Prête-à-apprendre: Design and Implementation of a Wearable Assessment Tag Game for Children

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Abstract

There is an increasing recognition that low physical activity in children is causing both mental and physical health problems. In some sense, an increased reliance on the Internet to learn is causing children to spend more time indoors. Therefore, it is imperative that children somehow reduce the 'screen-time' by spending more time in outdoor learning activities. This paper describes the design and development of a tangible wearable learning system called the prête-à-apprendre (ready-to-learn). This system allows the children to be outdoors and to learn by engaging in modified forms of the popular tag game. The wearable learning system is based on the Lilypad platform and employs a low-power Zigbee network protocol to form an ad-hoc wireless communication network. The design and implementation of the overall system, associated wearable components and the pedagogical motivation and evaluation of a simple tag game based on this platform is presented.

1. Introduction

Using the Internet to teach and assess children is widely practiced. For example, U.K. has government funded programs to help children learn a variety of concepts online [1]. In the United States a similar service is provided by the Public Broadcasting Network [2]. While such services have 24x7 accesses and provide interactivity to children, they also may have an unintended effect of increasing screen-time for children. According to the National Institute of Health (NIH), the physical activity in children 9 to 14 years has significantly dropped and this drop is directly related to an increase in obesity and related medical problems [3]. Recent focus groups comprising of 6th grade boys have found that the most barriers to physical activity are motivation and lack of resources [4]. Excessive sedentary behavior like T.V. watching and computer usage has been found to be positively correlated with high blood pressure in children [5]. It has also been shown that high levels of television and screen entertainment time and low physical activity interact to increase psychological distress in children [6]. Therefore, while there is a need for "computer-tied" technology for children, increasingly, learning technologies that combine learning with physical activities are required to create a balance between cognitive and physical aspects of development.

Tapping physical aspects for children leads one to immediately consider game-based learning scenarios. For example, [7] found that in a controlled study, students picked a game-based version of the same instructional sequence 50% more than they did the drill version indicating the higher motivational value of learning games for children. A 'game' has many definitions. For example, [8] defines game as organized play. After analyzing many definitions of a game, [9] define a game to be "a system in which players engage in artificial conflict, defined by rules, those results in a quantifiable outcome." (pp. 80). For the research presented here, instructional or learning games are defined to be a system where learners engage in artificial conflict, defined by rules, that results in quantifiable outcome and enhances learning. While [10] ,[11] have outlined various principles of digital game-based learning, recent studies like [12] have shown that game-based learning actually improved student motivation as well as performance. There is also emerging evidence [13] that when using game-based learning as opposed to self learning, students not only thought that game was the preferred method and was more enjoyable but also showed willingness to continue to use this method of learning. [14] show that not only did children do better while using game-based learning, but playing games also developed them as independent learners. The current generation of children also grew up with mobile devices. By their nature, mobile devices can contribute to learning that happens outdoors. Consequently, mobile or m-learning has received much attention recently [15],[16]. For example, [17] show that students learned history by walking around with their mobile phones and by sharing information about what they saw in the city. There are also efforts to move existing gaming platforms to m-learning platforms [18]. Mobile game-based learning has also been used in the context of providing mass learning in developing countries [19]. M-learning to extend a traditional LMS also received a positive response from college students [20]. Podcasting was also found to be more effective for revision of lectures than notes or other conventional means [21]. M-learning has also been shown to significantly increase environmental awareness [22]. A framework for designing m-learning games has been proposed [23]. Specific criteria for assessing the quality of learning games have also been proposed [24]. Issues addressing the quality of m-learning are also outlined in [25].

Pervasive games where children use location-based and mobile technologies to play a game in a technology-based physical environment have also gained popularity [26]. Cemelot [27] is an example of a pervasive game that does not include the 'screen' as a part of the game by embedding small microcontrollers in children's play environments. Similarly, the Heart Beat system [28] uses a small device measuring children's heart beat and broadcasting it to others to play an enhanced version of the tag game. [29] embeds sensors in the physical environment to augment traditional outdoor games. Use of technologically-augmented tangible objects has also been explored in the context of open-ended play [30]. Tagtiles [31] are the basis for similar technology-augmented tiles games. CurBall [32] is a tangible game between senior citizens and children and augments physical space with technology. SCORPIODROME [33] is a mixed-reality game where children interact with the environment by combining physical and virtual elements by overlaying physical trucks on top of a virtual display or terrain and behavior. Interactive slide [34] is also an example of augmenting traditional playground equipment by projecting pictures and games from inside the slide to engage children in physical activities.

Following the constructionist orientation spawned by the early work of Seymour Papert and influenced by philosophical traditions of Fröbel and Maria Montessori, a number of tangible kits for children have also been proposed; these learning kits can be used indoors or outdoors. PegBlocks was an early tangible kit that allowed children to explore relationship between kinetic and electrical energy [35]. More recently, [36] describe a toolkit that allows student as young as nine to construct various types of behaviors by putting together tangible cubes. [37] present a toolkit that helps children design and animate tangible robot behaviors. Posey [38],[39] is a ball-and-socket toolkit that, for example, allows children to build their own puppets or to play computational learning games. JabberStamp uses technology to help children augment paper drawing with audio-annotations [40]. Paper-based tangible computational kits that allow an easy integration of microcontrollers and sensors with potential educational applications have also been explored [41]. Body Suite project [42] attempts to combine bodily interfaces for children's play with musical interfaces allowing for both structured and unstructured play. E-Textiles use wearable computers and hence carry a great promise toward moving learning outdoors. In the constructionist tradition, one focus of this work has been to introduce tangibles in the curriculum to help children learn by building things [43]. For example, TeeBoard [44] is a t-shirt-based kit containing e-Textiles to teach electronics concepts. WeWrite [55] extends e-Textiles by connecting them to mobile phones and teaches tenth graders about technology in a constructionist manner as well.

This research presented here draws from much of the work presented above and provides a unique approach that combines wearable learning technology using e-Textiles with peer to peer learning. This approach is not constructionist in Papert's sense but rather, follows a constructivist orientation in that it allows children to learn by preparing assessments for their peers in the context of game-based learning. There are two major antecedents to the approach; game-based learning and peer to peer learning. Each is described next.

2. Background and Motivation

Games typically embody three levels of rules [46]. The operational rules are surface rules that come with the game. Constitutive rules represent the underlying formal or mathematical structure of the game. The implicit rules are unwritten rules of the game including soft issues like etiquette and sportsmanship. Simulation-based games like the Flight Simulator [47] are based on an isomorphism between the game and a real situation. An isomorphism is a map that preserves properties between two representations. For example, homeomorphism from mathematical topology is a type of isomorphism that preserves topological properties. For example, a 2D square disk and a 2D square are homeomorphic because it is possible to convert one to the other by preserving 'connectedness.' Games like Flight Simulator are based on isomorphic maps that preserve the most learning-relevant properties. For example, responses to changes in a flying surface based on pilot's actions are preserved in the game. Similarly, a tangible bowling game on the Nintendo's Wii game console [48] is an example of such an isomorphism because the game reproduces a direct analogue of the physical environment of bowling; the relationship between a bowler's arm and wrist movement and path of the ball is preserved. On the other hand, a learning game using the format of 'who wants to be a millionaire' game to teach concepts in chemistry, is somewhat different. The game-format has no deep relationship to competence in chemistry; the format simply acts as a container. Another example of such game-based learning is the use of the cross-word puzzles to teach a topic by selecting words and hints from a specific domain (say, chemistry); the syntactic relationships between chemical terms typically have no deep meaning in the domain of chemistry. In situation like these, it seems that the gaming format is primarily used for motivational impact; a learner who likes to do cross-word puzzles will learn chemistry to be able to play the game. Similarly, the excitement offered by 'who wants to be a millionaire' may be a reason to learn chemistry. [7] define such game-based learning formats to be *exogenous* fantasies because in such environments the game fantasy is directly driven by learning competence but not vice-versa. They give the example of a spaceship game where the ship moves forward on correct answers and backwards on incorrect answers. *Endogenous* [7] fantasies, on the other hand, depend on a learner's success being more directly dependent on desired competence. They give the example of a cave exploration game where reading and writing are required to be successful in navigating the cave. The point to note is that even in this instance, the endogenous fantasy acts as a motivational device for learning. However, unlike the chemistry example explained earlier, reading and writing will directly help the learner explore caves.

While desirable, it is difficult to construct endogenous fantasies in learning games. The specific game presented in this paper is based on using the common tag game as an exogenous fantasy. In this sense, the tag game is used as a container for a peer-to-peer assessment-based learning strategy. Chasing games including the tag game have a long history. For example, ancient Greeks played variants of this game in the second century and the tag game has existed in different version in various countries including Australia, Saudi-Arabia, Taiwan and Columbia [49]. Pieter Brueghel's 1560 painting *Children's Games* [50] shows a record of Dutch children playing various forms of the tag game. A study of school children conducted in 1930's predating T.V. and digital media shows that tag game was in the top two favorite games of children between ages of 8-10 in Minneapolis [51]. In short, the tag game is proposed as the exogenous fantasy for this game.

Peer-to-peer learning represents a second key component of game-design. Peer-to-peer learning is not a new concept. For example, upon observing Malabari children teaching each other alphabet in the sand, Andrew Bell invented the Madras system for schools based on peer-to-peer learning in the late 1700s [52]. Peer-to-peer learning fits well into a constructivist framework that requires learning though an active participation in the learning activity itself. As [53] points out, it is important to distinguish between peer tutoring and cooperative learning. Peer tutoring involves specific mentor or tutor and tutee roles being played by different students. Cooperative learning, on the other hand, may consist of pedagogical devices like the use of jigsaw [54] where students with different ability, preparation and background work towards a shared goal. Reinforcement is one of the key organizational variables that may impact the effectiveness of peer to peer learning [53]; some projects may involve extrinsic motivation like certification, course credit, or more tangible reinforcement such as money. Providing structured environment for peer learning also seems to have resulted in better learning as well [55].

3. The Game

The proposed game uses the familiar tag game format as a container and uses peer to peer assessment-driven learning. The game consists of two stages; preparation and gaming. In the preparation stage students are asked to study a topic of interest and are asked to formulate three questions each on the topic. This is in contrast to programs like MunchCrunch [56], for example, that use teacher-created questions to help children learn about which foods to eat. The students are told to make their own questions challenging because these questions will be used in the tag game at a later stage. The students study the topic assigned and formulate three unique true or false questions on the topic. This first stage represents the learning stage where the student gathers enough information about the topic at hand to formulate three difficult questions for their peers. However, the first stage is motivated by the promise of the second stage where the student will compete with others in a familiar setting of a tag game. At the of the preparation stage, the three questions are placed on a prête-à-apprendre shirt to be worn by the children who formulated the questions. The shirt is designed in a manner such that it has an ability to tell other children that one of the questions is being asked by lighting up the question. Figure 1 summarizes first stage of the game.

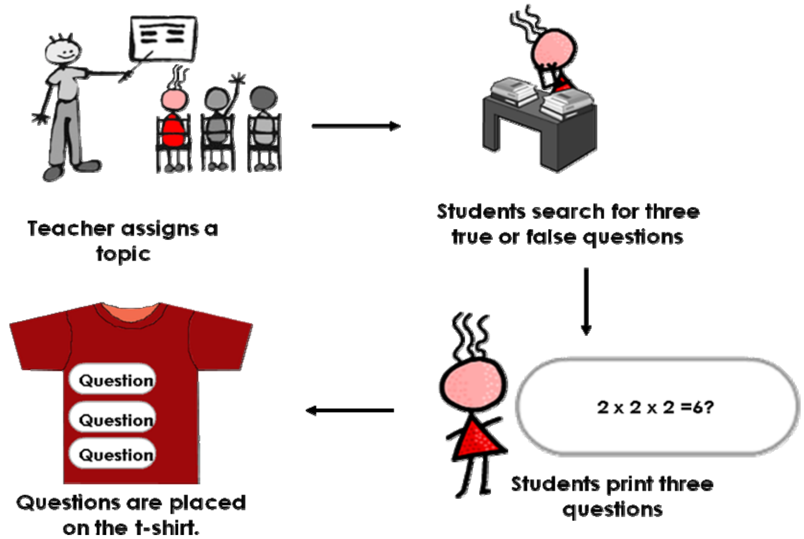


Figure 1. Preparation stage of the game based on prête-à-apprendre

Second stage of the game is a tagging game. The proposed game is based on 'butterfly tagging' where the children are only allowed a small tap on the shoulder of the child they are tagging. As Figure 2 shows, the tag game starts with two teams of students facing each other. The children are not allowed to move at this stage and are watching each other to see whose question lights up. As children face each other, a question based on the order of difficulty as judged by the teacher is lit up by the computer on one of the shirts; easier questions are asked first in order to build the confidence of children. For example, Figure 2 shows that a question lights up on the shirt of one child (Mary). This means that children in the other team (team B) need to answer her question. However, before they can answer the question, they have to catch Mary. Mary starts running as soon as her question lights up. The opposing team has a limited time to answer her question. Either the time runs out or the opposing team is able to catch Mary and answer the

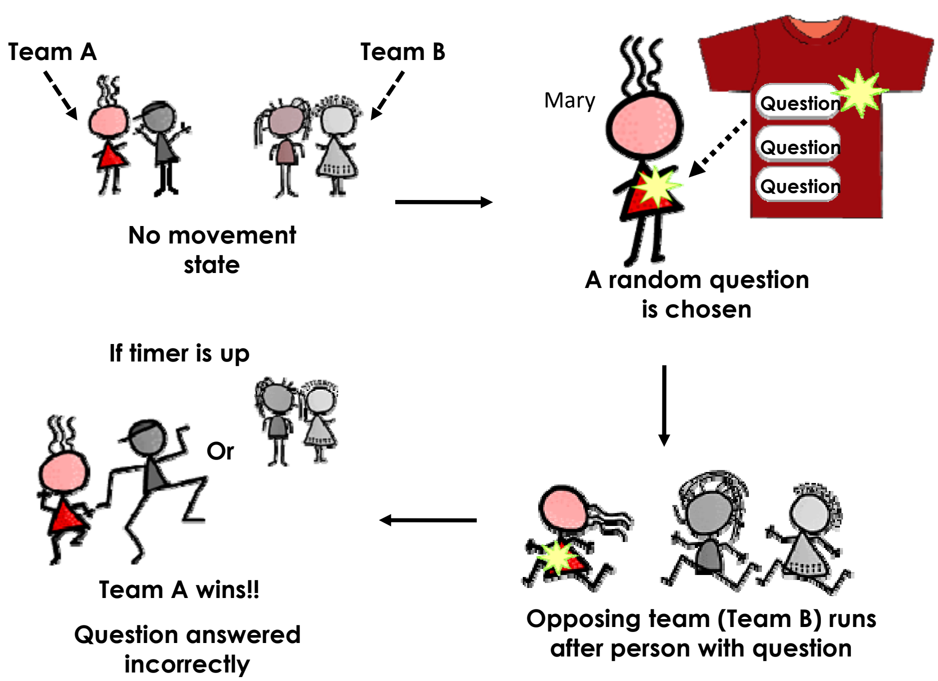


Figure 2. The tag game based on the prête-à-apprendre shirts

question by tapping on true or false buttons on her shoulder. This completes one round. Children face each other to start another round. Rounds are played until all the questions on shirts of all students are exhausted. For example, in Figure 2, four times three or twelve rounds will be played. In reality, rather than a single child's question lighting up, each round consists of multiple children's shirts from the same team lighting up at the same time. This gives the opponents a choice about which opponent to pursue. Results of the playing behavior of each child are transmitted to a computer using a wireless network. The team with the most correct answers and the minimum penalties wins.

4. Implementation

The hardware required to play the game is implemented using the Lilypad e-Textile components [57]. Communication between the onboard microcontrollers and the rest of world is carried out through an XBee module. XBee is based on the low-power, low-data rate Zigbee network protocol that belongs to the IEEE 802.15.4 family of PAN networks. Figure 3 shows the overall architecture of the system. The shirt worn by each child has a unique identification number. All the shirts arrange themselves in an ad-hoc wireless network in a star topology. Data from each shirt are transmitted to a main computer using the XBee module. Similarly, commands are sent back to each shirt using the same modality.

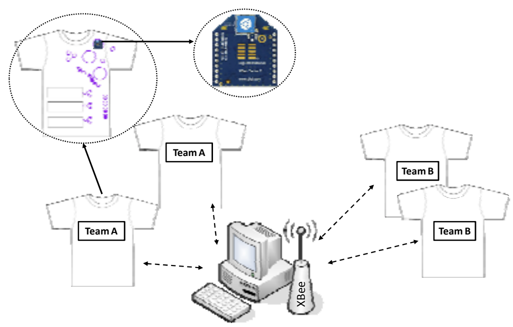


Figure 3. Prête-à-apprendre architecture

Figure 4 shows both sides of a prête-à-apprendre shirt. The front of the shirt consists of two sewn-in Arduino-based microcontrollers (LilyPad Arduino 328 Main Board) powered by a lithium battery. One microcontroller acts as a master while the other acts as a slave. The master microcontroller also talks to an XBee through a serial interface. A vibe-board is used to inform the wearer about important events. In addition, two tri-color LED's are used to inform a player about the various states of the game. For example, the player can not start running until the tri-color LED's have turned green. An accelerometer is used to detect movement and a penalty is recorded in the case of a player moving before the tri-color LED turns green. An LED-based count-down timer is provided on one side of the shirt to let a player visually see how much time they have left until the round finishes. Similarly, an LED "worm" made up of bright white LEDs creeps to the heart of the player based on the penalties and wrong answers they have given. For power considerations, XBee and the two microcontrollers are powered by two separate rechargeable lithium batteries (Polymer Lithium Ion Batteries – 1000mAh and Polymer Lithium Ion Batteries - 100mAh). As Figure 4 shows, the reverse side of the shirt consists of true and false buttons. Under each button is an array of three sewn-in input switches that register the results which are sent to the main computer using the XBee. Finally, three simple pouches are provided in front of the shirt where true or false questions can be printed and inserted. Each question has an LED-based arrow next to it to indicate which question is being asked. A lit up arrow next to a question means that it is one of the question that needs to be answered in the current round.

After the initial research and development, each shirt took approximately forty hours of labor including rework to ensure that there were no shorts or loose connections in the circuits. Out of these, twenty hours were typically spent in creating the thread traces. Because children are running, the shirts are intolerant of loose connections. In order to keep the conducting thread in place, after much experimentation, a sewing technique was developed that winds a transparent sewing thread (100% Polyamide) around the conducting thread and pins the thread down to the fabric. This technique seems to have worked well even when the children are running at a reasonably fast pace. However, it took about twenty hours of work per shirt to wind the Polymide thread around the conductive traces. Alternative techniques such as lamination or using an adhesive conductive tape are being experimented with to reduce this development time. The XBee module was found to be quite robust and did not have any problem transmitting even when the children were about thirty meters from the coordinator and running at a reasonable pace.

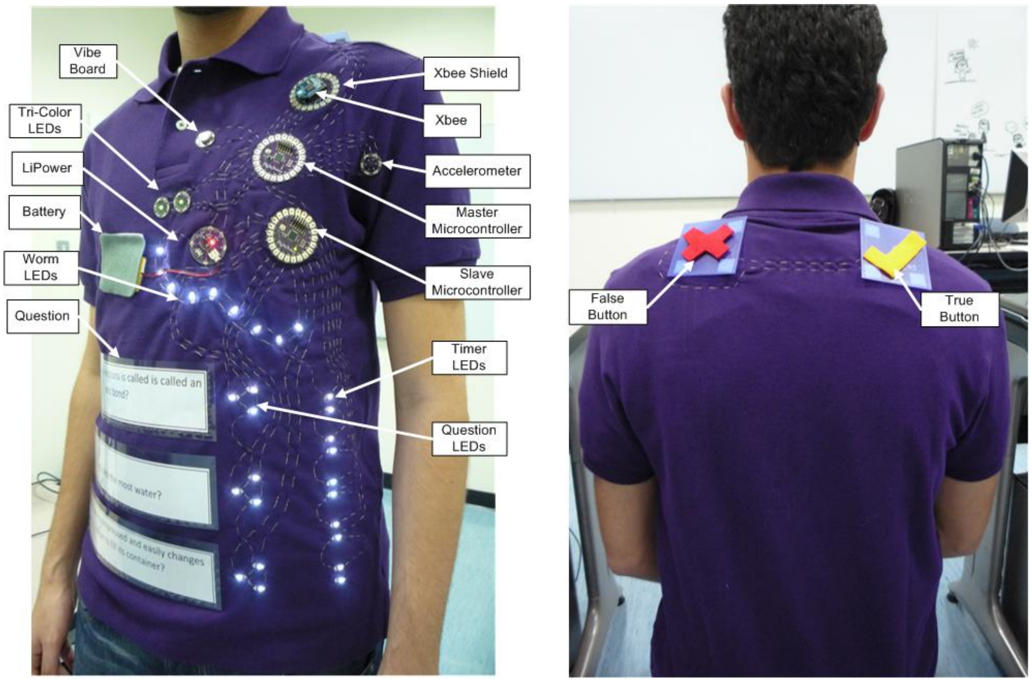


Figure 4. A prête-à-apprendre shirt

Figure 5 shows the deployment diagram for the system. As the diagram shows, each shirt consists of a master and a slave microcontroller. A slave microcontroller is required in order to light up the additional LED's. Master and slave microcontrollers communicate through an RS232 interface. The master microcontroller (LilyPad Arduino 328 Main Board) uses another serial port to interface to a XBee-based ZigBee stack (XBee 2mW Series 2.5 Chip Antenna on a LilyPad XBee board) based on the ZNET 2.5 protocol. This ZigBee node acts as an end-device in a ZigBee PAN network and communicates wirelessly with a coordinator ZigBee node which is hooked up o a PC or a laptop using a breakout board. Each shirt acts an end-node in a star-network topology where the various messages are broadcast to all the shirts and each shirt decided if it needs to act on a message based on its unique identification number.

Finally, as Figure 6 shows, the shirts were informally tested with children ranging in ages from 7 to 12 by running simple game rounds. Children 10 years or older did not have any problem comprehending the rules of the game. However, children under 8 had some initial difficulty in understanding how the game worked. However, they became comfortable after a few rounds were played. A more systematic evaluation of the pedagogical effectiveness of is currently underway.

5. Evaluating Learning Design

The learning design embedded in this tag game can be evaluated based on heuristics for designing intrinsically motivating instructional environments [7]. The heuristics are divided into *internal motivation* categories of challenge, curiosity, control, and fantasy and *external motivation* categories of cooperation, competition and recognition. Each of these as applied to learning design is discussed next.

The challenge criteria consists of four dimensions; goals, uncertain outcomes, performance feedback and self-esteem. Even though the goals of the game are fixed, the students are free to establish their own goals by formulating more difficult questions related to the topic. At another level, the students can postulate additional rules that make the game progressively harder by making the response time shorter, for example. Uncertain outcome is introduced into the game through the randomness of the order in which questions are asked. Performance feedback is provided immediately after a child hits the true or false button and through a worm that lets each child know how they, as well as other children, are fairing in the game at any point in time. The self-esteem dimension is addressed by gaining confidence of the students by first lighting up the easier questions as judged by the teacher and by building confidence through the game.

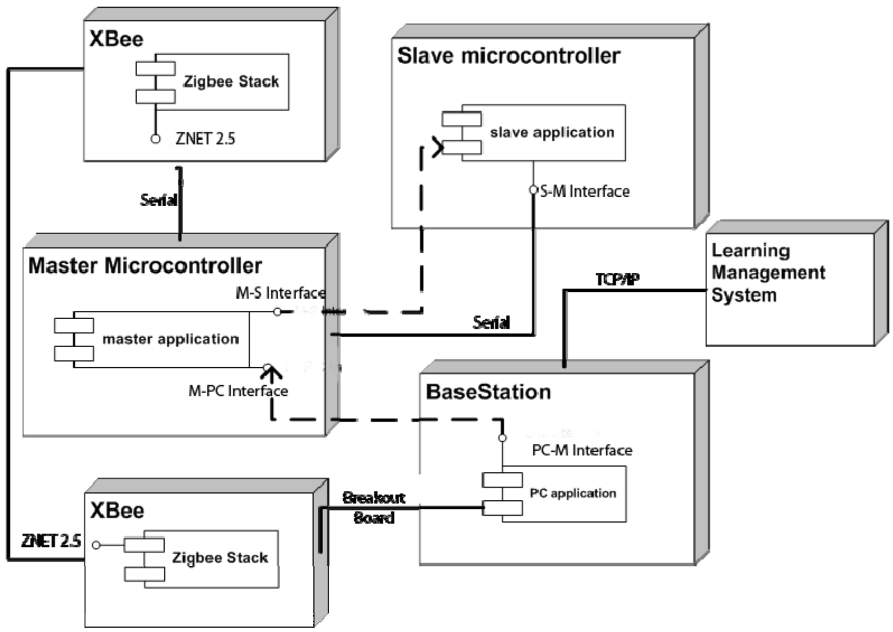
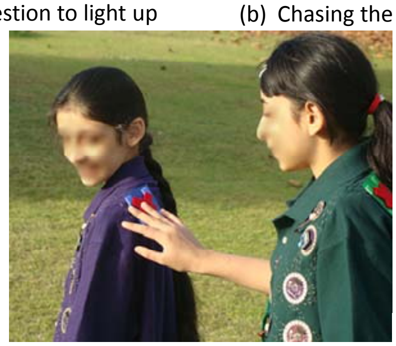


Figure 5. The deployment diagram of prête-à-apprendre

(a) Waiting for a question to light up

(b) Chasing the child with the question



(c) Tagging the child with true or false

Figure 6. Children playing a tag game using prête-à-apprendre shirts (faces have been blurred to protect children's identity)

[7] discuss two types of curiosity; sensory and cognitive. The sensory curiosity is typically achieved by providing variability in audio and visual effects. This is provided in the game via the various bright white

and colored LED's and the buzzer to provide sounds. Since cognitive curiosity is mostly a function of how the learning content is created in a controlled manner to evoke surprise, for example, there is no specific mechanism in this game for cognitive curiosity because the students arrive at the various questions independently. This is an inherent limitation of the game because of its peer to peer assessment model.

Learner control and self-determination is established in this game by giving learners the choice of whom to run after, based on their perception about who they can catch as well as their own ability to answer questions. The fantasy aspect of motivation is primarily embedded in the emotional or psychological aspect of this being a tag game. As mentioned earlier, tag games have a long history and are found across cultures; there is something intrinsic about children wanting to play tag games. However, by the same token because the questions do not have a direct relationship to the mechanism of the tag game, one should not expect this game to have cognitive or *endogenous* fantasy components. Again this limitation primarily results from self-created assessment content by children. If the content were actually designed by a teacher, it is possible to weave an endogenous fantasy similar to RPG games on top of the existing toolkit. Like most outdoor games that are played in front of a large audience, this game also scores well with respect to the recognition aspect of the interpersonal motivation category; a winning player or a team have immediate visibility and recognition. Similarly, the game has a strong component of direct competition both in terms of the cognitive as well as at the physical level. The game has a component of cooperation within a team as different team members need to decide which opponent to pursue to maximize their chances. However, due to the student generated-content, the across-team cooperation component currently does not exist in this game.

6. Conclusion

This paper has presented the design and implementation of prête-à-apprendre, a wearable learning framework for tagging games. The primary purpose of this system is convincing children to engage in more outdoor and physical activities while learning at the same time. This paper describes the start of a journey. The focus has been on a simple two team tag game. There is a large variety of individual and group tag games that can be modified to run on prête-à-apprendre. For example, one common group tag game played in south-east Asia is the game of *Kabaddi*. In this tag game, one challenger enters the opponent's area and has a limited amount of time to avoid being tagged. The traditional game requires an opponent to physically hold on to the challenger to prevent them from leaving opponent's area. Using prête-à-apprendre would, however, require the challenger to be gently tapped by a team member of the opposite team before their time expires with the correct answer. The three questions on challenger's shirt can be lit up in a rotating fashion therefore requiring the right person in the challenged team to tap the challenger at just the right time before the time runs out.

The current work includes extending the kit to include fabric-based question modules that can be tied to trees or hung around Museum pieces, for example. This will enable the construction of learning designs that combine peer to peer assessments with scaffolding from teachers. For example, a teacher may tie a multiple-choice question fabric around a tree and ask the class to identify the type of tree. This will lead to the construction of a variety of foraging games to help children learn about an environment.

The work presented in this paper is in its initial stages and requires empirical validation to ensure that the children will accept these types of games and will actually be motivated to learn. A study including various schools in the region is currently being planned to assess and fine-tune the toolkit before a tournament between the various schools in the region is conducted to collect empirical data.

Acknowledgements

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