Flood Adventures: A Flood Preparedness Simulation Game

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***Abstract*—Knowledge of how to prepare for flooding remains an important educational need as illustrated by the devastation caused by recent flooding events across the USA and in other global locations. To address this need, we are developing *Flood Adventures*, a two-stage VR learning game with best practices for flood preparation focusing on how individuals can prepare for flooding and communities can mitigate flood risk. We present our VR game learning model that guides our design and development work. Our prototype development work on the first game stage that focuses on flood preparedness is presented. We conducted usability testing with the initial prototype version of the game with twenty-four adults. Findings from our usability testing found that players used spam clicking strategies during game play. Recommendations to enhance the game are presented.**

Index terms—flood preparedness, virtual reality, learning game, flood risk

I. Introduction

As global temperatures rise and the hydrologic cycle intensifies [1], people and property are at a higher risk to flooding events [2]. Knowledge of how to prepare for flooding and where to find forecasts and preparedness information remains an important educational need as illustrated by the devastation caused by recent flooding events across the USA and in other global locations. It is important that people know what actions to take when a flood is forecasted and understand the risk flooding poses to infrastructure and lives. Game-based immersive VR learning environments can help individuals learn about best practices for flood preparation and how individuals and communities can prepare for and mitigate flood risk.

Our team hypothesizes that learning about flooding with VR can have a positive impact on engagement and learning, particularly in informal learning environments and at home. Engagement is critical to learning in informal STEM education. Research shows that during informal STEM education, learners are most engaged by experiences that offer interactivity [3]. VR learning games are one way to provide this interactivity and engagement. Features such as active control of the user experience, naturalistic, yet safe environments, and realistic representation of real-world situations can increase engagement and learning [4]. The VR experience can also provide a sense of authentic immersion and presence; users can virtually 'be' at specific geographic locations that are dangerous [5]. Furthermore, headset VR can focus users' attention on learning tasks in a game [4]. Our aim with a new Flood Adventures VR game prototype is to enhance the quality of visitors' experiences in informal environmental education centers while improving understanding of flood preparation and mitigation of flood risk.

II. Background and Theoretical Framework

Our VR game learning model (Figure 1) focuses on elements that lead to engagement and learning with VR game-based experiences. Engagement can be defined as one's focus, participation, and persistence within a task, and therefore, is related to adaptive or self-regulated learning [6]. Engagement is what happens during a task and is the result of the interaction between the learner and the characteristics of both the task itself and the supporting environment. Dorph et al. [6] discuss three dimensions of engagement: (1) behavioral engagement that focuses on what a person involved in a learning activity would be doing (e.g., actively participating in a learning task); (2) cognitive engagement that focuses on thought processes or attention directed at processing and understanding the content in a learning task; and (3) affective engagement that includes one's emotions that are experienced during a science activity. Research suggests that a combination of these three aspects of engagement supports learning [7]. In addition, agentic engagement, a fourth and more recent dimension of learner engagement, involves one's proactivity and valuable contributions into the received instructional sequence [8]. All four forms of engagement can be enhanced by VR learning games.

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Our project builds on two theoretical frameworks: (a) Malone's theory of intrinsically motivating instruction [9], and (b) Science Learning Activation Theory [6], which supports our design of engaging VR game-based activities for learning. Malone's theory of intrinsically motivating instruction [9] contends that intrinsic motivation is created by three qualities: challenge, fantasy, and curiosity. A main component of Science Learning Activation Theory [6] contends that the activated science learner is fascinated by natural and physical phenomena. A learner can have emotional and cognitive attachment/obsession with science topics and tasks that serve as an intrinsic motivator towards various forms of participation.

The model inputs (Figure 1) derive from the published literature pertaining to VR and game-based learning, including (a) perceived usefulness of learning with VR, (b) VR affordances, and (c) flexible game design features for individual and social learning. Previous research has identified *perceived usefulness* as an important component that influences learners' interactional experiences when using educational technology [10]. Perceived usefulness refers to the degree to which a VR user believes that using a platform will enhance their performance [11]. Recent VR implementation studies have found that perceived usefulness is important for promoting cognitive benefits and affective learning in a VR lesson [11], [12]. The *VR affordances* of immersion and presence are the main area of VR research studies primarily with headsets [13]. Immersion is the level of sensory fidelity that a VR system provides and describes the experience of using VR technology [14]. Presence is a user's subjective psychological response to a VR system where the user responds to the VR environment as if it were real [15].

Flexible game design features for individual and social learning are design principles that draw from the research literature on designing learning for informal science education environments and the affordances that gamified VR can provide. These include:

- **Engage learners in challenging tasks that are intrinsically rewarding.** Distinct challenges within a learning game keep players engaged and challenged. Designing for the right challenge-skill balance promotes engagement and an intrinsically rewarding experience for the learner [16], [17].
- **Promote curiosity.** Curiosity involves intrinsic motivation to learn and explore. Exploration, task simulation, and social simulation games with virtual characters have been found to stimulate curiosity [18].
- **Provide a strong narrative**. A game designed for informal use requires strong narrative elements to generate excitement, interest, or enthusiasm for science learning. Game-based narratives use questions, problems, or missions to enhance learners' motivation [19].
- **Provide supportive guidance and motivational feedback**. Guidance in the form of advice, feedback, prompts, and scaffolding can promote deeper learning [20]. Providing guided exploration and metacognitive support also enhances learning for transfer in informal settings [21]. Support is also enhanced by different forms of engaging feedback such as badges or points [22].
- **Engage in generative learning tasks to stimulate reflection within and among users**. Reflective learning is a generative learning strategy that involves actively reflecting upon one's own understanding of the material

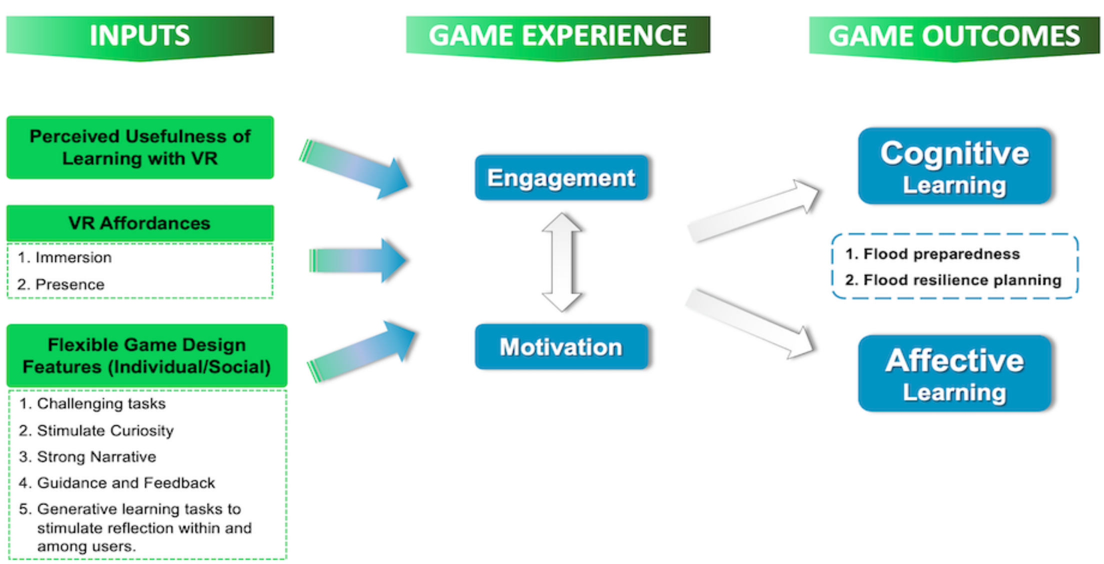

Fig. 1. VR game learning model

and generating inferences [23]. VR learning that incorporates generative learning strategies can be beneficial for promoting motivation and learning [24].

III. Flood Adventures: Prototype Design and Development

Guided by VR learning and game design principles, we are developing a multi-stage (level) VR game for adolescents and adults to learn about flood preparedness and community resilience planning. These authentic issues make science learning engaging since players need to feel the relevance and authenticity of the learning activity to their personal lives in some way [25]. The game is being designed for diverse populations and will be relevant to many people in the USA since millions are exposed to flood risk [26]. This should help players identify with flooding issues in personally meaningful ways to promote connections between science knowledge and their own lives. The game also uses combinations of imagery, 3D visualizations, animation, audio, and text to enhance learning, promote transfer, and foster sense-making of flood risks. We are using the *Quality of Education in Virtual Reality Rubric* [27] to guide our development process for learning goals, content development, pedagogy, metacognitive prompts, feedback, interface design, sound, language, navigation, engagement, ensuring content is culturally appropriate, and other VR design features.

Flood Adventures will take place in two game stages (levels). The first stage focuses on flood preparedness and the second game stage focuses on community resilience planning. Each game stage is designed to take 15-20 minutes to complete. The game experience will begin with a brief three-minute video to inform players how global climate change can result in a higher risk of localized flooding events that threaten lives and property. We present our development work to date on the first game stage.

Game stage one begins at a house located near a creek. The house includes multiple rooms with 50 household items (Figure 2). The player starts in the garage and a tutorial explains how to move, pick up and place objects into an inventory system (this is analogous to what one is carrying), and then put the gathered objects in the household's car. A weight system is employed that slows down the player's movement as they carry more object weight. The tutorial ends with the player going to the living room where a flood emergency warning goes off on the TV and their smartphone. The player learns that the nearby creek is flooding and hears "get all your essential items and evacuate the area immediately."

The scene changes to the area outside showing a nearby creek and surrounding area (Figure 3). A major thunderstorm occurs, water begins to flow faster in the creek, and debris start to rapidly flow downstream as the water level rises. The water begins to rise over the banks of the creek and approaches the house (Figure 4).

The scene then shifts back to the house where the player is given three minutes to gather items in the house to place in the car. The scene ends abruptly at three minutes with a cut scene showing the creek flowing over the bank and inundating the house. Feedback is given to the players about how many of the items they gathered were essential (needed that day), very important (needed it in the next few days in case you cannot get back into the house), and items that are useful, and not very important for daily survival. A point system ranks each of these four item categories. This game segment is designed for the players to initially fail and receive a low score. We envision that during this game segment, most players will not have appropriate background knowledge to differentiate between items that are essential or very important compared to items that are useful or not needed during a home flood evacuation scenario. Then, specific reflective prompts appear based on the player's decision-making choices (what they chose to take with them when evacuating) and will be reflected in a game score. Designing to have the initial attempt fail is meant to creating a learning opportunity for the player and highlights the importance of the tasks they must do in response to a flood threat.

The game continues with a loud TV sound. The player wakes-up and realizes it was just a dream. The player slowly walks to the living room to turn off the TV. Suddenly, they notice the content of the TV broadcast: an interview with a flood preparedness and resilience expert from the local nature center. She would be teaching the player how to prepare a "flood emergency kit."

The game continues with a short video from the TV in which the player learns about recommended items to have ready in case a flood occurs, the importance of preparing an evacuation route, and the dangers of driving into standing or rising water. During this game segment, players have time to gather essential items in the house and place them in a "flood emergency kit" container. Reflective prompts direct players to think about which items are essential and very important to place in the container. Feedback on the items' importance appears immediately after each item is placed in the container. The weight system keeps players from carrying too many heavy objects at one time. If the player's carry load exceeds twenty pounds, the player's movement slows down. This game segment concludes when they have prepared the container while reflective prompts encourage players to think about other very important items to gather if a flood occurs.

The next game segment begins with the flood emergency warning going off in the house. The player has three minutes to gather household items that now includes their "flood emergency kit" container and load them into the car and drive off. Feedback is provided and the intent is that the player will receive a much higher point score based on their new decisions. Reflective prompts focus on the decision-making choices. Finally, players have the option of either repeating this segment to improve their performance or moving on to game stage two.

IV. Prototype Testing And Next Steps

We conducted a usability study of the prototype house and its functionalities (movement and ability to pick up objects) with twenty-four adult participants 20–49 years old that played a desktop VR version on a PC laptop. Each player was informed that a flood was approaching the house and they had three minutes to grab as many essential items as they needed and were to place them into the car located in the house's garage. After the participants completed the task, we asked them to provide us

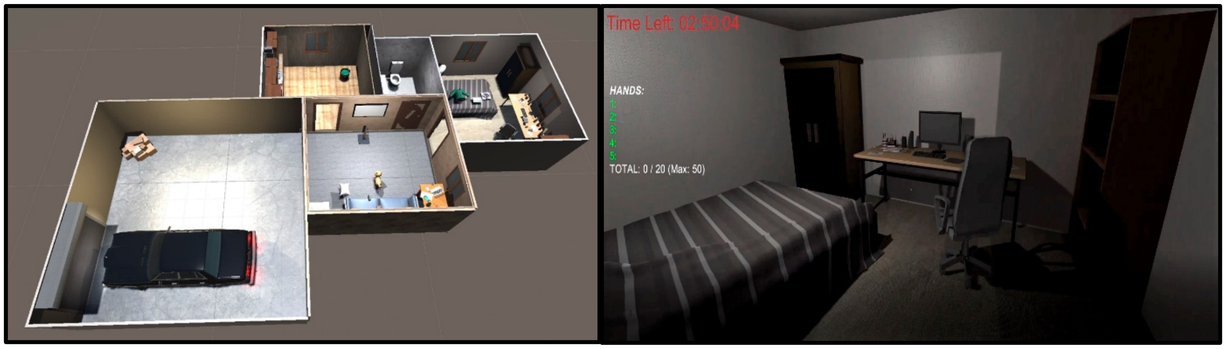

Fig. 2. The house where the game occurs. The left image displays a top-down view of the house showing the different rooms. The right image shows the bedroom.

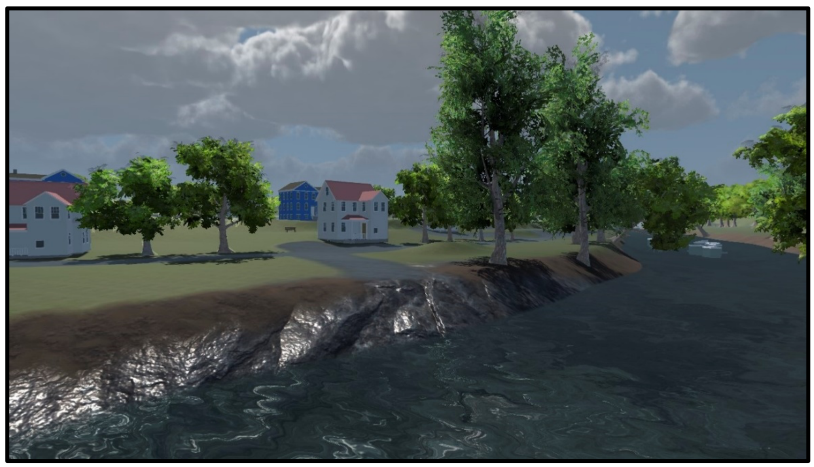

Fig. 3. The creek and surrounding area.

Fig. 4. Water rising over the banks of the creek approaching the house.

with feedback to enhance the game and if they enjoyed playing it. All participants were able to successfully move throughout the different rooms of the house and pick up objects. The participants reported that Flood Adventures was "so cool" and a "fun game." Some participants commented that they enjoyed the cat that walked around the house. Some participants reported that their movement was smooth and did not lag. During the usability testing sessions, we observed that many players used spam clicking strategies [28] to complete the game. That is, they were interacting with the user interface through quick sequences of mindless and random clicks during gameplay.

The prototype testers had many recommendations for improving the game. One player suggested that the feedback system provide a detailed explanation for their scores. Another player recommended providing more detailed game instructions. One participant stated it was unclear which items in the house could be picked up. One player commented that the game needed to prevent users from spam clicking. Other recommendations from players included enhancing the lighting in the rooms, using different textures on the floors of each room, providing the functionality to open the cabinets, changing the direction of opening the door into the garage, and using a more realistic looking cat or including a dog in the house.

We are currently refining the prototype of *game stage one* in the Unity environment based on our prototype implementation feedback. The house now has different textures on the floors of each room and enhanced lighting. We have developed a differential point system for the four different item types that are placed in the house based on their importance during a flooding event: essential (needed that day), very important (needed it in the next few days in case you cannot get back into the house), items that are useful, and not very important for daily survival. In addition, we are developing a more detailed feedback system to provide players important dialogue prompts to consider while they are gathering objects in the house.

After further revisions to the prototype are made, we will conduct another round of usability testing with a desktop VR version of the game and make revisions based on testers' feedback. After the last iteration of the desktop VR version, we will convert the game for headset VR implementation and conduct further usability tests. Additional prototype implementation data will inform revisions to this first stage of the game. Then, the revised headset VR version will be pilot-tested at two informal environmental education centers. After our iterative development process concludes, we will begin development on the second game stage which is a flood hazard mitigation, planning, and decision-making simulation game that takes place on a community level perspective.

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