An Open Platform for Full-Body Multisensory Serious-Games to Teach Geometry in Primary School

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ABSTRACT

Recent results from psychophysics and developmental psychology show that children have a preferential sensory channel to learn specific concepts. In this work, we explore the possibility of developing and evaluating novel multisensory technologies for deeper learning of arithmetic and geometry. The main novelty of such new technologies comes from the renewed understanding of the role of communication between sensory modalities during development that is that specific sensory systems have specific roles for learning specific concepts. Such understanding suggests that it is possible to open a new teaching/learning channel, personalized for each student based on the child's sensory skills. Multisensory interactive technologies exploiting full-body movement interaction and including a hardware and software platform to support this approach will be presented and discussed. The platform is part of a more general framework developed in the context of the EU-ICT-H2020 weDRAW Project that aims to develop new multimodal technologies for multisensory serious-games to teach mathematics concepts in the primary school.

CCS CONCEPTS

• **Human-centered computing** → **Empirical studies in HCI**;
Laboratory experiments;

KEYWORDS

Multisensory learning, multimodal technologies, serious games

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1 INTRODUCTION

1.1 Background

Technology is nowadays increasingly used in schools. Whereas it exists a vast literature on the benefit of multisensory and active learning ([7], [15] [14]), current technologies do not still sufficiently ground on this psychological and pedagogical evidences. Furthermore, at school the visual channel is often the one most exploited for teaching, leaving for the other ones just a marginal role. However, vision is not always the more powerful and effective perceptive channel for learning, as we can read in recent results from psychophysics and developmental psychology ([11], [9]) showing that children have a preferential sensory channel to learn specific concepts (spatial and/or temporal). There was, indeed, an effort to develop technology, such as sensors and mobile technologies for whole body and embodied interaction for learning; however, none of them sufficiently exploited multisensory integration for teaching, neither the last psychophysics development in this field. In this paper, we present the initial design stages and an initial prototype of a multisensory technological platform supporting a new methodology to teaching, grounded on this framework of multisensory and adaptive learning, where the optimal sensory modality is used in the most effective way, according to the specific concepts to be taught. We propose the use of multisensory feedback (haptic, audio and visual) and a full body movement platform to teach mathematics concepts underlie by teachers and pedagogues to primary school children, in an active teaching technology-mediated experience. Furthermore, the idea to base our approach on arts, like music and painting, is again grounded on scientific evidence, that we will discuss in next sections.

1.2 Psychophysics Evidence

Although perceptual learning in adults is considerably restricted if compared with developmental brain stages, there is a general consensus in scientific research on the advantage of multisensory redundancy comparing with a unisensory stimulation, as stated in [12], where researchers showed that there is a substantial difference between auditory-visual training and the unisensory visual one, if the motion detection and discrimination tasks are coherent between the two sensory channels. In an analogous way, a training

in any pair of multisensory stimuli might induce a more effective representation of the unisensory stimulus ([13]). In the same way, several studies show that adults integrate visual and haptic information in an optimal way ([10]) where the importance of the relation between the two sensory modalities is stressed. However, such psychophysics framework can be used just with a population of at least of 10 years old, as explained in [11], where a model based on Bayesian prediction is presented. Such model can predict the behavior of children only after the 10 years of age.

In children younger than that age one sensory modality dominate the others. The integration of visual and haptic stimulation, in fact, is not optimal, with either vision or touch full dominance, even if the dominant sense is less precise than the other one. The idea of mediating the learning experience through arts and music is not completely new and some neuro-scientific and psychological evidences can be considered to understand the role of performing arts in learning. Furthermore, drawing can be linked to geometry basing on studies that show that body movement associated with spatial feedback can be used to enhance spatial cognition. It can be argued that body movement is naturally associated to space and can represent a link between the spatial understanding, i.e. geometry skills, and drawing as an expression of it. In the same way, the idea to associate music and arithmetic is based on the evidence that temporal sequences are the base of rhythm and music elements can be easily associated with numerosity.

1.3 Multimodal Technology

The platform we propose is inspired by the multi layered framework for analysis of non-verbal expressive and affective motor behaviors in full-body movement described in [2] and [1]. Developing a technology that maps body movement and exploration into audio, visual and haptic multisensory signals will let the children experience multisensory learning, exploiting the link between proprioceptive feedback and feedback from the other modalities, creating and understanding the mentioned association between geometry and drawing on one hand, and arithmetic and music on the other hand. Moreover, the adoption of the proposed system may also contribute to the early diagnosis of learning deficits, such as dyslexia; in fact, it has been argued that poor rhythmic perception can be an indicator of this learning disease [5].

The audio, visual and haptic feedback (related to proprioceptive abilities and sensory modalities) is used in response to body movement to explore the environment, draw or produce the mathematics contents. One of the most challenging task is engaging users, especially if children. An educational technology should not just be about providing information but facilitating students' experience. Unfortunately, educational technologies are declined as an information distribution channel. A possible approach to develop new learning experiences and methodologies is to combine multimodal kinesthetic and serious games. Moreover, games are generally developed to satisfy the basic requirements of learning environments identified by [4].

The challenge is to create games engaging players while exploring the phenomena and testing hypothesis and not just support

Figure 1: The platform architecture information flow.

factual information. Considering the actual state-of-the-art of technology for active learning, there is the need of an integration between educational theories, psychological and cognitive evidences and multimodal kinesthetic technologies and game design to develop meaningful and engaging educational games.

2 EXPERIENCING THE CARTESIAN PLAN CONCEPT

2.1 Platform Architecture And Design

A positive impact of multisensory learning has been demonstrated in several studies; for example, in ([6],[8]) where the authors stated that interactive sonification and interactive multimodal experience can be very helpful and effective in improving cognitive tasks and learning. The main challenge, while prototyping multisensory serious-games for children's learning, is to make the game effective in transferring knowledge in the same way for each considered sensory modality and be understandable for children of different ages, despite cognitive, and learning or sensory impairment.

In this work, we present a prototype of an interaction-based learning environment where:

- (1) the interaction is based on automated measure of qualities of full body movement and attitudes;
- (2) the interactive sonification of movements is used to provide an engaging experience as a learning feedback to the child, stimulating a positive process of reflective exploration of concepts;
- (3) the gameplay is based on score and feedback output and the game mechanic is increasingly challenging, let the game be suitable for children with different age and/or educational levels.

The platform workstation consists of a Kinect, connected to a PC, using EyesWeb XMI to manage development, execution and evaluation of the serious games ([3], ([16])) EyesWeb XMI is a programming environment conceived to support research on multimodal expressive interface and interactive systems. It is actually used in a variety of applications for real-time dance, music, and rehabilitation and multimedia apps.

The platform built in this way is used to:

- (1) Design multilevel sequences of games suitable for each child, according to the learning target and the individual needs;

- (2) Store personal information and movement data on every use of the system;
- (3) Perform analysis and compute evaluation, based on movement features and scores, on child performance and progression.

The serious-game we present is designed as follows:

- (1) The interaction is based on children movement tracking in the Kinect tracked space, previously divided into an invisible chessboard;
- (2) The game is designed to be played by two children per time and the feedback system is an audio and video feedback;
- (3) The game UI is designed using Unity and connected to EyesWeb, that, as mentioned before, is used to manage the game experience;

A schematic representation of the platform architecture of the game is represented in Figure 1.

2.2 Gaming Scenarios

The choice of the game scenarios followed broad discussions with pedagogues, psychologists, educators and teachers. A major geometric concept that emerged from such discussions is the Cartesian plane. Particularly, it was pointed out that primary scholar students usually have difficulties into understanding the difference between geometrical shapes experienced and their representation in a bi-dimensional space. Furthermore, the above-mentioned challenges for the visually impaired children are particularly hard to manage since they have an egocentric conception of space that makes hard for them to understand the concept of Cartesian plane and of geometrical space in general. Following such considerations, as a particular instance of the presented platform, we propose a full-body platform game based on the idea of chessboard.

The physical space of the game is divided into cells (divided into rows and columns) representing the first Quadrant (where the signs of the (x,y) coordinates are (+,+)) and where the left bottom corner represents the origin of the plane and it is used as the starting point for the game interaction. The game is designed to let two children play together at time. It deeply relies on a narrative structure that guides the children during the exploration. A game session starts with the two players in the origin point. The players are asked to find two game elements that are defined by the story i.e., an environment (e.g., the woods, the sea, the countryside, and so on) and a character (e.g., the frog, the cat, the bear, and so on) in the game space. An example of game guideline is "Take the dog into the woods".

At each game space cell is assigned the sound of its corresponding element. As an example, while accessing on the cell assigned to the dog, a barking sound will be produced by the game.

The interaction is structured as follows:

- (1) the first player has to find the correct environment on the x-axis and only after that,
- (2) the second one needs to find the right character on the y-axis.

Once both players' choices are confirmed, the narrative goes on asking the children to meet each other in the right cell of the chessboard to perform an action that needs the character in the environment they found. In this way, the children can reach an

Figure 2: Sketch of the prototyped full-body interaction.

embodied understanding of the space point they make with the coordinates they represent. If the children are not able to find the correct cell, the narrative itself gives them a feedback about their mistake (e.g., they may find an incoherent feedback produced by the wrong animal in the wrong environment, e.g., a seagull in a forest). When the right space point is found, then the narrative ends.

3 CONCLUSION AND FUTURE WORK

The game we propose is the first designed prototype of a multilayer serious game to teach geometric concepts. The pre- and post-test and experiments on the efficacy of this methodology and game design we will conduct starting from September in primary schools in Italy and in UK. Based on the results we will collect, we will continue developing a second platform grounded on the evidence we will have from psychophysics, pedagogical and technical areas, to better design the multimodal and multisensory full-body interaction and game experience.

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