Modeling and Assessing Young Children Abilities and Development in Ambient Intelligence

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Abstract. This paper presents a novel framework, called Bean, which aims to monitor, evaluate and enhance pre-school children's skills and abilities through playing in Ambient Intelligence environments. The framework includes: (i) a model of children development based on the ICF-CY model and the Denver - II assessment tool, aiming at early detection of children's potential developmental issues to be further investigated and addressed if necessary; (ii) a reasoning mechanism for the automated extraction of child development knowledge, based on interaction monitoring, targeted to model relevant aspects of child's developmental stage, maturity level and skills; (iii) content editing tools and reporting facilities for parents and therapists. The framework has been implemented in the context of an AmI environment for supporting children play in AmI, deploying a collection of augmented artifacts, as well as a collection of digital reproductions of popular games.

Keywords: Child play · Development · Ambient intelligence · Evaluation process and/or assessment

1 Introduction

Ambient Intelligence (AmI) applications aim to improve and enhance everyday living activities for a variety of target user groups, including non-traditional users of interactive technologies. However, the potential benefits and impact of AmI technologies for children and their parents is still to be investigated.

According to [6], children constitute a substantial segment of the market for Information and Communication Technology (ICT) products and services in Europe. A large number of products are available to young children that incorporate some aspect of ICT [31]. These include activity centers, musical keyboards, tape recorders, programmable and radio-controlled toys as well as everyday items such as remote controls, telephones, televisions and computers. This range of toys and devices is part of the move towards pervasive or ubiquitous computing in which technology blends

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into the environment and is not necessarily visible. It is estimated that this market will be worth over €30B in a few years.

ICT has the potential to provide novel opportunities for children to develop and be creative, to develop generic learning skills and aptitudes and to practice their social skills [27]. Under this perspective, ICT can be seen as a new tool that could and should be incorporated into existing early-years practice in developmentally appropriate ways, supplementing, but not replacing, other important first-hand experiences and interactions and accompanied by quality adult input [33, 37]. By introducing state of the art ICT technologies, play can be expanded and enhanced. This is achieved, for example, when children use innovative equipment such as floor robots, smart artifacts, etc. ICT therefore, is seen as offering a range of potentially valuable pedagogic tools when properly utilized [7].

Ambient Intelligence (AmI) offers opportunities for supporting the needs of children and integrate ICT into children's everyday activities. By providing the appropriate modeling, monitoring and adaptation facilities, AmI environments can support day by day the development of young children through playing, and can help parents and experts follow and optimally facilitate this goal. This paper envisions an AmI framework which facilitates the automated extraction of knowledge regarding children's physical and cognitive skills, abilities and overall development based on interaction monitoring, so as to offer indications regarding the child's developmental stage, maturity level and skills. The framework has been design for children whose age of developmental stage corresponds to pre-school age. As a result, the provided technological infrastructure allows matching children's playing activities with their corresponding development stage, but also the detection of potential developmental issues to be further investigated and addressed if necessary. Parents are provided with general information about their child's play behavior. Finally, early childhood professionals are provided with extensive data in addition to the full interaction history for reasoning about whether the child is meeting certain developmental milestones. Child carers (parents and childhood professionals) are provided with information about child's playing behavior and about whether the child is meeting certain developmental milestones.

2 Related Work

2.1 Modelling User Abilities and Performance in Ambient Intelligence

User modelling (UM) has traditionally been concerned with techniques for modeling users and adapting interaction to their preferences, goals, and intentions, as well as to their cognitive and affective states. On the other hand, ubiquitous computing has produced approaches to recognizing and modeling the user's context, e.g., location, physical environment, and social environment. With the advent of smart and ubiquitous spaces, recent research efforts have focused on models that support intelligent environments to capture and represent information about users and contexts so as to enable the environment to adapt to both [20].

GUMO [17] is a general user model ontology for the uniform interpretation of distributed user models in intelligent semantic web enriched environments. Basic user dimensions represented in GUMO include ability and proficiency, personality, emotional state, physiological state, mental state, nutrition and facial expression. D-ME [10] is a multiagent architecture in which users and environments are represented by agents that negotiate tasks execution and generate results according to user in context features. User modelling in D-ME includes four main sections: IDENTITY (with identification data such as the user name, sex, id, password, and email), MIND (background knowledge, interests and know-how), BODY (disabilities or preferences in using a body part during interaction) and PERSONALITY (personality traits and habits). Agent-based user modelling in Ambient Intelligence is targeted to understanding human mental and physical processes and behaviour based on incomplete information provided by the environment in order to obtain appropriate agent reactions [3]. Models of human physiological and psychological states are formalized through a temporal logic and reasoning is performed through the derivation of agent beliefs.

Some user models have also been developed which focus on human functional limitations. For example, reference [5] discusses a model of older or disabled users leading to the creation of personas for design purposes. Reference [26] presents an open library of various categories of virtual user models, including VR models, covering a wide range of population groups and especially focusing on groups in risk of exclusion, e.g. older people and people with disability.

However, children as a dynamically evolving target user group have not been addressed in previous modelling efforts.

2.2 Software Assessment Tools

A range of software solutions have been developed to monitor potential developmental issues of children. Developmental skills can range from banging a toy on a table to displaying socially appropriate expressions [39]. A subset of these milestones are often used in screening diagnostics, and recent research suggests that the observation of object play interactions may help identify early indicators of certain developmental delays [1, 2]. Psychologists have created a coding scheme which quantifies the levels of sophistication displayed by infants while engaged in object play, as play is the most common therapeutic and educational intervention for children.

The Child's Play system [39] supports a subset of play activities, while automatically generating quantitative data from observations of children's behavior, based on the coding scheme of [2]. Measures include factors such as the frequency with which an object is played, the time spent attending between different objects, and the highest level of play sophistication reached by a child. Child's Play uses statistical pattern recognition techniques of sensor augmented toys and a mobile computing platform in order to receive data and identify play activities associated with developmental skills through the way in which children interact with objects [38, 39].

Plush Cube [2] is a system based on micro sensors which detects when a toy has been touched and how tightly it has been grasped, can be a considerably important tool for the professionals. CareLog helps occupational therapists collect better data for decision-making [16]. CareLog seeks to support teachers in a classroom in order to diagnose the causes of children's behavior by allowing retroactive video capture of events to help support systematic decision-making on the cause of the behavior.

Smart Pen has been developed as a tool that supports the therapy of developmental dyslexia, with particular regard to dysgraphia [9]. Smart Pen comprises a display monitor equipped with a high-sensitivity touchpad and specially designed writing tool equipped with pressure sensors. Smart Pen measures the pressure put on the surface of the display, eye-hand coordination and whether the pupil holds it properly or not. The application allows continuous monitoring of different parameters related to writing. All these parameters are stored in a database and can be easily reviewed by the therapist in order to observe the progress for each pupil.

KidCam is a prototype system designed to support the early detection of children with special needs [23]. It is a computer supported baby monitor that allows parents to collect pictures and videos of their child while also providing age-appropriate prompts for parents to enter developmental health-related information about their child. The basic functionality enables the recording of video, audio, and still pictures using either the front or the back camera, as well as reviewing multimedia data based on different annotations that are provided either during or after capture [22]. KidCam uses milestones from a standardized list applied in many pediatricians' offices across the United States, called the Ages and Stages Questionnaire [4].

LENA[1] (Language Environment Analysis) is a commercial system designed to help monitor language development in children, from new born to four years old. LENA uses digital signal processing to parse conversation into words. It monitors and measures linguistic progress by automatically monitoring child vocalizations, words spoken to the child, conversational turn taking, meaningful speech, and exposure to environmental language.

The emergence of AmI environments offer new opportunities in this research direction, as such environments encompass monitoring, modelling and reasoning facilities which can be exploited to the purpose of assessing children development in the context of usual everyday life activities such as playing, and provide a wealth of data on performance in different activities and task without necessarily formally testing each child.

3 Background

3.1 Play and Its Contribution to Child's Development

Child development is a progressive series of changes as the result of interactions between biological and environmental factors [32]. Development includes qualitative and quantitative changes, and is a product of intrinsic maturation and learning opportunities provided in the individual's environment [19]. The human developmental pattern is predictable, following specific phases and exhibiting specific characteristics. Children follow a similar developmental pattern with one stage leading to the next, even though there are individual differences in the rate and the manner that they follow the pattern [19].

[1] http://www.lenafoundation.org/.

Through play children learn, practice and improve skills, involve in social roles and experience emotions; therefore, play is a significant dimension of early learning [29]. According to Piaget, play stimulates interest, initiative, experimentation, discovery, and imagination of a child in order to enhance his capacity to learn [28].

Play "paves the way for learning", as it develops logical mathematical thinking, scientific reasoning, and cognitive problem solving [21]. In addition, it fosters creativity and flexibility in thinking, since there is no right or wrong way to do things [38]. During play, children construct knowledge by combining their ideas, impressions, and intuitions, experiences and opinions. They create theories about their world and share them with others. Due to the fact that play is self-directed, it leads to feelings of self-confidence and competence. As children play, they learn to solve problems, to get along with others and to develop the fine and gross motor skills needed to grow and learn.

Through play, children recreate roles and situations that reflect their sociocultural world, where they learn how to subordinate desires to social rules, cooperate with others willingly, and engage in socially appropriate behavior. Over time, these competencies are transferred to children's everyday behaviors [11]. Many forms of play that evolve over the course of early childhood, variously described as exploratory play, object play, construction play, physical play (sensorimotor play, rough-and-tumble play), dramatic play (solitary pretense), socio-dramatic play (pretense with peers, also called pretend play, fantasy play, make-believe, or symbolic play), games with rules (fixed, predetermined rules) and games with invented rules (rules that are modifiable by the players) [18]. Child's play develops in several stages from passive observation to cooperative purposeful activity [34]. For example, children of age 2–3 engage in symbolic and pretend play and begin to shift from parallel play to more interactive forms of play; between 3–5 years they engage in creative and group play, may begin to play simple board games. Associative play dominates by the 4th year of age as a child learns to share and take turns and is interested in friends; at 5–7 years the child enjoys games with rules, such as board games, plays well with others and enjoys social interaction and play to reach a common goal.

3.2 Knowledge Models and Assessment Tools

There is a great variety of evaluation methods and assessment tools used for identifying child's strengths, diagnosing developmental disabilities, determining eligibility for services, and making recommendations and offering resources where necessary. The work reported in this paper is based on the International Classification of Functioning, Disability and Health for Children and Youth (ICF-CY [40]) of the World Health Organization (WHO) as a universal modelling framework, and on Denver II [13], as a developmental screening test.

ICF-CY provides a common and universal language to facilitate the documentation and measurement of health and disability in children and youth. It is designed to record the characteristics of a child's development and the influence of its surrounding environment. ICF-CY can be used by providers, consumers and all those concerned with health, education, and well-being of children and youth [15]. ICF-CY can be used to document a single problem or a profile of limitations defining a child's difficulties related to health and functioning. ICF-CY provides an essential basis for the standardization of data concerning all aspects of human functioning and disability in the pediatric population by taking into account two relevant issues: (a) the dimensions of childhood disability which include health conditions, disorder, impairments, activity limitations as well as participation restrictions, and (b) the influence of the environment on the child's performance and functioning [30]. It is divided in two parts [30]: (a) Functioning and Disability, and (b) Contextual Factors. These parts are further subdivided into components. Functioning and Disability contains two components: Body Systems (Function and Structure) and Activities/Participation. Contextual Factors also contain two components (Environmental and Personal factors). Figure 1 shows these components and their corresponding functions [40].

Development tests are tools used by early childhood professionals to measure a child's developmental progress from infancy through adolescence. They may help to indicate early signs of a developmental problem and discriminate normal variations in development among children, depending on the age of the child. Such tools are designed according to the expected skills of children at a specific age. Types of development tests include infant development scales, sensory-motor tests, speech and hearing tests, preschool psycho-educational batteries, tests of play behavior, social skills and social acceptance tests [24]. There are many scales commonly used to evaluate and measure developmental skills, such as the Peabody Test [8], the Millani Comparetti scale [35], and the Denver Developmental Screening Test [12] which is the most widely used test for screening cognitive and behavioral problems for ages up to 6 years. The Denver Scale is not a tool of final diagnosis, but a quick method to process large numbers of children in order to identify those that should be further evaluated. It has been designed for use by the clinician, teacher, or other early childhood professional to monitor the development of infants and preschool-aged children. It enables the clinician to identify children whose development deviates significantly from that of other children warranting further investigation to determine if there exists a problem requiring treatment. In the work reported here, the Denver Scale II [13], a revision of the original one designed at the University of Colorado Medical Center, has been adopted. Denver II test uses both parent observation and direct observation for 125 included items in total. The scale reflects the percentage of a certain age group able to perform a certain task related to personal social, fine motor adaptive, language and gross motor skills.

In DENVER II, data is presented as age norms, similar to a growth curve. The more items a child fails to perform (passed by 90 % of his peers), the more likely it is that the child manifests a significant developmental deviation that warrants further evaluation [14].

4 The BEAN Framework

Against the background presented in the previous sections, this paper presents a novel framework, called Bean [41], which aims to monitor, evaluate and enhance children's skills and abilities through playing in AmI environments.

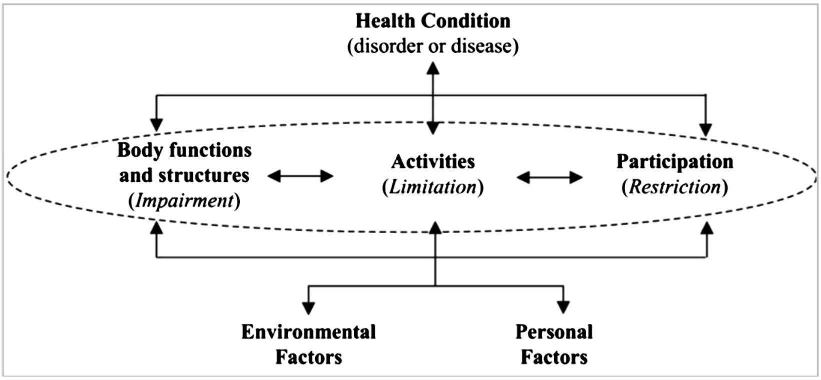

Fig. 1. ICF-CY

As a result, traditional games are turned into smart games that can be constantly adapted to the unique and continuously changing characteristics of each child, and at the same time the environment can act as assessment tool for early childhood professionals, providing relevant information about the activities occurred during playing. Moreover, parents can be informed at any time about children's behavior and performance during play. The system, apart from the initial knowledge about children's characteristics, continuously gathers and stores information about children's skills and abilities (i.e., interaction data) through the use of smart games in a predetermined protocol. The system analyzes this set of data and makes the results available back to the smart games for adaptation purposes, and exposes them to parents or early childhood professionals.

In more details, the framework includes:

- A model of children development based on the ICF-CY model and the Denver-II assessment tool, aiming at early detection of deviations in children's development that needs to be further investigated and addressed if necessary.
- A reasoning mechanism for the automated extraction of child development knowledge, based on interaction monitoring, targeted to model relevant aspects of child's developmental stage, maturity level and skills.
- Content editing tools and reporting facilities for parents and early childhood professionals.

The framework has been implemented in the context of an AmI environment deploying a collection of augmented artifacts, including an augmented children's table, a smart chair, a smart pen, augmented digital dices etc., as well as augmented common physical artifacts such as puzzle pieces, wooden identity cards, toys, etc. Such artifacts are capable of monitoring child play so as to provide the necessary data to the Bean framework to detect progress but also deviation from age-related expectations in playing skills and performance [43]. The ambient set up also offers a collection of digital reproductions of popular games such as puzzles, card games, labyrinths/mazes, (the tower game, the farm game, the mimesis game, etc.), designed with the involvement of

HCI experts and occupational therapists, which can be played on a smart table specifically designed for children [42].

4.1 Bean Model: A Knowledge-Based Data Model

A knowledge base was designed and implemented to act as a centralized repository of information relevant to children's profile and characteristics, smart games, data extracted from the activity analysis process, and interaction history.

The underlying entity data model is called Bean model (see Fig. 2). Adopting the structure of the ICF-CY, the top entity of the Bean model provides information (e.g., title) about each used ICF-CY component, such as body functions and activities.

The subset of skills and abilities selected as the target of the proposed monitoring and evaluation functionality was discussed and elaborated in collaboration with early childhood professionals. Such skills and abilities regard various ICF-CY codes of Activities and Participation) that a smart game may require. Each activity involves a number of body functions and this is reflected in the model through linking activities to the related body functions. Further properties stemming from ICF-CY are used to describe in more detail both activities and body functions. The Denver II scale is imported in the model in order to provide relevant information about expected child's capacity in selected activities. The entity representing expected capacity by age contains Denver II's scale data (i.e. age, capacity) that reflects the percentage of a certain age group able to perform the connected activity. Table 1 depicts a representative sample of the initial subset of activities and the involved body functions.

In the context of interaction monitoring, it is essential to model human tasks that a child may execute during play as reactions to system output.

Similarly, the Bean model describes system tasks regarding the employed communication functionality (both for input and output) between the user and the system (Table 2). Through the augmentation of everyday objects and the implementation of a novel sensory infrastructure [41], in the AmI environment a smart game is able to monitor and evaluate the play performance for selected required activities. These activities are categorized into general or specific according to the significance or impact they may have in child's play performance. Required activities are linked to: (a) the corresponding smart game, (b) the actual ICF-CY activity, (c) a subset of the activity's associated human tasks that may carry further description to define more accurately the user interactions during playing (with the corresponding smart game), and (d) a set of the employed system tasks required for the implementation of a certain smart game. A one-to-many relationship is established between required activities and a detailed description of a required activity's human tasks that may occur during playing a selected game. Similarly, a one-to-many relationship is established between required activities and system tasks.

The model also encodes the monitoring results during playing in a performance record. The latter is responsible to estimate the child's play performance in each required activity according to the current gameplay. In detail, the record contains an estimated score of child's play performance for a selected required activity within the

Table 1. Example of activities, expected capacity per age and body functions

ICF-CY Activities		Expected capacity				Involved body functions
		3y	4y	5y	6y	
Applying knowledge	**d1601**, Focusing attention to changes in the environment	25	50	75	100	**b1400** Sustaining attention
						b1401 Shifting attention
	d161, Directing attention	25	50	75	100	**b140** Attention functions
						b1400 Sustaining attention
						b1401 Shifting attention
						b1402 Dividing attention
						b1403 Sharing attention
	d130, Copying	25	50	75	100	**b147** Psychomotor functions
						b163 Basic cognitive functions
Basic learning	**d131**, Learning through actions with objects	25	50	50	100	**b760** Control of voluntary movement functions
						b1565 Visuospatial perception
						b163 Basic cognitive functions

Table 2. Modeled system tasks interfacing user for both input and output

1 Gesture/Posture recognition - (system input)	2. Presentation of still images – (system output)
3. Head pose estimation using – (system input)	4. Presentation of audio – (system output)
5. Face tracking – (system input)	6. Presentation of text – (system output)
7. Skeleton tracking – (system input)	8. Presentation of animation – (system output)
9. Speech recognition – (system input)	10. Presentation of video – (system output)
11. Physical object recognition – (system input)	12. Presentation of speech – (system output)

(*Continued*)

Table 2. (*Continued*)

13. Cursor recognition (Multitouch) - (system input)	14. Sign language - (system output)
15. Force pressure recognition at the interaction surface - (system input)	16. Braille; tactile writing system - (system output)
17. Force pressure recognition while sitting – (system input)	18. Other assistive devices for people with hearing, voice, speech, or language disorders
19. Force pressure recognition at the pen's tip – (system input)	20. Other assistive technologies for people with visual disorders
21. Motion sensing cube (e.g. dice) - (system input)	

range 0–100. Playing sessions are modeled as the time interval during which a child plays a specific game.

The basic user profile contains demographic user data as well as user roles in the system (such as child, parent, child development expert, administrator, etc.).

Children profiles are linked to: (a) sessions, (b) activity limitations, which refer to a list of activities in which the child has limitations, and (c) body functional limitations, which refer to a list of body functions in which the child faces (functionality) problems. Moreover, children profiles are linked to the respective parents' and professionals profiles. Finally, smart games are modeled and linked to a list of activities required for playing with a selected smart game and a list of sessions during which the game was played. The Bean Model is delivered with a software suite which provides content administration facilities and monitoring utilities suitable for use by early childhood professionals and parents.

4.2 Reasoning Mechanism

Child development monitoring is facilitated through a reasoning mechanism built upon the Entity Framework to access the Bean model. During play, the selected smart game is responsible to monitor and evaluate child's play performance and commit a representative score (range 0–100) to the reasoning mechanism. The latter monitors and assess child's maturity at the various levels of a selected smart game. In detail, it collects and analyzes the child's play performance commitments regarding specific and general activities required for the active game level and makes appropriate adaptation suggestions back to the smart game.

Activity analysis is based on the identification of the tasks which are involved during young children's play. Task monitoring (when applicable) may result into the measurement of the play performance and capacity which, in comparison with Denver II scale's expected scores, can drive to the extraction of useful indications about young children's development.

Play Performance is a measurement concept that describes what tasks a child performs while playing in a specific context and environment [41]. **Capacity**, on the other hand, indicates the highest probable level of functioning that a child may reach in the ICF-CY domain of Activities and Participation at a certain moment [41]. Capacity is measured in a standard environment, in order to reflect the environmentally adjusted ability of the individual. In summary, a capacity qualifier specifies what a child can do independent of context, i.e., in a standardized environment, whereas a performance qualifier specifies what a child does in a current environment, i.e., functional skills used in everyday life situations [25].

Data are collected from the first playing session of a game and repeatedly after some period of time, i.e., after one month or after a number of sessions. Through statistical analysis the reasoning mechanism extracts the current child's capacity in the execution of various activities and estimates the developmental rate based on the entire interaction history (i.e., play performance commitments). The analysis is conducted using time series forecasting methods (i.e., weighted moving average). The recorded data are imported to the time series in order to generate the developmental curve of the targeted specific activity of the currently active game level. In the weighted moving average model, every play performance value is weighted with a factor from a weighting group. Thus, recent data have greater influence. This approach was chosen because more recent play performance data are more representative and reliable than older data. Therefore, the reasoning mechanism is able to react more appropriately to a change in the play performance during playing. The accuracy of this method depends largely on the choice of the weighting factors which were determined with the help of early childhood professionals. The selected factors are $W_{15} = 15$, $W_{14} = 14 \ldots W_1 = 1$. The capacity of a required activity (AC) is the product of the following formula

$$AC = \frac{\sum_{t=1}^{n} W_t \times V_t}{\sum_{t=1}^{n} W_t}$$

where ***Wt*** is the weighting factor, ***Vt*** is the value of the play performance, ***n*** is the number of the weighting factors (n = 15) and ***AC*** is the average value representing the child's capacity to execute a required activity.

Based on the analysis' results, the reasoning mechanism is able to identify children whose play performance deviates significantly from the average of their age. Based on the result, a smart game can adapt to the child's evolving skills so as to choose the most appropriate level according to child's estimated abilities.

4.3 Reporting Facilities

Indications of the achieved maturity level and skills of the child are provided in reports to parents and early childhood professionals. These reports contain information about the child's capacity to execute the activities involved during game playing. Low capacity scores may be an indication of a functional difficulty that a child may have in a given developmental area. Capacity indicators are reported according to data collected at certain points in time, child's age, and degree of independent completion of the game or some specific tasks.

Two types of report are supported, a basic one for parents (see Fig. 3) and an extended one for early childhood professionals. Both types of report include child's profile characteristics such as impairments, system factors (information of the environmental factors in which the data has been collected), history of interaction (number of session, total number of sessions for the smart game, etc.), overall capacity according to age standards and the completion of the predefined levels (measured playing without help), level in game, explanation of the graphical representation specifying the level of difficulty encountered by the child in each task (no difficulty, slight/mild difficulty, moderate/medium difficulty, high/severe difficulty), and recommendations if the child reaches score values below age level.

The professional's report additionally contains information regarding child's performance in tasks or activities during a playing session. Performance data is collected throughout a session, and also contains information about the amount and the type of system guidance and the assistance that the child has been provided.

5 A Case Study: The Tower Game

Various smart games for pre-school children have been designed and developed to showcase, test and validate the Bean framework [41]. For example, the Tower Game [44] has been designed based on sound developmental theories and the definition of expected skills and tools [19, 32].

The Tower Game supports playing through tangible interaction with augmented artifacts. More specifically, the game allows children to learn, identify and compare six different colors on each side of a smart dice with those illustrated on the path of the game.

Some of the body functions involved in Tower Game are: (a) mental functions related to color discrimination and symbols representation of numbers, pictures and other visual stimuli, as well as to visual spatial perception and processing of acoustic

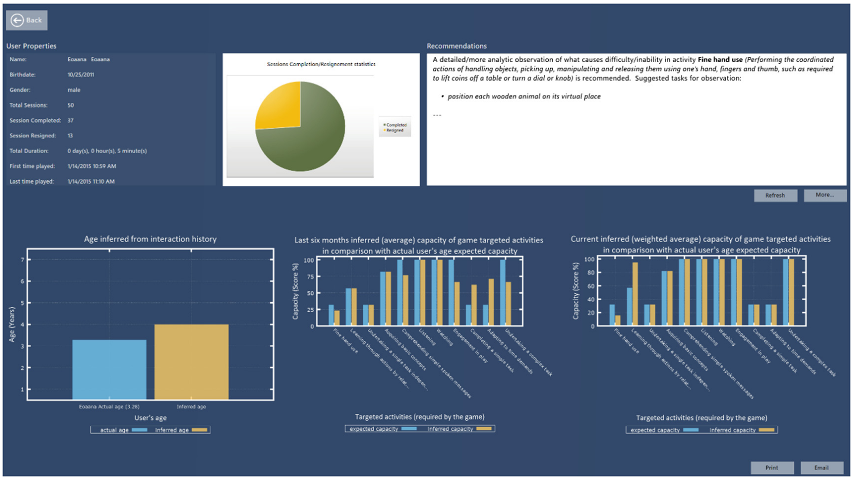

Fig. 2. Bean report for parents

stimuli, (b) mental functions involved in gaining knowledge about the use of objects and the organization and application of that knowledge in tasks, (c) mental functions to produce coordinated and targeted movements, (d) mental functions related to numeracy and writing, (e) higher level mental functions related to attention, thought processing, decision making, time management, space orientation, organization and planning functions, and (f) voice and speech functions. The performance skills of the game include: (a) remaining seated for a required period of time, (b) listening to spoken messages and responding properly, (c) responding to system instructions on time, (d) using various plain and smart objects necessary for playing the game, (e) locating and observing interactive virtual tiles of the maze and other pictures or visual elements, (f) handling objects in a coordinated fashion, (g) pointing an index finger onto virtual tiles in proper direction, (h) learning concepts such as colors and numbers, (i) learning to execute integrated sets of actions so as to follow rules and to sequence and coordinate movements, intentionally maintaining attention to specific actions or tasks for an appropriate length of time, (j) comprehending and responding to the messages conveyed by visual stimulus, drawings and pictures, and (k) ordering and counting.

The game is organized into four levels, each targeting a specific age range within 3–6 years old, following the performance expectations of child's play development. The difficulty of each level is adjusted according to developmental standards, while runtime adaptation is provided based on the child's estimated level of performance. In this way, the digital version of the game extends the age range supported by the original one.

The game is played using a smart dice, a smart custom-made pen and smart cards on a touch-sensitive surface small table specifically designed for pre-school children. In more details, the child rolls the colored dice and moves forward until he reaches the first tile of the same color. If the performed action is correct, he rolls the dice again and continues the previous procedure. If the dice roll is white, a card appears in a random position to which the young child should move. In case he reacts correctly, the card will be added to a staple of similar cards next to the display. The last tile of the path represents the entrance into the tower, however if the player rolls too high, he has to move backwards. The round is over when the rolling result is the exact color or number needed to enter the tower and simultaneously, the player has gathered all the cards. If the child enters at the tower while some cards are missing, he has to continue playing by rolling the dice again.

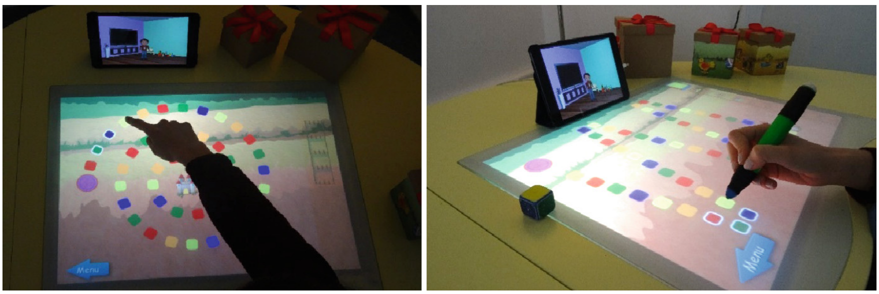

Fig. 3. Playing the tower game on bean table

Play performance in Tower Game is monitored and evaluated through the Bean framework, and appropriate adaptations are fed back to the game. In this way, the game can adapt to the child's evolving skills so as to choose the most appropriate level according to child's estimated abilities. For recording the play performance and player's abilities during interaction, predefined sets of activities for each level are used for elaborating the skills needed for to play the game efficiently.

A preliminary user-based evaluation of the framework has been conducted with the involvement of fourteen children, their parents, two occupational therapists, a psychologist and a special education teacher [41]. The evaluation mainly focused on the usability and playability of a number of games developed using the Bean framework, including the Tower Game, and was conducted though observation and picture cards for facilitating children in expressing their opinions. While the children were playing, parents and experts were observing from an observation room set-up in a remote location. In this observation space, a projector was projecting live video from the evaluation space, while a personal computer was showing information regarding the current play performance achieved by the child. The children were encouraged to play freely without any external interventions by adults. After each evaluation session, children, parents and early intervention professionals were required to fill in a posttest questionnaire developed separately for each user group. The experts completed their questionnaire after the completion of all the evaluation sessions. Despite the limited number of participants, interesting results were obtained which confirmed the validity of the Bean model and of the reasoning mechanism towards adequately capturing and following child development. In more details, for all children, the maturity levels detected by the system were consistent with the expectations of their parents and the judgment of the involved experts, while for two of them the system was able to correctly identify some skill immaturities potentially related to learning difficulties. A more extensive assessment of the framework on a larger scale is currently planned to further validate the validity of the results.

6 Conclusions and Future Work

Ambient Intelligence offer new opportunities to support young children development through play. To this end, this paper has presented a novel framework based on occupational therapy's expertise aiming at early detection of children's potential delays to be further investigated and diagnosed if necessary. The framework is composed of a model of children development based on the ICF-CY model and the Denver-II assessment tool, aiming at early detection of children's potential delays, a reasoning mechanism for the automated extraction of child development knowledge, based on interaction monitoring, as well as content editing tools and reporting facilities for parents and therapists. To the best of the authors' knowledge, the proposed framework is unique insofar it supports modeling and reasoning about children as users in Ambient Intelligence environments and embeds occupational therapy and child development knowledge for improving the playing experience of young children and supporting parents in following children's development. The framework has been implemented in the context of an AmI environment deploying a number of augmented physical artifacts, natural interaction techniques and a collection of purposefully designed digital reproductions of popular games.

Planned future work concerns the extensive assessment of the framework validity through testing with mixed group of children with and without diagnosed difficulties.

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