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A Multimodal Ambient Intelligence Environment for Playful Learning

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Abstract: This paper reports the design, development and evaluation of a technological framework for learning applications, named AmI Playfield, aimed at creating challenging learning conditions through play and entertainment. AmI Playfield is an educative Ambient Intelligent (AmI) environment which emphasizes the use of kinesthetic and collaborative technology in a natural playful learning context and embodies performance measurement techniques. In order to test and assess AmI Playfield, the "Apple Hunt" application was developed, which engages (young) learners in arithmetic thinking through kinesthetic and collaborative play, observed by unobtrusive AmI technology behind the scene. "Apple Hunt" has been evaluated according to a combination of methodologies suitable for young testers, whereas Children Committees are introduced as a promising approach to evaluation with children. The obtained results demonstrate the system's high potential to generate thinking and fun, deriving from the learners' full-body kinesthetic play and team work.

Keywords: Ambient intelligence, playful learning, pervasive gaming, child computer interaction, evaluation with children, multimodal systems
Categories: H.5.1, H.5.2

1 Introduction

Information and Communication Technologies (ICT) have proven their ability to induce radical changes in human habits, activities and life. ICT have changed what it means for partners to cooperate, for friends to communicate, for families to obtain better quality of life, etc. ICT have influenced the way children socialize, entertain and learn [Druin et al. 05]. Whereas it is evident that ICT change human life and everyday activities, this change does not always prove to be smooth.

While a fast transition has taken place in the private and working environments through the expansion of the (internet-enabled) Personal Computer, the educational environment has been equivalently influenced. Despite all grades of education are going through a wave of computerization, there has been no clear evidence of the educational benefits of ICT in terms of improvements in the students' performance [Cordes et al. 00]. An explanation of this fact possibly lies in the top-down imposed policy decisions for ICT adoption [Jimoyiannis et al. 07], as opposed to the emergence of a student-centred shift of education. According to [Roschelle et al. 00], to induce positive effects on learning, technology must support its four fundamental characteristics: (i) active engagement, (ii) participation in groups, (iii) frequent interaction and feedback, and (iv) connections to real-world contexts.

In the above context, Serious Games, namely games designed for a primary purpose other than pure entertainment, have a significant educational potential, as they are capable of combining all four characteristics in an entertaining environment for learning. Providing a fun and playful approach, games facilitate learning in three ways [McFarlane et al. 02]:

- Learning as a result of tasks stimulated by the content of the games;
- Knowledge developed through the content of the game;
- Skills arising as a result of playing the game.

This paper reports the development of educational technology that promotes kinesthetic and collaborative activity aimed at creating challenging learning conditions through play and entertainment. Kinesthesia, a key concept of this study, refers to the sense of feeling movements of the limbs and body (from ancient greek: *κίνησις*, transl. movement, and *αίσθησις*, transl. feeling).

2 Related Work

The essence of AmI Playfield constitutes an interdisciplinary concept relating to educative AmI environments, interactive floor projects and location-based games.

Educative AmI environments, such as [Karime et al. 08] and [Ndiaye et al. 05], aim at providing education through real-world context activities and are characterized by their facility to suit non-skilled learners and educators for any type of learning or teaching. [Marti et al. 03] argue that their "programming by building" scheme enables everyday people to program via a set of augmented LEGO components (I-BLOCKS). In fact, varied I-BLOCKS, when combined together, result in a tangible application similar to a coded one. While the majority of educative AmI environments implement Tangible User Interfaces (TUI) as a vehicle to learning content, kinesthetic interaction is considerably static, corresponding mainly to hand-manipulation of objects. The "Snark" project [Price et al. 03], implementing a role-playing quest, represents an exception in this category. Integrating multiple modalities, such as PDAs for trail tracing or pressure pads and accelerometer-enhanced jackets for visual interactions, the game activates a rich set of the learner's senses. Overall, existing educational AmI environments do not address performance measurement.

Interactive floor surfaces, firstly introduced as dance platforms, have emerged to more sophisticated versions. They are characterized by a high potential to promote full-body kinesthetic activity and collaborative play, while presenting diverging objectives closely connected to fun. Current prototypes fall under two main categories: Pressure-based and Vision-based interactive floors. In the first category, [Keating 07] and [Visell et al. 10] use a network of pressure-sensitive tiles to create an auditory environment of audiovisual effects and a multi-purpose interactive floor respectively. [Augsten et al. 10] and [Bränzel et al. 13] integrate frustrated total internal reflection (FTIR) into a back-projected floor, allowing for accurate user tracking and identification, based on individual pressure patterns. Overall, pressure-based sensing is beneficial in that (i) it provides whole-room consistent coverage, (ii) is less susceptible to occlusion between users, (iii) allows for the use of simpler recognition algorithms, and (iv) intrudes less on users' privacy [Bränzel et al. 13].

On the other hand, vision-based interactive floors present the advantage of enhanced interactivity through various parts of the body, above the floor level. iGameFloor [Grønbæk 07], performs limb tracking on a glassy floor to offer a framework for learning games, knowledge sharing applications and simulations. Its setup includes 4 underground projectors, each one associated with a webcam for tracking purposes, as well as one ceiling-mounted webcam for coarse-grained tracking of body contours. iFloor [Krogh et al. 04] also uses a ceiling-mounted webcam to track users' movements around a discussion board, projected on the floor. Users' limb gestures, proximities and directions are translated into "magnetic forces" affecting a shared cursor used for controlling the board. Evidently, regardless of their purpose, the majority of interactive floors are not utilized for learning purposes, despite their relative potential.

Location-based games (often referred to as "pervasive") are a remarkable paradigm of enhancing traditional games with technology or creating new real playful experiences, coupled by "life-sized" simulations. Utilizing mostly GPS location awareness and mobile devices, location-based games immerse players into a dual environment, where the limits of the physical and digital world are quite blurry. Well-known examples, such as [Benford et al. 05] [Rogers et al. 04], utilize GPS-based location awareness and PDAs to recreate traditional outdoor game experiences. Such environments which stimulate imagination through narrative elements, within the appropriate physical space, demonstrate a high educational potential [Avouris et al. 12]. Head-Up Games [Soute et al. 07] evolved through simple technology, such as microcontrollers, infrared communication, vibrators, etc., to bypass the inaccuracy of GPS technology. In fact, the Head-Up approach demonstrates such an alternative outdoor design that location awareness accuracy is insignificant. From an indoor perspective, Interactive Slide [Soler et al. 09] is an inflatable slide that embodies infrared artificial vision for location awareness, on which children engage in full-body interactions with projected animations (on its surface).

AmI Playfield, presented in this paper, combines location awareness with multimodality to promote entertainment and learning, enhancing physical play. AmI Playfield constitutes an interaction space, where the user has minimal immediate contact with technology. Offering a variety of modalities above the floor level, the system also supports more flexible forms of interaction. In addition, providing a customizable infrastructure for learning applications, it is suitable for a wide variety of educational subjects and concepts, determined by the content design of each application. Also, AmI Playfield introduces a performance measurement system, using an extendable metric set (see [Section 3.3] for further details).

3 AmI Playfield

AmI Playfield addresses the main objective of providing technological support in an Ambient Intelligent environment [José 10] appropriate for accommodating and encouraging learning processes based on playful learning [Resnick 04] and learning by participation [Roschelle et al. 00].

For this purpose, AmI Playfield embodies a multi-user tracking vision system [Zabulis et al. 10a] that observes activities unobtrusively and provides the basis for natural (kinesthetic) and collaborative interaction. AmI Playfield applications provide the content of learning and determine the logic of interaction. Such user experiences, in which the learner's whole sensory system participates, are believed to foster learning more effectively [Gardner 93], as opposed to the sedentary play style of typical computer games.

3.1 Hardware Setup

The system is installed in a 6 x 6 x 2.5 m^3 room, in which a 4.88 x 1.83 m^2 dual back-projection display is located at the wall opposite to its entrance. The display is implemented by two bright (3000lm) 1024 x 768 short-throw projectors and a projection screen. This setup helps create a large unified display capable of illustrating game activity in multiple views.

The setup also includes an information kiosk, used to host a remote game manager, and several Wi-Fi enabled mobile phones, used as additional game controllers. A surround speaker system, capable of localizing sound in relevance to player location, is installed on the ceiling. The hardware setup of AmI Playfield is illustrated in [Figure 1]

The vision system makes use of 8 *Dragonfly2 Point Gray* ceiling-mounted cameras, which obtain synchronized images. The cameras achieve a high frame rate (> 10 Hz) and a 4 cm localization accuracy. Taking advantage of the multiple viewing angles of the cameras, the vision system offers non-invasive multi-user tracking, as no additional garment or devices need to be carried or worn. Computational vision was preferred to floor-sensor technology for the wide breadth of its applications (localization, shape and gesture recognition, etc.) and the potential they can bring to learning. The main drawback of this decision is an identification confusion occurring when players approach each other at distances less than 10 cm. However, this issue can be overcome in several ways, depending on each game's rules and scenario.

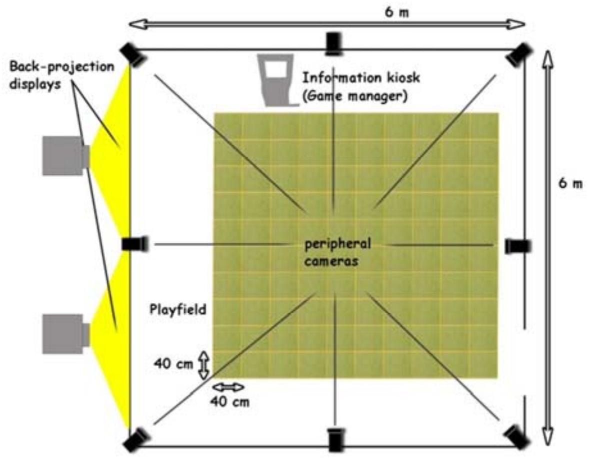

Figure 1: AmI Playfield's Hardware setup

3.2 Framework Design

The playfield consists of a 4 x 4 m^2 carpet, shaped as a grid of game positions by several equally-distanced plastic stripes, firmed with clips. This setup was chosen for safety reasons, while it creates a volatile set of positions, which can be easily modified. A convenient position area of 40 x 40 cm^2 allows for a total of 10 x10 positions grid, which proves very efficient with respect to the 4 cm accuracy of the vision system. Depending on the learning scenario, marks are assigned (both physically and digitally) to each game position that may vary from arithmetic or alphabetic to custom. In particular, arithmetic games use numbers, whereas alphabetic games use characters as identifiers. Extra flexibility is offered by the custom game type that allows any combination among symbols, numbers and characters. In order to mark positions physically, a set of typical stickers can be used.

In its current settlement the playfield ties the game play down to an amount of adjacent positions. However, this grid-form settlement was sought to help players orientate easier than seeking (position) marks in scattered places. On the other hand, the playfield's design can be highly flexible, as it does not impede the operation of the vision system.

Moreover, applications are offered with an empty, sequenced or randomly-marked playfield, according to their game type [*Figure 2*]. The respective floor design has to be applied each time. Within the playfield, players' moves are translated into mark choices by the system, which are further manipulated by application logic. In an alphabetic scenario, for example, a player's move to position "D" could denote the player constructing a word containing the specified letter. Depending on the application design, input from different player moves can be combined in various ways to yield collaborative results. In the above scenario, for instance, a teammates' move to position "A", could result in cooperatively building a word starting by "DA…" or containing the two letters.

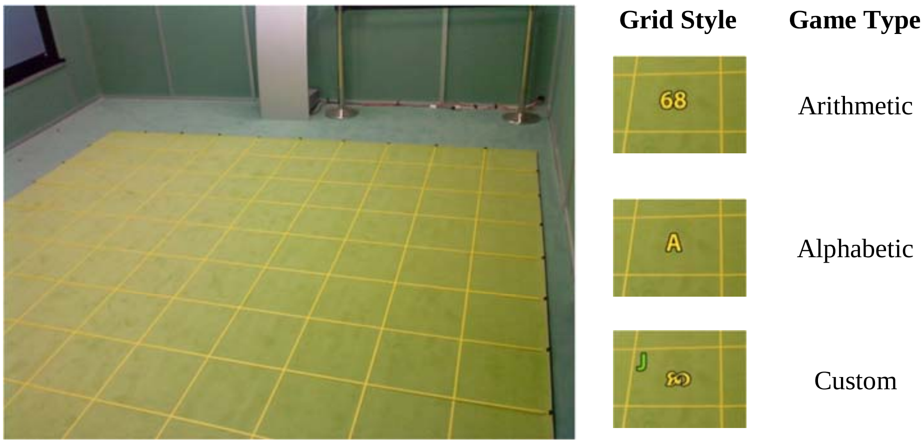

Figure 2: Playfield structure and supported game types

Furthermore, the system optionally generates static targets and obstacles, aimed at enriching the game strategy and defining levels of complexity. Any small objects (dummies) can be used for their physical representation, as their presence does not interfere with the operation of the cameras. Nevertheless, it is the players' responsibility to lay the objects down correctly. Depending on the game scenario, rival-players may also be considered as targets or obstacles. Projected in parallel on the dual back-projection display, various graphical user interfaces convey the image of the game's virtual world. The GUIs are designed to dynamically depict game action from different aspects, in order to aid in the players' decisions and activity [*Figure 3*]. The left view is focused on personalized information, whereas the right view depicts mainly the playfield activity.

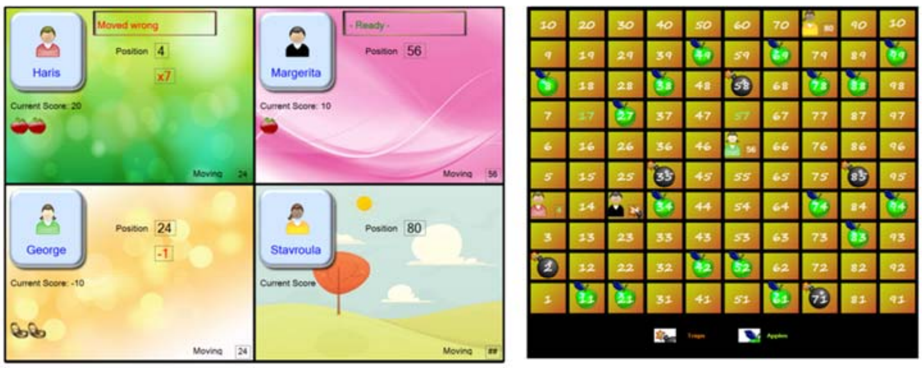

Figure 3: An instance of the back-projection display. Player performance is depicted on the left, whereas an overview of the activity is projected on the right.

Input, in the form of arithmetic operations, characters or/and symbols, can be combined in each application's logic with the positioning input to generate specific results from collaborative actions. Various mobile controller UIs were implemented as ASP.Net web pages [*Figure 4* – right]. Playing using one's own phone, instead of using a special handheld controller, was believed to be both intuitively accepted and attractive, which was justified by the project's evaluation [*Figure 9* – Questions 7, 8].

Speech synthesis is used to enrich acoustic interaction in a natural way. Sound effects are offered to cover routine (repetitive) messages, whereas background music is also available, in order to promote a feeling of joy and vigilance.

AmI Playfield modalities are orchestrated via the FAMINE middleware infrastructure [Georgalis 09]. In particular, FAMINE provides the abstraction required for framework – application communication, by providing an API for describing services and generating the related libraries in a multi-platform manner. Thanks to the middleware server-client architecture, applications (as clients) are enabled to easily extend the established user interfaces (UIs). Also, apart from the positions grid rationale, every constituent of AmI Playfield can be configured by a thorough description of its features under request (through an XML-based mechanism). Having integrated the FAMINE components, applications need to contribute their specific interaction logic and learning content, as well as any additional modalities that may not be covered by the framework. Section 6 is intended to demonstrate the framework's scalability through a couple of designs of playful learning applications.

Overall, the framework logic was entirely developed in .Net (mainly WPF), in conjunction with XML for its configuration facilities. .Net provides an efficient 2D GUI-designer and good interoperability with the MS Excel^{TM} sdk and MySQL databases, used for performance reporting purpose, and data storage respectively.

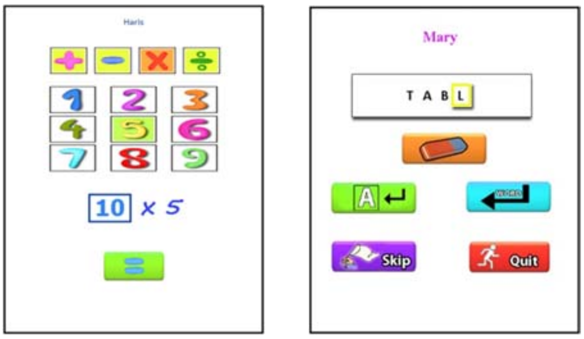

Figure 4: The mobile controller UIs developed so far. Left: The arithmetic UI, designated for arithmetic-scenarios. Right: The alphabetic UI,designated for word / letter - scenarios.

3.3 Performance Measurement

AmI Playfield supports performance measurement in a kinesthetic educational context. Using a MySQL database the system stores all player actions (moves, mistakes, wrong input, successful choices, etc.) for further processing. The results are presented to the players at the end of a game as "fun statistics", which summarize the game activity in the form of awards or improvement prompts. [*Figure 5* – left], describes the default metrics defined by the framework.

In addition, an analysis of the players' performance is output in Excel reports at the end of every game [*Figure 5* – right]. The default performance measurement scheme, visualized in [*Figure 5*], can also be extended by additional application-level statistics.

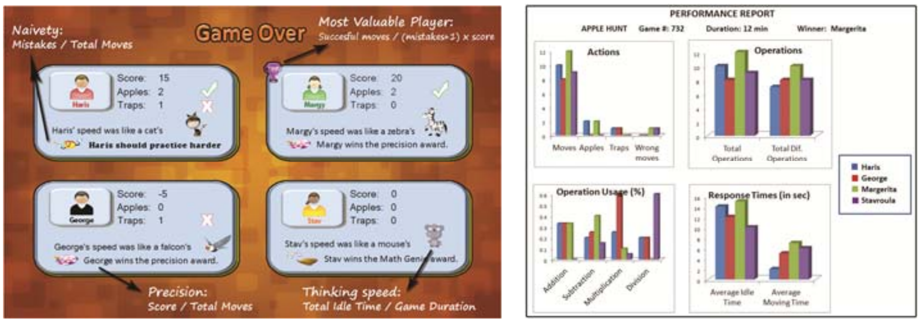

Figure 5: Left: An instance of Fun Statistics. Right: An extract of a Performance Report that summarizes each player's activity in terms of total moves, target hits, wrong actions, command usage, response times, etc.

4 Apple Hunt

AmI Playfield applications provide the content of learning and set the logic of play interaction. Influenced by the research on playful learning applications described in [Price et al. 03] [Zaman 05] , AmI Playfield applications are targeted to: i) fun; ii) challenge; iii) engagement; and iv) learnability.

Apple Hunt is an educational application that was developed in order to assess the degree to which AmI Playfield facilitates the development of kinesthetic educational games, and investigate whether educational games integrated within this environment can have a positive influence on learning. Apple Hunt addresses fundamental arithmetic operations and is oriented towards elementary school children. In this context, free-form collaboration is meaningful in the team mode, where teammates have to reach more targets in total than the rival team. A prototype of Apple Hunt has been implemented and runs in a laboratory space of ICS-FORTH.

4.1 Overview and Features

For the purpose of this game, the grid is transformed to shape 100 positions, marked with sequential numbers, from 1 to 100. Numbers follow a zig-zag order within a grid of 10x10 positions.

Apple Hunt defines various targets and obstacles, represented naturally by apple and trap dummies, which are randomly placed on the playfield, according to the system's output. The objective of the game is to pick as many apples as possible by the end of the game, avoiding the traps. By customizing the infrastructure of AmI Playfield, the game features:

- A four-player capacity;
- A variety of difficulty levels related to the ratio of traps (obstacles) to apples (targets);
- The entire range of AmI Playfield UIs. In addition, the game restricts the arithmetic controller from allowing decimal numbers or numbers higher than 9;
- Arithmetic-type performance reports, extended by the "Math Genie award" (gained by each player who achieves to use all four mathematical operations flawlessly).

Figure 6: The Apple Hunt game: Two teams compete in quick gathering the apples on floor, while executing simple arithmetic operations with their mobile controllers (in order to target their following positions).

4.2 Game Play

To log in the game, each player is provided with a mobile controller, which prompts for profile creation or the use of an existing one. Upon log-in, the system responds with the generation of random player, target and obstacle positions, and the controller interface displays a Calculator pad [*Figure 4*], enabling the user to submit commands in the form of arithmetic operations. The players then have to prepare the playfield by placing apple and trap dummies on the appropriate (system-generated) positions and occupy their own starting positions, which are also automatically generated by the game. Action begins.

The players collaborate freely in coordinating their actions to gather the most of the apples available on floor, while calculating simple arithmetic operations required for moving from one place to another [*Figure 6*]. In particular, players may add, subtract, multiply or divide the number of their position (1 – 100) by any number from 1 to 9. Running, yelling, jumping or even "cheating" with the help of the attendants are all part of the game, while traps impede in the players' efforts. Moreover, targeting out of bounds (lower than position '1' or higher than '100') signals the end of the game for the respective player. Each apple hit adds 10 points, whereas trap hits cost 5 points to the personal / team score. The game ends when all apples are picked, which normally lasts from 5 to 15 minutes, depending on its difficulty level.

To move around the playfield, each player must first target a desired position using the mobile controller, while no turn-restrictions apply. For this purpose, they have to input an arithmetic operation that begins with the number of their current position and results in their target one. For example, standing on position "5" and targeting "25" would require a "multiply by 5" command. Upon submit, they are allowed to move towards the targeted position.

Strategic play not only induces careful choice of target positions, but also leads to analytic thinking of the optimal arithmetic operation that will minimize the actions (commands and moves) required to reach the apples. Apart from the presence of apple and trap dummies on the game floor, strategic play is also accommodated by the visual display, which provides a dynamic sky-view of the game. In the end, the winner (or winning team) is judged by the highest score (or score sum), as a result of the best balance between apple and trap hits. The "fun statistics" (described under [Section 3.3]), presented in the end of each game, are designed to reward intelligent play.

5 Evaluation

Games, in contrast to productivity applications, are designed to entertain. [Pagulayan et al. 03] stress the importance of considering the differences between games and productivity applications in evaluation design, indicating that games evaluation should overrun typical usability assessment. The reason is that the emphasis in playful activities does not necessarily lie in efficiency, but rather in pleasure and fun.

The evaluation of Apple Hunt addresses this issue, by entailing a variety of children-oriented evaluation methodologies and theories [*Table 1*], while introducing Children Committees, a sort of evaluators committee constituted at the end of a game series. Moreover, the evaluation was aimed at measuring the objectives set for AmI Playfield applications along with the system's performance according to the seven types of problems in games [Pagulayan et al. 03], as per [*Table 2*].

The evaluation of the Apple Hunt game so far has involved 9 children in total. All children had a considerable experience with computers and technological gadgets, whereas most of them had been playing computer games since long. Their age varied from 7 to 11 years old, while 6 out of the 9 participants were 6th-grade elementary school students (10 – 11 years old, according to the Greek educational system).

Phase	Methodology	Duration
1. Familiarization (Practice)	Think aloud & active intervention [Zaman 05]	30 min
2. Free game	Observation [Hanna et al. 97]	60 min
3. Evaluators' committee	Children Committees & laddering [Reynolds et al. 98]	30 min

Table 1: An overview of the evaluation phases

Apple Hunt objectives	Types of problems in games
Fun, Challenge, Engagement, Learnability, Collaboration, Kinesthetic activity	Usability problems on the cognitive and physical level, Inefficiencies, Challenge problems, Fantasy problems, Curiosity problems, Control problems

Table 2: The evaluation parameters, applying to all three evaluation phases

During the *first phase* (practice), the children practiced in teams of two persons playing in turns, with only one team participating at a time. This arrangement helped the participants engage in discussions, which seemed to overweigh the drawbacks of the Think Aloud method. The main interest in this phase was to realize possible misconceptions or difficulties caused by the system's features.

In the *second phase* (free play), the game was played by two teams, but this time only one member per team was supposed to act within the playfield, while the others stayed aside to provide support, holding a pencil and a notepad, useful for calculating complex arithmetic operations. Therefore, during the test two rival players were acting in the playfield simultaneously. This phase was devoted to free game, since by this point the players had already been trained into the AmI Playfield and the rules of the Apple Hunt game. This phase was assessed by *observation*, as the most appropriate practice in understanding the children's feelings, according to [Hanna et al. 97]. This method proved valuable in figuring "what was fun" or "what was boring" (impacts in challenge and engagement), etc. The performance reports [*Figure 5* – right] produced by the system were used to extract information manually about regular problems (mistakes) during subsequent games. Controller logs were also analyzed to assess the controller's interface usability.

The third phase involved the composition of a children committee. Each child was provided with a variation of the Smileyometer [Read et al. 06] (see [*Figure 7*]) as their assessment tool. The children were placed in hemicycle fashion facing a facilitator, who addressed a series of questions to them [

Figure 9]. They were asked to answer each question by raising the appropriate card simultaneously, while he performed laddering (encouraging oral reflections) whenever judged necessary, in order to extract as much of the committee's comments.

Figure 7: The picture cards designed for the children committee in ascending order.

The children committee approach was partly influenced by the Problem Identification Picture Cards methodology [Barendregt et al. 05] in the sense of "assigning" feelings to the game's features under question. Nevertheless, this approach differs considerably in two main points. First, the cards used in this study reflect a Likert-type scale (1 to 5 rating scale), in contrast to the eight specific emotional conditions of Barendregt et al. (*Boring, Don't know/understand, Fun, Difficult, This takes too long, Childish, Silly and Scary*). Secondly, children committees are post-test oriented, whereas the Picture Cards methodology is utilized during the test. It is unclear if the latter can be efficient in fast-paced games, where testers' reflexes are important. Compared to the Smileyometer method [Read et al. 06], children committees address one key difference. Children hold immediate contact with a single researcher, who practices laddering upon their ratings. This process is more likely to lead to detailed observations and open discussions of all directions than the children just ticking the smiley faces.

5.1 Findings

Given that the same evaluation parameters where applied in each phase, the findings reported in this Section have turned up through a compilation of all phases' results.

Fun. Fun assessment based on observation, as according to [Hanna et al. 97], observing children's expressions has more to offer than expecting reliable responses from oral communication. The main findings relating to this parameter include expressions of joy and laughter, enhanced by all participants' spontaneous will to continue playing at the end of the sessions. Negative expressions or boredom were not observed.

Challenge. The participants appeared highly willing to play again and again, and half of them expressed their content for experiencing jointly "movement, thinking and team work during play". Moreover, some participants of different age appeared unevenly challenged, while their cognition level played a significant role on their perception of game complexity. This fact indicates that complexity scaling was not adequate to accommodate their age and cognition level range.

Engagement. Considering Whitton's theory on games evaluation [Whitton 10], engagement is closely related to challenge and the perceived value of play, which, in this case, relate to the player's age and cognition level. Hence, the younger were the children the lower was their perceived value of play. Conversely, the older they were the simpler they conceived the game. The fact that all participants were eager to contribute to the evaluation discussions, even by repeating foresaid suggestions, indicates an overall high level of engagement.

Learnability. Independently of the age and cognition variables, learning the game did not pose difficulties to the participants. Performance reports showed that wrong actions were minimal, whereas the game's rules were easily understood during the practice phase. The children's age and cognition level was positively correlated with their understanding of the playfield's arrangement and their orientation within it. In addition, 3 out of the 9 participants reported confusion deriving from the graphical interactivity of the display's and the controller's interfaces.

Kinesthetic activity. The children appeared considerably active during the free-game phase of the evaluation. As a fraction of time, their activity was approximately manifested as follows: Concentration & thinking (20%), oral collaboration (40%), body-turns (10%), walking or running towards new positions (25%) and jumping (5%). Apple Hunt proved to encourage a natural flow of body motion, which may not be constant - as players need to stand while calculating -, but is definitely intense while manifested. From the participant's aspects, this kind of kinetic play was unanimously preferred to the typical sedentary style of play promoted by most computer games [*Figure 9* – Question 2]. Examining *kinesthetic potential* through the framework of [Fogtmann et al. 08], the game can be enhanced in terms of sociality and kinesthetic empathy, meaning that there are possibilities for design of player interactions dependent on other players' movements (e.g. hunting players in addition to apples).

Collaboration. Intense team work was demonstrated during all the games played, which has been a critical factor of the players' immersion. It is believed that collaboration under a common goal worked as "ice-breaker" among them and also aided in that none of the young evaluators was stressed due to the presence of previously-unknown persons, thus unleashing fun. Even if collaboration was planned to be evaluated solely by observing the children's activities, the first group spontaneously mentioned their pleasure for "the game's team-spirit".

Thinking and learning. Observing the gameplay showed that the players sensed the more they mastered their thoughts the faster they would move. Thinking was supported by the presence of partners around the playfield, which helped players focus on their team work rather than on the rival's performance. Even if thinking is undoubtedly a prerequisite for learning, the evaluation of learning quality requires further testing in the long run, involving a stable sample of participants. The performance metrics set provided by AmI Playfield shall be used as a reference point towards this achievement.

5.2 Discussion

The adopted evaluation technique proved joyful and productive. This is attributed to the high variety of evaluation methodologies used (think aloud and active intervention, observation, children committees with picture-cards and laddering) and the unbound collaborative play performed during the second phase. Further, the evaluators' committee approach (during the last phase), helped the children imprint experiences from the uninterrupted play and commit in fluent discussions both among them and with the facilitator, producing useful feedback. The picture-cards concept, based on related ideas of [Barendregt et al. 05] and [Read et al. 06], appeared to be positively perceived by the children, as demonstrated by their desire to use the cards even when they were not required.

5.3 Post-evaluation Improvements

Apart from their strengths manifested, the framework and the game designs revealed several areas of improvement. First, the challenge variance, discussed above, indicates that Apple Hunt's difficulty levels and play modes could be redesigned, in order to enhance the complexity, which mainly depended on the ratio of traps (obstacles) to apples (targets). To address this issue, levels were redesigned to suit a wider variety of scenarios. The newer design facilitates inexperienced players experimenting with arithmetic operations, as they are allowed to play within a limited space for easier operations and even cancel their choices. Also, no traps are present and therefore, score can only rise. Completing a level, players may advance to more difficult ones or enable competitive play, while facilitating features progressively decline.

Secondly, the evaluators suggested higher independence from the information held by the visual displays. For this purpose, mobile controllers were redesigned to entail all information needed, in order to be used as an alternative source of feedback. Personalized sound effects were also included to aid in this process.

Thirdly, it was noticed that calculating complex operations (e.g. 89 : 7) was hard to accomplish mentally by the kids and could bring about frustration during play. As a result, a handwriting controller was designed [Figure 8] that allows both note taking and command submission. This new UI is available as an alternative controller and may be switched back to the default at any time.

Figure 8: The handwriting UI of the mobile controllers. Left: Targeting a position by forming the appropriate arithmetic operation. Right: Note taking can help at complex operations

Finally, music appeared to be a critical factor of performance during playful learning. In fact, a part of the players, which reported loss of concentration, were stressed due to the sounds of waltz chosen for Apple Hunt. While no clear conclusion was drawn with respect to this matter, music was disabled and reserved as a subject for further research.

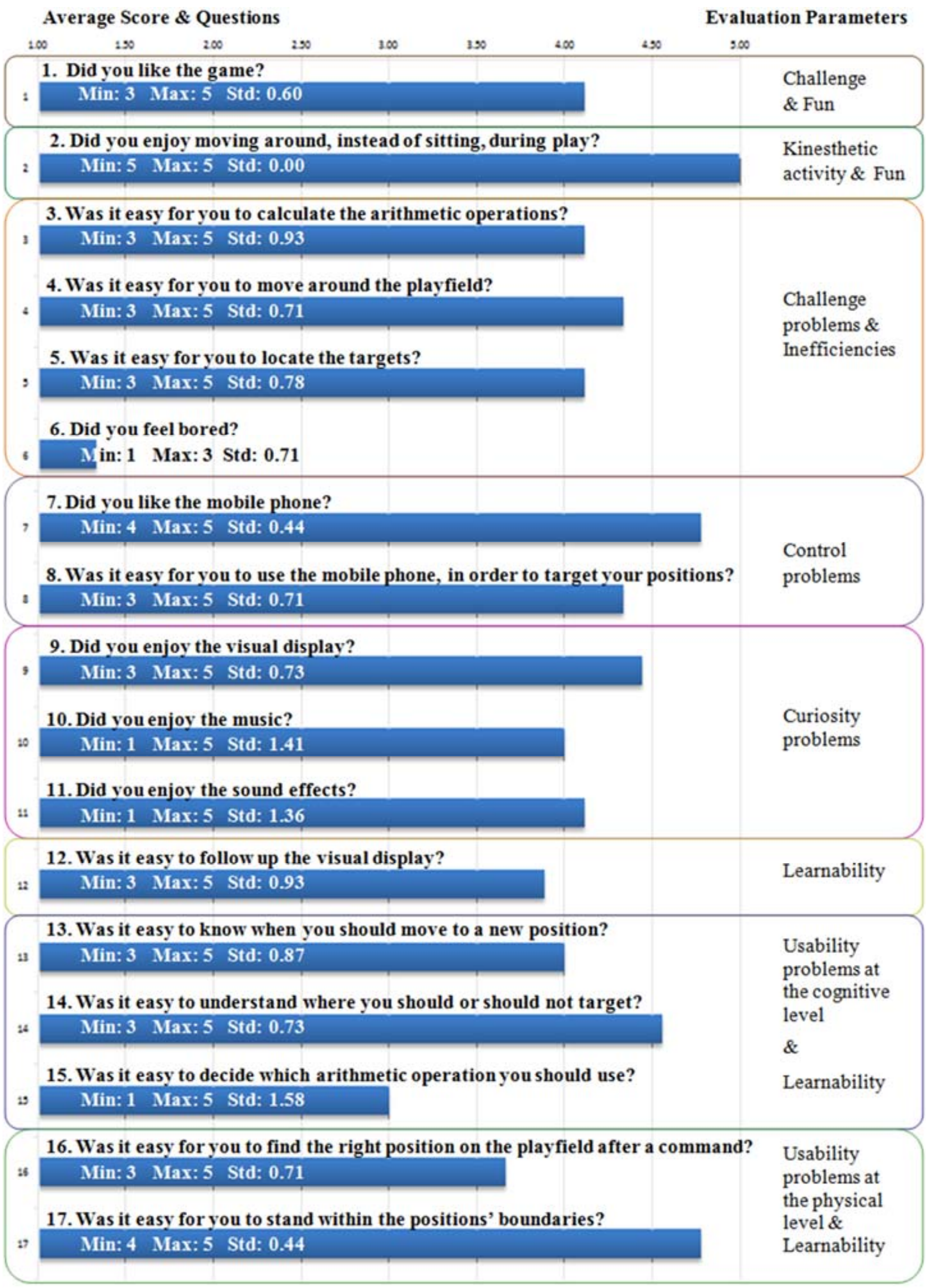

Figure 9: Average committee score per question in parallel to the corresponding evaluation parameters. The findings here consist only a part of the final assessment of each evaluation parameter.

6 Alternative games scenarios

6.1 An Alphabetic scenario (Scrabble variation)

Considering the board of the well-known Scrabble game [*Figure 10* – Right], AmI Playfield could easily serve for a kinesthetic variation. Scrabble is a word game in which two to four players score points by forming words from individual lettered tiles on a game board marked by a 15-by-15 grid. In the AmI Playfield scenario, the players use the (alphabetic) mobile controllers to assign one letter at a time to their positions. In particular, each player has to move on a selected position and then submit the letter using the controller. Physical lettered tiles can be used either simply as floor marks or as an alternative to the controller usage. In the latter option, the computational vision system needs to be configured to recognize the tiles. Obstacles can be utilized to neutralize positions and introduce difficulty levels, discriminated the number of obstacles in use. Moreover, the system takes care for performance reporting, by keeping track of a variety of metrics, such as 'characters usage', 'thinking time', etc.

Figure 10: A design of the kineshetic - Scrabble GUI (left), paralleled to the original board game (right)

On the other hand, the application logic encapsulates operations like word validation, spelling checks, score keeping and interaction extension. Word validation and spelling checks can be based on any open-source dictionary. Also, players' score rises on correct word submission and lowers on wrong words. Spelling mistakes affect the final score, whereas a bonus is offered for difficult word submission. Finally, the application offers additional GUIs for scoring rules and the players' letter availability.

6.2 The Farmer's Role Playing scenario

A role playing scenario would transfer players in a real-world situation, where they act as if it was really happening. For this purpose, a game was designed, which simulates a vegetable market, in which players undertake the responsibilities of farmers [*Figure 11*]. In short, each player (farmer) is offered with a part of the playfield to produce vegetables and sell them in the market. Therefore, farmers can plant dummy vegetables, by placing them on the grid. Vegetables "grow" in varied tempos and yield varied returns. Consequently, farmers have to cope with a limited budget, within a limited space in order to meet the (digital) customers' needs, which appear in irregular intervals.

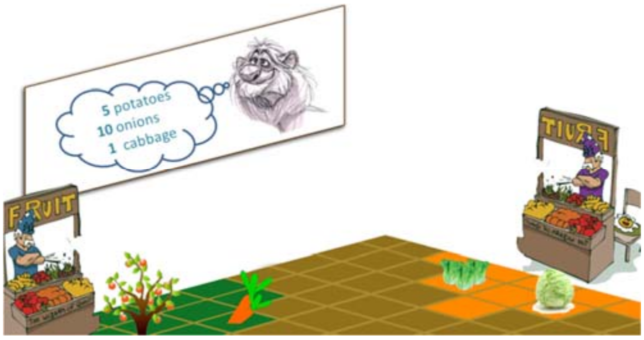

Figure 11: An imaginary design of the Farmer's role – playing game

The application makes use of mobile devices for price setting and selling agreements with the digital customers. Vegetable growth is shown in terms of potential harvest and displayed electronically. Also, the game requires the development of the customers' graphical representation, which is not included in the existing GUI set of AmI Playfield. This game is not motion-intensive, as it exercises mainly the players' accounting and negotiation skills (when transacting with other farmers). However, kinesthetic activity is required for planting, harvesting and, optionally, while engaging in agreements. Finally, cooperation is encouraged by the "customer satisfaction" rule that triggers extra credits for the farmer with the highest demand fulfillment. Hence, farmers are motivated to exchange products regularly in order to cope with demand gaps.

7 Conclusions and Future Work

This paper has reported the development and evaluation of a technological framework for learning applications, named AmI Playfield, which constitutes an educative Ambient Intelligent (AmI) environment aimed at creating challenging learning conditions through play and entertainment.

With respect to previous efforts, AmI Playfield emphasizes kinesthetic and collaborative technology in natural playful learning, while embodying an innovative performance measurement system. Providing an appropriate framework for developing learning applications with extended customization facilities, the system supports a wide breadth of educational subjects and concepts.

Addressing the objective of uncovering the system's potential to encourage kinesthetic and collaborative play, the prototype "Apple Hunt" game was developed. "Apple Hunt" is an educational game designed for elementary school children, which aims at exercising players in fundamental arithmetic operations. The evaluation of Apple Hunt intended to assess the effectiveness of the system's technological features that encourage and contribute to learning. Furthermore, children committees, a fresh approach to evaluation with children, were introduced. The application of this methodology is believed to bring an interesting potential in the context of Ambient Intelligent Environments and educational games, as demonstrated by the children's forward discussions and high engagement during the conducted process.

According to the evaluation results, Apple Hunt, and consequently AmI Playfield, prove to satisfy their purpose to a large extent. Their value lies in that they successfully promote kinesthetic activity, collaborative work and thinking in an entertaining multimodal environment. On the other hand, potential improvements of their current implementation are related to the lack of complexity scaling and to interactivity issues.

In conclusion, the work presented in this paper constitutes an encouraging step towards the adoption of entertaining educative practices for young learners that not simply foster their cognitive evolvement, but also benefit their emotional, social and physical development.

The future priorities set for AmI Playfield in the short run relate to interactivity and facilities enhancements. In particular, speech and gesture recognition, as alternatives to mobile controllers, are planned to minimize the players immediate contact with electronic media. Moreover, they are expected to enrich game play by new possibilities, such as communicating with digital characters or casting spells.

New games, such as the ones described in [Section 6], are planned to be developed in order to experiment with a wider variety of rationales and requirements. Parallel to the above, a full scale evaluation of the Apple Hunt game is scheduled. Finally, the learning quality achieved in the context of AmI Playfield is planned to be evaluated in the long run with different games through longitudinal tests.

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