Following the Carrot: The Design of Biofeedback Games as a Tool for Student Focus & Attention

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ABSTRACT
Previous studies have shown biofeedback self-regulation helps children positively manage stress and focus their attention on learning tasks, a skill that can translate into significant improvements on standardized test scores. This paper explores the design and use of biofeedback games using Heart Rate Variability (HRV) as a method of focusing student attention and decreasing stress specifically within the classroom space. Semi-structured interviews with educators, as well as classroom observation time, participatory design sessions, and iterative user testing with K-6 students were used to inform the design and development of our biofeedback game *CritterQuest.* The game offers a tool for K-6 children to gain critical skills in focus, attention and relaxation that have been shown to be important for character development, behavioral management, and learning. Additionally, the three methods used to evaluate the games provide a model for future game development and design within an educational context.

Author Keywords
Biofeedback, physiological computing, games, mindfulness in education, heart rate variability.

INTRODUCTION
Federal funding cuts in the United States have led to a decrease in teaching aides for special needs students, and cuts in programs focusing on emotional management in the state of California [1]. More than ever there is a need for tools that teachers' can utilize to facilitate student attention and positive behavior within the classroom. Biofeedback games (BFGs) offer a way to engage students while offering important learning skills regarding attention and focus within a classroom environment.

Numerous studies have shown potential benefits of biofeedback and mindfulness on positive educational outcomes, especially for children with ADHD and ADD [2]. This is particularly relevant given that 7% of American children between the ages of 3 and 17 are diagnosed with Attention Deficit Disorder [4]. Studies conducted within California classrooms have shown remarkable learning improvements after students were taught HRV self-regulation techniques. These techniques include focusing on slowed breathing, attention to heart beat, and positive visualization and associations [5].

One peer-reviewed study found that students who were trained in and practiced self-regulation techniques showed a 21% increase in test scores on an English Language Arts assessment and an 11% improvement in Math [5]. The use of biofeedback within a classroom offers great promise, yet much of the previous research does not adequately address how biofeedback can effectively be integrated within the educational environment itself.

This paper discusses the design and development of our biofeedback game *CritterQuest.* While several companies have developed computer games that utilize HRV or other biofeedback mechanisms, there is little known research on how to best design such games for use by students within a classroom space. This paper offers insight into several observed problems with the design of existing games, including appropriate use of scaffolding, walk-up usability, motor control, feedback, and the appeal of game content. Next, we show how our iterative design processes provided useful methods for overcoming these design barriers.

BACKGROUND
There are a several notable biofeedback games that have been developed both commercially and for research purposes. None of these games have been built explicitly for use by students or within the classroom space.

"Relax to Win," is an existing racing game where two players compete against each other to see who can "out-relax" the other [15]. Perhaps unsurprisingly, this element of competition was shown to create greater stress that the gamers had to overcome, which could serve as a barrier to beginners that were new to the relaxation techniques.

By contrast, a collaborative environment is present in the prototype "Water Game" out of the Helsinki Institute for Information Technology. This game follows a First Person Shooter (FPS) theme, which is obviously problematic for its use in an educational environment. The game does offer several distinctive design insights. Players use mobile phones as individual input devices, while a large screen provides an overview of the group performance. Though thematically troublesome, "Water Game" is a valuable example of potential uses for mobile devices in collaborative gaming [16].

Several computer games have been produced by the companies HeartMath and Wild Divine that utilize HRV or other forms of biofeedback as the primary mode of input. While these games offer difficulty setting that affect the thresholds for "successful relaxation, these settings are picked at the start of each session, and have no direct impact on gameplay. A one-size-fits-all model is employed in which the game does not adapt based on the users' ability to actually achieve HRV self-regulation successfully.

Scaffolding is a technique used in video and computer game design where the game gets progressively more difficult based on the users' ability [13]. In the few biofeedback games that did employ difficulty levels, the variation in challenge was based on controls that were separate from the biofeedback itself. For example in the Dual Drive racing game the level difficulty increased with greater obstacles on the racing course not a more challenging threshold for the HRV level.

USE OF HRV

There are numerous methods of gathering sensor data to evaluate attention and focus using biofeedback including HRV, galvanic skin response, and EEG. HRV was selected as the biofeedback method for our project for its accuracy and the non-invasiveness of the hardware components. Other methods, such as EEG can significantly restrict motion and pose a challenge for data collection.

DESIGN AND RESEARCH

We utilized several methods to evaluate game requirements and help craft the user experience. Our primary research was broken into three phases, pre-implementation background research, and early-development evaluation, and post-development evaluation. The first phase of methods consisted of an initial evaluation of existing games, a round of semi-structured interviews with teachers and educators, and a participatory design session with potential users.

We then conducted a round of user testing to validate our fundamental design, as well as to get additional feedback on potential improvements. Findings from this testing were fed into another iteration of the game. Phase three was taken an additional round of usability testing within a real classroom environment [Figure 1].

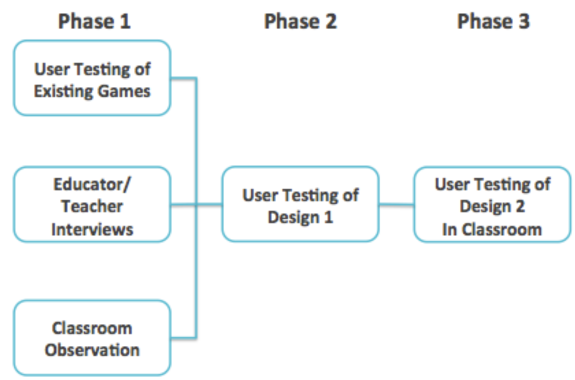

Figure 1. The three phases of methods used for our design.

EARLY STAGE DESIGN METHODS & RESULTS

Evaluation of Existing Games

We evaluated five existing, commercially available games that used HRV as an input. Our participants were ten students ages 6 – 13; three females and seven males. Snowball sampling was used to generate interest from parents and to recruit children for the study. Game evaluations were conducted in the Bay Area, California and in Austin, Texas. All games gave direct user feedback using three bars that were green (optimal HRV), blue (within several Hz of optimal) and red (non-optimal HRV). The HRV monitoring sensor used was an a emWave USB powered ear clip produced by the company HeartMath. The device calculates optimal HRV to be within .1 Hz of a sine-wave function.

Participants were trained for several minutes in techniques to regulate their HRV, including slow controlled breathing, focus on heart rhythms, and methods of positive visualization. They were also given several minutes to view a dynamically updated graph of their HRV to gain a better understanding of how the above methods could be employed to self-regulate their heart. Participants were then asked to select one of the five games to play, a step intended to evaluate initial interest and engagement with the different game options. After playing, each participant was then asked questions regarding previous game usage in home or at school as well as questions regarding engagement and likability of the game.

Figure 2 shows a comparison of optimal HRV reached during gameplay and the participant enjoyment rating of the game (HRV was normalized to a 1-10 scale). The *StarFire* game showed a significant increase in average HRV and also scored high for participant enjoyment.

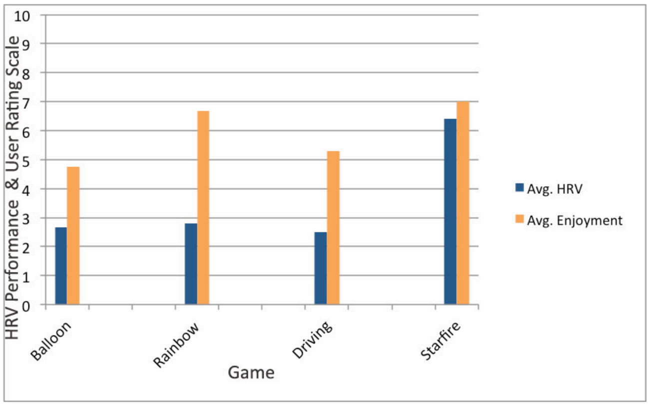

Figure 2. Average optimal HRV and enjoyment by game.

While the study results are not statistically significant given the small sample size for each game, the study did provide insight into the player preferences and challenges during play. The driving game, which received high initial user interest, proved too challenging for many children as it asked them to use the keyboard to steer a car through a racetrack while simultaneously practicing the fundamental concepts of HRV self-regulation (Figure 3). The StarFire game provided simple stimulus of a fireworks-like display of lights without any additional controls beyond HRV.

Figure 3. Assessment of breath and HRV in a driving game.

Several key findings emerged from the evaluation of existing games:

Customization & Choice: Children wanted choice and customization of both game type and characteristics.

Simplified Controls: Additional player actions and controls were too challenging when first learning HRV regulations and should be reserved for experienced players.

Free-Form Exploration: Unrestricted exploration of the driving game environment was seen as preferable and less challenging than the restricted path of the racetrack.

Rewards, not Punishments: We observed that for new users, some games gave feedback on HRV that were seen as a source of further stress. In particular, several participants gave a highly negative review of the racing game, in which a low HRV score caused the car to come to a halt. This interaction was viewed as extremely frustrating and not conducive to relaxation.

Educator Interviews & Classroom Observations

Seven semi-structured interviews were conducted in the California Bay Area with educators to determine how an HRV based game could be incorporated into existing classroom environments. Stakeholders interviewed included fourth and fifth grade teachers, a teaching consultant servicing failing middle schools, a school psychologist, and the director of a federally funded program on character education and violence prevention. Questions were asked regarding behavioral and emotional management in the classroom as well as daily uses of technology.

These interviews were supplemented with three classroom and after-school program observation periods in San Leandro and Oakland, CA. Both the interviews and in-class observations provided a design context for the HRV games that incorporated the challenges and opportunities of working in the classroom.

We distilled the following key findings and considerations from the interviews and class observations:

Variable Resources: While few classrooms had access to desktop computers in-class, most had access to mobile computing stations or a computer lab located in the school.

Training Challenges: Teachers felt poorly equipped to utilize sophisticated technology without specific training. That said, technical trainings could be expensive, including trainer time and the overhead of hiring substitute teachers. Additionally, high-turnover rates at poorly performing schools exacerbated the training problem. The training problem resulted in several technology usage failures. In one school, several classrooms were equipped with $1800 Promethean "smart boards" that went unused when the teachers that received the initial training left the school. Another school was given a grant of 20 iPads without training; none of them were ever employed in the course of instruction. These cautionary tales highlight the importance of having a strategy for training.

Teacher Time is Valuable: Teachers made it clear that their time is finite, and any time spent struggling with a new technology would take away from other classroom preparations. Technical help manuals were not used and a thick binder full of instructions was seen as a significant barrier to technology adoption. As one program director and former teacher said "Teachers don't read. They don't have time."

Existing Self-Regulation: Several teachers noted existing school initiatives to support emotional and behavioral self-regulation. One teacher described the use of "Peace Corners," safe spaces where children could remove themselves from the classroom community to calm themselves down when they felt frustrated or angry. Another teacher described a school-wide initiative called "How's my engine running?" Students were encouraged to take note of their own emotional and physiological state in times of stress. Teachers generally felt that it was okay for a child to leave the flow of the classroom when emotionally necessary, but though the child should be ready to return in ten minutes or less

Teacher Initiated Regulation: In school observations we saw teachers in both a 5th grade science classroom and a 4th and 5th grade after school program employ "time-out" techniques to deal with behavioral problems. Students that were distracting the class's attention were directed to read in a corner or sit outside in the hallway for several minutes until they calmed down.

Positive Reinforcement First: Many teachers mentioned that they felt it was important to not attach a negative valence to the self-regulation activity. There was general support for using technology as a "calm down" time, but several educators were insistent that it should not feel like "punishment."

Participatory Design

A participatory design session with two children, males ages eight and eleven was conducted to generate a more in-depth exploration of design concepts for our game. Both children were part of the initial ten children who evaluated current biofeedback games and were familiar with HRV regulation techniques. The children were asked to think through potential HRV based games that *they* would design and enjoy playing. They were then given materials to draw their game on paper and to explain the concept using visuals. Two distinct game concepts emerged from the session.

Object Collection Theme (Shane, Age 8): This game concept revolved around a space ship that the player controlled with the goal of collecting trash (Figure 3). The child described the use of HRV as a control, saying, "The more calm you are the more you'll have to dodge the litter, grab it and you'll have a huge trashcan … you have to collect it all." This theme of collection was seen to a degree in the existing *Rainbow* game previously evaluated, but whereas the *Rainbow* game only showed coins piling up at the end of a rainbow, the trash collection design concept described by Shane gave the player agency and movement in collecting objects. This agency was in fact integral to game play using words like "dodge" and "grab" to describe the players interactions with objects.

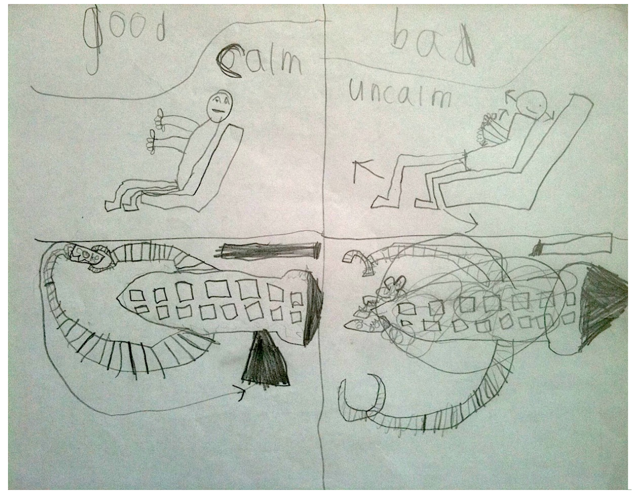

Figure 4. Spaceship trash collection game concept drawn during a participatory design session.

Puzzle Theme (Ryan, Age 11): The object of this game was to solve a series of puzzles using levers to open gateways before a pack of wild dogs are released on the player. The concept involved significant elements of choice. To quote the child designer: *"*at the beginning of the game you get to choose your character, Blacksmith, Archer, Swordsman or assassin." This focus on selecting characters or the game environment was a theme echoed by other children in the user testing of existing games.

Ryan connected the release of certain levers to the players HRV level noting, "there are puzzle parts where it says on the screen to require a certain ability you need to beat this puzzle… you need to be hyper or calm." While from an emotional and behavioral management stand point it is not beneficial to reinforce "hyper" states or negatively punish the player, this description does indicate the importance of clearly displaying how game interactions affect emotional state. Ryan also noted that "the game is really fun because it doesn't end … if you've beaten one section you can try the full game with all sorts of new stuff," suggesting the importance of leveling and having multiple environments for the player to explore and play. Ryan also described the ability to track progress through the puzzle saying, "you have a single heart in the beginning and you get hearts as you go."

It should be noted that several parts of the game concept borrowed heavily from the popular PC and console game *Assassin's Creed.* Still, the specific interactions and themes the children chose to highlight give insight into what is important to them. These aspects of choice, collection, player agency, leveling, and tracking progress over time fed directly into the process of designing and developing *CritterQuest*.

GAME DESIGN & EVALUATION

A list of game specifications and features were drawn from themes that emerged from the user evaluations, educator interviews, class observations, and participatory design sessions. These themes were mapped onto an affinity diagram and included the importance of choice and customization, providing adequate learning scaffolding as well as leveling to meet the child at her or his own level of ability, providing appropriate and clear feedback on HRV state, ensuring playing time was under 5-minutes, and ensuring the game could be learned quickly with minimal training or supervision (Table 1).

Theme	Collected from:	Design Specification
Choice	Testing R1, Participatory Design	Choice/ customization of character and game environment.
Clear Feedback	Testing R1	Clear and consistent feedback on HRV level during game play.
Learning Scaffolding	Testing R1	Game mechanics and HRV ability should meet the child at his/her level.
Short Play Duration	Interviews, Classroom Observation	Effective in under five-minutes.
Minimal Training	Interviews, Classroom Observation, R1 Testing	Training should be effective yet minimal and reinforced during gameplay.
Exploration	R1 Testing, Participatory Design	More advanced users can explore the game environment.
Positive Reinforce-ment	R1 Testing, Interviews	Rewards not punishment for HRV performance.
Collection is Rewarding	Participatory Design	Integrate collection/ acquisition into game play.

Table 1. List of design principles gathered from Phase 1.

Initial Game Play & Technology

The above specifications were integrated into our first design of the game *CritterQuest;* we focused on providing user choice and positive rewards, and centered our gameplay around the concept of object collection. We also consciously implemented a design that would scale to support varying difficulties of play.

The game asked users to choose one of two animals to guide through the meadow. The selected animal then automatically traveled around the game board collecting food. When a player successfully improved their HRV, the animal would move faster and collect more food. However, basic game play continued regardless of performance, ensuring that there was no frustrating failure condition. Additionally, the animal would glow different colors based on the level of HRV. We employed the red/blue/green scale for low/medium/high HRV coherence, a standard employed by a light on the sensor itself, as well as in existing games (Figure 5).

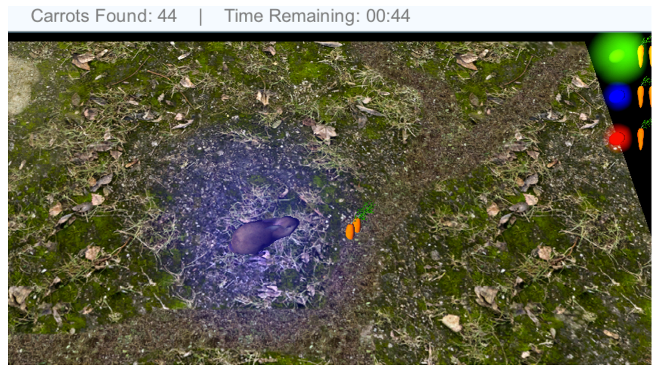

Figure 5. Screenshots of CritterQuest used for Round 1 evaluation & testing.

We built the game using the Unity 3D game development platform. The majority of the game logic was written in Unity's JavaScript-based language. We captured data from the emWave sensor by employing a prototype Software Development Kit (SDK) written in C++, provided by HeartMath. By embedding a UDP server in the SDK code, we were able to send messages containing HRV data to a UDP client listening within *CritterQuest*.

User Testing Round 1

A round of field usability testing using the initial prototype was conducted during UC Berkeley's "Cal Day." A table, chair, and laptop were set up near a main pedestrian thoroughfare. The players consisted of eleven children (seven female) between the ages of 4 and 13 who were drawn from a convenience sample of passing families. The children were given a brief (under one minute) training in HRV self-regulation techniques and were asked to play the two-minute game prototype. Both ability to successfully play the game and ability to control HRV were tracked. After the children finished their two minute play session, they were asked what design changes they might make to the game.

This early stage of prototype evaluation validated initial gameplay choices and lead to several new design suggestions that were explored in the next iteration of the game. While this early round of user testing was used to primarily evaluate user engagement and playability it was noted that seven of the eleven children were able to improve their HRV within noticeable levels (approximately between 1 - .5 Hz of a sine wave). Even the four year-old player, who was far below the initially intended age range of the game, was able to achieve optimal levels (within .1 Hz) for several seconds.

Several children noted that they enjoyed selecting animals but wanted an even greater selection (the early prototype only allowed players to select between a rabbit and horse). The most common animal suggested for inclusion was a dog (requested by four children), with the second most common animal being a cat (three children). We incorporated this feedback into the next design iteration by adding a dog player option. This aspect of choice and animal customization was further enhanced in the next round of design by allowing players to select one of three colors for each animal.

Two of the children and one observing parent mentioned that the game would benefit from an aural component to help them relax and engage with the game. Based on this feedback, a calming sound track was added to the next version. Additionally, a short audio clip was played each time a piece of food was acquired as a way of giving the player additional feedback on successful performance.

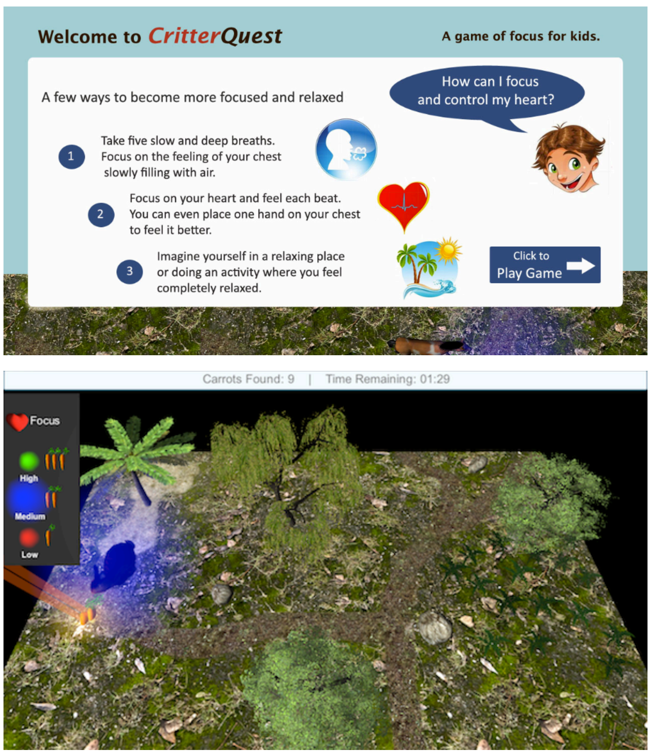

Figure 6. Screenshots of the game used in Phase 2.

USER TESTING ROUND 2

A second round of user testing was conducted with two 5th grade science classes over two separate visits to a San Leandro, CA public middle school. Each class consisted of 30 students and roughly reflected the demographics of the entire school body: 40% Latino, 15% black, 15% Filipino, 10% white and the rest of the student body are from various parts of Asia. Emotional management and conflict resolution techniques were already incorporated into the end of year curriculum and our game integrated well with existing teacher goals [1].

A five-minute instructional demonstration was given via projection to the entire class, then students were offered the opportunity to try the game. A station with a desk, chair and laptop were set up in the corner near the front of the room and students could then volunteer one at a time to play *CritterQuest* as one of the "labs" for their class (Figure 6). After completing the one minute and 45 seconds play session, they were asked to reflect on their experience playing the game.

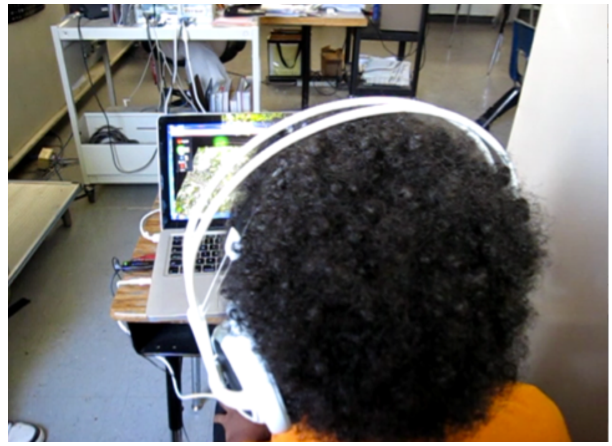

Figure 7. Student testing game in the classroom in Phase 2.

Changes in the game incorporated from Round 1 testing included the addition of calming music throughout game play as well as specific aural feedback when the animal collected food. A dog was added as an additional third animal based on the children's interest in expanding character selection. Also an up green or down red arrow was added next to the HRV level key to provide more precise feedback during shifting HRV states.

We varied four different variables (sound, color, speed, and rate of food creation) based on the users HRV. The most understood connection was color, though most users were able to identify at least one other factor. Giving extra feedback helped users to make the connection between HRV and game performance. Tips were also given to user when their heart rate dropped. In several cases we saw the participant take the corresponding action as soon as they read the tip [Figure 7].

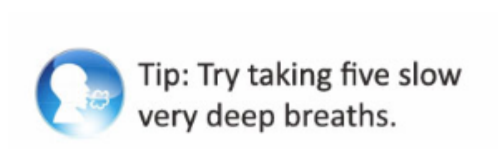

Figure 8. One of three tips that would pop to the top of the game screen during low performance.

Additionally, while the first round of testing provided only the "beginner" level, an "intermediate" level where the player utilized arrows on the keyboard to move the animal directionally towards food was added. Three children were given the opportunity to play this intermediate level as well. While they found it more challenging, they were still able to complete the game goals.

Students were given no further instruction proceeding or during game play (other than the initial five-minute instructional demonstration as an entire class). This lack of intervention and training allowed us to test the ability of students to learn the mechanics of game play and HRV regulation solely through the intuitiveness of the design and tips given within the framework of the game itself.

Overall results of game play showed that 16 of the 18 students or 89% were able to achieve medium to high HRV coherence (Figure 8). This rate is particularly notable given that this was accomplished in less than two minutes of game play. The average medium level of HRV for the total game sessions was 16.5 seconds and the high optimal level of HRV was 11 seconds suggested that the students could quickly learn game play and the ability to successfully regulate their HRV to reach optimal attention and focus.

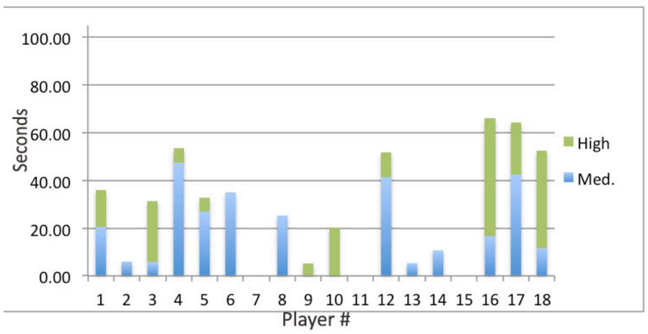

Figure 9. Seconds of each user in medium or high coherence HRV for Level 1 CritterQuest.

Three players opted to try the next game level showing additional capability in manipulating keyboard controls to affect character movement while also managing to successfully regulate their HRV level (Figure 9). User 2 did not show remarkable performance in Level 1 but opted to continue to Level 2 and performed slightly better by keeping medium HRV for 9.8 seconds as opposed to 6 seconds for Level 1. This was not entirely expected but suggests that even users that find HRV regulation initially challenging can maintain or improve their performance even given a slight increase in difficulty.

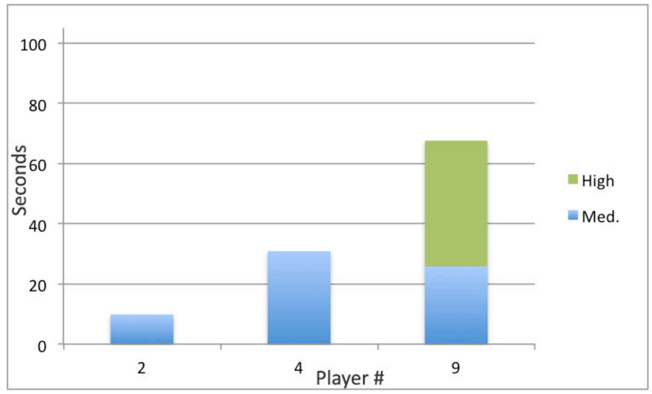

Figure 10. Seconds users are in medium or high coherence HRV for Level 2 CritterQuest.

CONCLUSIONS & FURTHER WORK

We identified numerous usability challenges in existing HRV computer games and utilized three design methodologies to develop *CritterQuest*, a game that can be rapidly integrated and deployed within a middle school classroom with minimal training or instructor effort. Combining several methods over three phases of our game design we were able to identify important design specifications that not only allowed successful HRV self-regulation but also increases enjoyableness of game play within the contextual needs of the classroom environment. User testing of our second design found that in less than two minutes of game play 89% of the players were able to attain medium to high coherence, a state conducive for focus, learning and retention.

Our design methodologies highlighted the importance of engaging multiple stakeholders early on in the design process and provide a potential model for game design within a classroom context. Feedback and participatory design from children provided important themes used to inform the mechanics and structure of gameplay. Engaging teachers and educators as well as observing classrooms early on in our process allowed us to better understand the role of the game within a larger classroom environment and as a "calm down" activity for disruptive or unfocused students. This understanding highlighted the importance of not only making a game that was engaging to students and allowed them to successfully self-regulate their HRV but also providing a useful classroom tool for teachers.

Additional avenues to explore include increasing the prominence of real time HRV trend signals and rotating or changing the timing of the in-game tips (giving students more noticeable feedback on HRV performance). We would also like to further investigate whether greater gains can be made through making the game harder to play (e.g. by requiring the user to control the animals), or making it harder to succeed (e.g. by setting higher thresholds for performance).

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