FLOOD GAME: AN ALTERNATIVE APPROACH FOR DISASTER EDUCATION

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ABSTRACT: *Flooding is a frequent disaster in typhoon season in Taiwan nearly every year. To prevent flooding, the decision-makers need to invest in costly constructions, such as embankments and disaster parks. They also need to carefully allocate resources, such as sand bags and pumps, to minimize the damage caused by the heavy rain during a typhoon. This paper presents an ongoing disaster education project, for disaster education for which we designed a flood game allowing high school students to play the role of the decision makers. We based the flood game on the popular "tower defense game," in which players need to allocate limited resources before and during random attacks because the decision behaviors are very similar between the decision makers of flood prevention and the players of tower defense. The flood game has two independent goals: happiness index and money. The happiness index represents the citizens' satisfaction. The money is a subtraction of the construction items from the total tax income. If the city is well protected, the tax income will increase and vice versa. The players need to wisely allocate the money to build the necessary facilities around the riverside in the right places and at the right time to maximize efficiency of the expenditure. We included six common construction items for flood prevention, including sand bags, pumps, dikes, disaster parks, green roofs, and green streets. We also developed six levels for the game, from the easiest (only one available construction item) to the most difficult (six available construction items) to help players progressively learn the game. If the city resists attacks from heavy rain successfully, the players can pass the level and proceed to the next one. To validate the use of the game, we tested the game with 148 high school students and found that it cannot only increase their interest in learning but also help students understand the complexity of flood prevention for the decision-makers. In the near future, we will develop follow-up teaching materials and videos to leverage the learning outcome after playing the game.*

KEYWORDS: *Game-Based Learning, Interactive Game, Flood Defense, Education*

1. CHALLENGES OF CURRENT DISASTER EDUCATION

Two critical challenges that need to be addressed in disaster education are student motivation and experience delivery. First, enhancing the learning motivation of students is a rising topic in research of education methods. Education methods play an important role in triggering students' learning motivation and furthering the enhancement of participation. Many studies indicate that there is a large increase in the learning motivation of students who receive the experiential education method. Experiential education is a method that involves the students in physical or virtual scenarios and makes them understand the knowledge behind the experience. During the experience, students have to look for the answer and figure out how things work all by themselves, which causes them to make more effort unconsciously. Motivation and participation are also enhanced naturally. In the field of disaster education, traditional education methods usually stress theoretical and conceptual knowledge rather than experiential ones. It is a great challenge to combine disaster education with the experiential method. The second challenge is to deliver field experience to students in the classroom. Traditional disaster education placed emphasis on the teaching methodology rather than the experience behind it. Past real world experiences indicate that many critical problems came from an inappropriate distribution of resources, and these problems usually differed in many cases based on disaster types, intensity, and geographic information, etc. Instead of teaching oversimplified experiential principles, letting students learn by doing gives them more flexibility and independent thoughts in disaster education.

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2. GAME-BASED LEARNING FOR DISASTER EDUCATION

Game-based learning is emerging as a hot topic in education. There has been growing interest in the potential of computer games in educational environments in recent years. The inception of educational gaming originated from the integration of computer science and operations research, associated with the issue of educational theories that stress on active, experiential learning and reflection. The first computer games with educational purposes were developed in the late 1960s after the first computer games were developed (Wolfe & Crookall, 1998). Playing games has a powerful influence on learning and it is fundamental to the development of both adults and children (Rieber, 1996), enhancing engagement and mastery with practical experience (Colarusso, 1993). Games are a fundamental part of the evolving human experience and learning method, providing the opportunity to practice and explore in a safe environment, teaching skills like aiming, timing, hunting, strategy and manipulation of resources and power (Koster, 2005). Game-based learning is an educational method that has defined learning procedures and goals according to a specific topic. It is designed to balance topic subjects with game play and requires the player to have the ability to retain and apply the given subjects to the reality. The learning would happen almost without the learners' realizing it, in pursuit of beating the game. We are encouraging them to learn by "stealth learning" (Prensky, 2001). When education or training is tedious, students are not engaged or motivated. In other words, they are not really learning. Rote memorization of traditional learning often leads to unsustainable learning outcome. Acquiring the skills and thinking processes needed to respond appropriately under pressure in a variety of situations is the great challenge of game-based learning.

In this case, we chose flooding as the topic of disaster education. Worldwide flooding has been brought to our attention by the media in recent years. Not just in Taiwan but also in other countries such as the United Kingdom (Lin Chen, 2013). Regardless of the time and location, flooding always brings a host of challenges to settlements and leaves both short-term and long-term impacts; the impacts are seldom beneficial, which is why it is crucial for students to understand the basics of flood protection. A game-based learning method in flood defense education should be developed since the lack of interaction between students and knowledge is a critical defect of the current flood defense education.

3. GAME DESIGN

We expect a game to enhance the learning motivation of students through learning by doing. This paper aims to develop a tower-defense-like computer game for disaster education. Game players need to defend multiple areas, which may be residential, commercial, or industrial areas in a city, and prevent those areas from waves of floods by using a variety of items representing different engineering approaches. They need to place appropriate construction items to prevent the city from flooding. The key to victory depends on how well the player manipulates the resources. Special policies can increase the items' effectiveness in specific regions. After a certain number of waves, the total score will be evaluated depending on designed indices.

Direct instruction is minimized to encourage students' active learning by exploration (Mitchel, 1998). Students play the role of decision makers (ex. mayor) of a city which suffers from flooding. They will learn different basic engineering methods and concepts regarding flood prevention throughout the game. The main purposes are to let students understand how to manipulate existing engineering approaches and resources to combat flooding before and after it occurs, and to instill knowledge regarding modern water conservation methods and policies in students. By experiencing the game, students not only acquire the knowledge they would not normally learn in traditional disaster education but they are also prompted to look at the bigger picture of this issue (Klopfer & Osterweil & Salen, 2009).

4. GAME CHARACTERISTICS

In order to answer the question of what makes a computer application enjoyable to operate, Malone (1980) proposed three essential characteristics: challenge, fantasy, and curiosity. In this game, challenge and curiosity are our main concerns; fantasy is not relevant to games that need to connect the experience to reality (Ebner & Holzinger, 2007). We therefore developed the design principles by implementing the challenge and curiosity elements.

4.1 Challenge

Design principles must encompass a predefined goal and allow the provision of performance feedback regarding the players' imminence to achieving their goal. The achievement rewards must be unpredictable. The gaming difficulty should be adjustable in this respect and a score calculation is needed for comparison.

4.2 Curiosity

Activities designed to trigger the players' curiosity must provide an optimal level of informational complexity (Piaget, 1951). This includes adding variety at random without making the tools unreliable. Game environments should be neither too complicated nor too simple with respect to the end-users' existing knowledge (Malone, 1980). During game play, the game must be novel and surprising while remaining comprehensible. An optimally complex environment will be one where the players knows enough to be able to anticipate what will happen but where their expectations are sometimes wrong.

5. GAME FEATURES

We defined four major features of the game. Each of them is an independent function but has shared variables and mutual influences. Every decision the player makes triggers a series of changes to the indices and scenario.

5.1 Multiple protection regions

The game includes three protection regions: residential, commercial, and industrial. Each region has its own properties such as population, tax rates, and resistance to floods. The residential region is where most of the population lives but generates the least amount of tax income. Contrastingly, the commercial region has the lowest population and the highest tax income among the three. In the industrial region, both the population and tax rates are of a moderate level. These designs simplify the reality reasonably while maintaining the balance of the game without involving complicated political issues.

5.2 Multiple evaluation indices

We defined two main indices for the evaluation of a single game play; happiness index (HI) and money. HI represents the satisfaction of the residents. As a decision maker, people's satisfaction is the main concern. The HI is designed to drop if any region suffers from flooding. Players will fail the game once the HI becomes 0. After the end of the final wave of a flood attack, the HI is one of the main references for the total score. Money resources are another important issue in disaster mitigation. In this game, money comes from the tax income of the three regions periodically. Different regions pay a certain amount of money according to the tax rates. Players can use money to buy flood prevention products, remedial measures, and infrastructure in this game. Players have to balance the HI and money while manipulating the arrangement of the different flood protection approaches.

5.3 Multiple approaches for disaster mitigation

Players can make use of multiple approaches for disaster mitigation to defend the shores from flooding. We want to design construction approaches and policies, each of which has their own properties of cost, durability, and efficiency. The design of the construction approaches are based on two types of approach for the decision maker, namely positive and passive approaches. A positive approach usually costs more but is efficient and guarantees sustained protection such as dikes and retention parks. Players have to save resources for positive approaches, meaning they have to give further consideration to pre-construction activities. Passive approaches are much more affordable compared to positive ones but the limited durability is unavoidable. Players use passive approaches as temporary and emergency approaches, such as sand bags and pumps, which are not the solution for a long-term flood protection plan. Another classification is the actual method of flood protection. We simplify and merge multiple methods into two categories: blockage and drainage. Blockage methods keep overflow water in the river by hard blocking. Drainage methods distribute the outflow of water to reduce the loading of the river. Since we have two categories and two different approaches, four different approaches are generated: sand bags, pumps, dikes, and retention parks. (Table 1)

Table 1: Classification of construction approaches

	Positive	Passive
Blockage	Dike	Sand Bag
Drainage	Retention Park	Pump

a. Sand Bag: Sand bags can be placed on the corners of a river to mitigate water overflow from flooding. Nevertheless, sand bags will be damaged over time and eventually destroyed by the impact of flood waves.

b. Pump: Pumps can extract a fixed amount of water from the river in a certain period but do not last forever. This is designed to reflect the fact that it is not a long-term solution.

c. Dike: Dikes function in the same way as sand bags, with the only difference being that dikes will not be destroyed by the sustained impact of flooding.

d. Retention Park: A retention park can distribute water continuously and has no limited lifespan. It also provides entertainment for residents whose satisfaction affects the HI.

Additional policies are designed as advanced approaches for a player to enhance a specific region's durability against floods. After reviewing current mitigation policies, we selected two policies for our game: green roofs and streets:

e. Green Roof: This policy can be applied to a specific region to increase its ability to store water. The durability of construction approaches around the region upgrades once this policy is conducted.

f. Green Street: This policy can be applied to a specific region to gain more storage for overflow water. With this policy, the region is able to absorb overflow from the surrounding rivers.

5.4 Sequential levels with increasing difficulty

Six levels are designed with different maps and difficulty levels. Each map has a unique river course and region distribution. With the increasing difficulty levels, flood-prone areas become harder to protect. It forces players to consider different strategies for manipulating the resources and the different approaches. Another challenge is that we reveal a new approach or policy in each level. Players get an additional more efficient approach in every level, that is, they have one approach in level 1, two in level 2, etc. In the last level, level 6, all approaches and policies are unlocked for players to use. This setup allows them to have more choice in the decision making process.

6. GAME DEVELOPMENT

We designed the game with the principles and desiring features mentioned above. First, we made an experimental cardboard game as a prototype (Fig. 1) of our computer game to define the game's functions and rules. It was easier for inspection and revision purposes before actually initiating computer software development. Second, after all major revisions were confirmed, we started programming the whole structure of the game on Adobe Flash CS6 platform using its language, Action Script 3. Third, we focused on the numerical setup and calculations such as the relation of indices, item prices, and timing, which have a great influence on user experience and game balance.

6.1 Prototyping

A cardboard game is an efficient method for the early stages of game development. It provides designers, artists, and programmers a handy and visual tool for thorough discussion. By playing step-by-step with cardboard, designers can discover and refine unexpected procedures, rule bugs, and gaming experience.

6.2 Implementation

The flood game was programmed and designed with Adobe Flash CS6 after detailed refinement with a cardboard game prototype. Flash is one of the primary tools for creating content for interactive software. The programming language Action Script 3 makes it possible to program end-user-dependent interactive and specially designed games. One main advantage of using Flash is the very compact file size that is a precondition for usable distribution. Furthermore, browser plugins are usually preinstalled in popular web browsers, which maximize the compatibility. We preferred Flash because of the possibility to quickly develop a usable and visualized game prototype.

Before programming the main game play, we first drew a skeleton of the desired game flow (Fig. 2) and linked each function. It presents a full cycle from starting the game, choosing the level, and the main game play, to showing the results. The players' entry interface is the *game main menu,* which includes three choices, *play*, *option*, and *help*. *Play* allows players to select a level and play the game. In the game play, we also designed a pause menu allowing players to restart, quit, and go to the *option* function. Every game play ends up with either success or failure as typical gaming feedback. A scoreboard showing players' gaming results appears if players succeed rather than fail in the game. The interface then goes back to the game main menu to start a new game. O*ption* has a switch allowing players to turn the sound effects on and off. He*lp* has several gaming tips for players to explore to see how the game reflects flood protection in the real world.

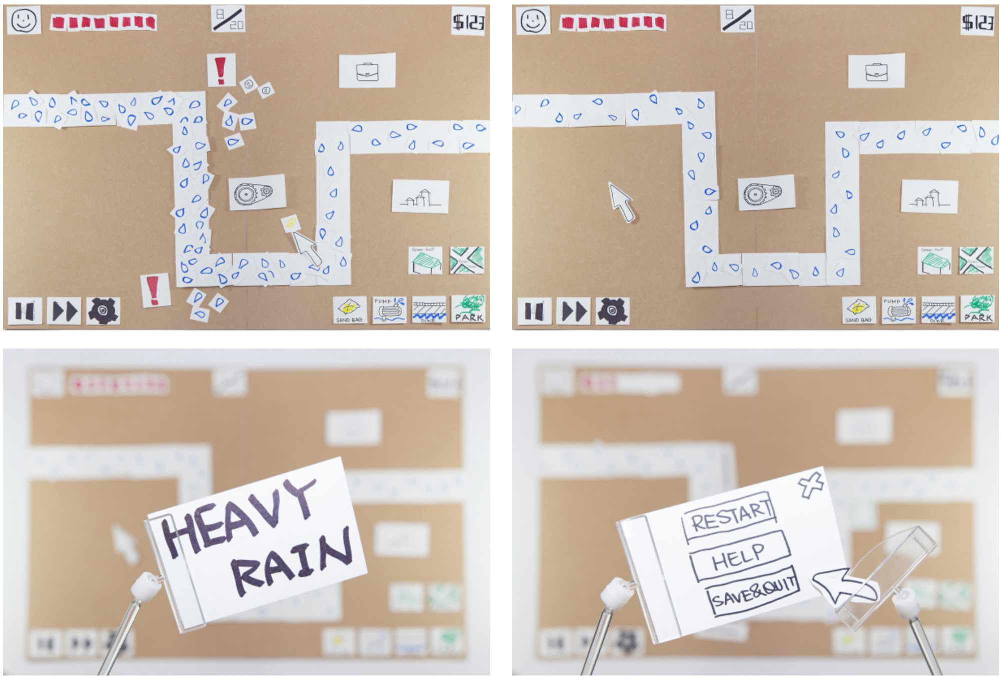

Fig. 1: Cardboard flood game prototype

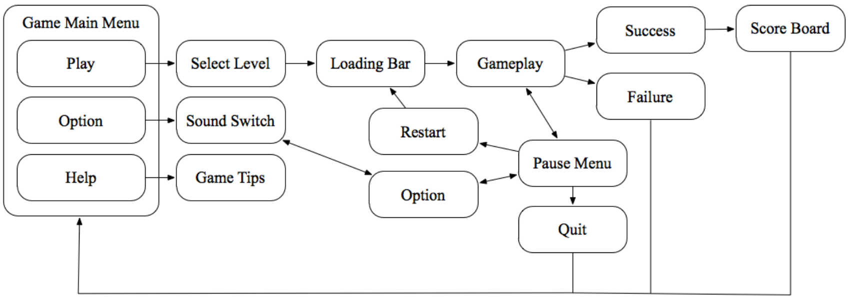

Fig. 2: Game flow skeleton

Next, we developed the main game play with the general gaming setup (Table 2.). This table simply explains the coding relationship between the major variables. Two parts, initial and conditional setups, are sectored according to whether the specific function needed to be updated in real-time. For example, in initial setup, money was initiated with a predefined value of 0, which is assigned a one-time variable (Table 2. (2)). However, in the conditional setup, money increases by collecting taxes from regions with values 3, 5, or 10 for every 3 seconds that pass (Table 2. (16)). Once all functions were programmed, we started to tune the numerical data used in functions to make the game more playable. These values provide a unique difficulty for the game. To improve usability, we created three tables (Table 3, 4, 5.) to show the customization of difficulty levels. The tables include numerical data for flood-prone regions, construction approaches, and policy approaches. We carried out the user test using values in the tables which provided a medium difficulty gaming experience for Taiwan high school students.

The final refinement of the software was to make the game look attractive. Our artists illustrated the six cities with a river passing through, the three regions with buildings, the construction and policy approaches, and every button and icon was designed in the same style. The unified graphic design style made the game look appealing for our target user, high school students. The game was then functional and ready for further user tests after replacing all temporary interface illustrations with the artists' designs (Fig. 3).

Table 2: General gaming setup

Type	Variable	Function	Relative Variables
Initial setup	HI	(1) HI is initiated with 500 units.	--
	Money	(2) Money is initiated with 0 units.	--
	Wave	(3) 5 waves of flood in every level.	--
	Wave	(4) 45 seconds lifespan for each wave.	--
	Water units	(5) Every water unit has a level property indicating its volume.	--
	Riverside spots	(6) Every riverside spot can endure a water unit of level 1.	--
	Riverside spots	(7) Every spot allows player to build 1 construction approach.	--
Condition setup	Water units	(8) Wave difficulty gradually increases with higher level of water units.	Wave
	Overflow units	(9) Water unit level beyond 1 will make an extra overflow unit.	Water units
	Overflow units	(10) 1 level higher, 1 more overflow unit is made.(ex. 3 overflow units are made by water unit level 4.)	Water units
	Overflow units	(11) Overflow unit counteracts 1 overflow durability of a construction approach.	Overflow durability
	Overflow durability	(12) Construction approach's overflow durability is predefined; it reduces after encounter overflow units.	Overflow units
	HI	(13) If overflow units hit a spot that have no construction approach, it means the specific region is attacked which causes a drop in HI.	Overflow units
	HI	(14) 5, 2, 1 HI drops when suffer from 1 overflow unit in residential, industrial, commercial region correspondingly.	Overflow units
	HI	(15) If there are no overflow unit hits for 10 seconds, residential, industrial, and commercial regions self-recover 3, 2, 1 HI every 6 seconds.	Overflow units, Time
	Money	(16) Residential, industrial, commercial regions pay 3, 5, 10 units of taxes every 3 seconds.	Time
	Result	(17) Pass all 5 waves without losing all HI to win.	HI, Wave
	Result	(18) Lose all HI means failure.	HI

Table 3: Flood-prone regions' numerical data setup

	Residential	Industrial	Commercial
Tax income per 3 seconds (money)	3	5	10
HI self-recovery per 6 seconds (HI)	3	2	1
HI drop per overflow unit hits (HI)	5	2	1
Overflow durability (overflow unit)	250	150	200
Satisfaction of residents (HI raised every 3 seconds)	0	1	5

Table 4: Construction approaches' numerical data setup

	Sand bag	Pump	Dike	Retention Park
Cost (money)	5	10	50	100
Overflow durability (overflow unit)	10	20	Infinity	Infinity
Satisfaction of residents (HI raised per 3 seconds)	0	1	2	5

Table 5: Policy approaches' numerical data setup

	Green Roof	Green Street
Cost (money)	150	150
Function	Upgrade surrounding constructions	Enhance the durability of region against overflow
Effect (per time)	- Extra durability for Sand Bag (+2) and Pump (+2). - Extra HI for Sand Bag (+1), Pump (+1), Dike (+2), and Retention Park (+2).	- 1 more overflow unit durability for all riverside spots around applied region.

Fig. 3: Flash flood game screenshots

7. FIELD TEST

We hosted two activities for high school students in Taiwan. Sixty-two high school students from different cities in Taiwan participated in a civil engineering camp hosted on January 24, 2013 (Fig. 4a). It was the first time that we introduced our flood game in public. We gained a substantial amount of user test data through observing their responses during game play. After analyzing these data, we found that we still needed more samples to resolve a precise validation. Therefore, we started planning for another activity which was held on February 5, 2013 in Hu-Wei high school, Yunlin County, Taiwan (Fig. 4b). Seventy-nine students and seven teachers participated. Furthermore, we also received many practical suggestions from a local professional flood mitigation team.

Fig. 4: (a) Civil engineering camp and (b) Hu-Wei high school camp

In each activity, we offered twelve desktop computers and divided participated students to played in groups of

three. The computer screen, mouse tracks and also students' voices and facial expressions were recorded during the gameplay. We also recorded the audio and video of the discussion and self-directed learning session. Two observers were assigned to each group to monitor their behavior during playing the game. The observers wrote down all notable discussion, emotional and motivation feedbacks. After these two activities, we sorted the collected data and summed up some ideas. The flood game generally raised students' learning motivation. Students liked to learn with the interactive game comparing with traditional lectures in which motivation is hard to maintain. Therefore, it is necessary to create game-based learning solutions that combine the attributes of motivating the students with designed software, which is joyful and does not feel like traditional learning. This idea was the incentive for the development of the flood game that was designed for disaster education.

8. RESULTS AND CONCLUSION

We conducted detailed behavior analysis by using the recorded video and observers' notes. We conclude that the flood game is an effective material in flood protection education. All the collected data are sorted into the four act indices: discussion, question, laughter, and screaming. These are valuable references for the motivators of hope and pleasure. Furthermore, we use the four status approaches (explore, aware, fluent, known), which can be used to evaluate the players' ability in the game; the observation of learning experience shows that students asked related questions and found strategies to fight against the floods. The flood game generally raised students' learning motivation. Students liked to learn with the interactive game comparing with traditional lectures in which motivation is hard to maintain. Students who have low motivation and high ability in a traditional learning environment were triggered after playing the game. The game-based learning in disaster education is a successful persuasive design. It has successfully enhanced students' motivation to learn more about flooding. The game does benefit disaster education, thus it indicates that an interactive game may promote students' motivation in disaster education and caused behavior change. Therefore, it is necessary to create game-based learning solutions that combine the attributes of motivating the students with designed software, which is joyful and does not feel like traditional learning. This idea was the incentive for the development of the flood game that was designed for disaster education. Further results will be organized and presented in future publication.

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