanks according to the sex ratio and waits until the female fish holds her eggs in her mouth. Once it is done, a notification will pop out from the tank indicating that the eggs are ready for collection. These processes are done while the player feeds, like the previous stages, the potential/resting brooders in the other tanks.

3.3 Game Aesthetics

The visual graphics of the game were created with the intention of engaging the players and helping them immerse themselves into the aquaculture experience. The design aspect of the game was based on Gameboy Advance RPG games such as *Pokémon, Harvest Moon*, and *The Legend of Zelda*. The game allows the player to control a 2D character from a non-isometric third-person, overhead perspective. The design specification follows an 8x8 pixel tiling scheme with a limited color palette for a clean aesthetic as shown on Figure 2. The idea for the game design was to generate the emotional response of comfort, ease, and nostalgia, and to simplify the complexity of the aquaculture process for better interpretation and retention.

Figure 2. Hatchery Scene.

The game is set in the Philippines and is centered around the Philippine aquaculture of the Tilapia fish. Despite working inside the laboratory, the artistic choice of including the Filipino *salakót* is due to the goal of representing the Filipino culture, especially those who work in the agricultural sector as seen on Figure 2. With the simplification of the actual processes in the game mechanics, the aquaculture facilities, stations, and items were also reduced to follow the 8x8 tiling scheme. All design assets follow the similar color pattern wherein the top portion of each station or item have lighter shades while the bottom portion have darker ones. Light edges give definition to the items to imitate the real-life light shadowing.

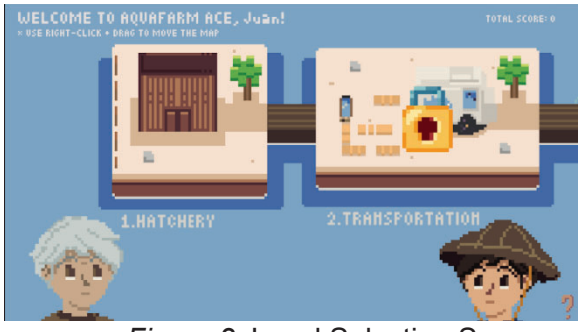

Figure 2. Level Selection Scene.

An AquaFarm Ace computer system concept was implemented to simplify some of the processes in aquaculture and to minimize the addition of guide characters. As shown on Figure 3, the developers opted to let a computer system handle most of the communication

and dynamics of the game. The character customization, introduction, tutorials, and level summary all utilize the same computer system theme to give the players information.

Figure 3. Computer System for feedback and tutorial.

4. Results and Discussion

4.1 Field Test

The research underwent two testing cycles with voluntary testers. The researchers took account the comments and suggestions of testers and have improved results between test cycles. Both testing cycle run on a 30-minute testing cycle. The testers were given a 5-minute pretest, were asked to play the game for 15 minutes and answer posttest and the Game Experience Questionnaire for the rest of the time.

The game was hosted on Unity Play through a WebGL adapter. The playtesting session was done at an schedule agreed upon by the researchers and the tester. The study made use of Google Forms for questionnaires. Each tester was tasked to do the following: answer a pre-test questionnaire, play the game, answer a post-test questionnaire, and answer the game experience survey taken from the Game Experience Questionnaire by IJsselsteijn et al. (2013) after playing the game. The pre-test and post-test questions ask the tester to self-evaluate their knowledge on aquaculture. Furthermore, the posttest asks the following open-ended questions to ask the testers what they recall from the game: (1) What aquaculture concepts have you learned after playing the game?; (2) What about the aquaculture process have you learned after playing the game?; (3) Finish the sentence: “Aquaculture is important because…”

4.2 Game Testing Results

The game was evaluated through three questionnaires given to the testers. These questionnaires are a game experience questionnaire, and the pretest and post-test on knowledge. There were a total of 7 testers per testing cycle. Mean was used as the measure of central tendency for the data set of the Game Experience Questionnaire, as per recommendation (IJsselsteijn et al., 2023). For the pretest and post-test questionnaires, median was used as the measure of central tendency due to the ordinate nature of the questions and to avoid outliers that may affect the central tendency.

4.2.1 Aquaculture Knowledge

Tester knowledge self-evaluation of knowledge on aquaculture and its process and importance, particularly aquaculture, and the demand for aquatic resources. Table 1 shows a comparison of the results on tester knowledge of the two testing cycles. The table shows that there is an increase in the self-evaluated knowledge of the testers in both cycles indicated by the higher scores in the post-test results.

Table 1. *Comparison of* tester self-evaluation *on knowledge*

knowledge item	cycle 1		cycle 2	
	pretest	post-test	pretest	post-test
aquaculture	4	5	4	5
demand for aquatic resources	4	4	3	5
aquaculture process	3	5	1	5
tilapia culture	2	5	1	5
importance of aquaculture	4	4	3	5

The testers were then asked to answer questions on what aquaculture and its process they learned after playing the game. Each tester had different answers which they had recalled from playing the game. These concepts were knowledge of the different stages of the aquaculture process, the segregation of male and female *O. niloticus*, and on maintaining the quality of fish. The open-ended question "Aquaculture is important because…" the testers provided more detailed and more specific feedback on why Aquaculture is important in the posttest. These answers include the effectiveness of fish harvest, the preservation of natural resources, and the importance of aquaculture in food security.

4.2.2 Game Experience

The Game Experience Questionnaire encompasses seven distinct components, each designed to gauge different aspects of player experiences. Illustrated in Table 2, the mean score of individual items within these components serves as a measurement of the players' experiences. These components, along with their corresponding items, are as follows: (1) Positive Effect - assesses player enjoyment, (2) Competence - measures the player's eagerness to excel, (3) Sensory and Imaginative Immersion - focuses on the player's sense of wonder within the game, (4) Flow - examines the player's state of mind while actively engaged in the game, (5) Tension or Annoyance - delves into emotions such as anger and frustration directed at the game, (6) Negative Effect - This component evaluates feelings of boredom or disinterest during gameplay, (7) Challenge - explores the player's perception of being tested in terms of their skills. These components are rated on a 6-item Likert scale, with a score of 6 representing the highest level of each aspect (IJsselsteijn et al., 2013). This comprehensive questionnaire offers a multifaceted approach to understanding the diverse dimensions of the player experience.

The testers mentioned that the gameplay, and aesthetics such as the design choice and background music of the game is enjoyable despite the amount of information the testers need to know at the beginning of the game. The visual cues on the icons help them navigate through the game. Additionally, the instructions manual provide aid to the players in providing information that they can refer to on the steps of the process.

Table 2. *Game Experience Questionnaire results*

Component	mean	
	cycle 1	cycle 2
Positive Effect	5.17	5.00
Competence	4.17	4.29
Sensory and Imaginative Immersion	5.21	4.86
Flow	4.46	4.40
Tension and Annoyance	2.14	2.57
Negative Effects	1.90	2.43
Challenge	4.14	4.50

5. Conclusions and Recommendations

5.1 Effectivity on Learning

As shown on Table 1, there is an increase in the self-evaluation of testers on their knowledge of aquaculture, the aquaculture process, and tilapia culture for both testing cycles. This shows that there is an improvement in tester knowledge upon playing the game.

The open-ended questions show recall of the topics and concepts introduced in the game. It was observed that the testers of Cycle 2 retained more specific information from the game as compared to Cycle 1 testers.

5.2 Game Experience

Results from the Game Experience Questionnaire indicate an enjoyable game experience. Sensory and imaginative immersion, positive effects, flow were the highest categories among the players' experience in cycle 1. The testers were not affected by the negative experiences of the game and were not annoyed while playing the game indicated by below the average scores in the questionnaire.

With both results of negative effect and tension or annoyance scoring below average on the game experience survey and the open-ended comments of the testers, it is concluded that the game provides an engaging and fun experience.

5.3 Recommendations

To enhance the player experience, the tutorial system should be made more intuitive and interactive for better information retention. One potential solution to address this issue involves implementing a tutorial run of a level before the player embarks on the first official level. This tutorial serves a dual purpose: it allows players to familiarize themselves with the game's mechanics and, simultaneously, gain an understanding of the aquaculture processes involved. This approach empowers players by providing them with the knowledge necessary to perform various tasks effectively. For instance, consider the hatchery stage. Prior to the timer commencing, a brief guided walkthrough of the game is presented. During this phase, players must follow the UI indicators, which guide them on where to go and what actions to take next. This introductory experience equips players with valuable insights into recurring UI cues that will continue to be relevant throughout the game.

Another recommendation is the addition of a well-defined storyline element. This will better immerse the player into the world of aquaculture as a story can highlight its demand and importance to societal issues, such as food or job security. As an example, the development team has already initiated work on a preliminary storyline. In this narrative, following the main gameplay, players are presented with various neighboring islands grappling with aquatic resource management challenges. The player's role then shifts towards aiding these islands and imparting essential aquaculture knowledge to help them overcome their difficulties. This approach not only enriches the player's understanding of why aquaculture matters but also fosters a more immersive and profound gaming experience. By intertwining the game's objectives with real-world issues, players can appreciate the broader significance of aquaculture in addressing societal challenges, although a thorough research on the stories of the people working in aquaculture is suggested to add more depth and relevance to the game.

Given the game's early stage, it holds potential. Researchers recommend improving the game's communication with the player: including tutorials, storytelling, and refining rewards and consequences to be more impactful. Awarding bonus points for consecutive perfect fish processing, deductions for missed station cooldowns should be considered. Moreover, adding animations and background sound effects can enhance immersion.

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