From Board Game to Digital Game: Designing a Mobile Game for Children to Learn About Invasive Species

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Abstract
Invasive species are species that cause economic and ecological harm and/or harm to human health. One challenge to managing invasive species is the lack of awareness about these species and the threats they pose. To mitigate this problem, the University of Florida Center for Aquatic and Invasive Plants developed a classroom board game for children to learn about trade-offs in managing invasive species. The game is effective in increasing knowledge about invasive species and promoting collaborative discussions. However, this board game is only accessible within the classroom. We created a mobile digital game that expands on the goals of the board game. In this paper, we discuss the design of the board and digital versions of the game, and provide some guidelines for designing digital learning games that address real-world problems that have no optimal solution, like the management of invasive species. Future work will evaluate the effectiveness of the digital game in enhancing children's knowledge about invasive species.

Author Keywords
Invasive species; Game design; Strategy games.

Figure 1: Lakeville Protectors main menu.

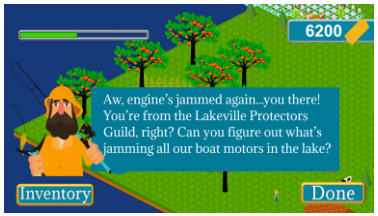

Figure 2: Consulting a citizen.

ACM Classification Keywords
K.8.0. [Personal Computing]: General - Games

Introduction

Invasive species are non-native species that cause ecological, environmental, and/or harm to human health [4,7,12,17]. Examples of invasive species are water hyacinth and hydrilla. Invasive species pose a threat to native wildlife; approx. 42% of threatened and endangered species are at risk due to invasive species [21]. Furthermore, these species are difficult to control because they grow and reproduce rapidly, leading to environmental losses that add up to approximately $120 billion annually [21]. This is especially severe in Florida where about $14.5 million is spent controlling hydrilla alone [11]. Zavaleta et al. [32] have found that there are also secondary effects that can occur from removing invasive species from the environment. Thus, invasive species make environmental resources difficult to manage.

The University of Florida Center for Aquatic and Invasive Plants (Center) developed an educational classroom board game – *Lakeville* – to help children understand the harm caused by invasive species. The game is a natural resource management activity designed for children in upper elementary and middle school (ages 10 to 15). In the game, children need to balance the species in the Lakeville ecosystem as a means to learn about invasive species and develop their civic responsibility, which is important in elementary education [16,19]. The game was deployed in local K-12 schools as part of a science classroom activity for children to collaborate with each other to accomplish the game goals. Results from knowledge-based surveys showed that children gained a 28.5% increase in knowledge of invasive species [Center staff, personal communication]. Though this game accomplishes the goal of educating children about invasive species, it currently can only be used in the classroom. Also, the board game does not include the mechanisms that are used to control invasive species, which is essential if children are to understand invasive species management. Thus, we collaborated with the board game developers at the Center to design a mobile digital game – "*Lakeville Protectors*" – that expands upon the goals of the board game (Fig. 1). We designed a single-player, multi-level strategy resource management game in which children can learn about the mechanisms needed to control invasive species. We focused on a single-player game for simplicity in the first version. Future work will extend it to multi-player.

In the main gameplay of *Lakeville Protectors*, the player protects Lakeville from invasive species. To do this, players must interact with game-world *citizens* to understand their preferences (Fig. 2), and hire *researchers* to investigate species and *workers* to control invasive species. Players must also manage their finances and race against time. The game actions were designed so that children can learn the role each species plays in maintaining a balanced environment, thus developing a mental model from the game that can be applied to their real-world environment.

In this paper, we will discuss the process of converting the *Lakeville* board game to the *Lakeville Protectors* mobile digital game. Based on our experience, we propose some guidelines for designing digital games with similar game narratives (e.g., learning to manage trade-offs among stakeholders when there is no optimal solution). Future work will evaluate the effectiveness of

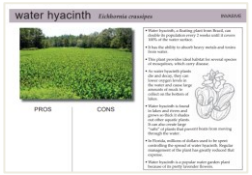

Figure 3a. Organism card showing a water hyacinth. © University of Florida/IFAS Center for Aquatic and Invasive Plants. Used with Permission.

Figure 3b. Citizen card for an angler. © University of Florida/IFAS Center for Aquatic and Invasive Plants. Used with Permission.

Figure 3c. Wheel of Focus. © University of Florida/IFAS Center for Aquatic and Invasive Plants. Used with Permission.

the digital game in enhancing children's knowledge about invasive species.

Related Work

The efficacy of educational games for children's learning has been studied in the literature. We mention a few relevant educational games, but for a more in-depth survey of educational games, see [25]. Sasha et al. [6] designed the Quest Atlantis game in which players address real-world issues by solving quests related to science and social studies in the game. Game evaluations found learning improved in these academic areas. Researchers have also proposed design guidelines to promote learning in educational games [8,10,15,20]. Pereira et al. [20] designed a "living forest" game and proposed that learning games should be designed such that players can develop a mental model that can be applied to the real world. Researchers [3,14,31] have studied games that incorporate the principles of board and digital game design. Golombek et al. [14] and Andersen et al. [3] designed augmented reality games that merge the design of board and digital games, while Xu et al. [31] proposed adding *chores*, an interaction experience formed by keeping records of progression in board games, to digital games to increase fun. For our design, we transitioned from a role-playing board game to a digital strategy game, and we propose guidelines when designing digital learning games for children where the concept being taught has no optimal solution.

Lakeville: The Board Game

Lakeville [26] is a natural resource management activity designed as a classroom collaborative role-playing game to educate children on invasive species.

Role cards

Children each get a role card to play during *Lakeville*, either an organism card or a citizen card. Organism cards contain information about the species such as the name, type (native, non-native, invasive), habitat, and the ecological effects of the species on the environment (Fig. 3a). Citizen cards contain details on stakeholders in Lakeville such as their priorities (Fig. 3b).

Wheel of Focus

This is a wheel containing the names of different species in the environment (Fig. 3c). The wheel is spun to select the next species to be played in the game.

Game Play

Lakeville's objective is for children to understand the differences between native, non-native, and invasive species, and to understand how decisions made can affect the environment. The game has been deployed in Florida classrooms for three academic years (2013-2014, 2014-2015, 2015-2016) as a science classroom activity. During the activity, a group of children role-play as citizens using information provided by the citizen role cards. The remaining children form groups and role-play as organisms using the organism role cards. When the wheel of focus is spun, the group representing the species chosen will try to convince the citizen advisory panel to include their organisms in the Lakeville ecosystem. A citizen's role is to decide the number of an organism to include in the habitat. For example, the water hyacinth is an invasive species known to cover water, thus reducing the amount of oxygen available to fish. For this reason, an angler may want less water hyacinth in Lakeville, while a nature lover may want more because the water hyacinth is a beautiful plant (Fig. 4).

Figure 4. Water hyacinth. © University of Florida/IFAS Center for Aquatic and Invasive Plants. Used with Permission.

Elementary/Middle School			
Years	**Avg. Pre-test score**	**Avg. Post-test score**	**Avg. % increase**
2013-2014	44.1/61.3	54.7/70.3	28.00/26.00
2014-2015	56.6/64.3	70.3/78.0	26.00/22.00
2015-2016	47.8/51.5	60.5/72.7	28.00/41.00
Total			**27.33/29.67**

Table 1: Evaluations of the Lakeville board game.

Evaluation
Knowledge-based surveys (pre and post) given to children to evaluate how effective *Lakeville* is in enhancing their knowledge of invasive species, showed that children gained a 28.5% increase in knowledge [Center staff, personal communication] (Table 1).

Limitations
The *Lakeville* board game has several limitations.

Inaccessibility: *Lakeville* was designed to be used as an additional activity in the classroom to introduce students to the effect of invasive species on the environment. Thus, the game is usually played in the presence of an *instructor*, a moderator who understands the game play, and a *domain expert*, who gives feedback at the end of the game on the effect of the players' decisions on the balance of the ecosystem. These requirements currently prevent children from playing *Lakeville* outside the classroom.

Control Mechanisms: There are four types of control mechanisms: (1) physical – manual removal of invasive species, (2) chemical – use of herbicides, (3) biological – introducing natural enemies, and (4) mechanical – use of machines. These mechanisms are not included in the board game; however, they are essential to understanding of invasive species management.

Lakeville Protectors: The Digital Game

We addressed the limitations of the board game by creating *Lakeville Protectors*, a resource management strategy game for mobile platforms, developed using Unity [27]. Our collaborators at the Center wanted to make a digital version of the game to reach more children. Their view was that digital games facilitate experiential learning because they have been shown to be effective in teaching real-world issues [4,9,20].

Transitioning from the Board Game to the Digital Game
We conducted a focus group session with two experts in invasive species who work at the Center (one of whom is a co-author on this paper). The domain experts wanted a game that children can have fun playing, both inside and outside the classroom, while educating them about invasive species. They also wanted children to understand the differences between native, non-native, and invasive species, and the appropriate resources to use to effectively manage invasive species. Thus, we decided on strategy and resource management as the genres for the game. We also reviewed similar games in these genres such as Feed the Dingo [30], Banished [23], and Hay Day [24] to understand effective game mechanics to include in the digital game.

Game Design
We designed a multi-level resource management strategy-based game. Our main aim was to create a game in which children can develop a mental model by controlling invasive species within the game, and apply it to their real-world environment in order to become informed citizens. We discuss the game components.

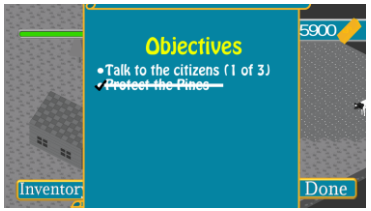

Figure 5: Lakeville Protectors objectives.

Figure 6a: Farmer.

Figure 6b: Land developer.

OBJECTIVES

There are two types of objectives in this game: learning objectives, and game objectives. Learning objectives are objectives focused on learning about the species in their environment and are implicitly accomplished. We have two learning objectives in the game – i) Learn the difference between native, non-native, and invasive species, and ii) Understand the mechanisms used to manage invasive species. Game objectives are goals players strive to accomplish in the game (Fig. 5). These objectives must be completed to progress through levels in the game, and are structured such that at the end of a level, players have saved Lakeville from invasive species within the time limit.

GAME MECHANICS

There are two main components that enhance the game play: a) Resources, and b) Rules.

a) *Resources* – These are usable assets in the game that children must develop strategies to manage due to their limited availability. The game has two resources, *time* and *money*, to address the domain experts' need for children to understand real-world resource management and effects of specific management decisions on the ecosystem.
b) *Rules* – Rules restrict players' actions [22], and govern what players can do and how the game will respond [2]. The rules of our game are – i) The player must earn 85 points or more to unlock the next level, and ii) The player fails a level once the time limit expires and points are insufficient.

GAME PLAY

The player is introduced to Lakeville through a game story that tells the player that he has been recruited as a member of the Lakeville Protectors Guild, and introduces him to the definition of native, non-native, and invasive species. We created a game story to immerse players into the virtual world of the game [1,13]. The player's task is to control the invasive species using funds provided in the game and before the time limit expires. To accomplish this, the player must gather information about the problem from citizens in Lakeville (Fig. 2). Each citizen has a different occupation: a) an angler, b) a farmer (Fig. 6a), or c) a land developer (Fig. 6b), and different priorities (which are the same as the priorities defined in the citizens' cards of the board game). When a player consults a citizen, a new objective appears (Fig. 5). The player must use limited funds provided to hire researchers to investigate the species in the environment, and workers to apply control mechanisms based on feedback from the researcher. The optimal strategy to progress in the game is for the player to control the invasive species while causing minimal harm to non-invasive species in Lakeville. Once the player is done (i.e., the time limit expires, or the done button is clicked), an inspector gives feedback and assigns up to 100 points: 20 points for the time and funds remaining, 10 points for consulting citizens, 30 points for controlling the invasive species, and 40 points for effect of control on the environment. If the player gets 85 points or more, they can progress to the next level, otherwise, the player has a chance to replay the level. We chose 85 to progress a level because this is a "B" on the academic grading scale [5], and shows that the player generally understands the learning goals of that level.

Educational Enhancement

We added three features to enhance learning.

a) *Tutorial* – We use a tutorial-based approach to ensure the child understands the game play,

similar to other strategy games [24,30].

b) *Feedback* – Previous research [18] has shown that providing feedback on the choices made during game play increases the learning retention rates in educational games. Thus, we provided detailed feedback on the effectiveness of their choices at the end of a level.
c) *Replayability* – When points are insufficient to unlock the next level, children can replay the level so they can reapply the knowledge gained on the first try to subsequent tries, thus solidifying the knowledge gained.

Design Guidelines

We discuss some design guidelines for digital games based on our experience so far on this project.

Streamline the Game Objectives

The digital game initially included many objectives players had to complete in a level since we were expanding upon the goals of the board game. However, when presented to our domain experts, they were concerned that these objectives would be overwhelming for children and decrease engagement. To resolve this challenge, we prioritized the main goals we wanted children to accomplish. For example, we chose "learning control mechanisms" over "balancing species". Thus, though digital games have a rich space for incorporating many objectives, designers may have to prioritize the objectives based on the knowledge goals they have for children playing the game.

Promote Guided Play

Another challenge in the design of the digital game was determining the "optimal strategy" to progress through levels since there is no one right answer in our real-world scenario. Our design approach to solving this challenge was to add a "researcher" in the game who served as a guide to help children make effective choices during game play. We adopted this approach from the concept of *guided play* [28,29]. Prior work [29] asserted that this concept improves child engagement while maintaining focus on a learning objective. Thus, when creating games for children where there is no one right answer, designers should include game elements that can promote *guided play* [28] for children to encourage them to explore the full space of the problem and understand the trade-offs.

Conclusions and Future Work

Since this project is still a work-in-progress, there are some limitations to this work. The digital game does not promote classroom collaboration since it is a single-player game. Future work will make the digital game a multi-player game. Another limitation is that the game has not been tested with children for feedback. Future work will include children as game design partners. We also plan to study the effectiveness of the digital game in enhancing children's knowledge about invasive species, and evaluate children's knowledge retention rates when using the digital game compared to the board game. This game establishes a foundation to explore educational game design for contexts in which there are trade-offs among the stakeholders and nuances to choosing a good solution.

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