EXERLEARN BIKE: AN EXERGAMING SYSTEM FOR CHILDREN'S EDUCATIONAL AND PHYSICAL WELL-BEING

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Abstract

Inactivity and sedentary behavioural patterns among children contribute greatly to a wide range of diseases including obesity, cancer, cardiovascular disease, and diabetes. It is also associated with other important health effects like mental health issues, anxiety, and depression. In order to reduce these trends, we need to focus on the highest contributing factor, which is lack of physical activity in children's daily lives. 'Exergames' are believed to be a very good solution in promoting physical activity in children. Such games encourage children to engage in physical activity for long periods of time while enjoying their gaming experience. The purpose of this thesis is to provide means of directing child behaviour in a healthy direction by using gaming enhancements that encourage physical exertion. We believe that the combination of both exercising and learning modalities in an attractive gaming environment could be more beneficial for the child's well-being. In order to achieve this, we present an adaptive exergaming system, the "ExerLearn Bike", which combines physical, gaming, and educational features. The main idea of the system is to have children learn about new objects, new language, practice their math skills, and improve their cognitive ability through enticing games and effective exercise. Three games have been incorporated to provide children with various educational benefits. The system has personalized features that allow guardians to customize the learning content, skill level, and required physical activity to meet their child's needs. A stationary bike is used as a gaming controller to encourage children to undertake daily aerobic exercise. A modular design approach was adopted so that it is possible to use any stationary bicycle as an input interface by simply attaching a number of devices to it. This thesis provides detailed information about the design requirements, the design model, the proposed system and its related hardware components, the design and

development of the gaming software, and the qualitative and quantitative evaluation of the system's performance.

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Table of Contents

List of Tables

List of Figures

Chapter 1: Introduction

1.1 Background and Motivation

Lack of physical activity and sedentary behavior patterns among children contribute greatly to a wide range of physiological and psychological diseases. For example, lack of regular exercise during childhood is the highest contributing factor for obesity, which is considered to be one of the most serious public health threats of the 21st century (TANSON, 2003) and(World Health Organization, 2011a). According to several studies and statistics, obesity among children is dramatically increasing to a point where it has become a pandemic. For instance, the World Health Organization (WHO), reported that the worldwide obesity rate has doubled since 1980 and that approximately 43 million children under the age of five were diagnosed as overweight in 2010(World Health Organization, 2011a). Moreover, The Centers for Disease Control and Prevention (CDC), states that obesity rates continue to increase among children, and this trend will negatively affect the next generations (Yee et al., 2006). In Canada alone, a study has reported that during the past 20 years, the percentage of childhood obesity has more than doubled (Spurgeon, 2002). Additionally, the Childhood Obesity Foundation estimates that over 26% of Canadian children aged 2-17 are currently overweight, and they expect that this number will increase to 70% within 20 years (Childhood Obesity Foundation, 2011). According to the American Herat Association, about 70-80% of obese children are expected to become obese adults. Based on these facts, it is clear that the world will be facing a serious problem in the near future, considering that the adults of the next generation are the children of today (American Heart Association, 2011).

This staggering number of overweight and obese children will eventually be challenged by the various related illnesses, such as high blood pressure and high cholesterol (Choudhary, Donnelly, Racadio, & Strife, 2007). In addition, the low level of physical activity among children is the main cause of several other diseases. For example, the absence of physical activity increases the risk for developing health problems like heart disease, stroke, diabetes, and cancer (Mokdad et al., 2003). According to a WHO report (World Health Organization, 2011a), 27% of diabetes is due to the absence of daily exercise. Also, it has been reported that physical activity is the most prevalent factor in about 30% of heart disease and stroke cases (Lloyd-Jones et al., 2009).

Children's psychological well-being is yet another factor impacted by an inactive lifestyle. It can translate into low self- esteem, anxiety, and depression. For example, a recent study states that active children are 20% less likely than inactive children to be diagnosed with depression (Rothon et al., 2010; Strong et al., 2005).

One major cause of this lack of physical activity among younger populations is excessive television viewing and video game playing (Hersey, J.C., Jordan, A., 2007; Vandewater, Shim, & Caplovitz, 2004); however, many studies have pointed out that digital video games are the main reason because children enjoy playing video games more than watching television, and their time is spent in front of the screen without exerting any physical effort (Setzer & Duckett, 1994). The Research Unit in Health and Behavioral Change indicates that Canadian children have become addicted to playing video games, and that the amount of time spent engaging in this activity is considered to be one of the highest in the world(Behavior And Health Research Unit BHRU, 2011). Another study states that children between the ages of 8 and 18 spend around 44.5 hours weekly watching television and playing video games – more than they spend on any other activity (Robert, Foehr, & Rideou, 2005).
Based on the fact that video games have become a significant and popular mode of entertainment for the younger population, prohibiting children from such activities is impractical. However, it is highly desirable to exploit the large amount of time that they consume playing video games by simultaneously engaging them in physical activity (Biddiss & Irwin, 2010; Yang, Smith, & Graham, 2008). For this reason, academic studies recommend fighting obesity by exposing children to a modified type of video game (Biddiss & Irwin, 2010; Papastergiou, 2009).

To promote exercise indirectly through video games, physical activity has to be incorporated as a requirement to interact with the games. A new genre of video games called ‘exergames’ could become a part of the solution as a way to encourage children to become physically active and to push overweight children towards a healthy lifestyle (Yang, Smith, & Graham, 2008). Recent studies have revealed the importance of exergames in providing children with effective exercise and making it more enjoyable (Bragt, 2005; Haddock, Siegel, & Wikin, 2009); however, exergames can be designed with different objectives and can have physical, health, educational, and entertainment purposes (Papastergiou, 2009; Yang, Smith, & Graham, 2008).

Exergaming is an emerging field that promotes exercise through gaming by incorporating ‘exertion interfaces’ as input devices (F. Mueller, Agamanolis, & Picard, 2003b). Mueller defines an exertion interface as “an interface that deliberately requires intense physical effort” (F. F. Mueller, Gibbs, & Vetere, 2008). While traditional video games are controlled by a keyboard and mouse or a game console, exergaming relies on sensing technology that uses body part movements as input to track the player’s reactions (Stach, Graham, Brehmer, & Hollatz, 2009). This new type of interaction has found its way into academic research and commercial companies and has recently been receiving lots of attention in the Human-Computer Interaction community.

Several studies have been performed to classify exergames such that one can understand the differences and similarities between them (F. F. Mueller, Gibbs, & Vetere, 2008). Based on these studies, exergames can be classified according to their interaction techniques and the input devices that are used to capture physical movement (Stach, Graham, Brehmer, & Hollatz, 2009). The interaction techniques are varied, and their capabilities are based on the hardware devices used. In addition, there is a wide range of input devices that are used to interact with the video games.
Most exergame designers have focused on incorporating attractive features while paying little attention to their ability to help children develop cognitive skills. Also, with regards to exercise, other exergames simply offer new ways to control the games and provide users with fun interfaces that are not considered to be true alternatives to sports (Parker, 2007). Moreover, based on the survey in (Stach, Graham, Brehmer, & Hollatz, 2009) and (F. F. Mueller, Gibbs, & Vetere, 2008), none of the

available exergames are modular, being designed for specific hardware platforms. For these reasons, we have been motivated to design an exergame system for a child that differs from existing exergames in the sense that it combines valued educational aspects as a primary focus but maintains attractive gaming technology and real physical activity.

1.2 Research Problems

The problems with the existing commercially and academically proposed exergame systems are various, and they differ from system to system depending on the system's characteristics and the goals it attempts to accomplish. The following points summarize these problems:

- Most existing exertion systems have been designed to entertain children rather than educate them or improve their mental and cognitive abilities. For example, systems like (Nintendo, 2011; Sony, 2011) and (Konami, 2011) have focused on the aspect of entertainment and, as a result, have ignored or largely overlooked the educational aspects.
- Most commercially available exergames use exertion interfaces as a new and novel form of interaction just for fun, not to provide children with real and effective exercise. For instance,(Nintendo, 2011) is interactive systems that use the child's physical movements as input; however, the required physical intensity in these systems does not meet the recommended level of exercise.
- The prices of some commercial exergames outweigh their benefits. Such systems are equipped with expensive devices or can sometimes require specialized peripherals that are sold separately, making them unaffordable for many families.
- Some exergames, like (Exergame fitness, 2011; Liljedahl, Lindberg, & Berg, 2005; F. Mueller, Agamanolis, & Picard, 2003a) are designed for specific hardware platforms. In addition, some systems, such as (Liljedahl, Lindberg, & Berg, 2005; F. Mueller, Agamanolis, & Picard, 2003a)require extremely large components, a large physical area, and a special setting in order to be played properly. These factors make them unsuitable for personal or home use.

- The physical movements that are required in order to interact with some exergame systems are not suitable for children, and the intensity is either too high or too low (Parker, 2007). For example, some exergames require too much exercise and would cause exhaustion in children and have negative results. Moreover, some systems require the users to attach hardware to the body, which would hinder free movement such as in (Mokka, Väätänen, Heinilä, & Välkkynen, 2003; Whitehead, Crampton, Fox, & Johnston, 2007). As in(Fisher-Price, 2011), most designers of these exergames have forgotten that children are different in their learning abilities and needs. Many of these games cannot meet a wide range of children's needs. Therefore, there is a need to customize learning content by involving both the parents and the teachers in the kids' learning process.

1.3 Research Objective and Contributions

The objective of this research is to help encourage children to exercise indirectly by developing an exertion interface and software system that provides children with a learning experience through an entertaining environment.

The following four points summarize the main contributions of this thesis:

1. Provide and analyze the aspects (requirements) of the ExerLearn Bike system that aim to provide children with adaptive physical activity and learning experiences through enticing and effective exercise.
2. Propose a Triple Flow Model which is an extension of the Dual Flow Model in order to fulfill our requirements.
3. Design an Algorithm to adjust the physical intensity level for each payer based on his/ her heart rate.
4. Design and develop the Exerlearn Bike system by Adopting a modular hardware design approach that makes it possible to use any stationary bicycle as an exertion interaction device.

5. Design three software games with different learning goals, and incorporate personalized features to suit children's needs and enable parents and guardians to be involved in the children's learning process.

1.4 Author's Publications

1. *Rajwa Alharthi, Rania Albalawi, Mahmud Abdo, Abdulmotaleb El Saddik*, "A context-aware e-health framework for students with moderate intellectual and learning disabilities" in Proceedings of the 2011 IEEE International Conference on Multimedia and Expo (ICME), July 2011, Barcelona, Spain.

2. *Rajwa Alharthi ,Ali Karime, Hussain Al Osman , Abdulmotaleb El Saddik*, "ExerLearn Bike: An exergaming system for children's educational and physical well-being " in Proceedings of Ambient Intelligence Multimedia Environments (AIME), 2012 IEEE International Conference on Multimedia and Expo (ICME) , July 2012, Melbourne, Australia.

1.5 Thesis Outline

The remainder of the thesis is organized as follows:

Chapter 2 presents an overview of the background literature on exergames and a survey of some closely related works in the commercial industry and academic field. It also discusses the classification of exergames, the drawbacks, and the suitability of the existing systems for children's use. It concludes by providing a comparison between the surveyed games and our system, based on some important characteristics.

Chapter 3 elaborates on the design requirements, the Treble Flow Model and the proposal of our system. Also, this chapter discusses the overall system architecture by illustrating the hardware components and software modules involved.

Chapter 4 presents the implementation of the system and explains the technical details of the modular hardware component and the different technologies that were used in developing the system. Also, it contains the software games scenarios that were implemented to evaluate the system.

Chapter 5 presents and discusses the experimental results of the qualitative and quantitative evaluation of the system's performance and learning experience.

Chapter 6 contains the conclusion that summarizes our work and indicates our vision for the future of the proposed system.

Chapter 2: Background and Literature Review

This chapter first provides a review of the background literature related to exergames and describes the different exergame classifications in Section 2.1. In Section 2.2, a survey of existing exergames in both commercial and academic research fields is then presented in order to show the broad range of interaction styles. The reasons for choose the ExerLearn Bike system's controller in Section 2.3. Finally, there is a brief comparison of these different exergames, including our proposed system in Section 2.4.

2.1 Literature Review

Exergames promote physical activity by masking the uninteresting side of traditional sports for children with the fun and enjoyment of gaming. Applications designed with exertion interfaces require active inputs and physical movements to control the software. This is unlike traditional computer games, which require inactive inputs such as pressing a button or typing on a keyboard.

In exergame applications, there are many ways designers can incorporate physical interfaces into their video games. This can vary and range from free movement to equipment-based exercises based on hardware devices and the exergame's desired objectives. Examples include cycling, dancing, throwing, jumping, and swinging. It is important to be familiar with all of the possible actions and hardware elements that can be incorporated into a game's design in order to determine the game's efficiency and attractiveness. Several studies have been performed to present a taxonomy of these approaches and to classify exergames so as to better understand the differences and the similarities between them (F. F. Mueller, Gibbs, & Vetere, 2008; Stach, Graham, Brehmer, & Hollatz, 2009).

One of the main differences between existing exergames is the interaction style. Interaction styles vary from one game to another, and their capabilities are based on the hardware devices used. After reviewing 107 research prototypes and commercial and fantasy games, Stach *et al.* classified six distinct input techniques as common forms of interaction style (Stach, Graham, Brehmer, & Hollatz, 2009).

The first technique is the use of gestures where the game matches the players' body movements over time with predefined patterns. This study counted 69 exergames that use physical gestures in their input style. For example, Nintendo Wii Sports includes tennis, baseball, boxing, golf and bowling in which the players use body movements similar to those in real life sports(Nintendo, 2011).

The second technique uses the game hardware to capture the position of different body parts at specific times to detect the user's stance. This study counted approximately 19 commercial games and 15 fantasy games that use this input mechanism. As an example in the academic field, Whitehead *et al.* developed an exergame that uses different accelerometers to detect the position of the player's body while he or she is performing dance steps (Whitehead, Crampton, Fox, & Johnston, 2007).

Pointing is the third technique. It was used in 9 games in which users are required to point to a specific portion of the screen in order to interact with the game. Players can point directly to icons on the screen or to specific entities using their fingers, hands, or any specific hand-held device. This style is used in some Nintendo Wii (Nintendo, 2011) and Sony EyeToy games (Sony, 2011).

The fourth interaction style is the continuous capture of power or physical energy. This technique was applied in 11 games where the game input was the physical intensity measured when players performed traditional sports movements. For example, in a research prototype exergame called "Heart Burn", the player is required to keep pedaling in order to navigate a track (Stach, Graham, Yim, & Rhodes, 2009). The more the player pedals, the faster the user will be in the game.

The fifth input style uses a continuous control mechanism to map the physical world with a virtual world in real time. 16 games used this technique as input. In these cases, the entire body in the physical space is mapped directly to the virtual position and used to guide the game or some characters in the game.

Tapping is the last interaction style and was found in 13 games. Users are required to make contact with a particular object or location by tapping it. For example, Dance Dance Revolution , a popular commercial game, simulates dance activity as players tap specific squares on a floor pad using their feet to match instructions displayed on a screen(Konami, 2011).

All the identified active inputs that deliver the experience of exergames to players are captured in real time using special-purpose devices.

Exergame design is flexible and supported by a wide range of hardware devices. Because of this, some studies present a different classification method for exergames based on input devices. Mueller *et al.,* for example, propose a taxonomy to distinguish between existing exergames based on the hardware devices used (F. F. Mueller, Gibbs, & Vetere, 2008). This study proposes four categories of device as follows:

First, some games use accelerometers for players to interact with and control the game, such as those for the popular Nintendo Wii(Nintendo, 2011). Others use a camera as an input device, such as the PlayStation Eye, which captures users' movements and positions using a computer vision system(Sony, 2011). In other studies, they use touch sensitive pads and mats with pressure sensors placed on the floor that sense the users' steps (Karime, Al Osman, Gueaieb, Alja'am, & El Saddik, 2011; Konami, 2011). Finally, exercise equipment is also used as input. This includes stationary bikes for PCGamerBike and Fisher Price games , which require users to pedal and steer to control the game(PCGameBike, 2011).

2.2 Related Work

In recent years, numerous exergames have been developed that, aside from the differences in interaction styles and hardware devices used, vary in their purposes. Some of these exergames are designed with the simple goal of pure entertainment, using an exertion interface as a new style of interaction. Other exergames concentrate on the purpose of exercise combined with other aspects like socialization, health or wellness.The following descriptions of existing exergames are grouped based on their hardware classification, and focus on exercise-equipment based systems. This section provides insight into the strengths and weaknesses of existing exergames in terms of goals, input styles, and hardware devices.

2.2.1 Camera-based Systems

Vision-based systems are a popular approach that can be used to capture a user's physical movements. Some exergame applications use built-in or USB cameras to determine the user's position and motions by finding the differences in continuously captured image frames. Examples of this approach include:

A. Sony's EyeToy

Sony's EyeToy is part of a popular commercial gaming series from *Konami* that was released in 2002(Sony, 2011). It is a digital camera device meant to be used with many virtual games for activities such as Karate, dancing, Kung Fu fighting, Window washing, Boxing a robot, and Bouncing soccer balls. It uses a compact camera connected to a PlayStation 2 to capture images of the user's body movements and position and translate those movements into controller inputs. The system incorporates basic computer vision algorithms and gesture recognition features to process and analyze all the images and videos the camera captures. In some games, users see an image of themselves on the screen as they interact with the game through motions that control their virtual character. For example, in one game, players are required to hit different objects using their hands and feet as those objects appear on the screen.

B. Breakout for Two

Mueller designed an initial research prototype called "Breakout for Two" that uses an exertion interface and a virtual game to provide sports over distances (F. Mueller, Agamanolis, & Picard, 2003a). The game combines the advantages of telecommunications technology and traditional sports to bridge geographical distance between players and support social interactions.

The game allows two players to play sports, such as tennis or soccer, against one another, even if those players are divided by physical distance. Players set up cameras and projectors, and the system requires the presence of a computer network. A life-size videoconference screen is provided to enable the players to interact through video and audio connections and observe each other's movements. Based on the game that both players choose, they can throw, kick, or smash a regular ball against the physical screen and then wait for the second player to observe and respond. In tennis, for example, eight virtual blocks are displayed on the video screen for each player. Players are required to strike as many blocks as possible before the other player hits them. The winner is the player who successfully hits more blocks than the other player. The drawback of this system is that the oscillation that normally occurs in a network connection causes the system's performance to be unpredictable.

C. Dodge-It

Tracking technologies can be augmented with technologies such as infrared (IR) tags to provide novel techniques for interacting with the video game. Dodge-It is an example of a game that is designed based on a head-tracking system that uses IR tags (Yim, Qiu, & Graham, 2008). It is a simple shooting game that consists of IR light-tracking techniques, a large screen, a Wii remote, and a three-dimensional virtual game.

In the system a user places a sensor bar on their head, and the Wii remote held in front of the player tracks the position of the sensor. A special camera captures and filters only IR light coming from the sensor bar on the player's head. In this game, a player is required to shoot all the displayed targets while dodging incoming projectiles by physically moving his or her body or head. This game is targeted mostly towards adults, and it is not suitable for children because it requires placing hardware on the head which may hinder a child's movements. Furthermore, a very limited amount of physical activity is required to interact with the game.

D. Shadow Boxer

Shadow Boxer is a physically interactive prototype game developed using tracking technology (Höysniemi, Aula, Auvinen, Hännikäinen, & Hämäläinen, 2004). The system uses computer vision, a hearing platform, and a web camera to capture the player's body movements.

Figure 2.1: The shadow Boxer game

The player interacts with a boxing game by getting the game character to perform certain boxing techniques as shown in Figure 2.1. They have to punch 'point gloves' that move across the screen, as they reach the correct position. The game encourages players to be physically active and improves their focus and speed. This is also unsuitable for young players due the violent subject matter and the fighting actions, which may affect their behavior.

2.2.2 Accelerometers and Sensors

Accelerometers are devices that can sense body position, movement direction, and changes in speed, all of which are extremely beneficial in developing exergames. The following section describes some exergames that use accelerometers or other sensors.

A. Nintendo's Wii system

Wii Sports, released by Nintendo in 2006, is the most popular exergame that uses motion sensitive controllers (Nintendo, 2011). The system includes a wireless motion-detecting controller that uses infrared sensors and accelerometers. Players interact with sport games by moving their bodies in conjunction with the controller. The games require holding the controller in specific positions and moving it while making sport-specific motions to respond to actions on the screen. The sensors detect the player's body movements to determine their speed and reaction time. The system offers a variety of virtual sporting games such as tennis, baseball, bowling, golf, and boxing. Depending on the game that is chosen, the player is required to hold the controller to simulate a bat, racquet, paddle, or gloves during gameplay; it then tracks hand movements. Wii Sports does not facilitate the same energy expenditure as the sports activities they are simulating. Therefore, the physical intensity is insufficient to meet the recommended amount of daily exercise for children (Parker, 2007).

B. Dancing Game

Whitehead et al. used numerous accelerometers as input devices when developing dancing games (Whitehead, Crampton, Fox, & Johnston, 2007). They believe that by using only a single motion-detecting device to control a game, the system will receive inaccurate inputs and not promote full engagement in the physical interaction. For this reason, they have implemented an exergame system that uses a sensor network distributed on the player's body. Four sensors are placed on each hand and one on each leg. These sensors detect the positions of the player's limbs and provide the game with more accurate input information about the user's movements. In their game 'Robot-Paint', the player is required to match the dance steps of an animated robot displayed on the screen. The robot's body is painted gradually as the player performs dance steps correctly, until it is fully coloured.

C. Ping Pong Plus

Ishii *et al.* designed a digitally-enhanced version of the traditional ping-pong game at the MIT Tangible Media Lab (Ishii, Wisneski, Orbanes, Chun, & Paradiso, 1999). This exergame aims to improve physical activity and social interaction by incorporating attractive digital augmentations into the classic game. The system consists of a reactive ping-pong table as the exertion interface and a projector placed above the table. The table is designed with a ball-tracking system that uses eight microphones mounted on the underside of the table. The ball-tracking system incorporates sensing and sound technologies to detect the ball's position.

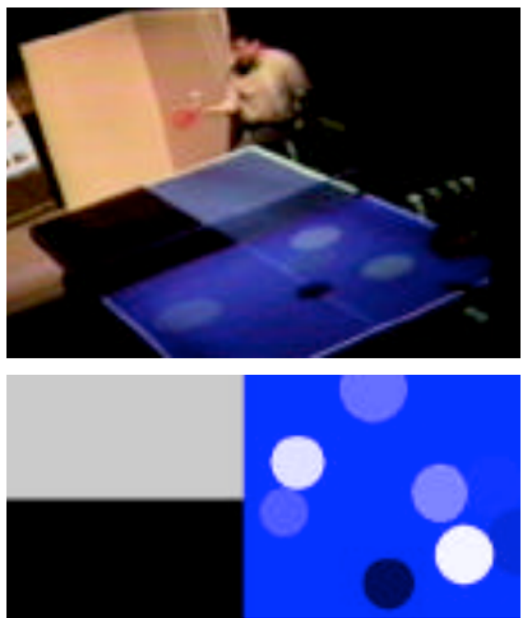

Figure 2.2: Painting mode in the Ping-Pong game

Players use standard ping-pong equipment, including bats (paddles) and a ball, to interact with the game. A graphics projection system is used to display different patterns of light and shadow on the table based on the chosen mode. More than 12 different modes have been developed for this game, which have names like Water Ripple, Thunderstorm, Black-Out, Painting, and Comets. For example, in the Painting mode shown in Figure 2.2 players have to be organized and collaborative to paint on a table. In the Water Ripple mode, the ball leaves images of rippling water on the table when the ball hits the table and is combined with music. In Black-Out players play in a darkened room where no light is present except a bright white projection on the table. When the ball hits the table effectively by one player, it takes the light away from the other player's side of the table, changing it into a large black spot. Playing this game can improve a player's physical and social communication skills since some modes require collaborative play.

D. DigiWall

DigiWall is another exergame which combines the features of climbing a wall with computer games (Liljedahl, Lindberg, & Berg, 2005). DigiWall is an artificial rock-climbing wall designed for children that promotes full body exercise in a fun and safe way. The system interface consists of a realistic rock climbing panel, a sound system, and a computer system to connect the panel's components with the sound system.

Figure 2.3: A child climbing DigiWall

The climbing panel contains many hand and foot grips equipped with multiple touch sensors and lights as can be seen in Figure 2.3. The sound system plays in the background while the lights guide the climber through the gameplay and provides him or her with feedback. The player is required to listen to sound information and respond to lights to figure out which grips to interact with. The system provides many games that vary from climbing to balancing to competitions. DigiWall supports physical activity by allowing children to move easily and freely without being dependent on a computer screen. The game size and shape, however, make the system unsuitable for use in a normal home environment.

E. Makoto

Makoto Sports Arena is a multidirectional interactive game that aims to improve children's visual, mental, and cognitive abilities as well as physical performance (Exergame fitness, 2011). The Makoto consists of three indestructible vertical towers, each equipped with 10 lights. As seen in Figure 2.4 the system's exertion interface is a triangular base with three vertical towers rising from the triangle's corners.

Figure 2.4: The Makoto Game

Each tower is wired electronically and equipped with 10 light locations. The lights appear randomly in any area of the three triangles and combine with different sounds based on a chosen pattern. The sounds include musical themes, animal sounds, and sci-fi tones. To play the game, children must listen for sounds as they are emitted from towers and identify which tower has emitted the sound. They must then quickly hit the light locations on that tower using their hands or feet before the light goes off.

Makoto is considered a competition exergame, in which the children are scored based on their reaction speed and accuracy. As such, the game can improve focus and concentration abilities. In addition, players can adjust the settings and customize the game to meet their needs and abilities. Unfortunately, children may hurt themselves when hitting the light locations with too much force.

2.2.3 Pads and Mats

Several games use footpads or mats as input devices to provide children with a new style of interaction. They are designed with multiple touch sensors that capture the player's movements and deliver these movements as input to the system. In the following section, a brief overview of two representative works is provided.

A. Dance Dance Revolution (DDR)

In this type of game, children can provide input through footsteps on a dance pad (Konami, 2011). DDR is a commercial video game in which players perform dance steps on the dance pad to match a changing pattern on the screen. It was released by Konami in 1998 and has rapidly become the most popular exergame product on the market.

The system consists of a touch-sensitive dance pad with four directional arrows (up, down, right, and left), placed in front of a television screen. Players stand on the pad, listen to music, and play the game by moving their feet to certain positions on the dance pad. They are required to step and sometimes hold down on the pad's arrows to match the flashing arrows that scroll on the screen. These flashing arrows match the music pattern as it plays in the background. The scoring system is based on the player's speed and accuracy. DDR is designed to improve children's health and to encourage them to exercise in a fun way with music. In addition, one study reports that some of DDR's players have suffered joint and knee pain, which is considered a drawback of the system, especially for young children(Hoysniemi, 2006).

B. Learn-Pads

Similar to DDR, Learn-Pads is another exergame developed using footpads as the exertion interface (Karime, Al Osman, Gueaieb, Alja'am, & El Saddik, 2011). It attempts to promote physical activity and to help children learn basic math skills in a fun and enjoyable manner.

Figure 2.5: A child playing with the Learn-Pad system

The Learn-Pad system consists of four foot pads connected to a computer screen that displays a set of math games. These games are enhanced with multimedia features as shown in Figure 2.5. Each footpad is equipped with a Force Sensitive Resistor Sensor in the middle of the inner surface to detect the child's footsteps and use them as input data. The footpads placed on the left and right are used to decrease or increase the numbers. The footpad on the top is used to submit an answer to the game, and the footpad at the bottom is used to restart the game.

To interact with the system, children answer math questions by stepping on the footpads to generate the correct answer. For example, “1+3?” is an addition question that may display on the screen. To answer this question, the child would then step on the incrementing pad four times. Each step is accompanied with a verbal spelling and visual representation of the number. The main idea behind the system is to allow children to play a math video game by answering a set of random arithmetic questions through a series of steps on the Learn-Pads.

2.2.4 Exercise Equipment

Several games use exercise equipment as input devices to provide children with a means of exercise. In the following section, brief overviews of exercise equipment based games are provided.

A. Heart Burn

Heart Burn is a research prototype game that combines entertainment and physical activity while supporting competition between players (Stach, Graham, Yim, & Rhodes, 2009). This game is a multiplayer exergame that consists of a stationary bicycle and a wireless game pad connected to a personal computer. Players compete in a race using an onscreen track. They must reach the end of the track by pedaling the bike and steering with the game pad. The more the player pedals, the faster the car will move. The game uses real-time heart rate data to determine the game speed and to balance the game performance to account for different levels of fitness.

B. Frozen Treasure Hunter

Frozen Treasure Hunter is another exergame that uses a stationary bike to promote physical activity (Yim & Graham, 2007). The system is comprised of the bike, and a Wii remote and Nunchuck controllers that act as input devices. In this game, two players share an avatar and cooperatively play by using two different interaction styles. By pedaling a bike and steering via the game pad, the first player controls the movement of the avatar. The second player uses the Wii remote and nunchuck controllers to swat away harmful snowballs that are thrown at the avatar.

C. Virku

Virku is an academic exergame. Researchers designed this exergame using a regular fitness bike and 3D virtual environment software (Mokka, Väätänen, Heinilä, & Välkkynen, 2003). Players are required to pedal in order to move through a virtual environment using the stationary bike and handlebars. The software has different landscapes that combine with natural sound effects, such as the sounds of birds and the humming noise of the wheels. The pedaling speed can be increased or decreased based on the game environment. Children can use the system as well, but the system does not provide any educational benefits.

D. Sinclair's GameBike

Sinclair *et al*. used a standard commercial CatEye GameBike to develop a modified version that would overcome some existing limitations (Sinclair, Hingston, Masek, & Nosaka, 2010). Because GameBike's heart rate functionality and resistance control cannot be attained using an external computer interface, the researchers added two connections to a Windows PC: one to provide speed feedback and a second to receive information on the user's heart rate. This modification allowed the user to control their cycling speed based on the information received. Consequently, the bike becomes an adaptive version of regular exergame bikes. Simple software was developed for evaluation purposes. To achieve a high score, a player has to pedal within a specific speed range to control a helicopter and collect items along a passageway. The helicopter crashes if the speed rate is not maintained. One limitation of this system is that the game's challenging levels were not successfully controlled based on the feedback information.

E. SmartCycle

SmartCycle is the most popular educational system commercially produced by Fisher-Price (Fisher-Price, 2011). The system targets children between the ages of 3 and 6 and consists of a small stationary bike that can be connected to any television and a set of software games that enable learning as shown in Figure 2.6.

Figure 2.6: SmartCycle system

SmartCycle provides learning, exercise, and entertainment benefits for preschoolers. Children control the game by pedaling and steering, while friendly characters guide children through their play experiences. The system comes with a variety of educational video games that teach children basic concepts like counting, colours, and letters.

2.3 ExerLearn System's Exertion Interface

The system proposed in this thesis is based on exercise equipment. We have decided to use this type of equipment for several reasons:

First, our proposed system targets young children. Therefore, we need to design a safe application with an exertion interface that brings outdoor sports to an indoor environment.

Second, we would like our system to have an interaction style and hardware that is familiar to children so that it is easily enjoyed and played. These goals can be achieved if the system incorporates the characteristics of a classic sport that can be simulated with regular exercise equipment.

Third, while some active games use an exertion interface for fun or as a novel way of interaction just to control the video game, we want to use an exertion interface that rivals the advantages of the original sport so that the child benefits from exercising. In his study, Bragt showed that using an exercise bike to control computer games can increase productivity by 17% more than using it for regular exercise (Bragt, 2005). Another study focused on children at risk for obesity who were 7-14 years of age (Haddock, Siegel, & Wikin, 2009) . In this study, children were asked to ride a stationary bike for two tests. In one test they exercised in a regular manner and in the other test they controlled a video game. The study concludes that the addition of video games to standard stationary biking will help overweight children by significantly increasing the total energy expended.

Fourth, the physical movements required to interact with the system should be suitable for children. This means, for instance, that the intensity should be in a range that is not too high or too low. Some exergames require too much exercise for the entire body, which will cause exhaustion and result in a negative experience. Furthermore, a game that is too intense will decrease the child's ability to focus on the gaming experience, especially if the exergame is combined with other aspects such as education. For this reason, we determined that leg-based exercise was the best choice since it is hands free, making it easy for children to interact with the games. Also, unlike DDR, this allows them to focus on the games and educational tasks more than on the controller device and the physical movements.

Finally, the proposed system is based on the fact that the amount of energy expended differs from one child to another. Some exergames cannot measure the amount of energy expended for each child individually as an input. In the Wii games, for example, children are required to perform physical movements to control the game, but sometimes large movements have the same effect as smaller ones. Some children might be so excited to play the game that they try to make large and sharp movements, which they think are better to achieve a high score. In this case, they will exceed the recommended amount of exercise and might hurt themselves if they play for a long time. On the other hand, using an exercise bike as a video game controller with an adaptive algorithm that takes into consideration the child demographic and physiological status would benefit each child effectively based on his/her needs.

2.4 Summary and Comparison

This section provides a summary based on the above literature review of existing exergames. They are compared based on the following aspects:

a. Educational capabilities: does the game provide educational benefits or cognitive enhancement to children?
b. Age range: the age of the target users of the system or users who evaluated and played with the game as mentioned in the work's description.
c. Input device: the hardware device is used as the exertion interface to interact with the software games.
d. Interaction style: body movements that a user is required to make in order to interact with the game.

e. Main exercise: The types of exercise the user is trying to replicate when interacting with the system.
f. Suitability for home use: is the exergame appropriate or can be used in average households?
g. Modularity: the controller device is not tied to specific hardware.
h. Adaptive intensity setting: the physical intensity level can be adjusted based the user requirements.
i. Personalized game content: parents or guardians are allowed to customize the game contents to meet the child's needs.

Table 2.1 summarizes points a through e, while Table 2.2 summarizes the remaining points.

Table 2.1: A summary of the related work in terms of education goals, age range, input devices, interaction style and main exercise.

Related Works	Educational Goals	Age	Input Device	Interaction Style	Main Exercise
Sony's EyeToy	Yes	All	Camera	Gesture Pointing	Free motions Depends on games
Breakout for Two	No	Youth, University aged	Camera	Gesture	Tennis, Soccer
Dodge-It	No	N/A	Camera, IR, Wii remote and sensor bar	Gesture	Head moving Eye gaze
Shadow Boxer	No	26 – 44	Camera	Gesture	Boxing
Nintendo Wii	Yes	All	IR sensors Accelerometers	Gesture, Stance Continuous control, Pointing	Depends on games

Dancing game	No	N/A	Accelerometers Sensors	Gesture, Continuous control	Dancing
Ping Pong Plus	No	N/A	Sound technologies	Tap	Hand moving, Tennis
DigiWall	No	Children	Touch sensors	Tap	Climbing
Makoto	Visual, mental,and cognitive abilities	Children	Touch sensors	Tap	Free movements
Dance Dance Revolution	No	Children	Touch pad sensors	Tap	Dancing
Learn-Pads	Math	7-12	Touch-sensitive dance pads	Tap	Leg movements
Heart Burn	No	N/A	Stationary bike	Power	Cycling
Frozen Treasure Hunter	No	N/A	Stationary bike Wii Remote	Gestures, Power	Cycling, Hand movements
Virku	No	22-41, Children	Stationary bike	Power, Tap	Cycling
Sinclair's GameBike	No	21-41	Stationary bike	Power, Tap	Cycling
SmartCycle	Math, alphabet, shapes	3-6	Stationary bike Joystick	Power	Cycling
ExerLearn Bike	Math, new objects	Children	Stationary bike Push button	Power ,Tap	Cycling

Table 2.2: A summary of related works in terms of home use, modularity, adjustable intensity levels and personalized game content.

Related Work	**Suitable for Home Use**	**Modularity**	**Adaptive Intensity Levels**	**Personalized Game Content**
Sony's EyeToy	Yes	No	No	No
Breakout for Two	No	No	No	No
Dodge-It	No	No	No	No
Shadow Boxer	Yes	No	No	No
Nintendo's Wii	Yes	No	No	No
Dancing game	Yes	No	No	No
Ping Pong Plus	No	No	No	No
DigiWall	No	No	No	No
Makoto	No	No	No	No
Dance Dance Revolution	Yes	No	No	No
Learn-Pads	Yes	No	No	No
Heart Burn	Yes	No	Yes	No
Frozen Treasure Hunter	Yes	No	No	No
Virku	Yes	No	No	No
Sinclair's GameBike	Yes	No	Yes	No
SmartCycle	Yes	No	No	No
ExerLearn Bike	Yes	Yes	Yes	Yes

Chapter 3: Proposed System

In this chapter we define the requirements of the ExerLearn Bike System and discuss the overall architectural design by detailing the hardware components and software modules involved. The design phase was challenging because it required extensive research on game design and exertion interfaces, and a strong understanding of effective learning theory. In Section 3.1, we outline the system requirements which are theoretically derived to effectively meet a child's physical, educational, and entertainment needs .In Section 3.2. we explain the Treble Flow Model. This is the design model for the ExerLearn Bike system and is an extension of the "Dual Flow Model". Section 3.3 presents the overall system architecture and Section 3.4 discusses its various modules and hardware devices. Section 3.5 provides the system use case diagrams.

3.1 Design Requirements

In this section, we outline the requirements of our proposed system based on the characteristics discussed in Section 2 of Chapter 1 and on our objectives mentioned in Section 3 of that chapter. Extensive research has been conducted in order to identify the most significant features and factors that the ExerLearn Bike should incorporate in order to fulfill our requirements and solve some existing problems. This section outlines our requirements that are based on existing educational games and exercising domains (Csikszentmihalyi, 1975; Sinclair, Hingston, & Masek, 2007; Sinclair, Hingston, & Masek, 2009; Sweetser & Wyeth, 2005).

Research in the education domain is aimed at developing improved and more effective learning methods (Tang, Hanneghan, & El Rhalibi, 2009). Most of these studies focus on the value of gaming in this learning process, and researchers expect the current generation to enjoy gaming activities to some degree within their education (Prensky, 2003). Recently, the predicted idea of using games to enhance learning experiences has received increasing attention, and there have already been attempts to incorporate gaming technologies into the learning process (Prensky, 2003; L. Smith & Mann, 2002; Tang, Hanneghan, & El Rhalibi, 2009). Since we are targeting young learners, the traditional methods used in learning games for older users need to be adapted.

Recent studies have also explored the use of game play with physical activity (Biddiss & Irwin, 2010; Yang, Smith, & Graham, 2008). However, very little effort has been focused on the benefits of adding an exercise dimension to the learning process in order to combine regular sports activities with educational gaming technologies (D. R. Michael & Chen, 2005; Papastergiou, 2009). Combining gaming, learning, and exercising will entice children to play and keep them engaged so that they can achieve their learning objectives. The challenge is in determining how to develop attractive exergames that promise a legitimate learning experience along with efficient exercise. The game needs to be carefully designed so it seems to focus less on learning and exercising and more on looking like an attractive game that children would like to play repeatedly.

To provide motivating educational goals, we explore the design requirements based on learning theory from research findings that result in effective learning experiences and valued outcomes (Ang & Rao, 2008; L. Smith & Mann, 2002; Wechselberger, 2009). In terms of gaming and exercising, we have extensively reviewed literature on exercise and game motivation and listed the requirements and concrete factors that help to design attractive and effective exergames (Sinclair, Hingston, & Masek, 2007; Sweetser & Wyeth, 2005).

3.1.1 Attractive Game

The system should offer challenges that match a wide range of abilities. It is important for the exergame to balance between an individual's abilities and the game's level of difficulty. Since it incorporates physical activity, it cannot follow the basic balancing principle as normal games do. This principle assumes that the more the user plays, the faster his or her skills improve. However, in exergames, the user should also reach a desired intensity level even if their skills need more improvement. Therefore, the exergame must consider the combination of user ability, game challenge level, and exercise intensity.

Games should be fun and should provide an enjoyable experience for children when performing learning activities. This keeps them motivated to play the game and to participate in physical activity frequently (J. Lee, Luchini, Michael, Norris, & Soloway, 2004). Fun provides deep and passionate involvement to build children's positive emotions toward the game activities. This will directly affect the efficiency of the learning process. In contrast, there will likely be no physical benefits or skill improvement if the game lacks excitement and thrills. Studies have defined and classified fun in a number of ways. For this requirement, we look to Malone who, in 1981, conducted many psychological studies that focused on designing fun and exciting games(Malone, 1981). He suggests three factors that can be included in the game design to make it fun: challenge, curiosity, and fantasy.

The game software should have a simple graphical user interface that is very usable by young players. Also, the system's strategies, rules, and instructions should be simple enough to be learned in only a few minutes. The game should provide children with clear steps and limited instructions that guide them through a simple user interface (Sung, Chang, & Lee, 2008).

3.1.2 Quality and Effective Exercise

Our system needs to follow some qualified guidelines for physical activity in order to provide children with beneficial exercise. There are many standards and guidelines that demonstrate the effectiveness of exercise such as the World Health Organization (WHO) , The Centers for Disease Control and Prevention (CDC)(Centers for Disease Control and Prevention, 2011; World Health Organization, 2011b). After reviewing all these qualified standards and guidelines, we considers these recommendations to design effective system for children to perform safe and beneficial physical activity. The recommendations for physical activity that we should consider while designing our prototype are the following:

A. Intensity of the exercise

Exercise intensity is an important factor for indicating whether the child performs an exercise effectively or not. The standard way to determine physical intensity is to use heart rate (HR) measurements. Based on this recommendation, the child is performing an effective exercise if his/her HR during physical activity is within the target zone. The target heart rate (THR) for this physical activity should be within 50% to 90% of the child's maximum heart rate $HR_{\max}$.The exercise intensity in general and the maximum heart rate in particular are dependent on child demographics like exercise experience, age, and gender.

For exercise experience, a recent study observed DDR players of varying experience over a long period of time (Sell, Lillie, & Taylor, 2008). The study concludes that experienced players achieve the recommended intensity level while inexperienced players do not. In terms of how age affects exercise intensity, another study shows that exercise energy and the level of intensity in boxing Wii Sports are varied based on the player age, and young players expend more energy than adults(Lanningham-Foster et al., 2009). Moreover, gender differences influence exercise intensity since females appear to be less active than males. For instance, one study proves that young boys expend more energy playing Wii Sports than young girls; however, the effect of gender differences among children is very small (Graves, Stratton, Ridgers, & Cable, 2008).

Based on the previous factors, we have reviewed several studies that compare equations for predicting the maximum heart rate for children (Machado & Denadai, 2011; Mahon, Marjerrison, Lee, Woodruff, & Hanna, 2010). The result, regardless of individual variation, is that Tanaka's formula (1) is the most valid and accurate for reflecting the relationship between a child's age and their maximum heart rate (Tanaka, Monahan, & Seals, 2001). This formula is based solely on the child's age.

$$HR_{\max} = 208 - (0.7 \times Age) \quad (1)$$

After obtaining the value of the maximum heart rate, it is possible to calculate the target heart rate zones using the Karvonen Equation (2) (Karvonen, Kental, & Mustala, 1957).

$$THR = (HR_{\max} - HR_{rest}) \times Intensity + HR_{rest} \quad (2)$$

This formula is very effective and presents a personalized method for calculating target heart rate zones because it takes into consideration the resting heart rate, which is unique to every individual. Here, HR_{rest} is the heart rate of the participant when he or she is completely at rest. $Intensity$ is a level that ranges between 50% and 90% of the maximum heart rate and is based on the desired level of intensity to be achieved. $HR_{\max}$ is the maximum heart rate from equation (1).

The target heart rate zones can be calculated based on the desired level of exercise intensity to be performed. There are different recommended intensity levels, ranging from light to hard or advanced, based on the percentage on the $HR_{\max}$. For example, light exercise (50%-60% of $HR_{\max}$) is for beginners, moderate exercise (60%-70% of HR_{max}) is for an intermediate or average level, and heavy exercise (70%-80% of HR_{max}) is for advanced users.

B. Duration of Physical Activity

The CDC and WHO physical activity recommendations state the importance of the exercise's duration. Based on these guidelines, the duration of the exercise should be 20 to 60 minutes of either continuous exercise or intermittent bouts of a minimum of 10 minutes each throughout the day. The limited duration of the physical activity can affect the exercise intensity, and accordingly, the effectiveness of the exercise. For example, children playing the DDR exergame achieved an average of 65% of their HR_{max} which falls within the child target zone (Tan, Aziz, Chua, & Teh, 2002). However, the duration of some versions of the game is only six minutes, which results in ineffective exercise.

C. Frequency

The previous guidelines recommend that physical activity needs to be performed three to five days a week in order to benefit from the exercise. In the exergames domain, it is easy to promote frequent playing sessions to influence the effectiveness of the exercise by increasing the degree of motivation through video games. For instance, a study compared the enjoyment and exercise benefit between two groups using regular training stationary bikes, one as a controller in interactive video game and one without (Haddock, Siegel, & Wikin, 2009). They found a significant difference in attendance after six weeks: 78% for the interactive video game group and 29% for the traditional training group. The results indicate that incorporating fun and enjoyment in exergames proves to increases the exercise motivation, leading to frequent playing sessions.

There are many experimental studies that review the effectiveness of physical activity in existing exergames based on some qualified recommendations. Based on these studies, some exergames have been found to provide sufficient exercise intensity based on these recommendations.

However, they use exertion interfaces as a new and novel form of interaction just for fun, and not all of these devices provide a real exercise experience. For example, a study examined the efficiency of Wii games compared to real-life sports based on the recommended daily amount of exercise for children (Parker, 2007). They found that Wii games do not provide enough exercise, and the energy used to interact with the game is not enough to contribute to the recommended activity levels. In another study, which examined the XaviX bowling game, children achieved approximately 49% of their maximum heart rates, falling short of the target heart rate (Mellecker & McManus, 2008).

With this in mind, our exergame system should provide children with the recommended levels of exercise intensity that meet WHO and CDC guidelines and recommendations.

3.1.3 Modular Hardware Design

The interaction style and the controller device are important factors when designing an effective and attractive exergame. However, some existing commercial exergames are equipped with expensive devices or sometimes require specialized peripherals that are sold separately. This makes them unaffordable for many families and their prices outweigh their benefits. In addition, some of them are tied to specific hardware platforms or require an extremely large component and a large physical area in order to be played properly. These factors make them unsuitable for personal or home use. Therefore, the controller device in our exergame system should adapt a modular design that makes it possible to use with any existing stationary bike.

3.1.4 Learning Experience

Our system should offer adaptation mechanisms to suit different needs so that children can enjoy the game experience as much as possible. The adaptation mechanisms in educational games may address a wide variety of aspects, such as customizing the learning content, supporting different learning goals, and adjusting the game challenge level. Some features that should be implemented in our prototype to provide children with an adaptive educational experience are:

1. The learning objectives must be identified carefully. Clear visions and expectations are key factors for developing an effective exergame. Educational goals should be embedded in meaningful content to be achieved while playing the game.

2. The game must provide children with appropriate feedback with suitable effects that are based on the goals that have been achieved so far. Feedback should be engaging and should motivate children to successfully complete their tasks. Many studies emphasize the importance of feedback in educational games, and researchers have found that feedback features have a strong potential for improving problem solving skills (Sweetser & Wyeth, 2005). Games need encouraging feedback to show children how they are doing with a current task and to help them learn from their mistakes. For instance, rewards that decrease in value with each wrong answer could be a good way to improve user performance.

3. The game should incorporate a progress monitoring feature as an additional service for guardians. This will allow teachers and parents to track the progress and actions of the children while they are playing and gather valuable information before and after the game activities. It must also include the ability to store the child's progress in order to evaluate his/her performance and achievements over longer periods of time.

4. An effective game design should provide supervisory users (parents or teachers) the ability to be involved in the child learning process. Designers of some exergames have forgotten that children are different in their abilities and learning needs. Many of these games cannot meet a wide range of children's needs without personalization, as in (Fisher-Price, 2011). Therefore, the system should be flexible enough to allow guardians to be involved in personalizing the content, media, and physical activities.

5. The game content must be age appropriate to satisfy children's needs. Since we are designing an educational game that motivates physical activity, the content should be integral for both sides (learning and exercising). Also, content should be delivered through the most appropriate media

(audio, text, images) to be accessible by young learners (Sung, Chang, & Lee, 2008). Moreover, the use of exploration and discovery processes within games will help children to practice new skills and learn new facts. For example, brain development games, such as memory games or puzzles, can enhance children's memory and brainpower. Also, games that uncover progressively diverse portions of images enhance memory, attention, and problem solving.

3.2 Treble Flow Model

The development of exergames for children has generally been focused on exercise, entertainment, or a combination of the two; different models have been proposed with regard to these domains (Sinclair, Hingston, & Masek, 2007; Sinclair, Hingston, & Masek, 2009). Some, if not all, of these approaches neglect to take education into consideration, and therefore, they cannot satisfy the children's educational needs.

Since we aim to combine the elements of attractive gaming, effective exercise, and learning features (experience), the Dual Flow Model (DFM) provides a good starting point for designing our exergame system (Sinclair, Hingston, & Masek, 2009). DFM is the extension of the theory of flow, which incorporates both mental and physical experience(Csikszentmihalyi, 1975) . The concept of this model has been applied in different domains, including sports and entertainment, and is considered to be the best model for exergame design. However, the original model falls short because it has only two dimensions: exercising and gaming. In order to fulfill all of our objectives, we need to extend the DFM by adding the learning dimension. Treble Flow Model is our extended version of the DFM, and it consists of all three dimensions to fulfill all of our requirements. The following subsections describe these three dimensions in detail.

3.2.1 Attractiveness

To design a successful exergame system, the designer must be sure that the game is attractive and enticing. The attractiveness of this kind of game can be modeled using a modified version of the flow model called the "GameFlow" model, as presented in (Sinclair, Hingston, & Masek, 2007; Sinclair, Hingston, & Masek, 2007; Sinclair, Hingston, & Masek, 2009; Sweetser & Wyeth, 2005). This psychological model, shown in Figure 3.1, illustrates skills versus challenges and how to balance between them to motivate children to continue playing. The model presents four quadrants, namely Boredom, Anxiety, Apathy, and Flow, according to this model.

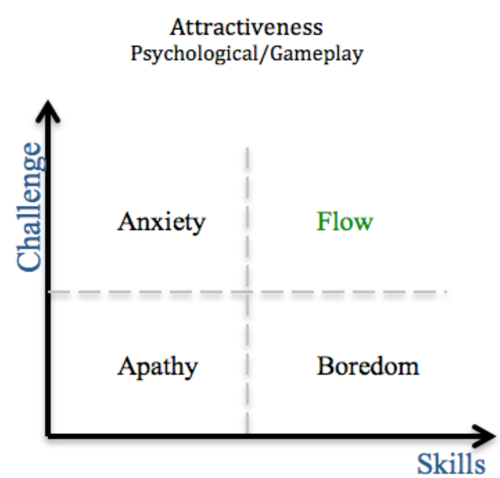

Figure 3.1: The Attractiveness model (Game challenge and player skill)

The Boredom state is reached when skills exceed those required for the presented challenge. In this state, the player will not be motivated to continue since the challenge of the game is too low with regards to his or her skills. On the other hand, if the level of challenge is too high and the players skills are lacking, the player tends to feel anxiety. The Apathy quadrant equates to having a game that elicits an absence of skills and is not challenging enough. The Flow state is reached by establishing a balance between the player’s skills and the challenge of the game.

3.2.2 Effectiveness

The effectiveness of the exergame can be modeled using a physiological model that displays the tradeoffs between intensity and fitness, as shown in Figure 3.2.

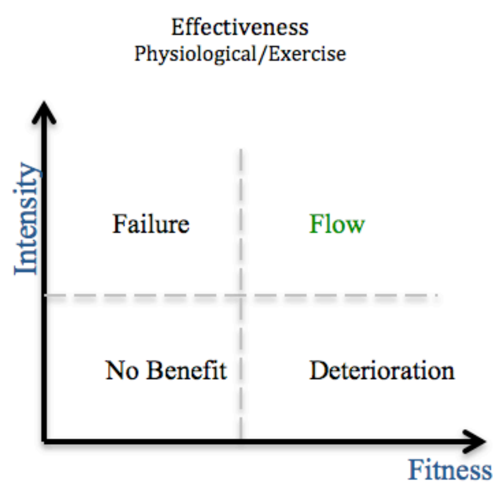

Figure 3.2: The Effectiveness model (exercise intensity and player fitness)

The optimal exergaming experience can be achieved when the player's fitness and the challenge of the exercise are matched; when this is achieved, and player is encouraged to continue exercising. Failure occurs when the intensity of the exercise exceeds the fitness level of the player. The player will not benefit when the intensity of the exercise does not match his/her low fitness level or when the intensity is minimal. The player will enter the state of Deterioration when their fitness level exceeds what is required for the exercise intensity.

3.2.3 Learning Experience

The learning achievements dimension is our extension to the dual flow model and reflects efficiency in the learning process. It is a theoretical-driven model for designing an exergame that motivates children to reach valuable learning milestones. Figure 3.3 illustrates the relationship between how clear the game's goal definitions are and how motivated the user is.

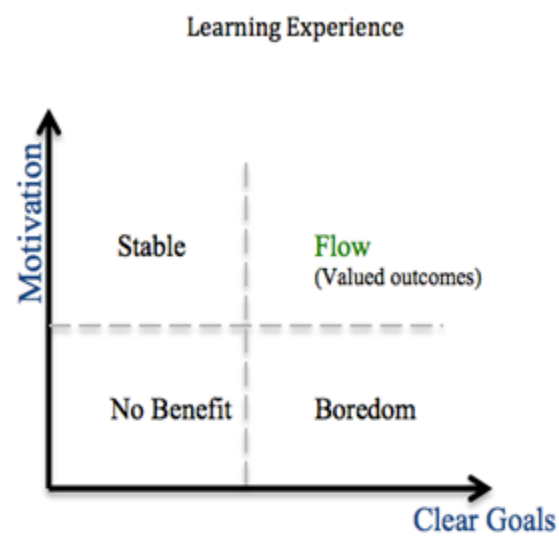

Figure 3.3: The Learning dimension (clear goals and motivation)

The four possible states are: No Benefit, Stable, Boredom, and Flow (Valued Outcomes). They are briefly described below for clarity.

No Benefit: Children will not benefit when they are not motivated to learn and there are no clear goals specified.
Boredom: there is a clear objective but the motivation level is very low.
Stable: When there is no noticeable improvement, children enter a stable state. They are highly motivated but the learning needs are not well defined.

Flow: We will obtain valued outcomes in the flow state, when the motivation level is high and the learning goals are clear.

All three of these dimensions can be divided into elements, and technical requirements can be incorporated directly into the implemented prototype to help reach the flow state as the following section illustrates in greater detail:

3.3 System Overview

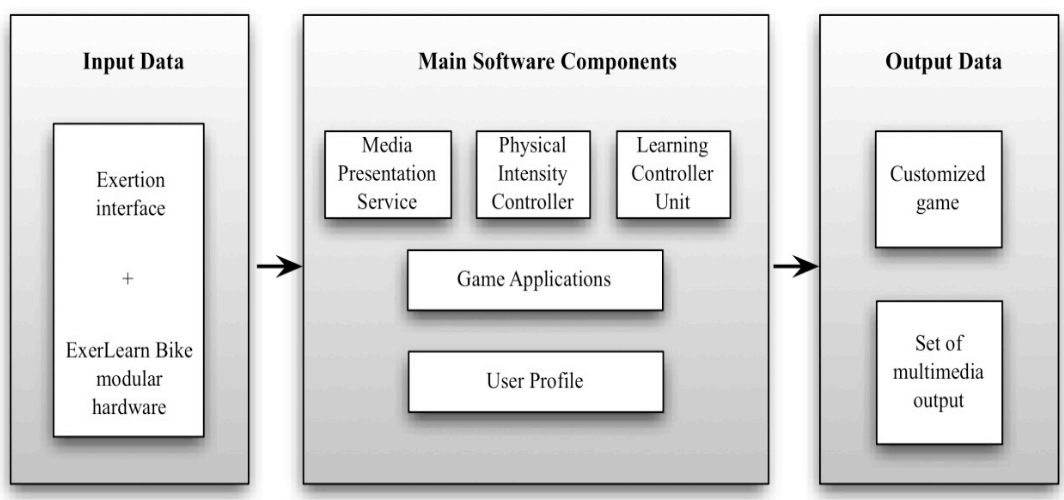

Figure 3.4: A high-level block diagram of the proposed system

The ExerLearn Bike System aims to provide children with an educational experience in a fun and enjoyable environment using their physical movements as input. This will be done by encouraging children to interact with the various games through performing a certain number of bike pedals (rotations) to reflect their answers. The system as depicted in Figure 3.4 is comprised of customizable educational software games that offer different goals and features and a set of hardware components. The games aim to improve and widen the children's knowledge in various topics such as mathematics and shapes, and will help in strengthening their memorization capabilities. We adopt a modular hardware design approach that can use any type of stationary bike without necessitating any particular hardware specifications.

Knowing that the cognitive and physical abilities of children vary from one child to another, the games are designed to be customizable in terms of physical intensity level and game content so that they meet the needs of a wide range of children with various cognitive and physical skills as described in the system flow chart in Figure 3.5.

The ExerLearn Bike system works as the following:

Parent starts creating a child profile by inserting the child's Physiological date into the system. The system then calculates the target heart rate zones for the child in different intensity. When the child starts playing and answering the questions, the system increases or decreases the physical activity (the required number of cycles to answer the questions) in order to keep the child within his/her target heart rates zone. The child's heart rates and the scores that achieved during playing will be saved in his profile.

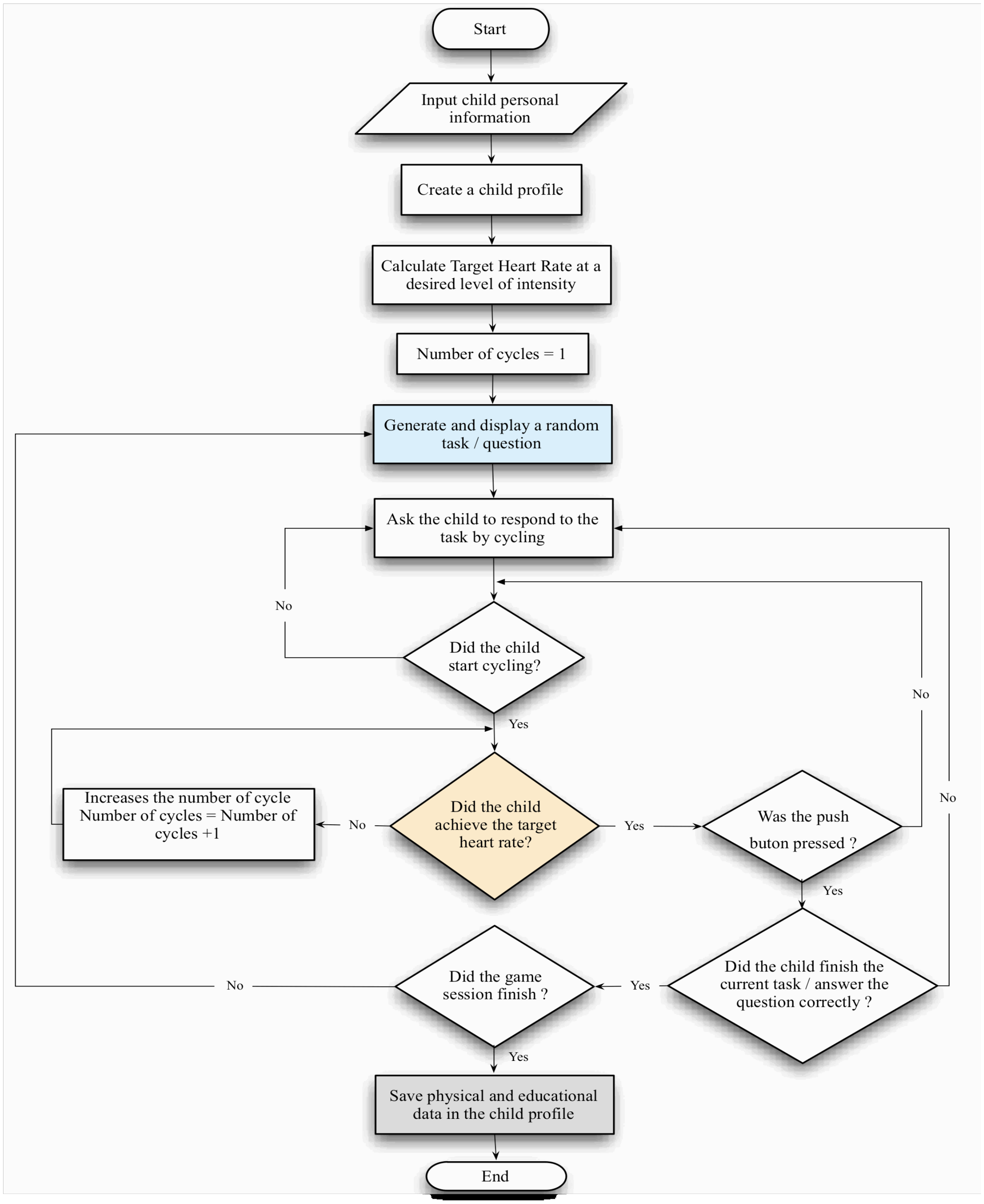

Figure 3.5: System flow chart

3.4 Overall System Architecture

This section provides an overview of the system architecture, including the hardware sensors and software modules that comprise the ExerLearn Bike System. Figure 3.6 shows the ExerLearn Bike system architecture diagram, demonstrating the different hardware components and software modules involved from the moment the child starts pedaling until the moment the output is displayed. Actual prototype implementation and technical details for the ExerLearn Bike System are clarified in Chapter 4.

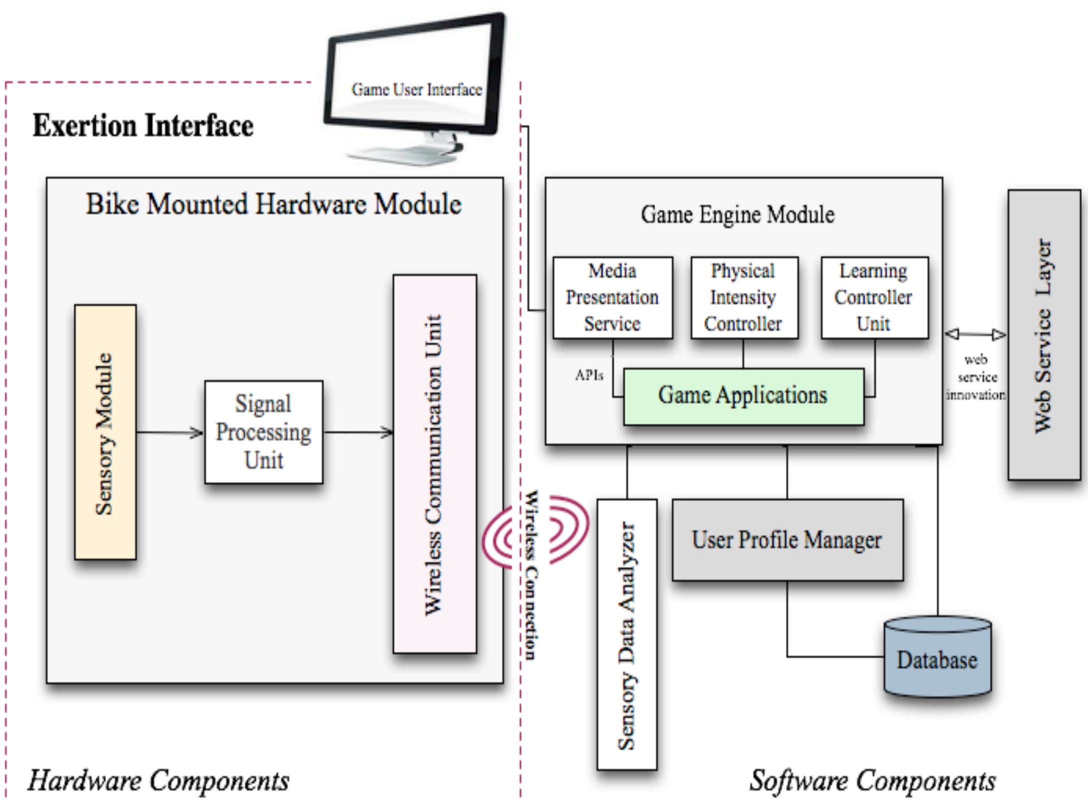

Figure 3.6: ExerLearn Bike architecture

3.4.1 Hardware Components

The ExerLearn bike hardware consists of a controller device as the exertion interface and our modular hardware. The controller device could be any available stationary bike; the system requires no particular bike specification. Our modular hardware components consist of a Sensory Module, a Signal Processing Unit, and a Wireless Communication Unit that provides the system with the input data as described below:

The Sensory Module:

This module is composed of the hardware sensors that are used to collect the user's physical movements and physiological data to provide them to the system software as input data. In our system we have employed the following:

1. ***Hall-Effect Sensors*** are used to detect a number of times the child performs a pedaling motion. These physical movements are provided to the Game Engine Module as input. The Hall-effect sensor is a transducer that varies its output voltage in the presence of a magnetic field in its proximity. We deploy one sensor for detecting the number of pedaling cycles in a forward motion. The sensor is positioned on the bike's shroud. A circular magnet that produces a sufficient magnetic field is attached to the bike's pedal facing the hall-effect sensor. Such a technique enables us to detect the number of times the pedal completes a rotation.

2. ***The Push Button*** is a touch-sensitive button that should be placed anywhere on the handlebar and used as a submit button to provide direct action within the games. For

example, this button would be pushed if the child wants to submit a final answer or a response to any task in a game.

3. ***Heart Rate Monitor*** is a small device containing an ECG sensor that monitors the user's physiological status and provides the system with real-time data. It used to sense, track, and record heart rate data by detecting the electrical activity of the user's heart.

The Signal Processing Unit is used as an analog-to-digital converter for the values captured from the Sensory Module. In addition, this unit is programmed to translate the raw digital data into a form that is readable by the Sensory Data Analyzer. For instance, this unit determines the number of cycles of the child's pedaling motion by either incrementing or decrementing a counter. It also indicates whether or not the button is pressed by sending an ON or an OFF command to the Sensory Data Analyzer.

The Communication Unit is responsible for sending the data from the hardware components to the computer where the system's software is running. This is done wirelessly using a Bluetooth chip connected to the hardware circuitry and a Bluetooth dongle connected to the computer.

3.4.2 Software Components

This section briefly explains each of the software modules and services presented in Figure 3.6.

The Sensory Data Analyzer analyzes all of the input data from the Sensory Module to determine which action should be provided by the Game Engine Module.

The User Profile Manager is used to gather and store the user's personal, physical, and educational information to customize the content delivered to them. In order to provide a better user experience, we use this profile to save a set of multimedia preferences and game settings that can be integrated easily into the system services to deliver customization. For instance, the User Profile Manager can be used by the adaptive Physical Intensity Controller Module to customize the physical activity in the games for each child based on his personal and physical information. This profile needs to be defined once, however, guardians can view, modify, or delete the child information and re-enter preferences at any time.

The Game Engine Module receives the necessary information from the Sensory Data Analyzer, translates the data into actions, and displays the customized games based on the child profile and the performed actions. Through this module, users will be able to create learning content, adjust the game challenge levels, and select the exercise intensity level, all independently. It consists of three modules that work together to provide children with personalized games that match their physical and mental abilities.

1. **The Learning Controller Unit allows** guardians to specify the child's educational objectives. This module provides a means for guardians to upload their desired custom learning content to the game so that it can be used to educate their children. Since young children are the target audience, the learning content could include images combined with letters or simple words. Also, in this unit, there is a simple feedback system with visuals and text accompanied by encouraging sound effects. Moreover, this unit allows guardians to monitor and track the child's learning progress after each session and save this data in the child profile.

2. **The Physical Intensity Controller** is used to specify the physical intensity level of the games based on the child's physical state and age. Guardians can specify the desired level of intensity by allowing them to customize the physical activity required to perform a

specific task within a game for each individual child based on his/her needs as shown in Figure 3.7. The desired level of intensity can be archived automatically using an adaptive algorithm that can balance between the child physiological status and their target intensity level. The intensity of the exercise can be identified by monitoring the child’s heart rate in real time to determine whether he/she needs to increase the physical activity to achieve the desired intensity. The predefined physical intensity levels used in the algorithm are based on the qualified physical activity guidelines previously discussed. Also, the Maximum Heart Rate and the Target Heart Rate zones are estimated and calculated based on accurate equations.

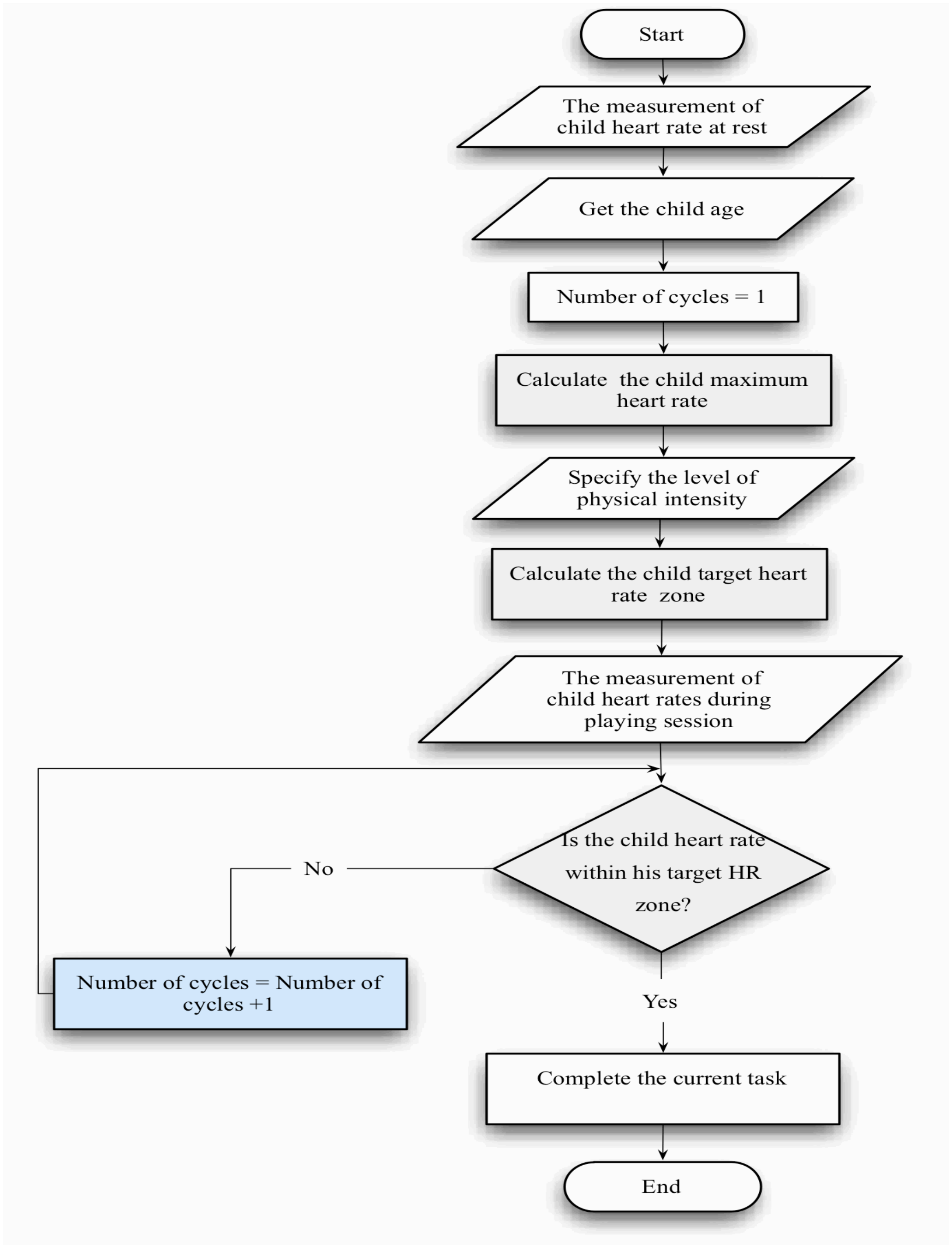

Figure 3.7: The physical intensity controller flowchart

Get Child's age

Get Child Heart Rate at rest

Get Child heart rate during playing session

Set Number of Cycles to be **1**

The desired level of Physical Intensity **=** **Get** choice from user

Either:

Low Physical Intensity **or**

Medium Physical Intensity **or**

High Physical Intensity

Calculate Maximum Heart Rate = 208 - (0.7 * child's age)

Calculate Target Heart Rate based on the desired level of Physical Intensity

If The desired level of Physical Intensity **=** Low Physical Intensity

Target Heart Rate **=** (Maximum Heart Rate – Heart Rate at rest) * 50% to 60% + Heart Rate at rest

Else

If The desired level of Physical Intensity= Medium Physical Intensity

Target Heart Rate **=** (Maximum Heart Rate – Heart Rate at rest) * 60% to 70% + Heart Rate at rest

Else

Target Heart Rate **=** (Maximum Heart Rate – Heart Rate at rest) * 70% to 80% + Heart Rate at rest

End If

End If

If Child Heart Rate during playing session < The desired level of Physical Intensity

Do

Increase the required Number of Cycles to perform a task

Until

Child Heart Rate during playing session > or = the desired level of Physical Intensity

End Do

Else

Keep Number of Cycles

Complete the current task

End If

3. **The Media Presentation Service** allows guardians to choose different types of media to be displayed for a particular child, based on his/her needs. The games are designed with optional media features to choose from, including textual, aural, and visual representations. For example, if a parent would like to introduce new types of fruit to their child, they can upload some real pictures of these different types of fruit to the game. In order to maximize the benefits from the learning process, they are allowed to select different types of media, such as verbal spelling or written words, to be combined with the pictures based on the child's learning style. Therefore, each time the child plays the game he/she will learn about different fruit, along with their pronunciation and spelling and without noticing that he/she is actually learning. This feature differs based on the game scenario, and more details will be discussed in Chapter 4 Section 4.4.

The Graphical User Interface for each game is carefully designed so that users with basic computer skills can easily grasp the functionalities of the system. They are designed with clear instructions, easy navigation, and cheerful presentation.

Database is a relational database used to store the system’s files in an organized way and determine the relationships between them, including between the system's users and the game information. It is important to easily access, manage, and update all the multimedia objects used in the system including text, audio, and image data.

The Web Service Layer is a mechanism based on web services that can be used to allow teachers/guardians and parents to remotely monitor data pertaining to a child's exergaming sessions. Every time a child, whether at school or at home, performs one of the exercises, the results of the sessions are automatically uploaded to a central server. Using a web interface, guardians can track the physical performance and the learning progress of a child whether the exercises are performed at home or at school.

3.5 Use Case Diagrams

The main use case diagrams for using the proposed system are shown in Figure 3.8 and Figure 3.9. The use cases interact with two primary actors to represent the main goals of the ExerLearn bike system.

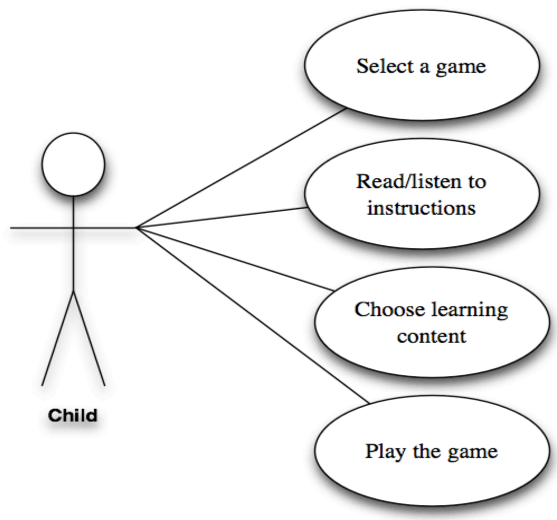

Figure 3.8: A high-level view of the main use case.

The system has two actors: children are the main actors and guardians, including parents and teachers, are external supportive actors.

Actor: Child

Description:

The system provides the following key functionalities to its primary user (children):

- Select a game from the menu to play
- Read or listen to simple instructions in order to play the game properly

- Choose game content to play with
- Play, learn, and exercise, which represents the goals of the proposed system

There are supportive functionalities for the external users, and these are illustrated in the use cases in Figure 3.9.

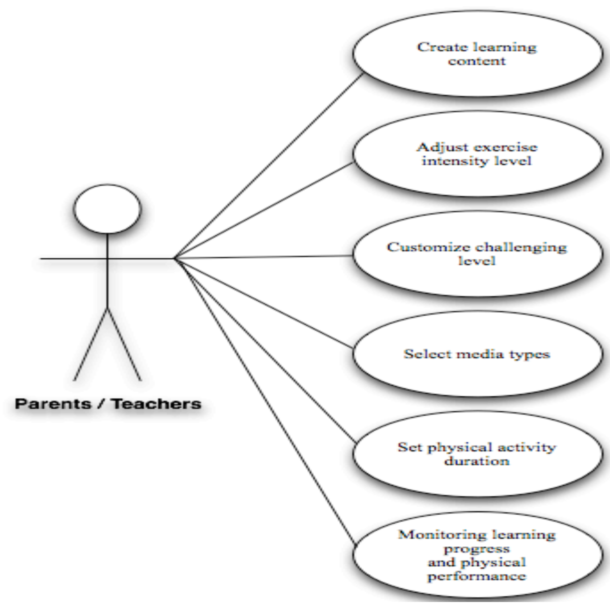

Figure 3.9: External users use case

Actor: Guardian

Description:

Teachers and parents can use the system to upload and create appropriate content for their children using the following functionalities:

- Create learning content by uploading images, audio, and text to the personal database
- Specify the game challenge level to meet the child's needs
- Select types of media to be displayed within the games
- Specify the physical intensity level to be performed
- Specify the duration of each game session

- Monitor the child's physical performance and learning progress after each game session

Chapter 4: Implementation

In this chapter, we provide a more detailed description of the hardware and software components used in the developed ExerLearn Bike prototype. Section 4.1, with the aid of Unified Modeling Language (UML) diagrams, explains the system components and how they interact with each other. Section 4.2 provides technical specifications for the different hardware devices integrated in the system. Explanations of the software components, graphical user interfaces, and application programming interfaces (APIs) are provided in Section 4.3. Finally, section 4.4 illustrates the ExerLearn Bike games scenarios in details.

4.1 System Components and Interaction Diagram

This section describes the structural relationships and interactions between the components of the ExerLearn Bike System as to provide an abstraction level for the implementation phase. To start, Figure 4.1 provides the software component diagram and illustrates the relationships between modules.

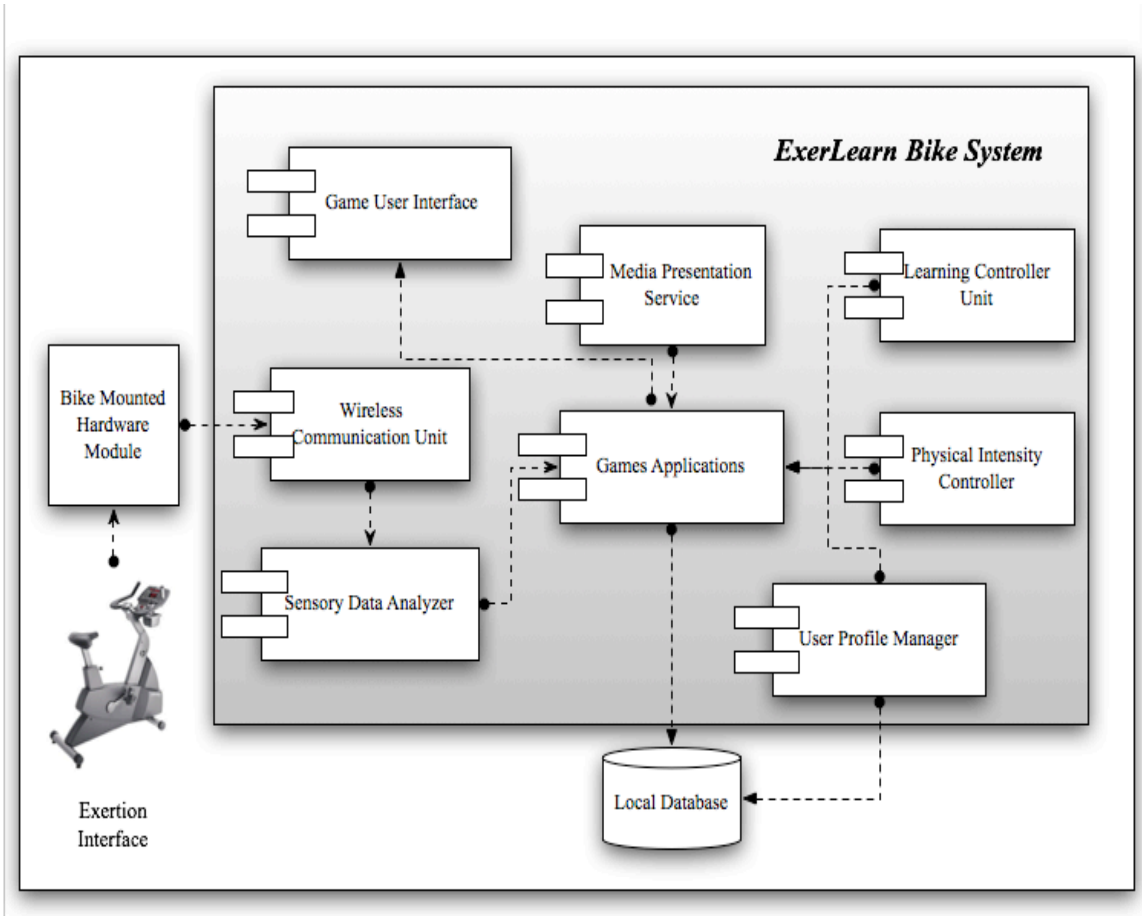

Figure 4.1: Component diagram of the ExerLearn Bike system

4.1.1 The Interaction Diagram of ExerLearn Bike System

The UML sequence diagram in Figure 4.2 shows the main interaction processes between the user and the system at an abstract level. Basically, the user is required to perform physical movements to interact with the system software through the exertion interface/controller device. After detecting the physical movements and collecting physiological data using the Sensory Module, the Signal Processing Unit converts the analog signals that come from the Sensory Module into digital data that is readable by system software.

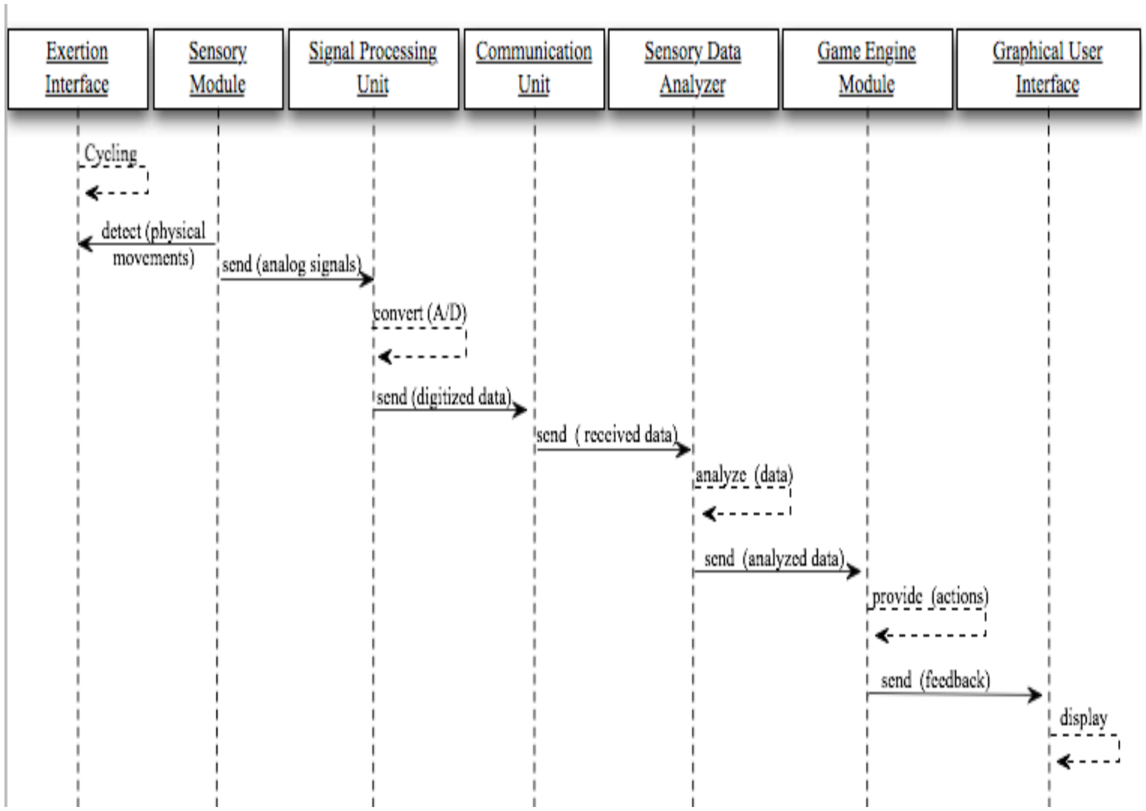

Figure 4.2: The main interaction diagram for the ExerLearn Bike system

The digitized input data is sent to the Game Engine Module through the Communication Unit. Then, the input data are analyzed by the Sensory Data Analyzer and sent to the Game Engine Module to provide the user with appropriate actions and feedback. Different feedback forms are displayed through the Graphical User Interface.

4.1.2 The Interaction Diagram for The Main User

The UML sequence diagram in Figure 4.3 shows the interactions between the main actor − a child − and the system components from the moment the child starts to play until the feedback is displayed. The user interacts with the system by simply performing a certain number of continuous cycling motions using the Exertion Interface. Also, the child may use other hardware devices to monitor and track his/her health stats in real time. All of the physical movements and physiological data that are collected using the Sensory Module and converted to digital data using the Signal Processing Unit. The Communication Unit then sends the digitized data to the Sensory Data Analyzer to be analyzed and to generate the appropriate response for the Game Engine Module. In the Game Engine Module each application communicates with the Physical Intensity Controller, the Learning Controller Unit, and the Media Presentation Service to get the required data to customize its features and settings. The Physical Intensity Controller gets the child's personal and health data from the User Profile Manager to execute the adaptive algorithm and control the physical activity. From the Media Presentation Service, the game gets the media preferences. The Learning Controller Unit retrieves the game contents to be displayed in the games from the local database. Responding to the child's performance and interactions with the game, real-time feedback for each physical and learning action is displayed in the Graphical User Interface. The User Profile is updated continuously after each game session with the results and the child's physical and educational information. All this information is stored in the personal database for future use.

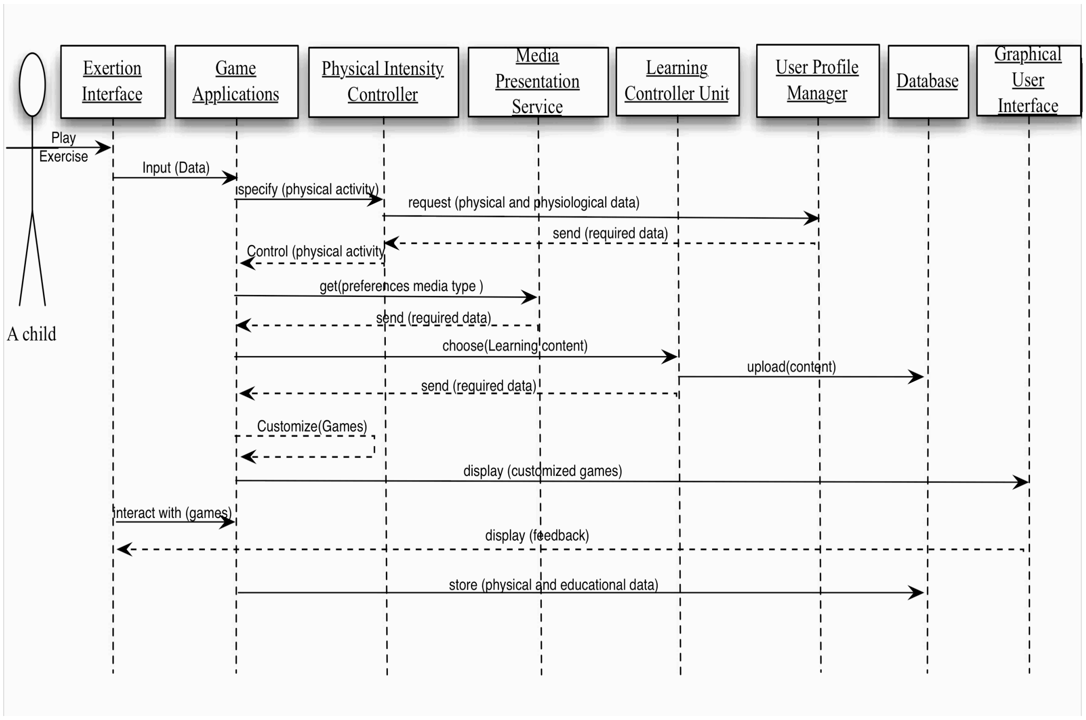

Figure 4.3: The sequence interaction diagram for the system with the main user

4.1.3 The Interaction Diagram for The Sub-users

Guardians are able to interact with the ExerLearn Bike system in order to customize the game content and the physical intensity levels to meet their child's needs. It is shown in Figure 4.4, which describes the following sequence of events:

Starting with the User Profile Manager, guardians must create a profile for each child for their first use. This includes personal information, game settings, and media preferences. All the information within the child profile are used by the software modules to provide a customized game. By interacting with the Game Engine Modules, guardians list media types that the child prefers, upload different learning content, and define physical intensity levels based on the child's needs.

The Game Applications acts as a hub that collects this information. It interacts with the Learning Controller Unit to create the desired content and then interacts with the Physical

Intensity Controller to specify the intensity levels. It also communicates with the Media Presentation Service to select a list of media types that should be displayed in the game. All the defined parameters and the specified settings in the User Profile are saved in the database and used by different game applications. Then the Graphical User Interface displays the customized game application. Guardians can track the physical performance and the learning progress remotely using a Web Service.

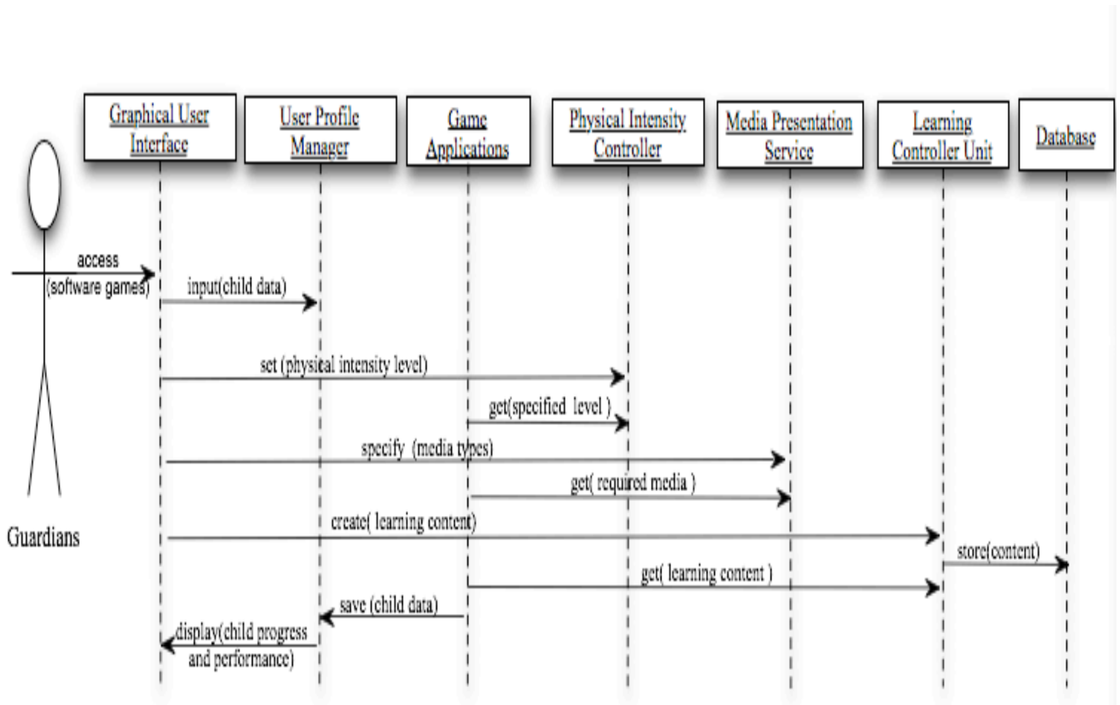

Figure 4.4: The sequence interaction diagram for guardians

4.2 Hardware Components

In this section, we provide the technical details and specifications of the different devices used to build the modular hardware of the ExerLearn Bike system. The ExerLearn Bike modular hardware unit consists of a microcontroller and various hardware devices. Figure 4.5 shows the component diagram of the devices used.

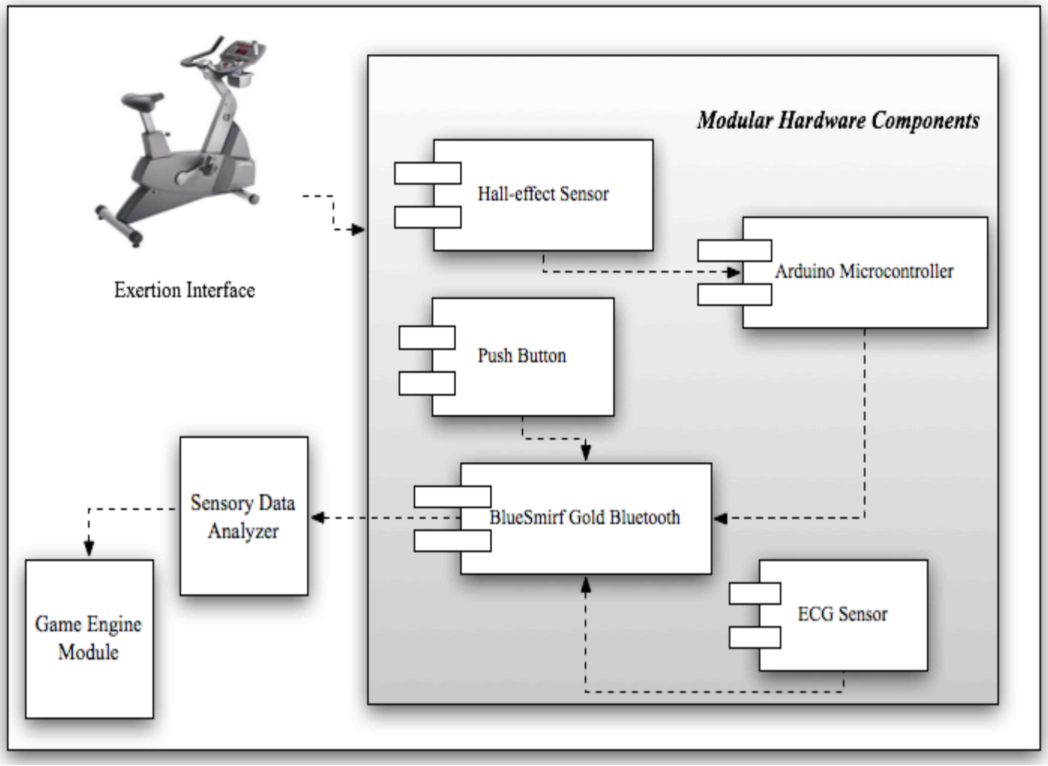

Figure 4.5: The ExerLearn Bike hardware component diagram

Devices were chosen based on their adequacy in allowing for a realistic feel with any stationary bicycle and were incorporated into a single modular unit that performs the desired overall functionality.

The ExerLearn Bike modular hardware is composed of the following:

1. **Hall-effect Sensor**

A sensor that is very small in size and weight is required to detect the cycling of the bicycle pedals without burdening the user. For this reason, we used two Parallax Melexis 90217 Hall-effect sensors. Their small size and weight, price, and high-speed operation meet our requirements more fully than other commercial sensors available on the market.

Figure 4.6: A Hall effect sensor

This very small chip, shown in Figure 4.6, varies its output voltage based on the presence and strength of a magnetic field. Its voltage output increases the closer it comes to a magnet. An external magnetic source needs to be employed to our system facing the sensor to allow the Hall-effect sensor to detect each cycle and convert it to an electrical signal.

2. Arduino Microcontroller

To convert from analog input to digital data (A/D), we use the open-source Arduino microcontroller that senses and collects the inputs from sensors and uses this information to control the physical outputs. It is a simple microcontroller board that is easy to use and offers a clear programming environment that enables us to create a control program and run it automatically.

3. Push Button

This is a physical button that executes a simple switch mechanism. While the button is pressed, a specific action is performed, and when released, the action stops. The selected push button is small, made out of plastic, and detects the child's press action. For example, in our implementation there are two tasks where the button press is used: the first is a selection from the ExerLearn Bike main menu, and the second is used to submit the child's answer for each question.

4. BlueSmirf Gold Bluetooth

For wireless communication, we deployed a BlueSmirf Gold Bluetooth chip to the Arduino microcontroller. The BlueSmirf Gold Bluetooth provides a robust wireless serial port connection that supports a baud rate of 9600-115200 bps from the hardware to the host PC within a 100-metre distance.

5. Zephyr's HxM Bluetooth Heart Rate Monitor

Is an accurate, small, lightweight, and less expensive device that monitors and captures high-quality data on the user's heart rate in real time. Zephyr's Smart Fabric sensor makes it suitable and comfortable for children since it reduces the number of other required accessories. It is a rechargeable chest-strap that collects and transmits heart rate data via a Bluetooth wireless signal. The device is activated when the child wears the strap and the sensors are placed against their chest skin. It can be used with any compatible mobile device running a relevant application that makes it possible for guardians to track the child's heart rate.

4.3 Software Module and APIs

On the software application side, the proposed system has been developed using Visual Studio 2010 (VB.Net) on a Windows 7 platform. Some APIs have also been incorporated in the system software to provide different functionalities. The APIs and system features can be described as follows:

4.3.1 The Microsoft Speech API

The Microsoft Speech API (SAPI 5.4) is a set of software services that support speech output by utilizing a text-to-speech engine with different available voices(Microsoft Speech API,). We used the TTS engine to provide children with verbal spelling of numbers and words, and feedback messages while playing. Microsoft Merlin is the voice name that we chose to include. We send a string of text to the Agent API and gather its response in the form of speech or a spelling of that string synchronously. Sample syntax shows in Figure 4.7.

```
String to Speech using Microsoft Speech API:
/* Add Speech Library:
SpeechLib;
/* Create an ISpVoice  object :
TTS= new ISpVoice ;
/* Call the speak method to create speech output from string:
TTS.speak (Textbox. Text);
/* Change some attributes:
TTS.SetRate(" ") ;  /*   Set the voice speed rate
TTS.SetVolume(" ") ;   /* Set output volume level
TTS.SetVoice(" ") ;   /* Change current speaking
```

Figure 4.7: Microsoft Speech API Text to Speech sample syntax.

4.3.2 Microsoft Translator API

The Microsoft Translate API allows translation from any language into any other supported language by the translator service. In order to use it, a service reference for the Microsoft Translator SOAP interface for the .NET framework must be added. Then an instance of the Translator Service must be created in order to use the needed methods. One must then simply provide a string (word that need to be translated) to the translator method, and the API service returns the translation of the string (translated word) in a specific language. In our implementation, we have associated translation from

English, which is the system default language, to French. However, the guardian can pick any language of their choice through the system's GUI. Figure 4.8 shows sample syntax that demonstrates how the translator service could be achieved.

```
Convert a string from one language to another steps using API Translator:

/* Add translator service: Microsoft Translator SOAP Interface
/* Get an AppID to access the Translator Service
/* Create an instance of Translate Container:
        TAPI = new TranslatorService.LanguageServiceClient ;
/* Call the translate method and provide all the required parameters:
        TranslatedString = TAPI.Translate("AppID", StringToTranslate.Text, "En","Fr") ;
        StringToTranslate.Text  = TranslatedString
```

Figure 4.8: A Microsoft Translate API send /receive sample syntax

4.3.3 Database

The database has been designed and created based on the need to access and manage many media sources, including text, audio, and image data.

A. Database Design

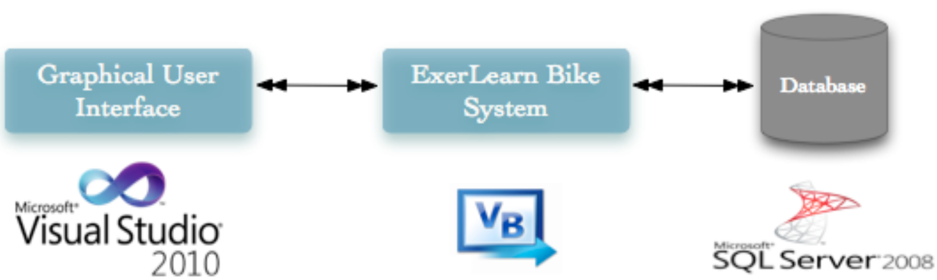

Figure 4.9: Database implementation tools

The system is implemented using the .Net platform and the compact SQL Server database. The graphical user interface and the background code of the system is implemented using the Visual Basic (VB) programming language. The database engine is SQL Server Compact 4.0. Figure 4.9 shows the database architecture's implementation tools.

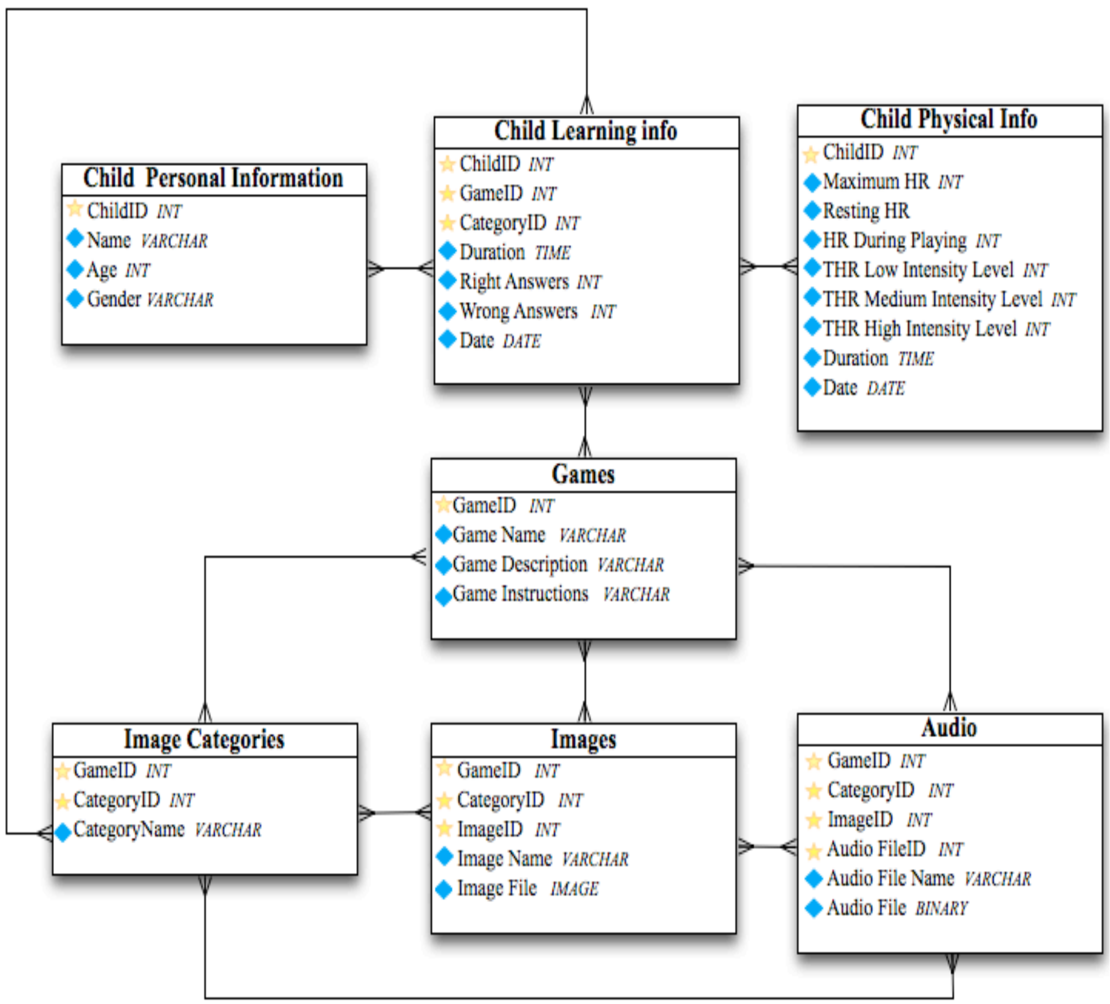

Figure 4.10: the entity relationship diagram of our system database

B. Data Tables

In this section we will list a short description of each database entity and its attributes that shown in Figure 4.10.

- Database Table: *Child Personal Information*

The Child Personal Information database table holds the child's personal information. Table 4.1 explains the table's attributes.

Table 4.1: Child Personal Information database table

Column	**Type**	**Description**
ChildID	INTEGER	A unique identifier for each child
Name	VARCHAR	Child's name
Age	INTEGER	Child's age
Gender	VARCHAR	Child's gender

- Database Table: *Games*

The Games database table holds the information for the games that have been designed and implemented for the ExerLearn Bike system. Table 4.2 explains the games database table **attributes.**

Table 4.2: ExerLearn Bike system's Games database table

Column	**Type**	**Description**

GameID	INTEGER	A unique identifier for each game
Game Name	VARCHAR	The name of the game
Game Description	VARCHAR	A brief description of the games including its short and long goals
Game Instruction	VARCHAR	Instructions and rules on how to play the game properly

- Database Table: *Images*

The Images database table holds the uploaded images that are used by the Game Engine Modules when displaying feedback to the children. Table 4.3 explains the games database table attributes.

Table 4.3: Images database table

Column	**Type**	**Description**
GameID	INTEGER	A unique identifier for each game
CategoryID	INTEGER	A unique identifier for each game's categories
ImageID	INTEGER	A unique identifier for each image
Image Name	VARCHAR	The name of the object shown in the image
Image File	IMAGE	The image file (.gif , .bmp, .jpg, .png)

- Database Table: *Images Categories*

The Images Categories database table holds the different categories that are used to split the images based on the object types and the learning goals. Table 4.4 explains this table's attributes.

Table 4.4: Images categories database table

Column	**Type**	**Description**
GameID	INTEGER	A unique identifier for each game
CategoryID	INTEGER	A unique identifier for each game’s categories
Category Name	VARCHAR	The name of the Category

- Database Table: *Child Learning Progress*

The Child Learning Progress database table holds the child learning progress for all sessions in each game. Table 4.5 explains this table's attributes.

Table 4.5: Child Learning Progress database table

Column	**Type**	**Description**
ChildID	INTEGER	A unique identifier for each child
GameID	INTEGER	A unique identifier for each game
CategoryID	INTEGER	The name of the images Category
Right Answer	INTEGER	The number of right answers

Wrong Answer	INTEGER	The number of wrong answers
Duration	TIME	The duration of the game session
Date	DATE	The date of the playing session

- Database Table: *Child Physical Information*

The Child Physical Information database table holds the child physical state and his/her heart rate information before and during gameplay. Table 4.6 explains this table's attributes.

Table 4.6: Child Physical Information database table

Column	**Type**	**Description**
ChildID	INTEGER	A unique identifier for each game
Maximum HR	INTEGER	The child maximum heart rate
Resting HR	INTEGER	The child heart rate at complete rest before playing
HR during playing	INTEGER	The child heart rate during gameplay
THR Low Intensity Level	INTEGER	The target heart rate zones at low intensity level from 50% -60% of the child maximum heart rate
THR Medium Intensity Level	INTEGER	The target heart rate zones at medium intensity level from 60% -70% of the child maximum heart rate
THR High Intensity Level	INTEGER	The target heart rate zones at high intensity level from 70% -80% of the child maximum heart rate

Duration	INTEGER	The duration of the physical activity (game session)
Date	DATE	The date of the physical activity

- Database Table: *Audio*

Audio database table holds Audio file information that has been chosen and uploaded by the guardians. Table 4.7 explains the Audio database table attributes.

Table 4.7: Audio database table

Column	**Type**	**Description**
GameID	INTEGER	A unique identifier for each game
CategoryID	INTEGER	A unique identifier for each category
ImageID	INTEGER	A unique identifier for each image
Audio FileID	INTEGER	A unique identifier for each audio file
Audio File Name	VARCHAR	A unique identifier for each audio file
Audio File	BINARY	The audio file (mp3,ra,wav)

4.3.4 Feedback and Rewards

Recent study emphasizes the importance of using feedback in exergaming development. They conclude that children enjoy receiving appropriate and useful feedback related to their performance and answers within the games. Also, as mentioned in Chapter 2, Section 2, feedback encourages them to undergo more physical activity. In our software prototype, we apply different types of feedback, including text, audio, and visual formats as shown in Figure 4.11 . For example, in the case of a wrong answer, motivating expressions like “I know you can do it”, “You've just about got it!”, or “One more time and you'll have it”, are shown with an animated character combined with an appropriate sound effect. The same idea can be applied in the case of a correct answer with expressions such as “SUPER!”, “FANTASTIC!”, or “I've never seen anyone do it better!”.

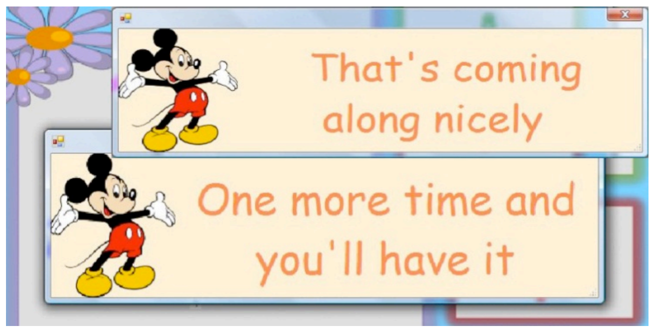

Figure 4.11: Samples of textual feedback in a game

Moreover, we offer age-appropriate rewards in our games to motivate children to continue playing and to provide validation of their answers. We use easy reward types that are based on gaining or losing points. For example, children gain points for each right answer and lose points for each wrong answer.

4.3.5 Customization

In traditional educational games, the system usually has default settings regarding the game challenge levels. Challenge levels in these games can be customized based on the child’s current skill level. However, in our system we cannot dynamically adjust features because it incorporates physical movements as input data. For example, if the child does well with the current task and the system increases the challenge level dynamically, the workout intensity will increase accordingly. As such, children may exceed a safe intensity of exercise, making them susceptible to injury.

Moreover, children’s mental abilities and fitness levels change continually. Based on the fact that the game’s challenge levels and the physical intensity level must be treated separately and should not affect each other's performance, our system provides guardians with the ability to create a custom game by independently adjusting the physical intensity and the game's challenge levels to best suit the child's needs.

The physical intensity parameter can be adjusted by choosing the number of pedal motions required to perform a task. Intensity can be increased or decreased based on the child's current heart beats. To choose an appropriate game challenge level, parents or teachers choose the level of challenge they think best suits the child's needs. After examining (monitoring) the child's learning progress at the end of each session from his/her profile, they can determine the best level to choose for subsequent sessions. If the current task generates a positive outcome but appears too easy, users can increase the challenge level to match the child's skills. If there is no improvement, they may decrease the level or maintain the current one.

4.3.6 Graphical User Interface

The Graphical User Interface is an important aspect that should be carefully designed to attract young children. For this reason, the ExerLearn GUI's are designed to be easy to use so that users with only basic computer skills can easily grasp the functionalities of the system. We have designed different interfaces: three for games and one for the main menu interface as shown in Figure 4.12. Each of the four interfaces is designed with clear instructions, easy navigation, and cheerful presentation. The GUI's colours, fonts, and animation style are chosen to be appropriate for children.

Figure 4.12: ExerLearn system's GUIs

Through the main menu user interface, children can select games to play from a list, or they can read and listen to the game instructions before playing. They can navigate between the options in the main menu by pedaling and select options by using the push button. The guardian can use the mouse and keyboard, and through the "Customize" button they can change the physical settings, upload new content, or select the type of media to be associated with each game.

4.4 ExerLearn Bike Game Scenarios

The proposed system's software games are designed to provide children with genuine educational benefits while motivating them to indirectly engage in physical activity. In this section we discuss the three games in detail, including their aspects, features, and goals.

Figure 4.13: The main menu user interface

In the system's main menu, shown in figure 4.13, a child has to choose from the following: The ExerMath Game, The Zoo Game, or The Memory Game. Each game has three options:

1. Play - start playing the game.
2. Descriptions - read or listen to simple steps on how to play the game.
3. Customize - where sub-users including parents or teachers can alter the physical and mental parameters to meet a child's specific needs.

4.4.1 The Memory Game

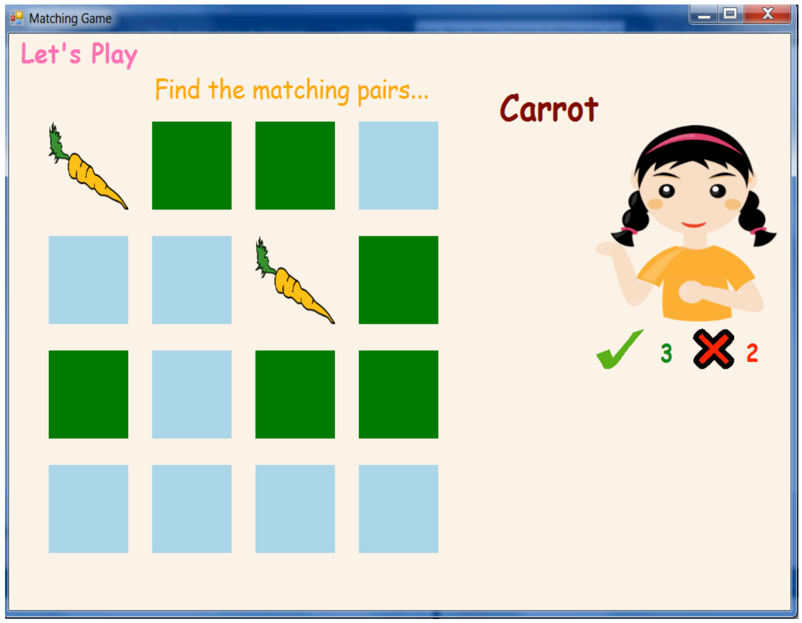

Figure 4.14: The Memory Game

The traditional "Memory" game or matching game is considered to be a fun game and has been scientifically proven to be beneficial to children's brain development . However, our memory game is different than the traditional one and more challenging because it requires children to be both physically and mentally active. It combines the traditional memory game's characteristics with learning and exercising features as shown in figure 4.14. This new game aims to improve many aspects affecting child brain development, including focus, speed, attention, and visual memory . Moreover, it teaches young children new objects and language skills while improving their cognitive, reading, and listening skills. In order to start this game, a simple options form for children is displayed on the screen as in Figure 4.15.

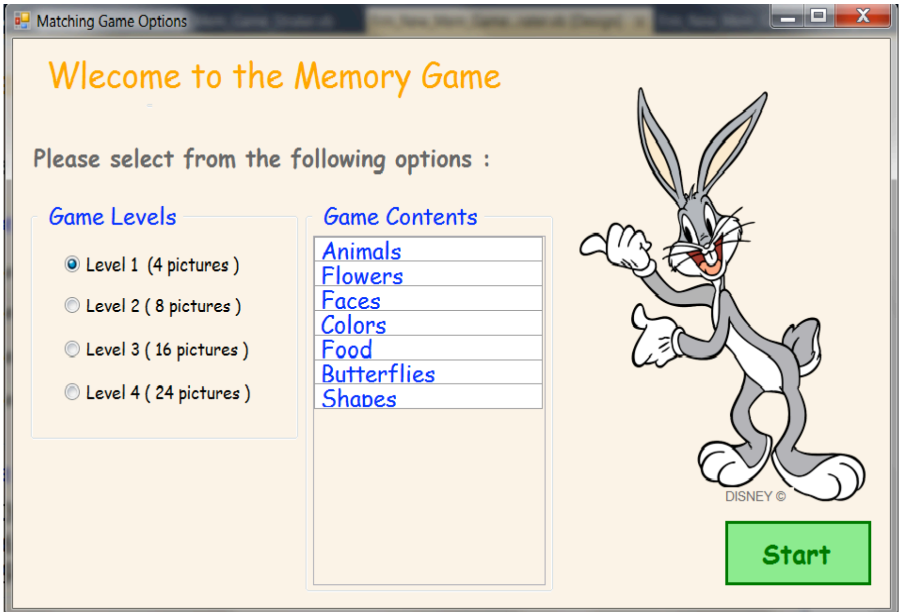

Figure 4.15: Memory game's start form

The following explains each of the options in more detail:

- Game contents: as a default, a child can choose from several different categories of images he/she would like to play with and learn about, such as numbers, animals, colours, etc. The supplied images are high-resolution, simple, and without excessive details, which enables children to identify the objects easily.
- Level of difficulty: a variety of levels of difficulty are available, and they control the number of pictures displayed on the game panel. The easiest level has 4 images while the hardest level contains 24 images. More pictures means there is more information to remember but does not mean there is more exercise required to complete the game since that aspect is based on another game setting.

The custom option in the main menu opens a new form for guardians to personalize the game in terms of content, physical intensity level, types of media, language, and the duration of the game session as shown in figure 4.16.

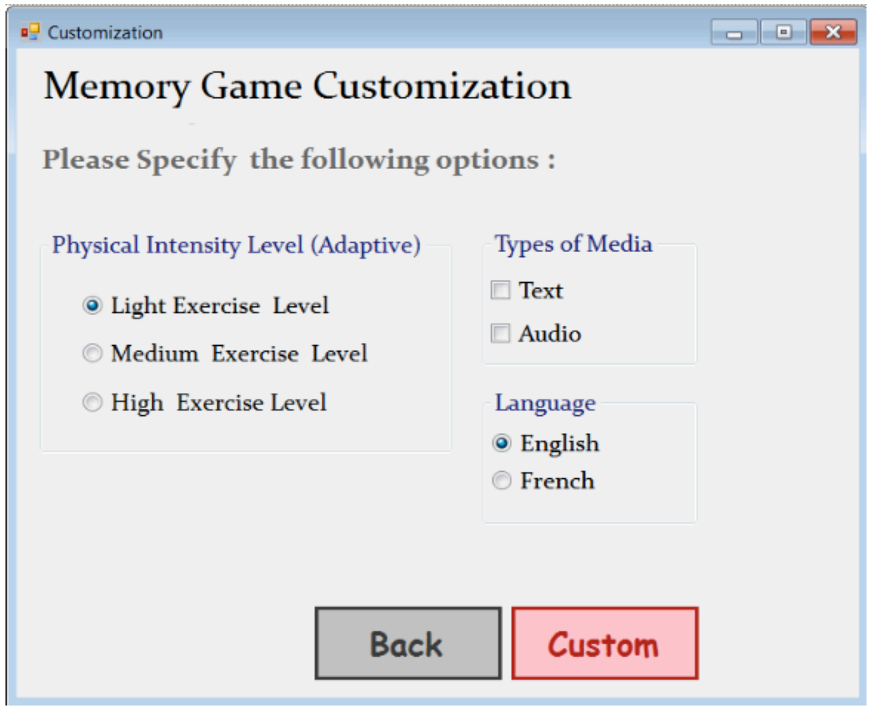

Figure 4.16: The Content's customization form

- Physical intensity level: Through this option, guardians can specify the level of the physical activity they would like their children to perform during the game session. They can use the adaptive option, which can promote their children to do the recommended level of daily physical activity, or they can specify their own level of intensity by choosing the required number of cycles to finish the game tasks. The adaptive option requires the heart rate monitor in order to keep the child within the target heart rate zone.
- Media type: for each game session, guardians can select the type of media to be displayed in the game. For example, they can choose text or audio to be accompanied with images. This can maximize the child's knowledge and help them to memorize the object image, name, and its verbal spelling.
- Language: This option allows them to choose the usage language for each session, either English, which is the default language, or another language. This can help children to learn a new language in a fun and easy way.

- <u>Learning content:</u> One of the essential features that helps promote the usage of the ExerLearn Bike system is customization. Keeping in mind that the target users in our system are young children and that we aim to teach them basic concepts, as a default, we have designed games with simple topics like the alphabet, numbers, colours, and shapes. However, due to the fact that children differ in their learning requirements, the system should be able to meet a wide range of needs. We enable guardians to customize game content and add more flexibility to our system by creating and adding their own content.

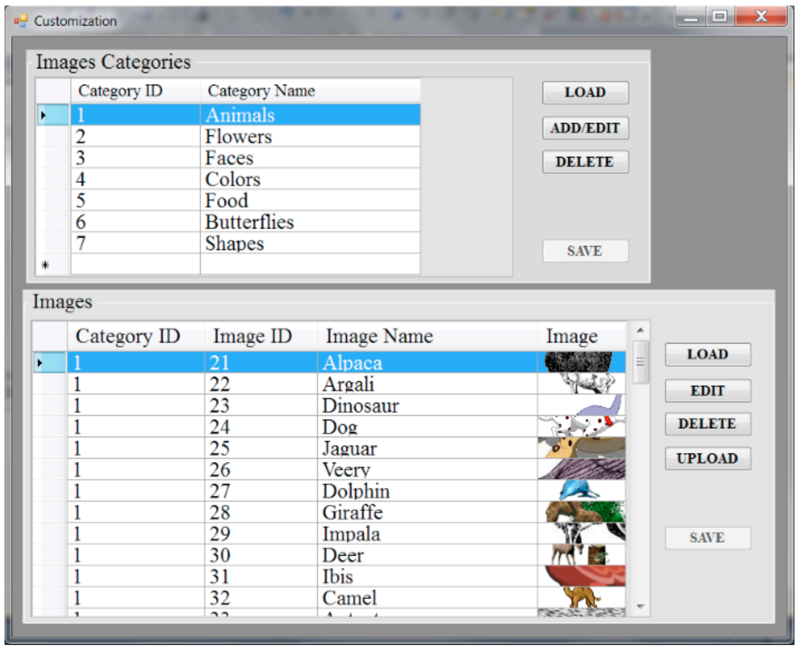

Figure 4.17: The memory game's content customization form

By using the customization features, as shown in Figure 4.17, they can upload the desired content of varied multimedia representations to the local database for use in this game and the Zoo game. For example, if parents would like to introduce new objects to their child, fruit for example, they can upload some real pictures and text about different types of fruit to the game. Then each time the child plays the game, they will be able to learn about the new fruit as well. If parents or teachers think that a child has successfully learned about a topic or improved a specific skill, they can simply change the content and choose its appropriate media types. The method of altering the content changes based on each game scenario.

After specifying all the options, starting the game causes the game's panel to be displayed. It consists of three sections: the images area, the text area, and the scoring area. In the images area, hidden, random images are shown in neat rows. The child must pedal in order to uncover the images. For instance, the system decrease or increase the number of cycles based on the child's heart rate let's say the system set "3" as a number of cycles. Then the child has to perform 3 rotations to uncover the image. After the first rotation, one third of the image will appear to the child; two thirds of the image will be shown after the second rotation.

Figure 4.18: Uncovering an image in the ExerLearn Bike's memory game

After the last rotation, the image will be completely viewable, and the name of the image will be displayed in the text area, accompanied with the correct pronunciation cues as shown in Figure 4.18. If the child performs a fourth rotation, the first image will be covered again and the next image will start to be displayed in the same way.

The child has to remember the appearance and the position of each image to be able to match them successfully. If he/she opens an image and thinks that they have seen its matching pair in one of the previous images, they have to press the push button to keep the image open and start searching for its match. By pressing the button, the round will start from the first image to allow the child to search and find the matching pair. Once the child think they have found the matching pair, he/she has to press the button again to submit the answer. If the answer is correct and the two images match, they are replaced with green covers to indicate that the images are no longer displayable. If the images are not a match, they will be covered as normal in order to play with them again.

4.4.2 The ExerMath Game

This game aims to teach children basic math concepts and sharpen children's math skills by getting them to practice a variety of math operations including addition, subtraction, multiplication, and division. The game has been developed to be mentally appropriate for a wide range of abilities. Figure 4.19 shows the graphical user interface for the ExerMath Game.

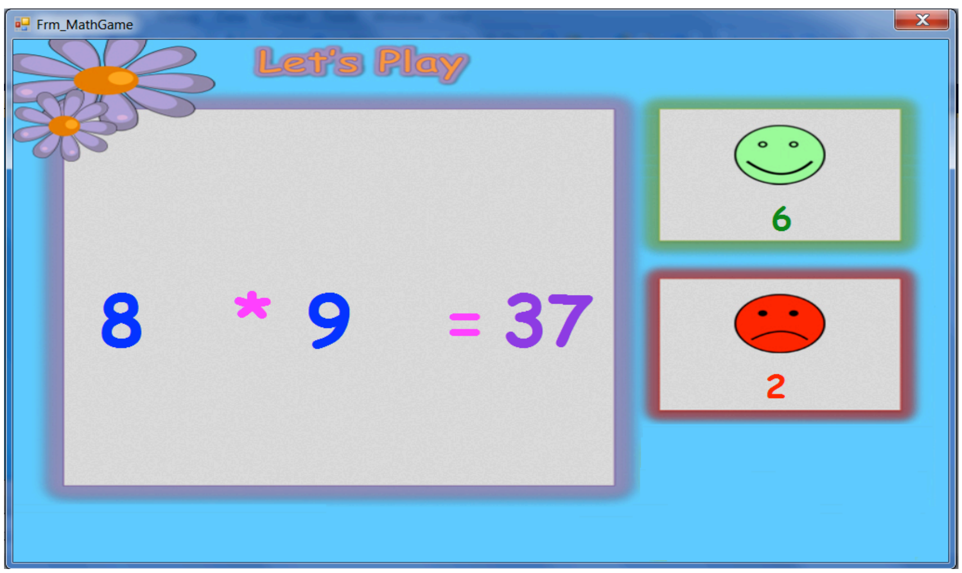

Figure 4.19: The ExerMath game

In this game, children must answer a set of random arithmetic questions using the bike's controls. Using the game's default setting, 10 random questions of varying difficulty are generated per session; all 10 must be answered within the allocated time. In order to answer these questions, the child has to complete the number of pedals that equals the value of the correct answer. For instance, to answer the addition question of "13 + 2", the child must perform 15 pedals and press the button to submit his/her answer. Each pedal is accompanied by the audio and visual presentation of the number.

<u>Customization options:</u>

- Guardians can choose the math operation type including addition, subtraction, multiplication, and division as shown in Figure 4.20.
- They can specify the math operation levels as easy, medium, or high.
- They can specify the duration of the game session. The game will keep displaying random questions until the specified time has elapsed.
- They can choose the physical intensity level as discussed in the previous game.

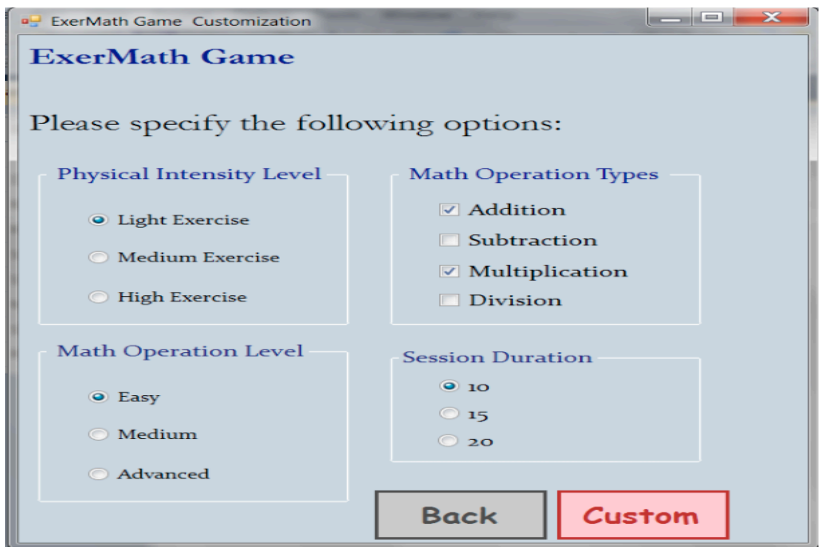

Figure 4.20: ExerMath's customization form

Different forms of feedback are provided according to the validity of the answer. Short encouraging expressions are displayed after each response with an appropriate sound and smiley face. For example, if the answer is incorrect, positive feedback is provided such as "I know you can do it", "You can figure it out!", and "You've just about got it." Combined with smiley faces, this keeps the child motivated and encourages them to continue playing. Each time the child plays or repeats this activity, the paths in the brain that form understanding of the math concept become stronger.

4.4.3 The Zoo Game

In the Zoo Game, children can improve their listening and reading skills in a fun way by exploring the animal world. This game can be completely customized. Guardians can choose other interesting topics and upload the pictures and media to the local database to be displayed in the same way. Similar to the previous games, the types of media and the exercise intensity can be customized. Also, guardians can fully control the game by choosing the way the questions are displayed and the required time to answer those questions. They can choose to display random text or words as questions or use the uploaded audio files. For example, for the animal theme, we choose to display some animal sounds and animal names as clues, and the child must find this animal among the images.

Figure 4.21: The Zoo Game's UI

The game contains approximately 54 pictures of different animals including fish, birds, and mammals as shown in figure 4.21. It starts by displaying a random name or sound, and by pedaling the bike, children can move through the "zoo" and select the right answer. As a default, each rotation the child performs moves him/her from one picture to the next until he/she finds the right answer. After selecting an animal, the appropriate feedback is displayed. The game combines a set of multimedia representations, such as images, audio, and text, related to the chosen animal.Users can choose one or more media forms to be displayed according to the child's needs.

Chapter 5: Evaluation

In this chapter, we present the evaluation of the ExerLearn Bike system. We evaluated the system by analyzing the performance of a group of children during three gaming scenarios. The main goals of the evaluation were based on the four evaluation criteria explained in section 5.1. The experimental setup follows in Section 5.2, and in section 5.3 we evaluate the ExerLearn Bike system quantitatively. In Section 5.4, we provide the qualitative evaluation. The chapter ends with a learning experience evaluation in Section 5.5.

5.1 Evaluation Criteria

To assess the ExerLearn Bike system, we crafted an evaluation based on the following criteria:

1. Exercise effectiveness: This is a determination of whether the system can engage children in physical activity and provide them with the recommended level of exercise intensity based on their age and heart rate (HR) level. To determine the recommended level of exercise intensity, we use the CDC and WHO recommendations. These recommendations guarantee that the children perform safe and effective exercise in terms of frequency, intensity, and duration. We quantitatively evaluate the intensity level of physical activity in our system based on these recommendations to ensure that children can safely perform real physical activity at the desired intensity level. The heart rate measurements for each

child are used to assess how the system can adapt and strike a balance between the fitness level and the exercise intensity (Sinclair, Hingston, Masek, & Nosaka, 2010). Also, a minimum intermittent duration of 10-minute bouts was used to evaluate the system. To evaluate the effects of frequency, children must be evaluated over a long period of time. If there is a high degree of motivation for playing the system's video games, one can promote frequent playing sessions. However, if they are not fun, frequency of use will decline. This enjoyment factor can be assessed through the next criterion.

2. Attractiveness and enjoyment: This is the determination of whether the ExerLearn Bike System is fun and enjoyable for children to interact with. The attractiveness of the ExerLearn Bike system was evaluated qualitatively using the GameFlow Model (Sweetser & Wyeth, 2005) and the direct observation method. The GameFlow Model as discussed in Section 3.2 is a widely accepted model used to design, evaluate, and understand enjoyment. The model consists of eight elements: concentration, challenge, skills, control, clear goals, feedback, immersion, and social interaction. These elements are constructed from the literature on usability and user experience in games. Each element in the GameFlow Model has a set of criteria to help evaluate the attractiveness and enjoyment factors of games.

3. Learning experience: This is the determination of whether our system can motivate children to learn new concepts like language and math skills. At this point the amount of learning is a secondary goal as long as there is proof of the children performing learning tasks. The learning outcomes and the skill improvements cannot be evaluated in only a few sessions, so again we must motivate them to play and keep them engaged. By observation, we can assess the level of engagement and enjoyment while the child interacts with the system. In addition, a questionnaire is used to assess the children's learning experiences in terms of fun and enjoyment, system interaction, and challenge

levels of the games. Each child filled out the questionnaire at the end of each evaluation session. Also, we interviewed and asked the attended guardians to evaluate overall system aspects and, particularly, the customization feature after creating and uploading their own content.

4. **Modularity:** the ease with which we can use the hardware with other available stationary bikes.

5.2 Experimental Setup

Our experiments for all three game sessions were conducted at the Discover Research Laboratory. We mounted our hardware on an exercise bike ‘Ergo bike’ made available by the lab. The bike was positioned in front of a TV screen that was connected to a PC where all the required software was installed. A Zephyr HxM Blutooth heart rate monitor was used to track, control, and record the user's heart rate continuously throughout each session.

5.2.1 Participants

We conducted our evaluations with 13 children, 7 boys and 6 girls, between the ages of 7 and 13. This information is detailed in Table 5.1. The children were all assigned Participant IDs. All the children who participated in the evaluation were healthy and had no previous history of heart problems. We selected participants with different ages to assess this variable within our system. Each child participated in three experimental sessions one session per game. Before each evaluation session, participants were shown a demonstration that explained the nature of each game. Then, a one-minute tutorial was performed in front of them to show them how to play and use the bike as a controller. A child profile for each participant was then created. Each child was outfitted with the heart rate transmitter device over his/her chest prior to each session. The device is activated when the straps sensors are placed against the skin.

Table 5.1: Participants' Physiological Data

Days	Day one							Day two					
Participant ID	**P_1**	**P_2**	**P_3**	**P_4**	**P_5**	**P_6**	**P_7**	**P_8**	**P_9**	**P_{10}**	**P_{11}**	**P_{12}**	**P_{13}**
Gender	M	M	M	M	F	M	F	F	M	M	F	F	F
Age	10	11	7	12	13	13	9	11	12	13	8	10	11

5.2.2 Evaluation Metric

To evaluate the effectiveness of the exercise aspect of the ExerLearn Bike System, we chose the heart rate as the most significant metric. This was chosen because it is considered a direct measurement of physiological response to any physical activity due to the correlation between the number of heartbeats (or beats) per minute (bpm) and the exercise intensity. Therefore, we monitored and recorded the heart rate for each child before and during the gameplay session and compared it the with his/her target heart rate (THR). By doing so, we determined whether or not the child achieved the recommended level of exercise intensity. The following explains this process in detail:

Using the child profiles and Equation (1), the system calculates the maximum heart rate $HR_{\max}$ for each participant based on their age as shown in Table 5.2. The $HR_{\max}$ is the maximum heart rate that a participant can safely achieve while exercising.

$$HR_{\max} = 208 - (0.7 \times Age) \qquad (1)$$

The target heart rate is the heart rate that participants should achieve to maintain the recommended level of physical intensity. It is calculated using the Karvonen method shown in Equation 2.

$$THR = (HR_{\max} - HR_{rest}) \times Intensity + HR_{rest} \qquad (2)$$

Table 5.2 : Participants' maximum heart rates $HR_{\max}$

Participant ID	P_1	P_2	P_3	P_4	P_5	P_6	P_7	P_8	P_9	P_{10}	P_{11}	P_{12}	P_{13}
Age	10	11	7	12	12	13	9	12	12	13	8	10	11
$HR_{\max}$	201	200.3	203.1	199.6	198.9	198.9	201.7	200.3	199.6	198.9	202.4	201	200.3

5.3 Quantitative Evaluation

5.3.1 The ExerMath Game Evaluation

We assessed the effect of the ExerMath game based on the predefined metric stated above. The game challenge levels, including the math concept level and the math operations, were selected based on the child’s math skills and age. The THR that participants should achieve is calculated based on each child's maximum heart rate, their heart rate at rest, and the desired level of exercise intensity, as shown in Table 3.

Based on the reviewed recommendations, we chose to evaluate our system using a duration of 10-minute minimum bouts of light to medium intensity levels. The following tables contain the participants' target heart rate, their resting heart rate, and the recorded heart rate for each participant during the evaluation session. The THRs for the first 7 participants is between 50% and 60% of their maximum HR, and these values are shown in Table 5.3 This range of physical intensity is considered to be a light level of exercise . However, the other 6 participants were asked to perform a medium level of physical intensity, with their THR falling between 60% and 70% of their maximum HR. These values are shown in Table 5.4.

Table 5.3: The children's resting heart rates HR_{rest} , heart rates while playing HR_{child} and target heart rates for a light level of physical intensity

Participants ID		**P_1**	**P 2**	**P_3**	**P_4**	**P_5**	**P_6**	**P_7**
HR_{rest}		89	83	90	81	80	82	86
HR_{child}		147	141	132	144	145	141	149
THR Zone	**50%**	145	141.65	146.55	139.95	139.45	140.45	143.85
	60%	156.2	153.38	157.86	151.74	151.34	152.14	155.42

Table 5.4: The children's resting heart rates HR_{rest} , heart rates while playing HR_{child} and target heart rates for a medium level of physical intensity

Participants ID		**P_8**	**P_9**	**P_{10}**	**P_{11}**	**P_{12}**	**P_{13}**
HR_{rest}		82	85	78	84	84	87
HR_{child}		142	155	153	139	151	148
THR Zone	**60%**	152.98	153.76	150.54	155.04	154.2	154.98
	70%	164.81	165.22	162.63	166.88	165.9	166.31

Results and Discussion

As seen in Figure 5.1, the participants' heart rates increased significantly in response to the exercise, with an overall average of 61.23 bpm higher than their resting heart rate. This includes an average increase of 58.28 bpm for those doing light exercise and 64.66 bpm for those doing a moderate level of exercise.

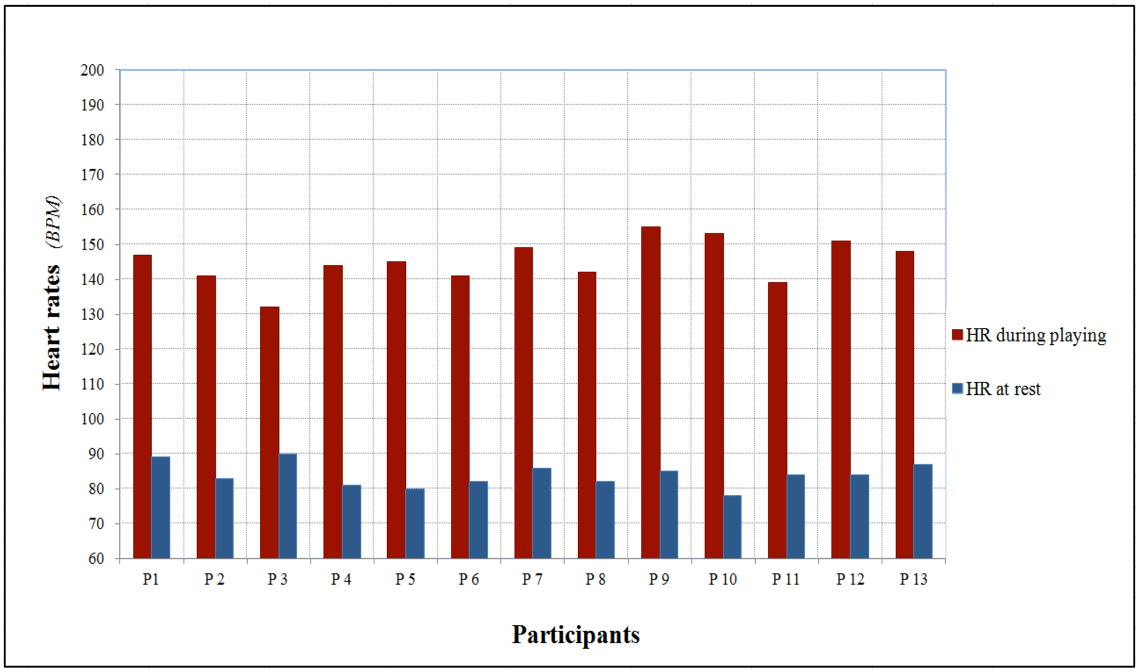

Figure 5.1: A comparison between each child's heart rate while playing the Exermath Game and their resting heart rate

Based on the WHO and CDC intensity recommendations, 7 of the 13 participants actually achieved heart rate values that fell within their THR zones. Of these 7, 5 participants (P_1, P_4, P_5, P_6 and P_7) met the recommended level of light aerobic exercise intensity, while P_9 and P_{10} met the moderate intensity level. On the other hand, the heart rates of the other six participants (P_2, P_3, P_8, P_{11}, P_{12} and P_{13}) were lower than expected and did not achieve the desired level of intensity. While participants P_2, P_3 and P_{11} could not achieve the recommended level of exercise intensity for any THR, participants P_8, P_{12} and P_{13} could not achieve their desired level of intensity (moderate exercise), but still met the light intensity level as shown in Figure 5.2.

The result of this analysis indicates that the ExerMath game raises the children's HR to an average of 142.71 beats per minute during light exercise and 148 beats per minute for moderate exercise. These levels fall within the light to moderate intensity range recommended for children.

We expect that better results can be achieved with higher energy expenditure. However, the increments of the heartbeats might be affected by other factors such as the exercise experience or physical and emotional stresses. Also, some participants need more time to think about the questions to provide correct answers. For this reason, the heart rate will decrease based on how much time the participant spends pondering the questions. However, as they increase their learning, they will be able to answer the questions quicker and will elevate their HR again.

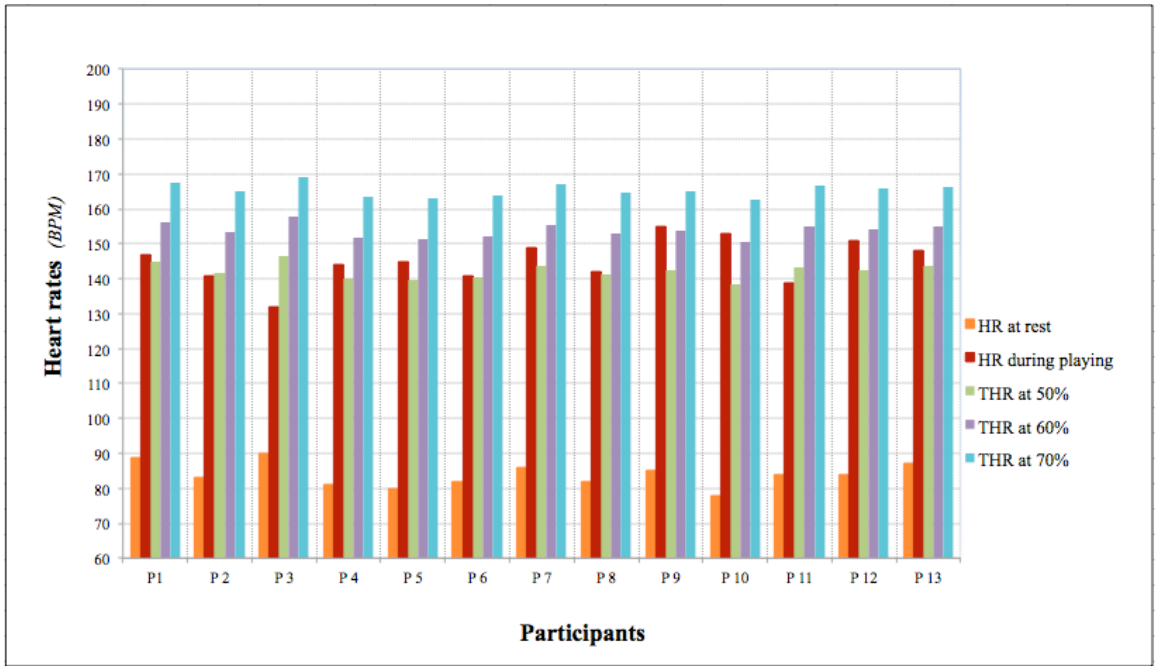

Figure 5.2: Children's heart rates while playing the ExerMath game compared to their target heart rates

5.3.2 The Memory Game

In this section, we present the evaluation of The Memory Game using the same criteria explained previously. Similar to the previous quantitative evaluation, we attained the physical intensity levels by monitoring the participants' heart rates HR_{child} during gameplay. Children's heart rates HR_{child} should ideally be within the THR zone during physical activity to meet the recommended level of physical activity. The measured heart rate at rest HR_{rest}, the calculated THR based on light to moderate levels of intensity, and the child heart rate during gameplay HR_{child} are shown in Table 5.5 and 5.6.

Table 5.5: Participants' heart rates at rest HR_{rest}, while playing the memory game HR_{child}, and the calculated THR for the light intensity level

Participants ID		P_1	P_2	P_3	P_4	P_5	P_6	P_7
HR_{rest}		90	87	89	89	85	84	91
HR_{child}		158	147	128	153	134	153	154
THR Zone	**50%**	145.5	143.65	146.05	144.3	141.95	141.45	146.35
	60%	156.6	154.98	157.46	155.36	153.34	152.94	157.42

Table 5.6: Participants' heart rates at rest HR_{rest}, while playing the memory game HR_{child}, and the calculated THR for the moderate intensity level

Participants ID		P_8	P_9	P_{10}	P_{11}	P_{12}	P_{13}
HR_{child}		90	87	84	92	93	85
HR_{child}		160	156	153	144	159	155
THR Zone	**60%**	156.18	154.56	152.94	158.24	157.8	154.18
	70%	167.21	165.82	164.43	169.28	168.6	165.71

Results and Discussion

From Tables 5.5 and 5.6 and the results in Figure 5.3, we can see that while playing the memory game the heart rates for the participants significantly increased over their resting heart rates, with an average of 61.92 bpm. This includes an average increase of 59.42 bpm for participants who performed light exercise and 65.83 bpm for those who performed moderate exercise.

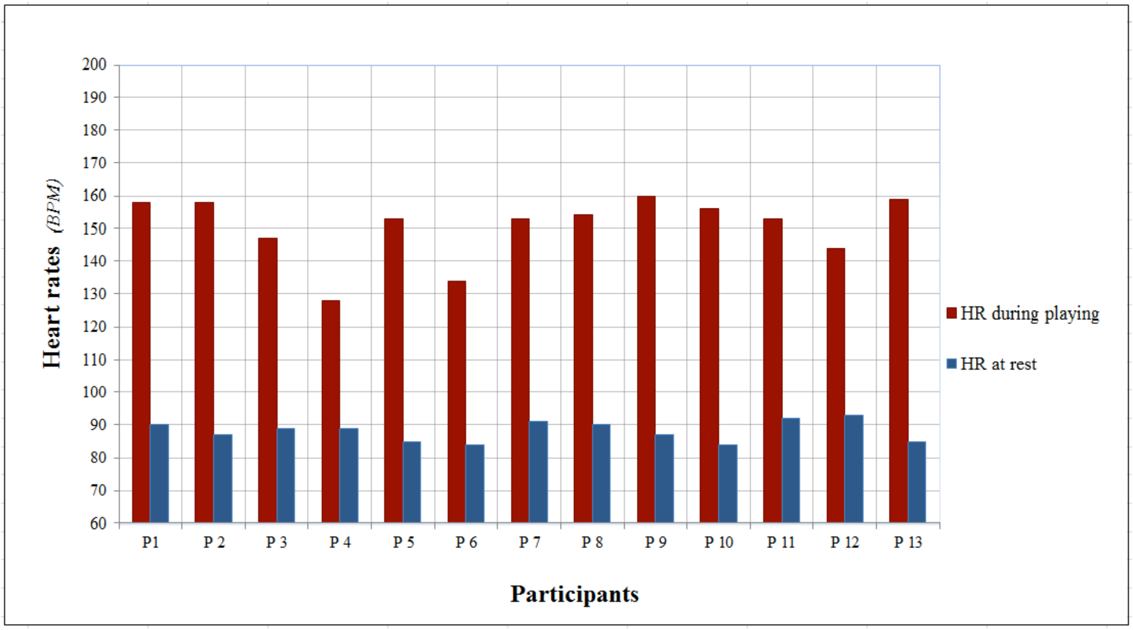

Figure 5.3: A comparison between each child's heart rate while playing the Memory Game and their resting heart rate

Based on the WHO's and CDC's physical intensity recommendations, 8 of the 13 participants achieved heart rate values that fell within the desired THR ranges and met the recommended level of exercise intensity. 7 of the 13 participants achieved heart rates higher than 60% of their maximum heart rate. This indicates that this game allows children to achieve a moderate level of exercise. Although participants P_1 and P_6 were selected to perform light exercise, they actually achieved their target heart rate for moderate exercise. Participants P_2, P_4, and P_7 obtained their intended light level of exercise between 50% and 60% of their maximum heart rates. On the other hand, the heart rates of P_3, P_5, and P_{11} were lower than expected. However, the reason behind this might relate to the difficulty levels of the game during the participant's session, the participant's exercise experience level, or due to the bike's size.

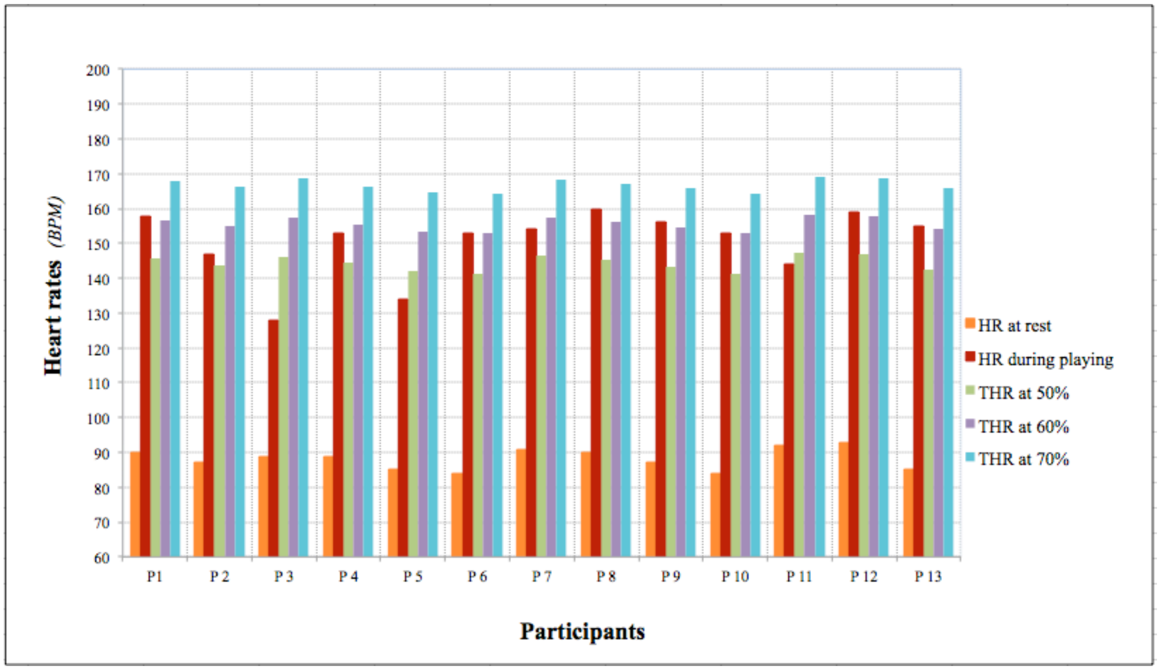

Figure 5.4: Children's heart rates while playing the Memory Game compared to their target heart rates

The result of the analysis shown in Figure 5.4 indicate that the Memory Game for the ExerLearn Bike system could provide children with different levels of intensity that raise their HR above normal. The obtained levels were within the range of light to moderate intensity recommended for children's aerobic exercise. The intensity levels in our system varied based on the physical activity level selected in the game.

5.3.3 The Zoo Game

In this section, we present the evaluation of the Zoo Game**.** To meet the interests of a wide range of children, we chose the zoo subject matter for our evaluation. We followed the same steps as in all the previous games. Table 5.7 and 5.8 present the participants' heart rate at rest HR_{rest} and during a play session HR_{child} , as well as their THRs for light to moderate exercise levels.

Table 5.7: Participants' heart rates at rest HR_{rest}, while playing the Zoo Game HR_{child}, and the calculated THR for the light intensity level

Participants ID		P_1	P_2	P_3	P_4	P_5	P_6	P_7
HR_{rest}		86	85	86	88	80	79	88
HR_{child}		141	138	135	146	140	145	142
THR Zone	**50%**	143.5	142.65	144.55	143.8	139.45	138.95	144.85
	60%	155	154.18	156.26	154.96	151.34	150.94	156.22

Table 5.8: Participants' heart rates at rest HR_{rest}, while playing the Zoo Game HR_{child}, and the calculated THR for the moderate intensity level

Participants ID		P_8	P_9	P_{10}	P_{11}	P_{12}	P_{13}
HR_{rest}		89	90	81	90	92	89
HR_{child}		143	148	154	149	152	157
THR Zone	**60%**	155.78	155.76	151.74	157.44	157.4	155.78
	70%	166.91	166.72	163.53	168.68	168.3	166.91

Results and Discussion

From Table 5.7 and 5.8, the children's heart rates increased an average of 57.61 bpm compared to their resting heart rate. The average heart rate increase for children who performed light exercise was 55.1 bpm higher, and for children who performed moderate exercise, it was 60.5 bpm higher. This increase over the children's resting heart rates shown in Figure 5.5 indicates that the Zoo Game encourages children to be physically active while playing the game.

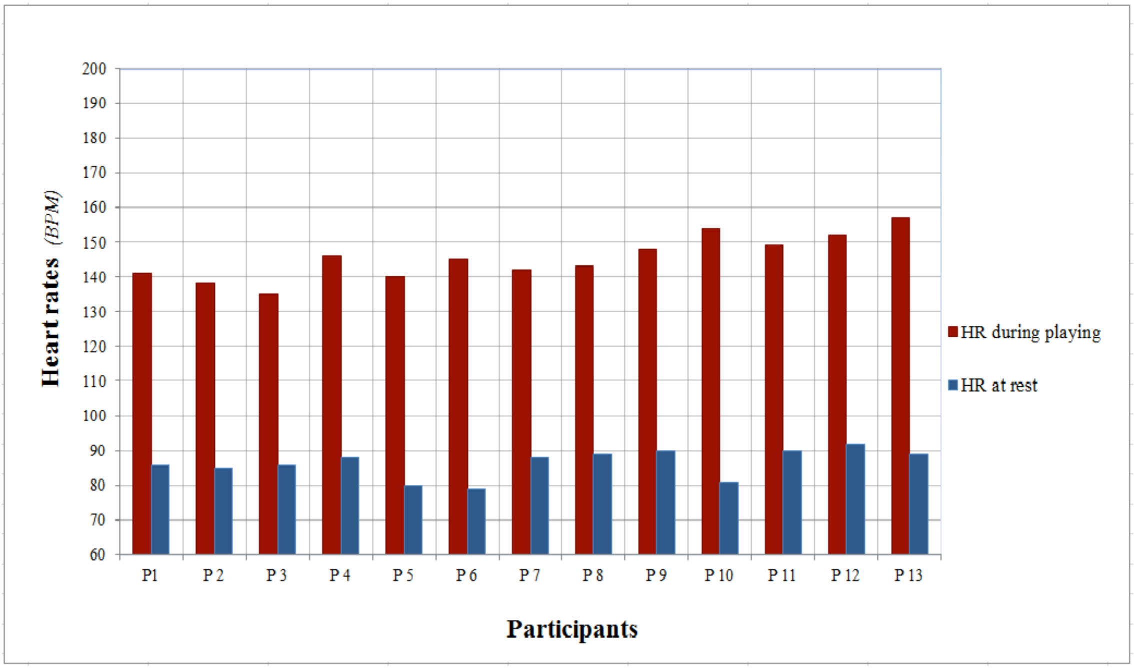

Figure 5.5: A comparison between each child's heart rate while playing the Zoo Game and their resting heart rate

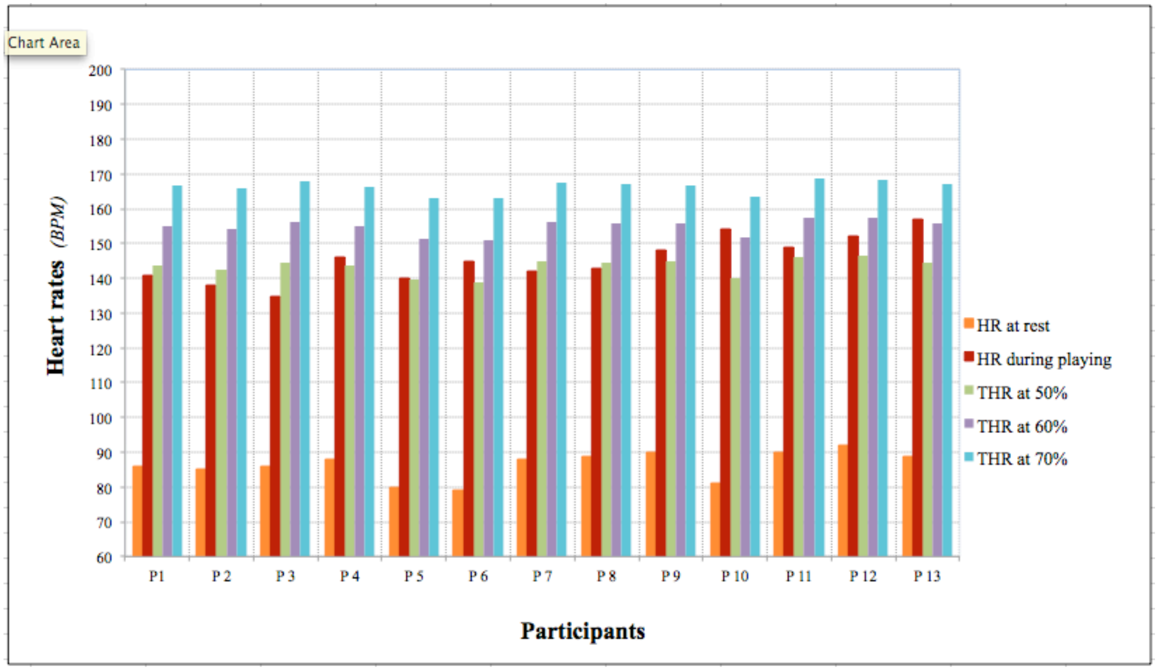

Figure 5.6: Children's heart rates while playing the Zoo Game compared to their target heart rates

Upon analysis of the heart rate data in Figure 5.6, we found that 8 participants met the CDC and WHO guidelines. In detail, 5 participants ($P_{4,}$ $P_{5,}$ $P_{6,}$ $P_{10 \text{ and}}$ P_{13}) achieved the desired heart rate values that fell within their target range, while the heart rate values achieved by the others fell close to or below their target heart rate zone. Three participants (P4, P5 $_{\text{and}}$ P_6) of the 7 who got light exercise reached their target zone, yet the other four participants achieved heart rate values that were below or very close to their target zones. For moderate exercise, 2 participants ($P_{10 \text{ and}}$ P_{13}) reached their THR, while the other 4 participants ($P_{8\ ,}$ $P_{9,}$ P_{11} and P_{12}) could not achieve their target heart rate. However, $P_{9,}$ P_{11} and P_{12} still benefited from light exercise while P_8's heart rate was below the recommended intensity level for even light exercise. The reason for not reaching the THR is that some children needed more time to listen to animal sounds and read the displayed questions.

5.4 Qualitative Evaluation

To evaluate the attractiveness and the quality of experience of the ExerMath game in particular, we rated our system based on the GameFlow Model criteria in Table 5.9, followed by a more detailed explanation and discussion.

Table 5.9: GameFlow Model elements and criteria checklist

Flow Elements	**Criteria**	**Criterion was met?**
Concentration Games should require concentration, and the player should be able to concentrate on the game.	Games should provide a lot of stimuli from different sources.	✓
	Games must provide stimuli that are worth attending to.	✓
	Games should quickly grab the players' attention and maintain their focus throughout the game.	✓
	Players should not be burdened with tasks that do not feel important.	✓
	Games should have a high workload, while still being appropriate for the players' perceptual, cognitive, and memory limits.	✓
	Players should not be distracted from tasks that they want or need to concentrate on.	✓
Challenge	Challenges in games must match the players' skill levels.	✓

Games should be sufficiently challenging and match the player's skill level.	Games should provide different levels of challenge for different players.	✓
	The level of challenge should increase as the player progresses through the game and increases their skill level.	✓
	Games should provide new challenges at an appropriate pace.	✓
Player Skills Games must support player skill development and mastery.	Players should be able to start playing the game without reading the manual.	✓
	Learning the game should not be boring, but be part of the fun.	✓
	Games should include online help so players don't need to exit the game.	✗
	Players should be taught to play the game through tutorials or initial levels that feel like playing the game.	✓
	Games should increase the players' skills at an appropriate pace as they progress through the game.	✓
	Players should be rewarded appropriately for their effort and skill development.	✓
	Game interfaces and mechanics should be easy to learn and use.	✓
Control	Players should feel a sense of control over their characters or	✓

Players should feel a sense of control over their actions in the game.	units and their movements and interactions in the game world.	
	Players should feel a sense of control over the game interface and input devices.	✓
	Players should feel a sense of control over the game shell (Starting, stopping, saving, etc.).	✓
	Players should not be able to make errors that are detrimental to the game and should be supported in recovering from errors.	✓
	Players should feel a sense of control and impact onto the game world (like their actions matter and they are shaping the game world).	✗
	Players should feel a sense of control over the actions that they take and the strategies that they use and that they are free to play the game the way that they want (not simply discovering actions and strategies planned by the game developers).	✗
Clear Goals Games should provide the player with clear goals at appropriate times.	Overriding goals should be clear and presented early.	✓
	Intermediate goals should be clear and presented at appropriate times.	✓
Feedback Players must receive appropriate feedback at appropriate times.	Players should receive feedback on progress toward their goals.	✓
	Players should receive immediate	✓

	feedback on their actions.	
	Players should always know their status or score.	✓
Immersion Players should experience deep but effortless involvement in the game.	Players should become less aware of their surroundings.	✓
	Players should become less self-aware and less worried about everyday life or self.	✗
	Players should experience an altered sense of time.	✓
	Players should feel emotionally involved in the game.	✓
	Players should feel viscerally involved in the game.	✓
Social Interaction Games should support and create opportunities for social interaction.	Games should support competition and cooperation between players.	✗
	Games should support social interaction between players.	✗
	Games should support social communities inside and outside the game.	✗

Explanation and Discussion:

- *Concentration*

The ExerLearn Bike meets the concentration criteria by allowing children to concentrate on the game tasks. By observing the children during the evaluation session, we can say that the system grabs the children's attention quickly because of the unconventional interaction style of the bike, the simple gameplay, and the age-appropriate content incorporated in the games, such as animation, audio, speech, graphics, and rewards. The simple interface and design make it easy for children to focus on the important and central learning tasks while avoiding any distractions. It also has a high workload since it incorporates physical activity as the input, so the player is required to use both cognitive and physical skills.

- *Challenge*

The game challenges must match the player's skills as discussed in the Dual Flow Model. This balance can be achieved via different levels and player progress. The ExerLearn Bike easily meets the challenge criteria by providing variable levels of challenge difficulty that are appropriate for children and not too hard or too easy (rendering them depressing or boring). The system allows guardians to select the appropriate level of difficulty and adjust this level after monitoring the child's learning progress.

- *Player skills*

The game must improve and support player skills development. Most of this element's criteria have been met by our system. Since we are using a well-known input device, children were able to start playing the game and become familiar with the system very quickly. The system has a brief description explaining each game's scenario, including a few steps on how to play them. Through our educational games, children can learn and practice skills that are in need of improvement. Moreover, the system has a reward feature that rewards the children after each achievement to promote continuous playing. The graphical user interface is simple and well-labeled to make it easy for children to interact with the system.

- *Control*

The ExerLearn Bike allows guardians and children to feel in control of all the system's aspects. For example, the children control the game through their physical movements. Also, the users are able to customize the game content and the intensity of the physical activity to meet a wide range of children's needs. The system additionally provides the user the ability to customize the media displayed through his/her interface. For example, the images in the memory game can be combined with text, speech, or both. We provide complete control of the game shell. The child controls all the game actions through pedaling. As long as the child is pedaling, the game is continuing and when they stop, so does the game. For guardians, any important actions like deleting content or changing settings are followed by a confirmation question to avoid any harmful sequences.

- *Clear goals*

One of the ExerLearn Bike requirements is to provide users with clear overriding goals and specific intermediate objectives. The overriding goal is to motivate children to get the recommended level of exercise through the use of the bike. The intermediate goal is to allow children to learn about new objects and languages, and to practice different skills based on their needs. The game's goal and steps on how to play are presented in the game description before starting to play.

- *Feedback*

Children playing with the system receive appropriate and immediate feedback reflecting their answers and progress towards the objectives. Different forms of feedback are provided, including text, speech, and sounds to guide users through each task and after completing each small objective. Also, the system has a rewards feature that increases or decreases user's scores based on their answers.

- *Immersion*

From our observations during the evaluation session, we found the children are excited to play with the system and become immersed in the game idea. The system requires children to concentrate on the questions and provide the system with the right response through thinking and exercising. There is no period when the child is inactive or waiting because the random questions are displayed continuously until the required time finishes. The children feel excited about increasing their scores before the session ends. Children can become viscerally involved in the game to prove that they are smart, especially when playing the memory game.

- *Social interaction*

Social interaction as stated in the study (Sinclair, Hingston, Masek, & Nosaka, 2010) is not as important as the other flow elements. The ExerLearn bike's current prototype does not support social interaction. However, one of our future works is to create opportunities for children to be involved in competitions and cooperative game experiences.

5.5 The Learning Experience

The children's satisfaction, impressions, and motivation for learning are subjective, but could be assessed directly using a questionnaire together with the observation method.

From our observations during the evaluation sessions over two days, the game seems to be easily controllable by children. Figure 5.7 shows four participants playing the ExerLearn Bike games during the evaluation sessions. The children appeared happy and were able to perform the physical movements easily while responding to the game's tasks.

Figure 5.7: Children playing ExerLearn Bike games

The results from the questionnaire showed that most children enjoyed playing the games and liked the idea of the interaction. Most of the participants (12 of 13) like the games, however P_3 did not like the system in general because of the size of the bike. Responding to Q2, (10 of 13) participants found it fun and were excited to answer the math questions using the bike, while P_7, P_{12} and P_{13} preferred solving them on paper. A 12 year old girl responded by saying that "it is a good way to answer questions while getting some exercise instead of writing the answer because a lot of children like to ride bikes. So, this activity makes children enjoy doing math and learning."

For Q3, most of the participants (12 of 13) found the math questions easy to answer, and two participants, P_4 and P_9, suggested increasing the level of difficulty. However, the youngest child said the questions were a little bit hard.

Most of the children had played traditional memory games before, but none had played one using an exercise bike. However, responding to Q4, most of the children (11 of 13) said the memory game was easy to play. Nine of the participants embraced the idea of using the bike as an interaction tool and responding to Q5 by preferring using it as the input to the Memory Game . P_3, P_5, P_8 and P_{12} prefer cards or a mouse for matching pairs.

The answers to Q6 show that children were excited and actively involved in the Zoo Game. By seeing different pictures of animals and listen to their sounds, all of the children found it more compelling and enjoyable than reading a book.

As for Q7, 10 of 13 participants answered positively, which shows that most of them were focused on the game while exercising, yet P_3, P_6 and P_{12} got tired in the middle and could not focus enough.

Responding to Q8, nine participants stated that they did not get tired while exercising, and they got a good amount of exercise during the play session. However, three participants (P_3, P_6 and P_8) felt a little bit tired, and P_{11} said it was very hard to exercise due to the uncomfortable seat of the bike.

For Q9, nine participants said the they would recommend the ExerLean Bike games to their friends, while four said they would not.

According to Q10, some of the participants have the following suggestions for improving the memory game: P_8 proposed to add a racing game for competitions, while P_6 suggested making the games faster. P_6 also asked to use a more comfortable bike.

Finally, the attending parents indicated that they liked the games idea in general. Before beginning the ExerMath game session, one mother was asked to use the customize button in the ExerMath game to specify the math level for her child, including the type of operations to be displayed and the number ranges. At the end, she stated that the game could help her child to review and practice math concepts he has already studied at school while getting some exercise at home. In the memory game, another mother participated by creating new content and uploading some pictures. She created a shapes category, uploaded pictures, and typed the shape names using the customize panel. When we asked her opinion after the game session, she reported, "It is useful to use the game to introduce new stuff to the child for the first time," and added that "reading the written word and listening to its pronunciation twice while looking at the object picture allows the child to memorize it easily." Yet another parent expressed her admiration about being allowed to personalize the content and adjust the game settings.

Chapter 6: Conclusion and future work

Due to the wide range of diseases associated with Inactivity and sedentary behavioural patterns among children including obesity, cancer, cardiovascular disease, and diabetes, the need for physically interactive systems has become apparent. In this thesis, we have proposed an exergame system that combined the features of attractive gaming, effective exercise, and a solid learning experience. The developed ExerLearn Bike System aims to provide children with educational experiences in a fun and enjoyable environment using their physical movements as input. Children can interact with the system through specially designed, modular hardware mounted on a stationary bike that detects and counts the number of pedal motions. Extensive research has been done in order to identify the most significant factors that the ExerLearn Bike System should integrate in order to meet children's requirements in three dimensions: gaming, exercising, and learning. The hardware components and the supportive software components, including the implementation and technical details, have been described.

The system incorporates three software games that differ in their goals and aspects, namely : the ExerMath game, the Memory game and the Zoo game. They allow children to practice basic math skills, improve their cognitive abilities, and expand their knowledge, all while exerting physical force. In addition, the system allows certain "guardian" users to personalize the game content and challenge levels as well as adjust the required physical settings to suit their child's needs. Another benefit is that our hardware, which consists of different sensors and a microcontroller, is modular and can be attached to any available bike at home or school and does not require particular hardware specifications.

In order to assess the system's performance, we have conducted qualitative and quantitative evaluations on three games played by 13 children aged 7 to 13. The qualitative experimental results show that children liked the idea of the Exerlearn Bike and easily interacted with software games using the bike as input. From our observations, children were excited during the experimental sessions and really enjoyed playing. The quantitative results obtained using Zephyr heart rate monitor indicated that children were physically active and their heart rates noticeably increased from their resting rate. Also, most of children met the physical intensity recommended by the CDC and WHO physical activity guidelines. However, we have realized that very fast pedaling prevented the hardware from accurately detecting the number of pedal cycles, which will affect the input data, especially in the ExerMath game.

Directions for future work are divided into the following parts:

First, we should conduct long term study where the kids use the ExerLearn Bike system daily for a couple of weeks and have them for example do math tests before and after the experiment to see how much better the kids were at the end. Second, the system should be improved by incorporating new features, such as social interactions including competitions and cooperation, in a way that does not disturb the child's concentration on the learning task. Finally, we would like to add special features for children with special needs in order to accommodate some types of disability. In addition, we intend to integrate haptic feedback by using a vibration actuator.

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Appendix A: ExerLearn Bike Questionnaire

Name: Age:

Q1: Did you like the ExerLearn bike games?

- Yes
- No

Q2: Is it more fun to solve math questions using the bike or paper and pens?

- Bike
- Paper and pen

Q3: Do you think the math game questions were difficult to answer?

- Yes
- No

Q4: Was the memory game easy to play?

- Yes
- No

Q5: What do you prefer in the memory game? Matching the pictures using:

- Cards
- The mouse
- Bike

Q6: How much did you enjoy exploring the zoo using the ExerLearn Bike instead of books?

- Little
- Normal
- Very much

Q7: Were you able to focus on the games while exercising?

- Yes
- No

Q8: Did you get tired after playing?

- Yes
- No

Q9: Do you recommend ExerLearn Bike games to your friends in school?

- Yes
- No

Q10: Do you have any suggestions to make the games better?