A Digital Game Fostering Spatial Abilities

P. Barros, A. Breda, E. Rocha, M. I. Santos

***Abstract*—As visual and spatial awareness develop, children apprehension of the concept of direction, (relative) distance and (relative) location materializes. Here we present the educational inclusive digital game ORIESPA, under development by the Thematic Line Geometrix, for children, aged between 6 and 10 years old, aiming the improvement of their visual and spatial awareness. Visual-spatial abilities are of crucial importance to succeed in many everyday life tasks. Unavoidable in the technological age we are living in, these abilities are very important, for instance, in mathematics. The game, set on a 2D/3D environment, focuses in tasks/challenges categorized on the following categories: (1) static orientation of the subject and object, requiring an understanding of the notions of up–down, left–right, front–back, higher-lower or nearer-farther; (2) interpretation of perspectives of three-dimensional objects, requiring the understanding of 2D and 3D representations of three-dimensional objects; and (3) orientation of the subject in real space, requiring the reading and interpreting of itineraries. In ORIESPA, simpler tasks are based on a quadrangular grid, where the front-back and left-right directions and the rotations of ± 90°, ±180° and ±270° play the main requirements. The more complex ones are produced on a cubic grid adding the up and down movements. In the first levels, the game's mechanics regarding the reading and interpreting maps (from point A to point B) is based on map routes, following a given set of instructions. In higher levels, the player must produce a list of instructions taking the game character to the desired destination, avoiding obstacles. Being an inclusive game, the user has the possibility to interact through the mouse (point and click with a single button), the keyboard (small set of well-recognized keys) or a Kinect device (using simple gesture moves). The character control requires the action on buttons corresponding to movements in 2D and 3D environments. Buttons and instructions are complemented with text, sound and, soon, with sign language.**

***Keywords*—Spatial orientation ability, digital game, inclusion, itinerary.**

I. Introduction

NOWADAYS, inclusive school basic principles – based upon humanistic beliefs concerned with human rights, equity and social justice – are unquestionable. Digital technologies can assist and transform the teaching and learning process of students with special education needs, providing them with a range of different opportunities and enabling the creation of constructive environments for the development of differentiated and meaningful activities. These tools can allow children to work autonomously on computers with minimal support, working at their own pace and skill level, increasing their learning rate as well as improving their attention span, social behavior, interactions with peers, responsiveness and performance, see for instance [1]. As stated in [2], there are evidences pointed out by several researchers, see for instance [3]-[6], that having a high level of spatial skills is positively related to the success for students in the STEM (science, technology, engineering and mathematics) disciplines.

While the consensus about the importance of spatial ability is beyond question, the approach to improve this ability is yet unclear. However, what it is well known is that when applied to teaching contexts, that could be conveyed in the form of a digital game, the attention, motivation and engagement of the learner increases significantly. Besides, as pointed out in [7] digital game environments provide opportunities for a new type of cognitive learning experience. The facts, here presented, fully justify our intention in developing an inclusive digital game fostering spatial abilities.

II. Spatial Abilities

The development of spatial abilities based on visualization is indispensable. Students usually explain their observation in words. However, as specified in [8], visual explanations are also of great significance, playing a crucial role in the development of the inference procedure.

Visual images of objects, in visualization activities, are performed according to specific processes. Namely, to visual processing (conversion of abstract information into visual images) and to the process of transformation of an already formed visual image in another, being that the interpretation of figurative information (the inverse of the visual processing) corresponds to the process of understanding and interpreting visual representations.

As argued by [9], the procedure to visualize and to orient an object, a subject or a space, does not only include the ability to "see" objects and spaces, but also the ability to reflect on them, on their possible representations, on the relationships between their parts, and to examine the effect caused by the action of a geometric transformation. Following this point of view, the authors have distinguished three large families of tasks promoting the development of space orientation and visualization, namely, (1) static orientation of subject and objects; (2) interpretation of three-dimensional object perspectives; and (3) guidance of the subject in real spaces.

Following a game-based approach, here we report the design of the inclusive digital game ORIESPA, a game for children aged between 6 to 10 years old, framed according to these three task families. ORIESPA is under development by GEOMETRIX, a research and development interdisciplinary- oriented thematic line of CIDMA (Center for Research and Development in Mathematics and Applications). Targeted at assorted target groups (running from primary to higher education level), GEOMETRIX is committed to the study, use and creation of digital environments, to promote knowledge and skills in mathematics, reflecting a transformation in the way they are grasped and applied.

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III. ORIESPA GAME

A. Specific Learning Objectives

ORIESPA, an inclusive game focused on the acquisition and development of spatial visualization and spatial orientation skills, is embedded in a tridimensional context having in mind the three identified task families pointed to these goals.

B. Base Architecture and Game Dynamics

ORIESPA is being developed as a browser-based game, using current web technologies. The 3D scenes are supported by the widely used WebGL Javascript library: Three.JS (https://threejs.org). Therefore, it runs on any current computer (desktop or laptop) and some mobile devices. Being a browser- based game, it can be available to a large number of children. All they need is a computer and an Internet connection.

Regarding the state-of-the-art on web games, the main contribute of ORIESPA is to show that current technologies can (and should) be used for educational games in a simple and effective manner, similar to any commercial web and/or mobile game. Regarding the philosophy and purpose of the proposed subgames (tasks), ORIESPA does not use any physics-based mechanics, but this can be easily introduced. There are many good and open source libraries for this. Whenever possible and effective, positional audio has been used.

ORIESPA was conceived for children to play alone (and even offline) whenever they feel up to, having a login feature: the user or tutor creates an account where all configurations and progress is saved (in a central database, if/when online). This gives tutors (teachers/parents/educators) a way to monitor each child´s progress and, mainly, to access to repeated errors that may require a personal guidance. The monitoring process can be made remotely: the tutor may access to the student´s account by logging into the central platform. Recall that all they need is a computer and an Internet connection.

The game ORIESPA is made of subgames (tasks with a specific learning objective), or scenarios, intended to train a specific skill. Each subgame is composed by a set of tasks with increasing levels of difficulty, being, most of them, built on the skill(s) developed on previous ones. Subgames and levels are locked *a priori*, being unlocked whenever the user solves the corresponding level game challenges. This strategy is a way of evolution and accomplishment being an incentive for training, learning, and overcoming obstacles, being enthusiastic to reach the next level and/or subgame. This procedure takes advantage on children´s natural sense of curiosity and hunger for discovery.

By remotely accessing the child´s account, tutors can unlock the access to any level or subgame to prevent the child from being stuck in a level and become demotivated to play.

A score system, depending on the subgame nature, is implemented. It may take in consideration the response time, the number of executed attempts and the use of help mechanisms provided in each level game. All levels share a common and well known "star system". Whenever played and at any level, the system provides the player with three stars. Every failed attempt costs the loss of a star. If no stars are available, the game is not over but the player returns to the previous level. Hence, the player has the possibility of 3 failed attempts at each level and still be in play. The child can repeat any unlocked level at will and is encouraged (by the use of motivational dialogues) to achieve 3 stars (no failed attempts) at each game level.

When the child makes a failed attempt, Oriespa will show a slightly humorous animation: making mistakes a natural component of the learning process, not a drama. Children also relax with non-linear character behaviours, and experience shows that some errors are purposely made just to activate a character reaction and have some laughs. Note that a conscious error may imply the knowledge of the correct answer.

Scores are not shared among players: there is no "wall of fame". The focus is on self-progression, not competition.

ORIESPA is built upon the mainstream architecture for children games. Accordingly, ORIESPA provides:

- an introductory screen, presenting the game title, the protagonist character, the menu icons for common tasks such as game configuration, information, achieved scores, and game play;
- a main menu screen offering to the user information about all the subgames and levels, specifying if they are available to play (unlocked) or not, and, in the case of an unlocked level, the number of stars achieved is also shown. This gives to the player a notion of his/her progress and achievement being a focus of motivation to pursue the goal to finish each level with 3 stars (no errors);
- each subgame and corresponding levels are presented on a single page/screen, not overwhelming the child with visual information.

C. Interaction

Children with physical disabilities have limitations in terms of external stimuli: sensory processing and motor responses. These aspects lead to limitations in the acquisition of basic skills at every stage of their development. A reduced control of movement and muscle weakness makes it difficult to use a standard mouse. To overcome this difficulty, in ORIESPA, the user may perform all interactions through the keyboard (small set of well-recognized keys) or a Kinect device (by using simple gesture moves). Kinect technology has potential in training different skills in children with special education needs. In fact, Kinects may be used for rehabbing balance and motor skills, increasing autonomy and citizenship inside and outside school situations [10]. The character control requires the action (click, key press, hand gesture) on a button corresponding to movements in 2D and in 3D environments. Some interactions require that these actions be performed on game objects (for instance, boxes).

In the case of users with specific auditory deficiency, the main difficulties are focused on the perception of sound signals, location, and access to voice messages or to any kind of information in audio. To overcome this obstacle, sign language videos will be included to support students with hearing deficiency.

Nowadays children are very familiar with computers and standard input devices. In ORIESPA none was excluded. All menu and game actions are based on *point and click with a single button*. This generic *point and click* actions can be

performed with a mouse, a keyboard, or a Kinect. All interactions with ORIESPA can be made using exclusively one input device. With *point and click* as the main input mechanism, special care was taken on the design of menu items and game objects. They should be always visible, well recognized and distinguishable, and be big enough to facilitate selection by users with motor and/or visual impairment.

ORIESPA´s input devices:

- Mouse - this is the main input device used to interact with ORIESPA. Only one button is required (left and right buttons can be used interchangeably throughout the user interface).
- Keyboard - although (written) text inputs are not used, keyboard interaction is also important. It is a common interface very familiar to all children. Users with some sort of motor impairment may find difficult to manipulate the mouse and/or point a target (due to trembling or inability to perform fine movements). Simplicity and clarity is an important factor. Accordingly, a small set of well- recognized keys are used. Namely,
  - «Arrow keys» are used to simulate the movement of a mouse (being the acceleration implemented and configured on the settings menu);
  - «Enter» and «Space bar» keys are used to perform a selection;
  - «Tab» key is used to navigate between targets as it is common in other computer applications;
  - «Esc» key is only used to pause/resume the game.
- Kinect – this type of device is becoming less expensive and more available at local stores. Its functionality to assist, among others, interaction and socialization was one of the key motifs to be considered another input device of ORIESPA. In the game, the cursor follows the hand movement and the hand closing (making a fist) is interpreted as a click. No other body movements are required (for instance: left, right) which might require more free space in the room or make interaction difficult (if not impossible) for children on wheel chairs or with any other movement difficulty.

D. Feedback

When the cursor enters a target space (hovering), both visual and sound feedbacks are given. Menu icons and game objects produce one same sound when hovered and one other when clicked. Menu items share the same visual appearance (with an icon image providing good contrast) and gain a border when hovered, the border changes color when clicked.

When a menu item is hovered for more than 3 seconds, a label is shown, usually a white text on a black background or on other high contrast set-up, with the item´s name followed by the action description: for example, "MENU: cancel the game and go back to main menu". These labels are used in conjunction with audio descriptions.

As the user gets familiar with menu items and dialogues, it may no longer feel the need of text labels and/or audio descriptions. The user may also feel this as intrusive. So, this behavior (seconds of delay and use of text labels and audio descriptions) may be configurable on the settings menu. It is worthwhile mention that it is possible to have both text and sound, only text or sound, or none.

E. Subgames

All subgames were designed taking into account the orientations given in [11].

- All solved subgames and levels can be played whenever the player wants to, allowing the child to practice thoroughly the learnt abilities.
- All user's data (personal interface choices, performance, score, statistics, etc.) are stored in a central database allowing the user to face always the same environment, even if he connects to ORIESPA from different devices.
- Performance data are collected and made available to tutors, making possible the detection, among others, of repeated errors (an alert for personal guidance). The data also give a detailed notion of the time required for the execution of each task and the progression of the skills involved.
- All subgames are structured in a sequence of situations organized into increasing difficulty levels.
- All game messages are given in both text and audio (and soon in sign language).
- The game environment is simple and consistent: For any given context, all menu icons are visible and are big enough to facilitate hover and click actions; all menu icons and game objects produce the same sound when hovered and when clicked; visual cues are also included for hover and click actions; all icons and buttons have a text and/or image label in a high contrast with the background and when hovered for some time produce text and/or audio descriptions of their action.

Subgame 0 – Warm-up

ORIESPA begins with a warm-up subgame. Oriespa, the game protagonist, has 4 boxes on his front/back/left/right positions. The player is invited to explore the 3D scenario by clicking on the boxes. When a box is hovered, Oriespa explains the box location (text and audio information): "*That box is on my left.*", see Fig. 1. After clicking the 4 boxes the first level finishes. This subgame is made of 5 levels according to the player views of Oriespa. From his: 1) back, 2) front, 3) left, 4) right, and 5) viewpoint randomly chosen whenever a correct click is done (no two consecutive viewpoints are the same).

On level 5 a control panel with 4 buttons appears on the screen. The player/child is invited to explore them. Each button sets the view to a different position: view Oriespa from its back/front/left/right. The starting position is from the back, player and Oriespa share the same reference.

Fig. 1 - Subgame 0, Warm-up: Oriespa explaining the box location

This warm-up subgame works like a tutorial: introduces the game protagonist and the game behaviour; describes the way to interact with the subgames and explains to the player the four basic directions. The changing of the viewpoint puts in evidence that a scene may look different when viewed from different positions and that position references are dependent on the subject.

Subgame 1 – Click on the boxes (left, right, front, back)

This subgame is built on the warm-up scenario: Oriespa chooses a random direction and tells the player (child): "*Click on the box on my left.*", see Fig. 2. When the box is clicked, Oriespa moves to the box location, picks the box and 4 other boxes appear, 1 in each one of the 4 main directions. This introduces movement to the game: when Oriespa moves towards a box the camera moves along; Oriespa may, also, rotate 90° or 180°, making the whole scene be seen from a different viewpoint. If the child clicks the wrong box, the warm-up behaviour is replicated (an explanation is shown) and a star is lost (consecutive errors on the same box do not cause the loss of a star so that the player can review the explanation).

The level finishes when 10 correct answers are given (the number can be redefined by the tutor). A progress bar is on the screen so that the child can actually see the end goal getting closer.

This scenario fits in the first family of tasks presented in [9]- *static orientation of subject and objects*. A degree of difficulty is added when Oriespa moves since the scene's perspective changes; reinforcing that references change according to the subject's position and orientation.

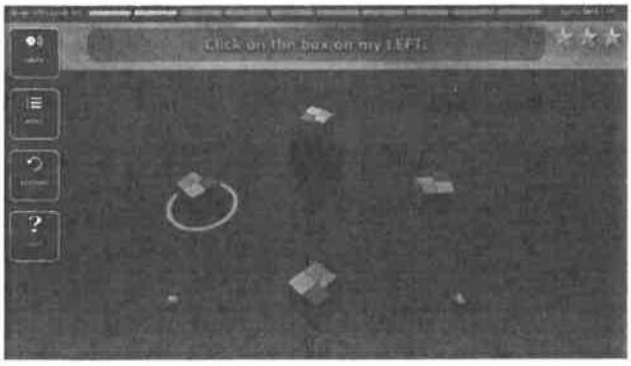

Fig. 2 - Oriespa receives an instruction and moves to the correct box. After clicked, the scene rotates and the perspective changes but the viewpoint, from Oriespa's back, is kept

Subgame 2 – Which will be the box? (mental rotations)

This subgame, presented on the same scenario as subgame 1, trains a new skill: **mental rotation**. Again, Oriespa is surrounded by four boxes and he raises a question of this nature: "*If I rotate 90 degrees to my right, which would be the box on my left?*", see Fig. 3.

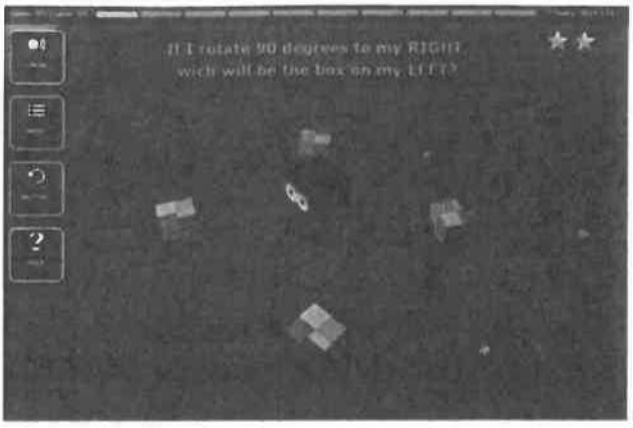

Fig. 3 - Subgame 2: A task requiring mental rotation

The child has to perform two operations: 1) perform the mental rotation of Oriespa; and 2) determine the correct box given the new (mental) Oriespa's orientation.

This scenario fits in the second family of tasks in [9] (*interpretation of three-dimensional object perspectives*) and is creating the foundations for the tasks fitting in the third family: *guidance of the subject in real spaces*.

Subgame 3 – Closest and farther away (relative distance)

In this subgame Oriespa has only two boxes and the player is invited to click on the box which is closest to/further away from Oriespa; see Fig. 4. On level 1, the boxes are in line with Oriespa (the boxes and Oriespa form a straight line). On level 2 the boxes and Oriespa form a 90 degrees angle. From level 3 to level 5 a third box is added. On level 5, additionally, Oriespa's orientation changes whenever a correct answer is given.

This scenario fits in the first family of tasks presented in [9]- static orientation of subject and objects.

Fig. 4 Subgame 3: Oriespa is telling the child to click on the box that is farther away from him (on the right there is a control pannel to change the viewpoint)

Subgame 4 – Take Oriespa to the target box (movement)

In this subgame the child is introduced to a pair of control panels allowing the translation and rotation movement of Oriespa. Namely (1) the MOVE control panel, with a single button allowing Oriespa movement one step forward; and 2) the ROTATE control panel with a pair of buttons making Oriespa rotate 90 degrees to the left and to the right.

Oriespa has 4 boxes around him and the game gives instructions to the player, one at each time, to take Oriespa to

one of the boxes (randomly selected), see Fig 5. The player must act accordingly to the given instructions, using the MOVE and RORATE control pannels' buttons.

In the levels 1 to 4, the viewpoint is respectively from Oriespa's back, front, left and right. On level 5 the viewpoint changes randomly whenever a correct answer (button click) is given.

This subgame fits in the third family of tasks presented in [9]- *guidance of the subject in real spaces*.

Subgame 5 – Stairs and platforms (step up/down)

In this subgame a new pair of buttons are added to the MOVE control panel making Oriespa take one step up or down. The novelty is the notion of steping up/down stairs or platforms bringing to the scene the three dimensions.

As in subgame 4, the player receives instructions, one at a time, to take Oriespa to one randomly selected box from the 4 available, see Fig. 6.

Due to the presence of obstacles (stairs and platforms) that might block the view of Oriespa and/or the target box, another control panel is present: the VIEW control panel with 4 buttons allowing the change of the Oriespa's viewpoint (back/ front/left/right). This control panel can be freely used, independently of the given instructions.

This subgame fits in the third family of tasks presented in [9]- *guidance of the subject in real spaces*.

Subgame 6 – Take Oriespa to the target box

In this subgame there is only one instruction: "*Take Oriespa to the box.*" see Fig. 7. The child can move and rotate Oriespa freely (and change the viewpoint). The subgame ends when Oriespa reaches the box

Two additional buttons are present on the ROTATE control panel to make Oriespa perform 180 degrees rotations.

Penalties (loss of a star) and explanations are given if Oriespa is instructed to: a) crash against a platform or a stair; b) fall from a platform or stair; and c) go outside the playing area.

Scores are given taken into account the number of translation and rotation movements made by Oriespa.

This subgame fits in the third family of tasks presented in [9]- *guidance of the subject in real spaces*.

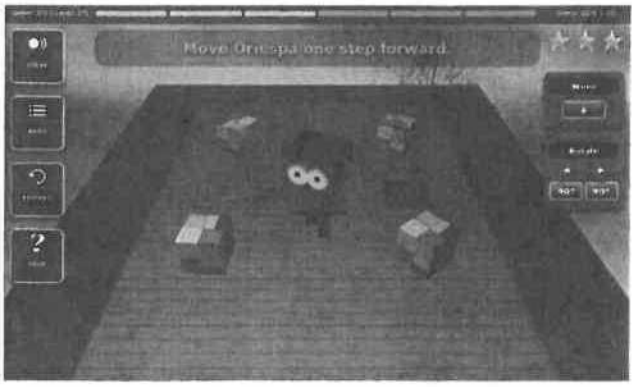

Fig. 5 - Subgame 4: The player controls Oriespa's translation and rotation movements clicking on the control panels' buttons

Fig. 6 - Subgame 5: introduction of platforms and stairs and two new buttons on the MOVE control panel (step up/down)

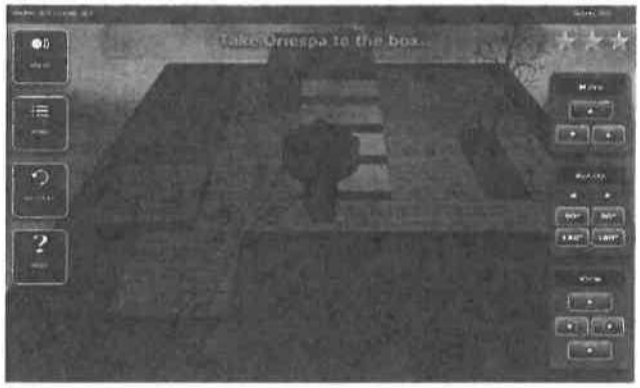

Fig. 7 - Subgame 6: The player moves Oriespa (translations and rotations) and change the viewpoint at will

Subgame 7 – The helicopter (above and below)

In this subgame Oriespa is on an helicopter. Above and below the helicopter are two boxes. Oriespa tells the player to "*Click on the box BELOW me.*", see Fig. 8.

Fig. 8 - Subgame 7: Oriespa is on an helicopter The player must click on the box located below him.

The mechanics are the same of subgames 1 and 2. With each correct answer, the helicopter rotates 90 or 180 degrees to show that the references above and below do not change with the subject's orientation.

This scenario fits in the first family of tasks presented in [9]- *static orientation of subject and objects*.

Subgame 8 – Click on a box (mixed concepts and multiple correct answers)

In this subgame the child is presented to a scenario with varied concepts. Besides, multiple correct answers are

available.

Oriespa is in a scene with 3 platforms stacked vertically.

On level 1, Oriespa is on a platform in it's center. There are 5 boxes on other platforms above and below the one where is Oriespa. Oriespa gives an instruction to the player, like this one: "*Click on a box ABOVE me.*", see Fig 9. When a correct box is clicked it disappears and another instruction is given. Besides, Oriespa may rotate 90 or 180 degrees and/or move along the middle platform to show that, in this scenario, the references above and below do not change with the subject's orientation and horizontal translational movement. The level ends when there are no more boxes to be clicked.

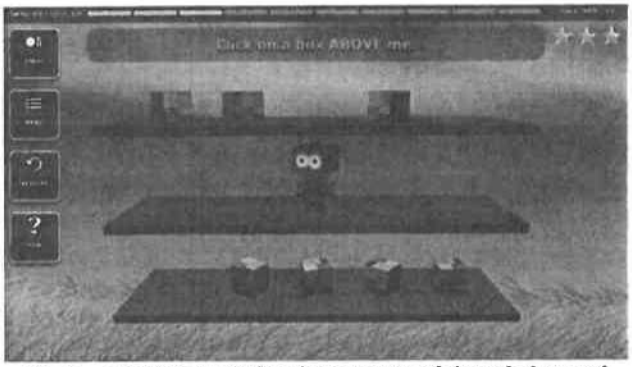

Fig. 9 - Subgame 8: mixing the concepts of above/below and left/right or front/back along with translational and rotational movements.

On level 2 Oriespa is also in the center of the middle platform. Now, 12 boxes are present (4 on each platform) and only on Oriespa's left and right. Similar to level 1, the child is instructed to click on a box located on Oriespa's left/right (or front/back, depending on Oriespa's orientation). When a correct box is clicked Oriespa may rotate 90 or 180 degrees or even jump to another platform. This shows that the notions of left/right (front/back), in this scenario, do not change with the subject's orientation and vertical movement.

On level 3 Oriespa is also in the center of the middle platform. There are 14 boxes present (5 above, 5 below and 4 in the middle platform). This time Oriespa gives an instruction containing two critical distinct information. Here is an exemple: "*Click on a box that is both ABOVE me and to my LEFT.*". Again, multiple correct answers might be available.

On level 4, the difference to level 3 is that each time a correct box is clicked it disappears and Oriespa jumps to that empty spot. This movement changes some boxes' relative position to Oriespa (and introduces a novelty to the game: Oriespa can jump).

This subgame fits in the first family of tasks presented in [9]- *static orientation of subject and objects.*

Subgame 9 – How many boxes? (orthogonal perspectives)

In this subgame Oriespa does not appear. On the grass there is a random placement of cubic boxes forming a three dimensional object (on a 3 x 6 grid). On the screen are also shown the three orthogonal views of the boxes composition (top, front and left/right side). The following question is raised "How many boxes are on the grass?", see Fig 10.

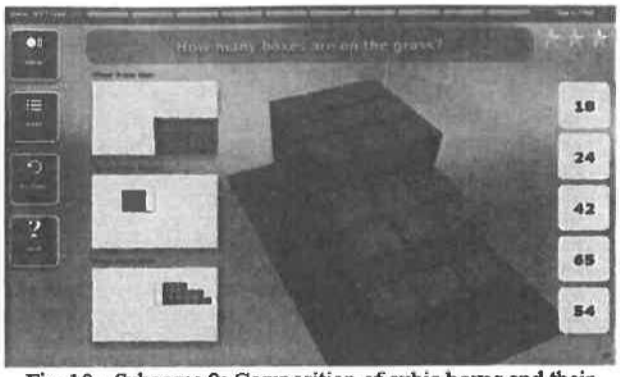

Fig. 10 - Subgame 9: Composition of cubic boxes and their orthogonal views (projections).

By hovering a cubic box, its relevant faces are highlighted on each of the projections, to enhance the understanding of the three dimensional composition and its orthogonal views.

On the screen are also shown 3 to 5 possible answers and the player must choose (click) one of them. Clicking a wrong answer activates an explanation, the answer disappears and a star is lost. The subgame ends when the correct answer is given (clicked) or all stars are lost.

The subgame level limits the height (in number of cubic boxes) of the composition: level 1, "flat" composition; level 2, cubes composition with a maximum height of 2 cubes; etc...

This subgame fits in the second family of tasks presented in [9]- *interpretation of three-dimensional object perspectives.*

IV. Future Work

Further developments may include:

- Interaction with semaphores, zebras, elevators and escalators to promote the child's autonomy in real life scenarios;
- Inclusion of a 2 dimensional representation of the scenario (i.e. a map) and the location of Oriespa to promote the child's capability of relating a map with the three dimensional scene it represents and train the skills necessary to navigate in real life by means of a map;
- Inclusion of life-like situations: take Oriespa from it's house to the bookstore, using the zebras and obeying to semaphores;
- Interaction with time-tables: take Oriespa to the bus station, consult the timetable and check when (hour) and where (bus lane) the next bus to a nearby city leaves the station.

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