The Design and Evaluation of a Classroom Exergame

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ABSTRACT
Balancing academic, physical and emotional needs of students while maintaining student interest is increasingly challenging in the resource constrained environments of the modern classroom. To answer this need we created and evaluated an exergame system called Vortex Mountain, which leverages the physical benefits of exercise and the motivational benefits of educational games to provide a healthy and engaging classroom activity for middle school students. Through a controlled study, we demonstrate that our classroom exergame provides similar affective, engagement, and learning benefits to an exercise or game intervention, while leveraging the valuable ancillary benefits of each. Thus, we believe that exergames have a future in the modern classroom and possess significant potential for future technical and pedagogical research.

CATEGORIES AND SUBJECT DESCRIPTORS
H5.2 [Information interfaces and presentation]: User Interfaces. - Graphical user interfaces.

GENERAL TERMS
Design, Human Factors.

KEYWORDS
Kids, games, exergames, gamification, classroom.

INTRODUCTION
Regular physical activity has many benefits, impacting a person’s physical, emotional, and cognitive wellbeing [31]. The Canadian Society of Exercise Physiologists recommends that children and youth achieve 60 minutes of moderate- to vigorous-intensity physical activity daily [30]; however, only 7% of youth accumulate 60 minutes per day on 6 days of the week [5], creating health risks among children and teenagers [26]. Recent work has shown that alongside the benefits provided by physical activity, there are also negative consequences associated with sedentary behaviour [29]. Interestingly, the physiological effects of sedentary behaviour are distinct from those of a lack of physical activity [29], so even if a child is physically active (e.g., bikes to and from school), she can also be sedentary (e.g., by primarily sitting for the remaining waking hours). Because of the potential negative effects on health, the Canadian Society of Exercise Physiologists now has sedentary guidelines for children and youth [30] alongside their recommendations of exercise.

To encourage physical activity among kids, researchers and developers have created a variety of exergames that encourage children to exercise, by integrating exercise into the game mechanics (see related work). In addition, a few games have been created that target sedentary behaviours by focusing on short play times and ease of entry. For example, Gao et al. created the Kinect-based casual exergame GrabApple [14], in which the player has to move, jump, and duck to collect apples. Because the player’s body weight acts as resistance in GrabApple, playing the game yields moderate to vigorous exertion levels, but it is rated as fun as a sedentary mouse-based version of the game [13].

An evaluation of GrabApple with university-aged adults showed that playing the game could meet target levels for exertion, while also providing acute cognitive benefits as measured by a standard test of attention [13]. Gao et al. suggest that an exergame, like GrabApple, could be integrated into the classroom and played several times daily to improve students’ concentration, while also helping them meet their physical activity requirements and prevent long stretches of sedentary behaviour in a fun and engaging way. The deployment of exergames in classrooms would have the benefits associated with the motivational pull of games [23], while simultaneously targeting sedentary behaviours via exerbreaks throughout the day. However, current exergames designed to promote physical activity have no relationship with classroom curricula; customizing exergames for every topic is not feasible. An exergame designed for reconfigurable content and classroom play could provide kids with the physical activity they require, while improving concentration, and engaging students with their curriculum. To create a reconfigurable classroom exergame though, we need to understand how students engage with games, exercise, and the combination of both in the context of classroom activities.

To address this need, we created a general-purpose classroom exergame called Vortex Mountain. Our game system was iteratively designed with feedback from middle school students and employs game mechanics that attempt to engage students with their curriculum in a fun and engaging way. In an experiment with 68 grade 7 children, we compare Vortex Mountain to traditional classroom activities, traditional classroom activities with additional exercise, and a sedentary version of the electronic game. Our intention at this stage was not to evaluate whether these types of games can improve learning, but to determine how exercise and gameplay differentially contribute to engagement with an interactive technology deployed in a classroom context. We show that adding either exercise or game components to classroom activities improves enjoyment, and player experience (competence,
autonomy, relatedness, and immersion), and that adding game elements improves the proportion of correct responses on a retention test.

Our study demonstrates that there a potential for incorporating exergames into the classroom to provide physical activity and the cognitive benefits that go along with it, while also reinforcing the classroom curriculum in an engaging and motivating way.

RELATED WORK

Gamification of Exercise

Exercise has a tradition of gamification, both in research prototypes and in commercial games (e.g., DDR, Kinect Adventures). A comprehensive review of exergames is outside the scope of this paper; however, research focuses on providing in-game rewards for out-of-game physical activity (e.g., [2], [27]) or using exercise as the mechanic through which the game is played (e.g., [13], [18]).

Research-based exergames have been shown to raise heart rates to levels in line with the recommendations for daily physical activity [16]; however, most active commercial games do not produce the recommended intensity for children [15]. Although exergames may not produce the same exertion as their physical game counterparts, they are generally more motivating than traditional exercise [28] and can provide cognitive benefits [33] [13].

Learning through Video Games

Video games can be effective learning environments [21]. Students can learn: through educational games designed to teach a specific curriculum, with commercial games used as examples to teach relevant terms concepts and methods, and by developing games in a way that teaches about what the content of the game is about [9].

There are several benefits to learning through games. When compared to traditional lectures, games can increase motivation and academic performance [19]. Games can be used to improve academic performance; Cordova found that adding fantasy elements to gameplay – unrelated to game content – can increase enjoyment and academic performance [6].

Exergames as a Learning Resource

It is largely accepted that students learn with different learning styles and matching these with teaching styles can increase motivation and academic success [7][11]. In 2001, Fleming developed the VARK (visual, aural, read/write, kinesthetic) model to describe perceptual preferences for the input of information [12]. Kinesthetic (K) learners prefer to learn through direct practice [11] [12], which may include hands on examples or other resources such as songs or games that include full body motor movements [20][8]. Exergames have been suggested as kinesthetic resources [4][17], though we are unaware of any formal evaluations.

An extensive body of literature exists for educational games (see [34] for a recent review), which prohibits inclusion in this paper. Games that incorporate kinesthetic learning such as iGameFloor [17], Frequency 1550 [19], Savannah [10], and Tangicons [24] most closely match the combination of activity and curriculum discussed here. However, none of the systems described are independent of the curriculum in the same manner as Vortex Mountain, and none performed a controlled study to investigate the relative impact of game, activity and curriculum on student experience and engagement.

VORTEX MOUNTAIN

To understand how students engage with exercise, games, and the combination of both in the context of classroom activities, we created a game system called Vortex Mountain. In Vortex Mountain, players are challenged to move between physical locations to complete challenges that reinforce concepts already introduced through traditional classroom activities. The design of Vortex Mountain is meant to leverage the acute cognitive benefits of moderate exercise [13] and the affective impact of digital games, through a collaborative experience.

Game Concept

From a remote uncharted desert island a group of scientists has unleashed a catastrophic computer virus upon the world. A crack team embarks on an audacious mission: to use the recently completed Time Vortex to travel back in time to the island. If the team can find the nine passwords on computers spread around the island, they can hack the final mainframe password and avert catastrophe. The teams must race the clock to save the world. While the Time Vortex can no longer provide vast jumps in time, it can set the clock back a few minutes, but requires players to run up Vortex Mountain to reach the vortex.

Low and Medium Fidelity Prototyping

1.1.1 Low-fidelity Session

We performed a low fidelity prototyping session with 70 Grade 7 local schoolchildren in April of 2012. Half of the students simulated computers in a ‘Wizard of Oz’-style prototype, and the other played the game. The simulators stood in pairs at 9 pylons throughout the gymnasium with cards from the children’s game Cadoo™. Teams of players visited each pylon and attempted to complete the challenge on the card. If the team was successful, they received a sticker, which they could take to the ‘server’ – a graduate student – for a clue to the final puzzle. If the students got the question wrong, they would go to the ‘reset station’ – a graduate student who would prescribe short callisthenic exercises to simulate the run up Vortex Mountain.

The low fidelity prototype was successful. Teams reported that the games were fun and that they felt as though they were exercising. Observation of the players indicated they enjoyed the punctuated play provided by spatially-distinct stations, but that challenging stations could result in long periods of inactivity.

1.1.2 Medium-fidelity Session

The same group of 70 students returned in June of 2012 to test the medium fidelity prototype: a collection of one
exergame using a stationary bicycle (Flashlight) and two traditional video games employing the mouse (Whack-a-Mole) and keyboard (Snake). Detailed game descriptions are provided in the following sections. Each game was installed on nine machines in a large computer lab. Students were required to move to each computer and complete the gaming challenge. Successfully completed challenges provided a code, which could be presented at the ‘graduate student server’ to obtain a letter for the final word scramble. Unsuccessful attempts at completing the challenges required players to climb Vortex Mountain and activate the Time Vortex, done as a team by stepping on four parallel Wii balance boards.

Again, post-game interviews indicated that the concept was fun and engaging. Minor issues with game difficulty were noted. In addition, a single path up Vortex Mountain proved to be insufficient, as there were often queues of teams waiting to climb the mountain, resulting in inactivity.

**Game Description**

The final Vortex Mountain game was informed by both prototype sessions. Although we provide only an overview of the system due to space constraints, game elements were individually assessed through the prototyping sessions (which involved observation and interviews), iterated on, and in some cases were also suggested by the participants.

In Vortex Mountain, players must visit stations on the island and solve educational puzzles to uncover a password to stop the virus. Unsuccessfully completing a station resulted in a Vortex Mountain climb. The final version was fully automated with team logins, station locks and station unlocks managed by a central server, implemented using Google App Engine.

**Game Implementation**

The Vortex Mountain stations consisted of 6 minigames distributed over 9 desktop computers. Players physically travelled from station to station and entered their team number to launch the game (Figure 1b). Each minigame poses a question with a single answer. Players answered the question by selecting letters, employing the principle of the lusory attitude, where game play is created through taking an objective and making it artificially challenging [23]. Players must select the correct letters in the correct order to solve the puzzle. A retry is required if the word is incorrect, misspelled, or the players fall victim to an internal game failure mode (e.g., hitting the wall in Snake).

We also created a sedentary version of the game where each team sat at a single computer with a set of controllers (one for each player) and navigated from station to station by selecting locations on a virtual map of Vortex Island (Figure 1a). Minigames were identical in both versions, (except for input) as described in the following sections.

1.1.3 **Minigames**

**Balloon Pop:** Figure 1c. Players use a dart to pop a balloon with the correct letter as the balloons drift past. In the Kinect exergame, players shuffle left and right, crouch, and jump. The sedentary version uses a keyboard.

**Whack-a-Mole:** Figure 1d. Moles appear randomly from holes holding letters for the question answer. In the exergame, players shuffle left and right and crouch. Players click on moles using the mouse in the sedentary version.

**Snakes and Ladders:** Figure 1e. Players control an avatar that climbs ladders and falls down snakes. This game is a maze because if players do not navigate correctly, they can reach a point where they must select an incorrect letter. In the exergame, a player moves by shuffling left to right, climbs by doing jumping jacks, and crouches to fall. In the sedentary version, a game controller is used.

**Snake:** Figure 1f. Players control an ever-moving snake to select letters while avoiding rocks, the edges of the play area, and the snake’s tail. The tail of the snake grows with each letter. The snake moves towards the midpoint of player’s hands in the Kinect exergame and is controlled with the arrow keys in the sedentary version. The Kinect controls for Snake (used at a single station) were not well parameterized for the varying player heights found in this age group, so keyboard control was used in the experiment.

**Flashlight:** Figure 1g. Questions and letters float around the screen in the dark and the team must power the flashlight to find them. In the exergame, one player powers the flashlight using a stationary bike, while another uses the mouse to select letters. In the sedentary version, the flashlight is powered by repeatedly hitting a key.

**Vortex Mountain Climb:** Figure 1h. In the exercise version, all team members perform aerobic step exercises by alternating left and right feet on individual WiiFit boards. The minigame that provoked the climb is reset and accessible once all team members reach the top. In the sedentary version, all team members alternate between the game controller triggers to climb the mountain.

**EXPERIMENT**

Using Vortex Mountain, we performed a study with participants from a local elementary school over the course of a day. Our goal at this stage was not to test whether our system improved learning, but to determine how exercise and gameplay differentially contribute to engagement with an interactive technology deployed in a classroom. Participants provided informed parental consent and individual assent. The experiment took place in a set of computer laboratories on a single floor of the university.

**Participants**

68 students (32 female), aged 12 or 13 participated in the study. A single student refused assent for the use of their data, and that data was removed from the analysis. Students with special needs were aided during the learning portions of the experiment by their regular teaching assistant. No students reported physical disabilities.
Figure 1. Screenshots of the minigames. a) Sedentary game map, b) Team login, c) Balloon Pop, d) Whack-a-Mole, e) Snakes f) Snake, g) Flashlight, h) Climbing Vortex Mountain.
Most students (53) played video games regularly and participated in regular exercise activities outside of school (65). More than half (41) played games that require physical activity. Participants were divided into four groups and each group was divided into teams of 3 to 4. Each team and individual player was assigned a number.

**Conditions and Procedure**

In the experiment we tested four different conditions: traditional classroom (Class), traditional classroom with physical activity (PhysEd), game (Game), and exergame (Exergame). Each group performed each condition, and the order of conditions was counterbalanced so that all four conditions ran simultaneously all day. One experimenter managed each condition. Participants were given 10 minutes to read an age-appropriate short story. The order of presentation of stories was kept constant and balanced across the conditions. After reading the short story, participants completed the activity. Participants were allowed to retain a copy of the story for the duration of the activity for reference. Following the completion of the condition, we collected the stories and participants answered a series of online surveys at individual computers. First, they completed the Positive Affect Negative Affect Scale (PANAS) [32], followed by the Player Experience of Needs Satisfaction (PENS) [22], and finally, they completed a knowledge test (see results section). The four conditions were:

**Class:** The classroom activity was intended as a baseline. Teams were provided with questions related to the short story they read; answers were in the form of word scrambles. In the first session this process was automated, however due to high server load, an instructor provided the scrambles for the remaining sessions.

**PhysEd:** Teams received questions in the same manner as the automated classroom activity. After every question, regardless of a correct answer, students performed a short bout of physical activity (assigned by a teacher), such as jumping jacks or burpees.

**Game:** Each team shared a computer and each team member had his or her own game controller. Questions were presented in the minigames, which were triggered as players explored the Vortex Island map (Figure 1a). Some of the minigames were single player; however, all team members could help by solving the scramble. Flashlight required two players and Vortex Mountain Climb required all team members.

**Exergame:** In this condition, teams of players physically moved between stations. There was the same distribution of minigames as in Game. Incorrect answers required that the team climb Vortex Mountain to try again.

Each condition was explained at the beginning of the experiment and again prior to play. Two conditions were completed in the morning; two more after a lunch break. We gave 15 minutes for Class and PhysEd, 20 minutes for Game, and 30 minutes for Exergame. In general, teams completed the Class and PhysEd conditions, mostly completed the Game, and mostly did not complete the Exergame within the allotted time. Within each condition, we collected subjective exertion using the Borg Rating of Perceived Exertion (15 pt) [3] for each player. These values were aggregated for each player across a condition to give a measure of central tendency.

**Measures and Analyses**

Because we were interested in the effects of game and exercise separately, the Borg, PANAS, and PENS scales, along with three measures from the knowledge test were analyzed in a single 2 (game) by 2 (exercise) RM-ANOVA in SPSS 20 with \( \alpha = 0.05 \). Pairwise comparisons of main effects and interactions were corrected for potential Type 1 error using the Bonferroni method.

**RESULTS**

We present results for the exertion followed by results of play experience in each condition. We conclude with results related to correct responses. All results are shown in Figure 2.

**Exertion**

We measured exertion using the Borg Scale [3] for each player to check that adding exercise is indeed increasing exertion. As expected, results confirm that adding exercise increases exertion (\( F_{1.59} = 67.6, \ p = .000, \ \eta^2 = .53 \)); adding game elements decreases exertion (\( F_{1.59} = 15.0, \ \ p = .000, \ \eta^2 = .20 \)), but the significant exercise by game interaction (\( F_{1.59} = 42.4, \ \ p = .000, \ \eta^2 = .42 \)) reveals that the addition of game elements only decreases exertion in the case where exercise was added (\( p = .000 \)). There was no difference in exertion as a result of game in conditions where exercise was not present (\( p = .336 \)).

**Player Experience**

Part of the appeal of game-based learning is that games are enjoyable [21] and provide a mental pull [22] through mastery of challenge. To evaluate the efficacy of the activities, we first assessed enjoyment by gathering positive affect via PANAS [32]. We then used the PENS instrument [22] to assess player experience through competence (how capable the player feels), autonomy (how in control a player feels), relatedness (how related to other people the player feels), immersion (how immersed the player is in the experience), and how intuitive the controls are.

**Affect:** Results showed that both exercise (\( F_{1.59} = 54.0, \ \ p = .000, \ \eta^2 = .48 \)) and game (\( F_{1.59} = 7.1, \ \ p = .010, \ \eta^2 = .11 \)) increased positive affect. However, the significant game by exercise interaction (\( F_{1.59} = 19.2, \ \ p = .000, \ \eta^2 = .25 \)) shows that exercise only improves affect when there is no game (\( p = .000 \)); there is no effect of exercise when a game is present (\( p = .085 \)).

**Competence:** In terms of the PENS data, exercise increased feelings of competence (\( F_{1.59} = 12.6, \ \ p = .001, \ \eta^2 = .18 \)), whereas game did not (\( F_{1.59} = 1.2, \ \ p = .269 \)).
significant game by exercise interaction (F₁,₅⁹=12.5, p=.001, $\eta^2=.18$) showed that exercise only increases competence when there is no game (p=.000); when a game is present, exercise does not improve competence (p=.448).

**Autonomy:** Both exercise (F₁,₅⁹=24.8, p=.000, $\eta^2=.30$) and game (F₁,₅⁹=18.4, p=.000, $\eta^2=.24$) increased feelings of player volition and being in control. However, the significant game by exercise interaction (F₁,₅⁹=12.6, p=.001, $\eta^2=.18$) shows that exercise only improved autonomy when no game was present (p=.000); in game conditions, exercise did not improve autonomy (p=.483).

**Relatedness:** Exercise improved feelings of relatedness (F₁,₅⁹=11.8, p=.001, $\eta^2=.17$); however, there was no main effect of game (F₁,₅⁹=2.4, p=.129) and no interaction between game and exercise (F₁,₅⁹=2.7, p=.104).

**Immersion:** Both exercise (F₁,₅⁹=12.4, p=.001, $\eta^2=.17$) and game (F₁,₅⁹=16.1, p=.000, $\eta^2=.22$) increased immersion. There was no significant interaction (F₁,₅⁹=0.4, p=.529).

**Intuitive Controls:** There were no main effects of exercise (F₁,₅⁹=0.2, p=.665) or game (F₁,₅⁹=1.8, p=.182) on intuitive controls. However, a significant interaction between exercise and game (F₁,₅⁹=9.1, p=.000, $\eta^2=.24$) showed that when there was no game, exercise significantly improved intuitive control (p=.000), but when there was a game, exercise significantly reduced intuitive control (p=.002).

**Correct Responses**
The post-tests were graded out of 9 possible points. Because participants did not always complete the game conditions (due to time limitations), they may have not been exposed to all questions. Our server recorded the number of questions that each participant was exposed to and we used this number to calculate a percentage of correct responses out of the total number of questions to which they were exposed (normalized correct). Finally, because participants may have better remembered the answers to some questions through repeated exposure, we also considered the number of times a participant visited the reset station, which indicates them getting a question wrong and repeating it.

**Correct**:
There was no effect of exercise on the number of correct responses (F₁,₅⁹=0.1, p=.750); however, Game decreased the number of correct responses (F₁,₅⁹=7.1, p=.010, $\eta^2=.11$). There was no significant interaction (F₁,₅⁹=0.4, p=.507).

**Normalized Correct**:
When expressed as a percentage of the number of questions that participants were exposed to, exercise still had no effect (F₁,₅⁹=2.1, p=.151); however, game increased the proportion of correct responses (F₁,₅⁹=16.9, p=.000, $\eta^2=.22$). There was no significant interaction (F₁,₅⁹=1.2, p=.272).

**Resets**:
Exercise increased the number of resets (F₁,₅⁹=9.1, p=.004, $\eta^2=.13$), as did game (F₁,₅⁹=291.9, p=.000, $\eta^2=.83$). However, the significant game by exercise interaction (F₁,₅⁹=18.8, p=.000, $\eta^2=.24$) shows that exercise only increased resets when there was a game (p=.000), but did not affect resets when there was no game (p=.756).

![Figure 2. Means (#standard error) for dependent measures.](image)

**Summary of Results**
Adding exercise to the classroom activity increased positive affect, competence, autonomy, relatedness, and immersion. Exercise had no effect on the number of or proportion of correct responses. This suggests that teachers can make changes to improve the student’s experience using exercise, without sacrificing learning outcomes.

Adding a sedentary game element increased positive affect, autonomy and immersion. Game decreased the number of correct responses but increased the proportion of correct responses. Playing the game meant that participants were exposed to the same questions repeatedly and this improved responses. This confirms previous research that educational games can be both effective and fun.

In most cases adding either exercise or game to a classroom activity resulted in improvements, but there was no compounding improvement of adding both.

**DISCUSSION**
Our research demonstrates that although both gaming and physical activity can add to classroom experiences, the
effects are not cumulative. In each of physical activity, game, and exergame, student affect improved. However, this effect was likely due in part to the novelty factor of engaging in non-standard classroom experiences. We do not intend that these activities replace traditional classroom instruction, but rather be incorporated to maintain student interest, improve affect, motivation, and concentration, while providing physical activity. While the execution of the games unfolds somewhat automatically, an instructor familiar with the students and curriculum should tailor the questions. Part of the appeal of our PhysEd condition was the instructor, who presented personalized physical challenges for the students, and encouraged them.

Our results showed that adding either game or physical activity components improved affect and experience. While there were often no differences between the exergame, game, and physical education conditions, they were all generally improved over the traditional classroom condition. However, the exergame has significant ancillary benefits associated with incorporating both physical activity and game-based learning tools.

**Physical Activity:** Unlike the computer game scenario, but like the physical education scenario, the exergame can help to provide recommended levels of exertion [13]. The integration of physical activity and learning can help ameliorate the decrease in physical activity present in many schools due to cut backs in dedicated physical education, and the game-based approach to physical exertion is likely to better motivate students over the long term.

**Automated Repetition of Content:** Unlike the physical education scenario, but like the game scenario, the exergame can be deployed for multiple students. Once the syllabus has been set, students can interact with the system with limited supervision, freeing the instructor to spend more focused time with those who require assistance.

**Detailed Data:** Using a classroom exergame can provide detailed data on both the revision of material through the game logs. This rich source of data can be mined to provide information to instructors, or can be combined with student modeling software to better understand the needs of the student.

Because our classroom exergame provides similar affect and engagement as the game or PhysEd condition, but also provides significant ancillary benefits without sacrificing learning outcomes, we believe that well designed classroom exergames have a role to play in the modern classroom. A major focus of our future work will be in deploying the system for ecologically valid longitudinal studies in classrooms with integration into the curriculum. To fully implement an exergame in a classroom setting, we will work closely with teachers and health professionals.

**Limitations and Future Work**

One advantage of our experiment design was that we collected a significant amount of data. Including so many participants simultaneously in our study resulted in tradeoffs that limited our work. There were emerging issues that had to be addressed on site: such as, moving from computer-based to paper-based activity in the Class session to combat server delay; and replacing the Kinect exergame Snake with the keyboard version (explained above).

The idea of our game is to get students moving in the classroom; however, movements are not necessarily relevant to the material. This means that participants get the benefits of physical activity, but perhaps not those of embodied learning [1]. It can also be interpreted that physical activity is being used as a punishment for wrong answers. However, all minigames included physical activity, and students overwhelming reported Vortex Mountain Climb as their favourite minigame.

Instructors noticed that participants were answering the Borg scale ‘by committee’, where the team would agree on a rating and use the same rating for all players. So, for example, even though researchers observed that participants using the bikes were showing signs of physical exertion (e.g., panting) all team members would report the same exertion. To confirm our findings, physiological measures of exertion (e.g., heart-rate) should be collected.

This study was only concerned with short-term reading comprehension retention. It should be noted that solving shorter scrambles (5 letters) was much easier than longer scrambles (10 letters) and this was not controlled in the study, however the same questions were used across conditions. Long-term retention and learning outcomes should be assessed in future work. It may also be interesting to compare single player classroom exergames to collaborative games such as Vortex Mountain to quantify the benefits of social play.

**CONCLUSIONS**

In this paper we have described a novel system – a classroom exergame – that leverages the physical benefits of exercise and the affective benefits of games to provide a healthy and engaging classroom activity for middle school students. Through a controlled study with 68 students, we demonstrate that our exergame provides similar affective and engagement benefits to an exercise or game intervention, while leveraging important ancillary benefits. Based on the successful deployment of this system we believe that classroom exergames have a future in the modern classroom and possess significant potential for future technical and pedagogical research.

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